DOCUMENT RESUME

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TITLE	Electronic Principles IV, 7-8. Military Curriculum Materials for Vocational and Technical Education.
INSTITUTION	Air Force Training Command, Keesler AFB, Miss.; Ohio State Univ., Columbus. National Center for Research in Vocational Education.
SPONS AGENCY	Department of Education, Washington, DC.
PUB DATE	75
NOTE	574p.; For related documents, se^ CE 039 201-210.
PUB TYPE	Guides - Classroom Use - Materials (For Learner) (051) -- Guides - Classroom Use - Guides (For Teachers) (052)
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DESCRIPTORS	Behavioral Objectives; Course Content; Course Descriptions; Electronic Equipment; *Electronics; Individualized Instruction; Learning Activities; Learning Modules; Pacing; Postsecondary Education; Programed Instructional Materials; Secondary Education; *Semiconductor Devices; *Technical Education; Transistors
IDENTIFIERS	Military Curriculum Project; *Solid State (Electronics); *Troubleshooting

ABSTRACT

This fourth of 10 blocks of student and teacher materials for a secondary/postsecondary level course in electronic principles comprises one of a number of military-developed curriculum packages selected for adaptation to vocational instruction and curriculum development in a civilian setting. Prerequisites are the previous blocks. This block on solid state principles contains five modules covering 72 hours of instruction on PN junctions and diodes (12 hours), transistors (12), amplifier principles (22), troubleshooting solid state amplifiers (12), and selected solid state devices (14). Printed instructor materials include a plan of instruction detailing the units of instruction, duration of the lessons, criterion objectives, and support materials needed. Student materials include a student text; five guidance packages containing objectives, assignments, and review exercises for each module; and a comprehensive programmed text on solid state devices. A digest of the modules in the block is provided for students who need only to review the material. Designed for self- or group-paced instruction, the material can be adapted for individualized instruction. Additional print and audiovisual materials are recommended but not provided. (YLB)

MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

The National Center Mission Statement

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

- Generating knowledge through research
- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Installing educational programs and products
- Operating information systems and services
- Conducting leadership development and training programs

FOR FURTHER INFORMATION ABOUT
Military Curriculum Materials
WRITE OR CALL

Program Information Office
The National Center for Research in Vocational Education
The Ohio State University
1960 Kenny Road, Columbus, Ohio 43210
Telephone: 614/486-3655 or Toll Free 800/848-4815 within the continental U.S. (except Ohio)

THE NATIONAL CENTER FOR RESEARCH IN VOCATIONAL EDUCATION

Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

Agriculture	Food Service
Aviation	Health
Building & Construction Trades	Heating & Air Conditioning
Clerical Occupations	Machine Shop
Communications	Management & Supervision
Drafting	Meteorology & Navigation
Electronics	Photography
Engine Mechanics	Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

EAST CENTRAL
Rebecca S. Douglass
Director
100 North First Street
Springfield, IL 62777
217/782-0759

NORTHWEST
William Daniels
Director
Building 17
Airdustrial Park
Olympia, WA 98504
206/753-0879

MIDWEST
Robert Patton
Director
1515 West Sixth Ave.
Stillwater, OK 74704
405/377-2000

SOUTHEAST
James F. Shill, Ph.D.
Director
Mississippi State University
Drawer DX
Mississippi State, MS 39762
601/325-2510

NORTHEAST
Joseph F. Kelly, Ph.D.
Director
225 West State Street
Trenton, NJ 08625
609/292-6562

WESTERN
Lawrence F. H. Zane, Ph.D.
Director
1776 University Ave.
Honolulu, HI 96822
808/948-7834

ELECTRONIC PRINCIPLES IV

Table of Contents

ELECTRONIC PRINCIPLES IV

Classroom Course

Developed by:
United States Air Force

Development and Review Dates:

July 1974 through November 1975

D.O.T. No.:
003.081

Occupational Area:
Electronics

Target Audiences:
Grades 11-adult

Print Pages:
560

Cost:
$11.25

Availability:
Military Curriculum Project, The Center for Vocational Education, 1960 Kenny Rd., Columbus, OH 43210

Contents:	Type of Materials: Lesson Plans	Programmed Text	Student Workbook (No. of pages)	Handouts	Text Materials	Audio-Visuals	Instructional Design: Performance Objectives	Tests	Review Exercises	Additional Materials Required	Type of Instruction: Group Instruction	Individualized
Block IV – *Solid State Principles*												
Module 29 – PN Junctions and Diodes	•	•	13		•	*	•	*	•		•	•
Module 30 – Transistors	•		13		•	*	•	*	•		•	•
Module 31 – Amplifiers Principles	•		24		•	*	•	*	•	*	•	•
Module 32 – Troubleshooting Solid State Amplifiers	•		36		•		•	*	•	*	•	•
Module 33 – Selected Solid State Devices	•		34		•	*	•	*	•		•	•

* Materials are recommended but not provided.

Course Description

This block is the fourth of a ten block course providing training in electronic principles, use of basic test equipment, safety practices, circuit analysis, soldering, digital techniques, microwave principles and troubleshooting basic circuits. Prerequisites to this block are Blocks I, II, and III covering DC circuits, AC circuits, and RCL circuits. Block IV *Solid State Principles* contains five modules covering *72* hours of instruction on PN junctions, diodes, transistors, amplifier principles, troubleshooting, and solid state devices. The module topics and respective hours follow

Module 29	**PN Junctions and Diodes** (12 hours)
Module 30	**Transistors** (12 hours)
Module 31	**Amplifier Principles** (22 hours)
Module 32	**Troubleshooting Solid State Amplifiers** (12 hours)
Module 33	**Selected Solid State Devices** (14 hours)

This block contains both teacher and student materials. Printed instructor materials include a plan of instruction detailing the units of instruction, duration of the lessons, criterion objectives, and support materials needed. Student materials consist of a student text used for all the modules, five guidance packages containing objectives, assignments, and review exercises for each module; and a comprehensive programmed text on solid state devices. A digest of modules 29 through 33 for students who have background in these topics and only need to review the major points of instruction is also provided.

This material is designed for self- or group-paced instruction to be used with the remaining nine blocks. Most of the materials can be adapted for individualized instruction. Some additional military manuals and commercially produced texts are recommended as references, but are not provided. Audiovisuals suggested for use with the entire course consist of 143 videotapes which are not provided.

VOCATIONAL CURRICULUM MATERIALS PROCESSING FORM

AN ACCESSION NUMBER

TI TITLE OF MATERIAL (Include edition and series title)

YR YEAR 1975

Electronic Principles (Modular Self-Paced). POI 3AQR3002C-1.

SA SPONSORING AGENCY

ST FULL NAME OF STATE

Department of Defense

A1 Street or P.O. Box

A2 City State (Ab.) Zip

DV DEVELOPER (Agency Name)

United States Air Force, Keesler Technical Training Center (ATC)

D1 Street or P.O. Box

D2 City Keesler Air Force Base State (Ab.) MS Zip 39534

D3 Person(s) Name

SM SUBJECT MATTER (Write in terms from NCES classification)

LEVEL 1

LEVEL 2

LEVEL 3

LEVEL 4

EL EDUCATIONAL LEVEL

01	02	03	04	05	06	07
___ K-6	___ 7-8	___ 9-10	✓ 11-12	✓ 13-14	✓ Adult	___ Higher Ed

IU INTENDED USER

01	02	03	04	05
✓ Student	✓ Teacher	___ Administrator	___ Teacher Educator	___ Counselor

SP STUDENT TARGET POPULATION

01	02	03	04	05
✓ Regular	___ Disadvantaged	___ Handicapped	___ Limited English	___ Bilingual

PM PRINT MATERIAL

1	___	Administrative Manual	11	___	Directory/Catalog
2	___	Curriculum Guide	12	✓	Competency-Based
3	✓	Teaching Guide	13	___	Task Analysis
4	✓	Reference Material	14	___	Criterion Referenced Evaluation
5	___	Textbook	15	✓	Behavioral Objectives
6	✓	Evaluation Instrument	16	___	Individualized, self paced
7	___	Learning Module	17	✓	Programmed Instruction
8	✓	Workbook	18	___	Field-tested/Validated
9	___	Game/Simulation	19	___	Illustrated
10	___	Bibliography	20	___	Other (Specify) ___

FO FORMAT

382 ___ Number of Pages

NM NONPRINT MEDIA

1 Film	10 Videotape	20 Audiotape	30 Filmstrip	40 Slides	50 Transparency
2 Min	11 Min	21 Min	31 Frames	41 Frames	51 Number
3 Size	12 Size	22 Reel	32 B&W	42 B&W	52 B&W
4 B&W	13 B&W	23 Cassette	33 Color	43 Color	53 Color
5 Color	14 Color	24 Cartridge			54 Master
	15 Cassette				
	16 Reel				60 Microfiche
					61 Number
					62 Reduction Ratio

Other (Specify)

DN DESCRIPTIVE NOTE (Additional Information)

CI COPYRIGHT INFORMATION

Explain any copyright restrictions

AV AVAILABILITY

Free ______ copies

Sale $ ______

ED ______

Loan ______ Time

Rent $ ______ Time

V1 Contact The National Center for Research in Vocational Education, Program Information Office

V2 Street or P O Box 1960 Kenny Road

V3 City Columbus, State (Ab) OH Zip 43210

V4 Phone (800) 848-4815; (614) 486-3655

CC CURRICULUM COORDINATION CENTER CODE

EC ______ MW ______ NE ______

NW ______ SE ______ WE ______

AA ADDITIONAL AVAILABILITY

Curriculum Coordination Centers

NATIONAL CENTER USE ONLY

Person Completing Form ______

Street or P O Box | City | State (Ab) | Phone

Date Received	Date Entered	Remarks

8/14/81

PLAN OF INSTRUCTION

(Technical Training)

ELECTRONIC PRINCIPLES

(Modular Self-Paced)

AIR TRAINING COMMAND

KEESLER TECHNICAL TRAINING CENTER

20 November 1975 - Effective 6 January 1976 with Class 760106

Volume 4

7-8

ATC Keesler 4-2148

DEPARTMENT OF THE AIR FORCE
USAF Sch of Applied Aerosp Sci (ATC)
Keesler Air Force Base, Mississippi 39534

PLAN OF INSTRUCTION 3AQR30020-1
20 November 1975

FOREWORD

1. PURPOSE: This publication is the plan of instruction (POI) when the pages shown on page A are bound into a single document. The POI prescribes the qualitative requirements for Course Number 3AQR30020-1, Electronic Principles (Moduler self-paced) in terms of criterion objectives and teaching steps presented by modules of instruction and shows duration, correlation with the training standard, and support materials and guidance. When separated into modules of instruction, it becomes Part I of the lesson plan. This POI was developed under the provisions of ATCR 50-5, Instructional System Development, and ATCR 52-7, Plans of Instruction and Lesson Plans.

2. COURSE DESIGN/DESCRIPTION. The instructional design for this course is Modular Scheduling and Self-Pacing; however, this POI can also be used for Group Pacing. The course trains both non-prior service airmen personnel and selected re-enlistees for subsequent entry into the equipment oriented phase of basic courses supporting 303XX, 304XX, 305XX, 307XX, 309XX and 28XX AFSCs. Technical Training includes electronic principles, use of basic test equipment, safety practices, circuit analysis, soldering, digital techniques, microwave principles, and troubleshooting of basic circuits. Students assigned to any one course will receive training only in those modules needed to complement the training program in the equipment phase. Related training includes traffic safety, commander's calls/briefings and end of course appointments.

. TRAINING EQUIPMENT. The number shown in parentheses after equipment listed as Training Equipment under SUPPORT MATERIALS AND GUIDANCE is the planned number of students assigned to each equipment unit.

. REFERENCES: This plan of instruction is based on Course Training Standard KE52-3AQR30020-1, 27 June 1975 and Course Chart 3AQR30020-1, 27 June 1975.

FOR THE COMMANDER

C. H. HORNE, Colonel, USAF
Commander
Tech Tng Gp Prov, 3395

OPR: Tech Tng Gp Prov, 3395
DISTRIBUTION: Listed on Page A

6

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

b. Given a PN junction diode characteristic curve, identify the points of structural breakdown; the operating region. CTS: 5a Meas: W (2.5)

(1) Describe the effects of excessive forward or reverse bias on structural breakdown with regard to thermal runaway and avalanche current.

(2) Identify the normal operating region.

c. From a group of PN junction circuit diagrams, select the arrangement that identifies proper forward bias; proper reverse bias. CTS: 5a Meas: W (2)

(1) Determine voltage requirements for P-Type and N-Type material to accomplish forward and reverse bias on a diode.

d. Given a circuit diagram of PN junction diodes indicating direct current paths, select the arrangement that identifies the majority current; the minority current. CTS: 5a Meas: W (1.5)

(1) Explain forward biasing with respect to majority current flow.

(2) Explain how reverse biasing results in minority current flow.

SUPPORT MATERIAL AND GUIDANCE

Student Instructional Materials
KEP-GP-29, PN Junctions and Diodes
[illegible]-17, Semiconductor Principles
[illegible]

Audio Visual Aids
T/K [illegible]0-2[illegible]1, Solid State Principles

Training Methods
Discussion (9 hrs) and/or Programmed Self Instruction
CTT Assignments (3 hrs)

Instructional Guidance
[illegible] specific objective assignments to be completed during CTT time in KEP-GP-29. [illegible] "carriers produced by heat" and "carriers produced by doping". The [illegible] is to relate this to a single type of carrier, electron or hole, rather [illegible] minority and majority carriers. In the N type material, holes are produced [illegible] heat and electrons are produced by doping. Point out that in "P" type material the minority carriers (electrons) are produced by heat and the majority carriers (holes) are produced by doping. Majority and minority current flow in opposite directions.

5

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
IV	Solid State Principles

1 COURSE CONTENT	2 DURATION (Hours)
1. PN Junctions and Diodes (Module 29)	12 (9/3)
a. Given a PN junction diode characteristic curve and values of forward and reverse bias voltage, compute forward bias resistance; compute reverse bias resistance. CTS: 5a Meas: W	(3)
(1) Use an energy level diagram to identify the valence, forbidden and conduction bands of P and N type material.	
(2) Relate the amount of doping to the number of majority carriers in both types of semiconductor material.	
(3) Explain the effects of heat on current carriers.	
(4) Explain junction recombination and electrostatic field development in P and N material.	
(5) Relate depletion region, barrier width and resistance to electrostatic field development.	
(6) Relate changes in temperature to the number of minority and majority carriers in terms of electron-hole pair generation.	
(7) Construct a characteristic curve for a P-N junction diode and explain conduction in terms of forward and reverse bias.	
(8) Calculate forward and reverse resistance using Ohm's Law.	

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

SIGNATURE	DATE	SIGNATURE	DATE

PLAN OF INSTRUCTION NO.	DATE	PAGE NO.
3AQR30020-1	20 November 1975	1

COURSE CONTENT

c. Given schematic diagrams for grounded emitter NPN or PNP transistors in static configurations indicating direct current paths, select the arrangement that identifies the proper direct current paths. CTS: 5b(1) Meas: W (1)

(1) Identify the grounded emitter configuration.

(2) Identify current flow from negative to positive.

(3) Identify electron flow against the arrow.

d. Given a list of statements, select the statement that describes the forward current transfer ratio (Beta) for the grounded emitter configuration. CTS: 5b(1) Meas: W (1)

(1) Explain Beta as the maximum theoretical current gain of a grounded emitter configuration.

(2) Given the formula for Beta, explain a change in the output resulting from a change in the input.

e. Given schematic diagrams for grounded base NPN or PNP transistor configurations indicating direct current paths, select the arrangement that identifies the proper current paths. CTS: 5b(1) Meas: W (1)

(1) Identify the grounded base configuration.

(2) Identify current flow from negative to positive.

(3) Identify electron flow against the arrow.

f. Given a list of statements, select the statement that describes the forward current transfer ratio (Alpha) for the grounded base configuration. CTS: 5b(1) Meas: W (1)

(1) Explain Alpha as the maximum theoretical current gain of a grounded base configuration.

(2) Given the formula for Alpha, explain a change in the output resulting from a change in the input.

g. Given circuit diagrams for grounded collector NPN or PNP transistor in static configurations indicating direct current paths, select the arrangement that identifies the proper direct current paths. CTS: 5b(1) Meas: W (1)

(1) Identify the grounded collector configuration.

(2) Identify current flow from negative to positive.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
IV	Solid State Principles

1 COURSE CONTENT	2 DURATION (Hours)
2. Transistors (Module 30)	12 (9/3)
a. Given the schematic diagram for a properly biased NPN or PNP transistor, determine the effect bias changes have on I_E, I_B, I_C, and I_{CBO}. CTS: 5b(1) Meas: W	(1.5)
(1) Explain the effect on barrier height and width for Emitter-Base forward bias.	
(2) Explain the effect on barrier height and width for Collector-Base reverse bias.	
(3) Describe current flow with regard to majority and minority current carriers.	
(4) Explain the effects of changing bias on a transistor in terms of barrier height, width, I_E, I_B, and I_C.	
(5) Show how heat effects majority and minority carriers.	
(6) Explain I_{CBO} in terms of leakage current.	
(7) Describe how a change in junction temperature affects I_{CBO}.	
b. Given a group of NPN or PNP circuit diagrams, select the arrangement that identifies the proper biasing method. CTS: 5b(1) Meas: W	(1.5)
(1) Explain normal bias on emmiter-base and collector-base junctions.	
(2) Explain how proper biasing can be achieved through the use of 1 or 2 power sources.	
(3) Give examples of properly biased NPN and PNP transistors.	

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

SIGNATURE	DATE	SIGNATURE	DATE

PLAN OF INSTRUCTION NO.	DATE	PAGE NO.
3AQR30020-1	20 November 1975	3

ATC FORM APR 75 133 ATC Keesler 6-1020 REPLACES ATC FORMS 337, MAR 73, AND 770, AUG 72, WHICH WILL BE USED.

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

( ) Identify electron flow against the arrow.

b. Given a list of statements, select the statement that describes the forward current transfer ratio (Gamma) for the grounded collector configuration. CTS: 5b(1) Meas: W (1)

(1) Explain Gamma as the maximum theoretical current gain of a grounded collector configuration.

(2) Given the formula for Gamma, explain a change in the output resulting from a change in the input.

. Measurement and Critique (Part 1 of 2 Parts) 1

a. Measurement test

b. Test critique

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-30, Transistors
KEP-ST-IV
KEP-110

Audio Visual Aids
TVK 30-153, Transistor Triodes (Construction)
TVK 30-154, Transistor Triodes (Operation)

Training Methods
Discussion (9 hrs) and/or Programmed Self Instruction
CTT Assignments (2 hrs)

Instructional Guidance
Give students specific objectives to be covered during CTT time. These objectives are covered in KEP-GP-30 and the digest for Block IV. Discuss the terms "common" and "grounded" as they apply to transistor amplifier configurations. Show methods of identifying the common element of a transistor amplifier. Insure that all students understand biasing principles. Inform students that Part 1 of the measurement test covers modules 29 and 30.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
IV	Solid State Principles

1 COURSE CONTENT	2 DURATION (Hours)
4. Amplifier Principles (Module 31)	22 (17/5)
a. Given the schematic diagram for NPN or PNP common emitter amplifier configuration and a list of statements, select the statement(s) which describe(s) the effect of input signal current and input signal voltage changes on current in each element and collector voltage; of load resistor changes on actual voltage, current, and power gain. CTS: 5b(1) Meas: W	(4)
(1) Using the characteristic curve, schematic diagram, values of V_{CC}, R_L, I_E, R_{EB} and input amplitude, construct a load line; determine the operating point; compute actual current (A_I), voltage (A_V) and power gain (A_P).	
(2) Describe the changes in A_I and A_V with variations in R_L using the characteristic curves and load lines.	
(3) Explain the effect on impedance matching and the resulting power gain with changes in R_L.	
(4) Develop an output waveform resulting from an input.	
b. Given the schematic diagram for NPN or PNP common base amplifier configuration and a list of statements, select the statement(s) which describe(s) the effect of input signal current and input signal voltage changes on current in each element and collector voltage; of load resistor changes on actual voltage, current, and power gain. CTS: 5b(1) Meas: W	(3)
(1) Recognize that common base configuration characteristic curves represent values of emitter current rather than base current.	

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

SIGNATURE	DATE	SIGNATURE	DATE

PLAN OF INSTRUCTION NO.	DATE	PAGE NO.
3AQR30020-1	20 November 1975	7

ATC FORM APR 75 133 ATC Keesler 6-1029 REPLACES ATC FORMS 337, MAR 73, AND 770, AUG 72, WHICH WILL BE USED.

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

(2) Using the characteristic curve, schematic diagram, values of V_{CC}, V_{EE}, R_E, I_E, and input amplitude, construct a load line; determine operating point; compute actual current, voltage and power gain.

(3) Explain the changes in actual voltage, current and power gain as the load resistance is changed.

(4) Develop an output waveform resulting from an input.

c. Given the schematic diagram for NPN or PNP common collector amplifier configuration and a list of statements, select the statement(s) which describe(s) the effect of input signal current and input signal voltage changes on current in each element and emitter voltage; of load resistor changes on actual voltage, current, and power gain. CTS: 5b(1) Meas: W (2.5)

(1) Explain that characteristic curves are not normally supplied for a common collector configuration.

(2) Recognize that changes in R_L have similar effects on current, voltage and power gain for all configurations.

(3) Using a circuit diagram with values of R_{EB}, R_E and input voltage, justify a gain of less than one for a common collector configuration.

(4) Develop an output waveform resulting from an input.

d. Given a transistor amplifier schematic diagram and a list of statements, select the statement that describes the cause of amplitude distortion; of frequency distortion; of phase distortion. CTS: 6(1) Meas: W (2)

(1) Describe amplitude distortion as it relates to the amount of forward bias.

(2) Identify the relationship of amplitude distortion and excessive input signal level.

(3) Explain frequency distortion resulting from reactive components.

(4) Define phase distortion resulting from reactive components.

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

e. Given temperature stabilized transistor amplifier schematic diagrams and a list of statements, select the statement(s) that describe(s) how collector current variations are minimized. CTS: 5b(1) Meas: W (3)

(1) Review the effects of temperature on base-emitter resistance.

(2) Identify the emitter resistor as a means of minimizing base current changes with temperature changes.

( ) Explain the degenerating properties of emitter resistors unless used with bypass capacitors.

(4) Show the thermistor as a means of limiting base current with temperature changes.

(5) Explain the operation of a T-type low pass filter (between collector and base) in reducing degeneration.

( ) Describe the use of a forward biased diode in limiting the effects of temperature change.

( ) Explain how the reverse biased diode presents a high resistance to I_{CBO}.

f. Given a list of statements, select the statement that describes the capabilities of direct, RC, impedance, and transformer coupling as related to frequency and gain. CTS: <u>5b(1)</u> Meas: W (2.5)

(1) Identify frequency ranges.

( ) Identify gain relationships throughout the normal operating range for the four basic types of coupling.

( ) Explain low frequency loss in RC coupling.

( ) Describe high frequency loss resulting from the following capacitance:

(a) Stray

(b) Interelement

(c) Distributed

SUPPORT MATERIALS AND GUIDANCE

<u>Student Instructional Materials</u>
[illegible], Amplifier Principles
[illegible]

PLAN OF INSTRUCTION NO	DATE	PAGE NO.
3AQR30020-1	20 November 1975	9

ATC FORM APR 75 133A ATC Keesler 6-0207 REPLACES ATC FORMS 337A, MAR 73, AND 770A, AUG 72, WHICH WILL BE USED.

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

KEP-110

Audio Visual Aids
TVK 30-323A, Amplifier Principles
TVK 30-325, Distortion
TVK 30-415, Construction of Load Lines
TVK 30-425, Transistor Stabilization
TVK 30-358, Transistor Audio Amplifier

Training Equipment
Ammeter Panel 4657 (1)
Voltage Amplifier Trainer 5960 (1)
Signal Generator 4864 (1)
Multimeter (1)
Oscilloscope (1)

Training Methods
Discussion (17 hrs) and/or Programmed Self Instruction
CTT Assignments (5 hrs)

Multiple Instructor Requirements
Safety, Equipment, Supervision (2)

Instructional Guidance
Insure that CTT time assignments are given in KEP-GP-51 and the Digest for Block IV. Discuss the steps used to establish a load line, and show how it is used to predict an amplifier's operation. Have the class perform an exercise and collectively plot a load line on a characteristic curve. Explain the effects of parameter changes on all amplifier configurations. An optional laboratory exercise can be performed to reinforce the theoritical concepts that have been discussed.

14

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles
BLOCK NUMBER IV	BLOCK TITLE Solid State Principles

1 COURSE CONTENT	2 DURATION (Hours)
5. Troubleshooting Solid State Amplifiers (Module 32)	12 (9/3)
a. Given a trainer having an inoperative transistor voltage amplifier circuit, schematic diagram, multimeter, signal generator, and oscilloscope, determine the faulty component two out of three times. CTS: 1a, 2c, 2b, 5c Meas: PC	(9)
(1) Review the operation of a common emitter amplifier circuit incorporating an emitter resistor and bypass capacitor.	
(2) Identify the effects of the following troubles:	
(a) Open biasing	
(b) Open emitter	
(c) Open collector	
(d) Open collector load resistor	
(e) Shorted collector to emitter.	

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

SIGNATURE	DATE	SIGNATURE	DATE

PLAN OF INSTRUCTION NO.	DATE	PAGE NO.
3AQR30020-1	20 November 1975	11

ATC FORM 133 APR 75 ATC Keesler 3-1029 REPLACES ATC FORMS 337, MAR 73, AND 770, AUG 72, WHICH WILL BE USED.

COURSE CONTENT

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-32, Troubleshooting Solid State Amplifiers
KEP-ST-IV
KEP-110

Training Equipment
Ammeter Panel 4657 (1)
Voltage Amplifier Trainer [illegible] (1)
Multimeter (1)
Signal Generator 4864 (1)
Oscilloscope (1)

Training Methods
Performance (9 hrs)
CTT Assignments (3 hrs)

Multiple Instructor Requirements
Safety, Equipment, Supervision(2)

Instructional Guidance
Insure CTT time assignments are given in KEP-ST-IV. Stress safety of equipment and personnel, by performing the laboratory exercise in an acceptable manner and using established maintenance techniques. Discuss the variables that may be encountered while performing the laboratory exercise and the importance of requesting instructor assistance as opposed to misusing the time available. Have the class scan through the exercise to acquire a general idea of the procedures before assigning them to the trainers.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
IV	Solid State Principles

1 COURSE CONTENT	2 DURATION (Hours)
6. Selected Solid State Devices (Module 33)	14 (11/3)
a. From a list of statements, select the statement(s) that describe(s) the high and low conduction conditions of the Unijunction Transistor. CTS: 5b(2) Meas: W	(2.5)
(1) Describe the basic construction of a unijunction transistor.	
(a) N-Type bar and P-Type emitter	
(b) P-Type bar and N-Type emitter	
(2) Describe the characteristics of the unijunction transistor.	
(a) High conduction between Base 1 and the emitter with a minimum resistance	
(b) Low conduction between Base 1 and Base 2	
(3) State two uses of the Unijunction Transistor utilizing a sawtooth generator circuit as an example.	
b. From a list of statements, select the statement(s) that describe(s) the conduction conditions of a Junction Field Effect Transistor. CTS 5b(3) Meas: W	(1)
(1) Describe the construction of the Junction Field Effect Transistor (JFET) and identify	
(a) the symbols.	
(b) the leads.	
(c) the "P" Type.	

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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PLAN OF INSTRUCTION NO.	DATE	PAGE NO.
3AQR30020-I	20 November 1975	13

ATC FORM APR 75 133 ATC Keesler 6-1020 REPLACES ATC FORMS 337, MAR 73, AND 770, AUG 72, WHICH WILL BE USED.

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

(d) the "N" Type

(2) Describe the requirements for proper biasing and the effects of reverse bias (Gate circuit) on the conduction of the JFET.

(3) Explain the development of characteristic curves for a JFET with respect to channel pinch off and breakdown voltage.

c. Given a schematic diagram of a Junction Field Effect Transistor amplifier in the common source configuration, determine the effect input voltage changes have on drain current. CTS: 5b(3) Meas: W (1)

(1) Identify the schematic diagram of a common source JFET amplifier.

(2) Explain the operation of the JFET amplifier by tracing the

(a) DC Path for current.

(b) signal path.

(3) Determine the effects that the input signal has on output voltage (Vds) and drain current (Id).

d. Given a list of statements, select the statement(s) that describe(s) conduction in enhancement and depletion Metal Oxide Semiconductor Field Effect Transistor. CTS: 5b(3) Meas: W (1)

(1) Identify the schematic symbol and leads of the Metal Oxide Semi-conductor Field Effect Transistor.

(a) Depletion MOSFET

(b) Enhancement MOSFET

(2) Describe the effect on the number of carriers in the channel when biasing a depletion type MOSFET and the conduction of current (Id).

(3) Describe the effect on the number of carriers in the channel when biasing an enhancement type MOSFET and the conduction of current (Id).

e. Given a characteristic curve for a tunnel diode and a list of statements, select the statement(s) that correlate(s) its operation to areas and points on the curve. CTS: 5b(4) Meas: W (1.5)

(1) Identify the schematic symbol of a tunnel diode.

(2) Describe the characteristics of a tunnel diode to include

(a) doping.

(b) barrier width and barrier height.

(3) Given a tunnel diode characteristic curve, identify the

(a) negative resistance region.

(b) peak point.

(c) valley point.

(d) region where tunneling occurs.

(e) normal operating region.

(f) region where conventional diode conduction occurs.

f. Given a list of statements, select the statement(s) that describe(s) the effect of a changing bias voltage on the capacitance of a varactor diode. CTS: 5b(6) Meas: W (.5)

(1) Identify the symbol of the varactor diode.

(2) Relate the N and P material to the plates of a capacitor.

(3) Compare the depletion region to the dielectric material of a capacitor.

(4) Relate bias voltage and capacitance.

g. From a list of statements, select the statement(s) that describe(s) the operation of a Silicon Controlled Rectifier in terms of breakover voltage; high conduction; holding current. CTS: 5b(5) Meas: W (.5)

(1) Describe a Silicon Controlled Rectifier in terms of

(a) number of junctions. (b) number of layers.

(2) Using a block diagram of an SCR and a schematic symbol of a battery, determine the bias (forward or reverse) at each junction and current direction.

(3) Using an SCR characteristic curve, describe the operation of the SCR in terms of

(a) breakover voltage

(b) high conduction

(c) holding current

h. Given a list of statements, select the statement(s) that describe(s) the effect of gate to cathode potential on breakover voltage of a Silicon Controlled Rectifier. (1)
CTS: 5b(5) Meas: W

(1) Using an SCR curve chart and a block diagram of an SCR, describe the effects of gate to cathode potential on

(a) minority current carriers in Section 2 in respect to reverse bias and current flow across the J-2 junction.

(b) breakover voltage.

(c) holding current.

i. Given a list of statements, select the statement(s) that describe(s) the operation of a Zener Diode in terms of voltage regulation. CTS: 5b(7) Meas: W (1)

(1) Describe the construction of a zener diode in terms of doping.

(2) Describe the purpose of the zener diode.

(3) Identify the schematic symbol.

(4) Using a zener diode characteristic curve, identify

(a) forward conduction.

(b) reverse bias break down voltage.

(c) avalanche current.

(d) voltage regulation (BV_R).

(5) Using a schematic of the zener diode voltage regulator, describe the

(a) purpose of the series limiting resistor in the circuit.

(b) voltage regulation.

j. Given a list of statements, select the one which describes applications of integrated circuits. CTS: 5b(8) Meas: W (.5)

(1) List applications of integrated circuits to include

(a) airborne equipment.

(b) missile systems.

(c) computers.

(d) spacecraft.

(e) portable equipment.

k. Given a list of statements, select the one which describes the physical characteristics of integrated circuits. CTS: 5b(8) Meas: W (.5)

(1) Describe the construction of integrated circuits in terms of

(a) components within a chip.

(b) monolithic circuits.

(c) hybrid circuits.

(2) List advantages of integrated circuits.

(a) Size and weight

(b) Increased reliability

(c) Lower cost

(d) Circuit performance

(e) Power requirements.

2

PLAN OF INSTRUCTION/LESSON PLAN PART 1 (Continuation Sheet)

COURSE CONTENT

(3) Describe disadvantages of integrated circuits.

(a) Low power handling capabilities

(b) Not repairable without replacing complete circuit.

7. Related Training (identified in course chart) 2

8. Measurement and Critique (Part 2 of 2 parts) 1

a. Measurement test

b. Test critique

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-33, Selected Solid State Devices
KEP-ST-IV
KEP-110

Audio Visual Aids
TVK-30-412, Field Effect Transistor
TVK-30-417, Tunnel Diode Amplifier

Training Methods
Discussion (11 hrs) and/or Programmed Self Instruction
CTT Assignments (3 hrs)

Instructional Guidance
Assign specific objectives to be covered during CTT time in KEP-GP-33 and portions [illegible] KEP-ST-IV for Block IV. Stress the doping characteristics of all selected solid state devices. List the solid state devices to be discussed in this module and cite practical applications for each. Since there are numbers of different solid state devices discussed in this module, and each is supported by a theoretical analysis of operation, stress the importance of logical organization to avoid confusion. Inform students that Part 2 of the measurement test covers modules 31 through 33.

31

PLAN OF INSTRUCTION NO. | DATE | PAGE NO.

ATC ST 3AQR3X020-[illegible]

Prepared by Keesler TT[illegible]

KEP-ST/Digest [illegible]

Technical Training

Electronic Principles (Modular Self-Paced)

Modules 29 - 33

DIGEST

1 August 1975

AIR TRAINING COMMAND

Designed For ATC Course Use

ATC Keesler 6-3728

DO NOT USE ON THE JOB

23

Electronic Principles Branch
Keesler Air Force Base, Mississippi

Student Text 3AQR3X020-X
KEP-ST/Digest-IV
1 August 1975

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)
MODULES 29-33

DIGEST

These Digests provide a summary for each module in the course. The Digest is designed as a refresher for students with electronics experience and/or education who do not need to study any of the other resources in detail.

After reading a Digest, if you feel that you can accomplish the objectives of the Module, take the Module Self-Check in the back of the Guidance Package. If you decide not to take the self-check select another resource and begin study.

CONTENTS

33

MODULE 29

PN JUNCTIONS AND DIODES

Understanding of the basic structure of an atom is essential to the study of all solid state devices. Silicon and germanium are the two basic elements used in their construction. Figure 29-1 illustrates a single atom of each element.

The outermost shell of an atom that contains electrons is the valence shell. Silicon and germanium have four valence electrons. When atoms of silicon or germanium are brought close together, they will share their valence electrons. This sharing of valence electrons is called COVALENT BONDING and is illustrated in figure 29-2.

The maximum number of electrons that an atom can have in its valence shell is eight and because of covalent bonding, the valence shells of silicon and germanium appear to be completely filled.

Another significant fact to consider is the energy positioning of the valence electrons. Electrons have both kinetic and potential energy. Their kinetic energy is the result of their movement in orbit about the nucleus and their potential energy is the result of being a specific distance from

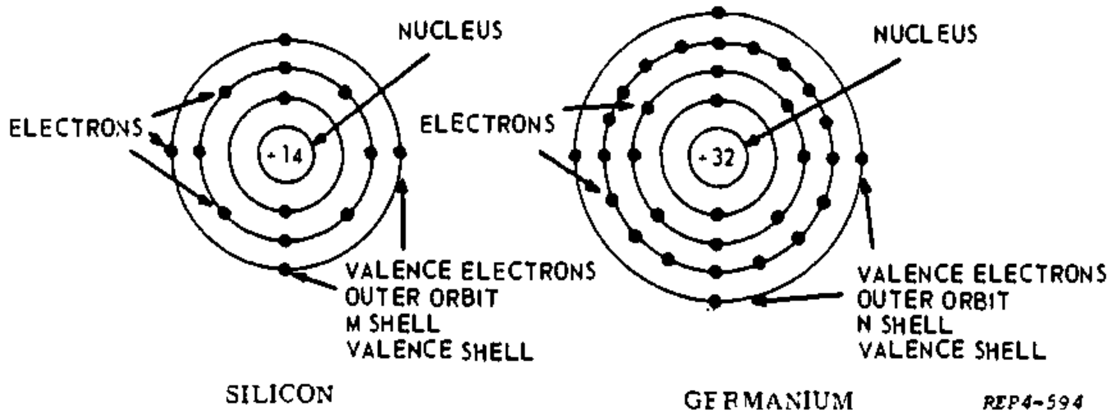

Figure 29-1. Pictorial Diagram of Atoms

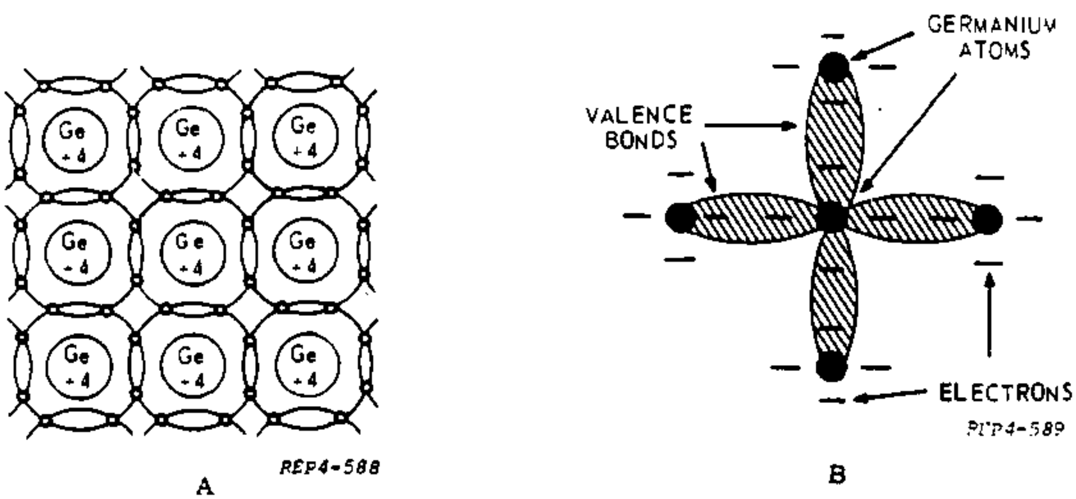

Figure 29-2. Covalent Bonding of Germanium Atoms

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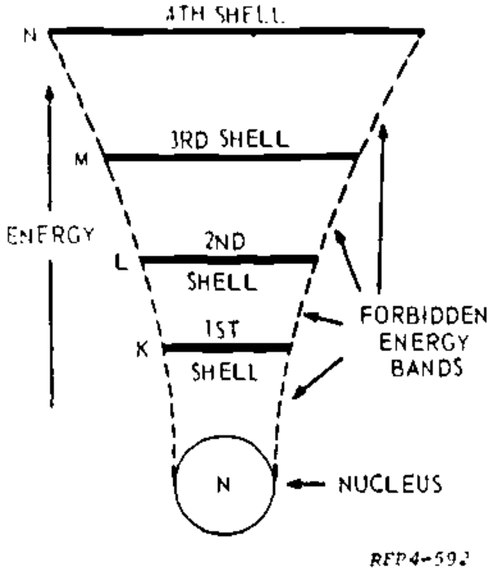

Figure 29-3. Energy Level Diagram of an Isolated Atom

the nucleus. Figure 24-3 illustrates these facts. The horizontal axis depicts the length of electron orbit and the vertical axis depicts the displacement of the electrons from the nucleus. Electrons in the third shell contain more energy than those in the second shell.

Figure 29-4A illustrates two isolated silicon atoms separated so that the electron orbits do not overlap. In figure 29-4B, the distance has been reduced so that the electron orbits of the valence electrons overlap. This results in the formation of a continuous band of energy throughout the material. This band of energy is referred to as the VALENCE BAND. Because of covalent bonding, the valence bands of silicon and germanium are completely filled with electrons.

The valence band of silicon is formed by the interaction of the M shell electrons. The next higher shell, the N shell, will also interact between adjacent atoms and form the conduction band of energy throughout the material. In germanium, the interaction will occur between the N and O shells, forming the valence and conduction energy bands, respectively.

The area between the shells in any atom is forbidden for electron orbits. That is, an electron cannot exist in this area. The interaction between the atoms that occurs when brought close together results in the formation of the forbidden energy band, and is an area between the valence and conduction bands. Because electrical conduction is confined to the valence, forbidden, and conduction energy bands, we will confine our discussion to these areas.

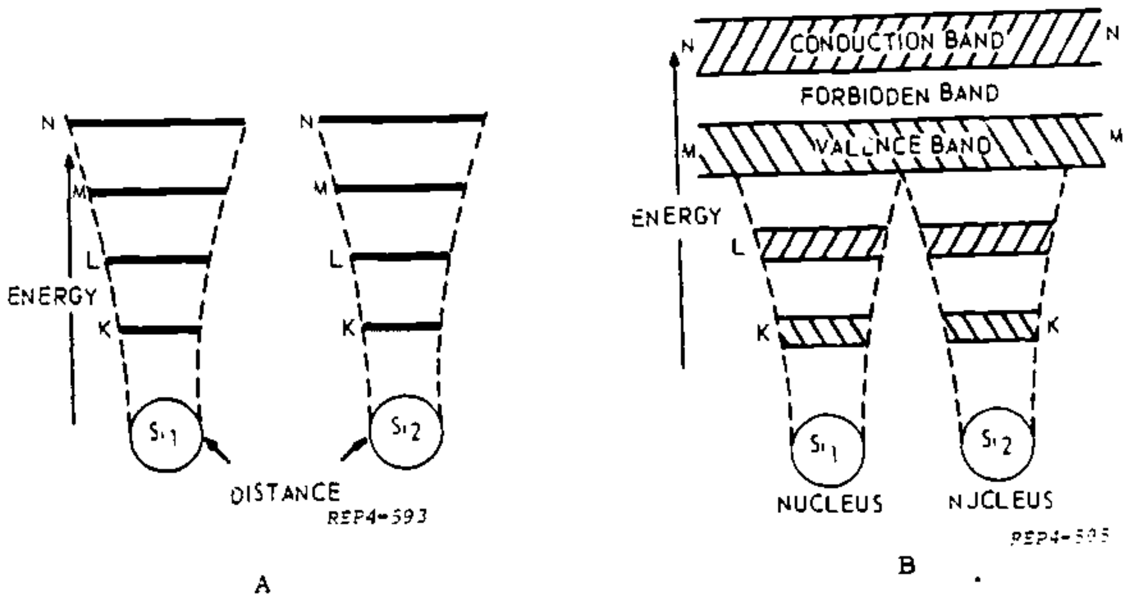

Figure 29-4. Energy Level Diagrams of Silicon Atoms

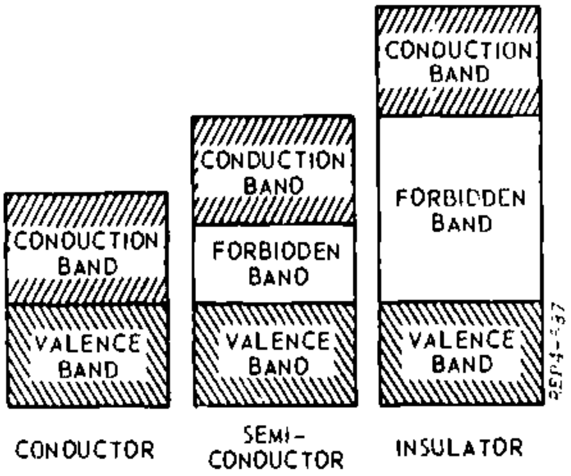

Figure 29-5. Energy Level Diagrams

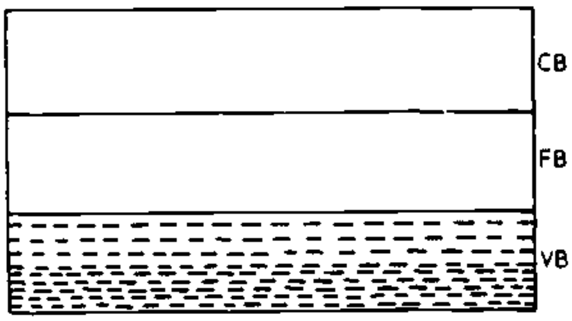

Figure 29-6. Energy Level Diagram of a Semiconductor at a Very Low Temperature

Figure 29-5 illustrates the energy band relationships that exist between conductors, semiconductors, and insulators.

The width (in energy) of the forbidden band is relative to the conductivity of a material. Silicon and germanium are semiconductor materials. Before a material can enter into electrical conduction, electrons in the valence band must be provided sufficient energy to move them into the conduction band. This energy can be in the form of heat, light, or an EMF. In a conductor, there is sufficient heat energy at room temperature to readily move valence electrons across the very narrow forbidden band into the conduction band. In a semiconductor, some of the valence electrons will react to heat energy and move into the conduction band. The

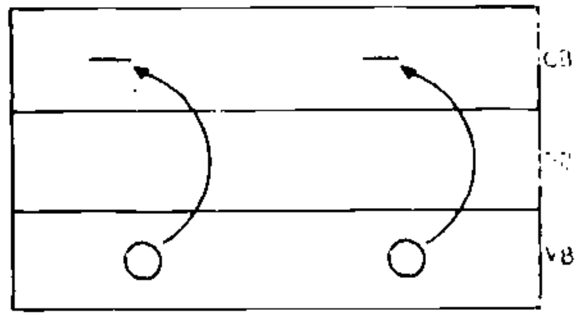

Figure 29-7. Energy Level Diagram of a Semiconductor at 25°C

number that moves is dependent on temperature. In an insulator, there is very little electron movement due to heat because of the extremely wide forbidden band.

Figure 29-6 illustrates an energy level diagram of silicon at a very low temperature where there is no movement of valence electrons across the forbidden band. The dashes (-) in the valence band indicate the presence of valence electrons.

When the temperature is increased to 25° Celsius (room temperature), some of the valence band electrons will pick up this thermal energy and move across the forbidden band into the conduction band. Figure 29-7 depicts this movement. The result is a small number of electrons in the conduction band. Electrons in the conduction band are FREE ELECTRONS and available for conduction. Another significant point to consider is that for each electron that is elevated into the conduction band, a vacancy is created in the valence band. The vacancies are referred to as HOLES and are represented on figure 29-7 as O. They are equal in magnitude but opposite in polarity to an electron. The process of elevating an electron into the conduction band and creating a hole in the valence band is referred to as ELECTRON-HOLE PAIR GENERATION. Holes and electrons will both respond to an electrostatic field. If an external voltage source is impressed across a piece of silicon or germanium, both the holes in the valence

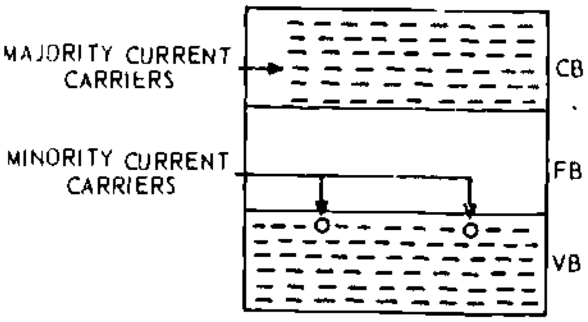

Figure 29-8. Energy Level Diagram of N-Type Material at 25°C

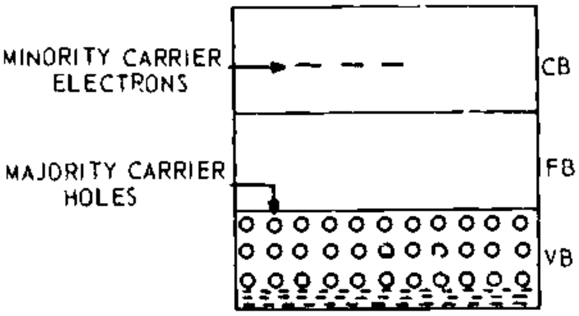

Figure 29-9. Energy Level Diagram of P-Type Material

band and the electrons in the conduction band will enter into electrical conduction. The holes move toward the negative voltage and the electrons move toward the positive voltage. Current flow will be small (microamperes) and is dependent upon temperature. Increasing temperature will increase electron-hole pair generation and thus increase current. Because of this characteristic, semiconductor materials exhibit a negative temperature coefficient of resistance. When temperature increases, the resistance of silicon or germanium decreases.

The structure and electrical properties of germanium or silicon are modified by the introduction of specific impurities to make them useful semiconductor materials. The process of introducing impurities is called DOPING. When germanium or silicon is doped with a pentavalent impurity such as arsenic, the structure is modified so that the number (concentration) of electron carriers in the conduction band is increased without increasing the concentration of hole carriers in the valence band. Four of the five arsenic valence electrons enter into covalent bonds with adjacent atoms and the fifth valence electron is excluded and appears in the conduction band of the semiconductor material. Figure 29-8 shows the result of adding a pentavalent impurity. The increased concentration of electron carriers (electrons have a negative charge) results in the material being named N-TYPE MATERIAL.

In the N-type material, the electron carriers in the conduction band are referred to as the MAJORITY CURRENT CARRIERS. The valence band holes, by comparison, are few in number and are referred to as the MINORITY CURRENT CARRIERS. Both majority and minority carrier concentration increases with an increase in temperature.

When germanium or silicon is doped with a trivalent impurity (such as aluminum) the structure is modified so that the concentration of hole carriers in the valence band is increased without increasing the concentration of electron carriers in the conduction band. The three valence electrons of the aluminum impurity enter into covalent bonds with adjacent atoms. This results in a deficiency in covalent bonding which produces a hole carrier in the valence band of the structure. Figure 29-9 illustrates the result of adding a trivalent impurity to a semiconductor. Because the hole carrier (holes have positive charges) concentration has been increased without increasing the electron carrier concentration, the material is named P-TYPE. In P-type material, the MAJORITY CURRENT CARRIERS are the holes and the MINORITY CURRENT CARRIERS are the electrons. P-type material also exhibits a negative temperature coefficient of resistance. Increasing the doping in both N- and P-type material increases the concentration of the majority current carriers.

Combinations of P- and N-type materials are used in the construction of solid state devices. The most basic combination is a simple PN junction diode. This device is manufactured by the chemical joining of a

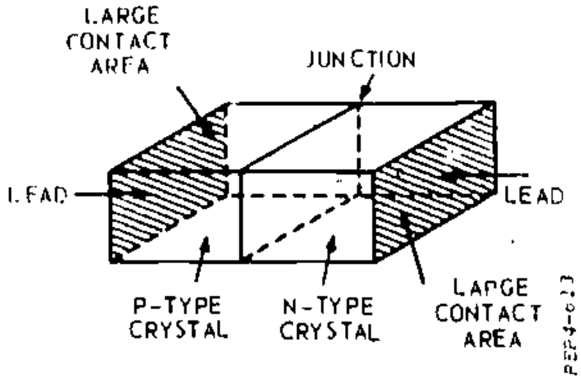

Figure 29-10. PN Junction Diode Pictorial Diagram

piece of N-type material to a piece of P-type material as illustrated in figure 29-10.

At the moment the P and N materials are joined, there will be a movement of electrons from the conduction band of the N-type material into the conduction band of the P-type material and at the same time there will be a movement of holes from the valence band of the P material to the valence band of the N material. This action is referred to as JUNCTION RECOMBINATION and will continue until equilibrium is reached.

The result of this diffusion is the formation of an area at the junction of the P and N materials that is [illegible] current carriers. In addition, on each side of the PN junction there will be a layer of ionized particles. The N material will become positively charged and the P material will have a negative charge at the junction. This ionization causes the energy bands of the P- and N-type materials to be displaced from each other. That displacement results from the fact that when a negative charge is applied to any material, it raises all of the energy levels of that material and when a positive charge is applied to a material, it lowers the energy levels. The displacement is represented in figure 29-11. The amount of displacement is called BARRIER HEIGHT and is proportional to the amount of doping. As doping concentrations are increased, the barrier height increases.

The area in the vicinity of the junction that has no current carriers (holes and electrons) is referred to as the DEPLETION REGION and its width is called BARRIER WIDTH. The barrier width is inversely proportional to the doping concentration and will decrease as doping is increased. Increased doping increases the carrier concentration in the vicinity of the junction and equilibrium is reached sooner.

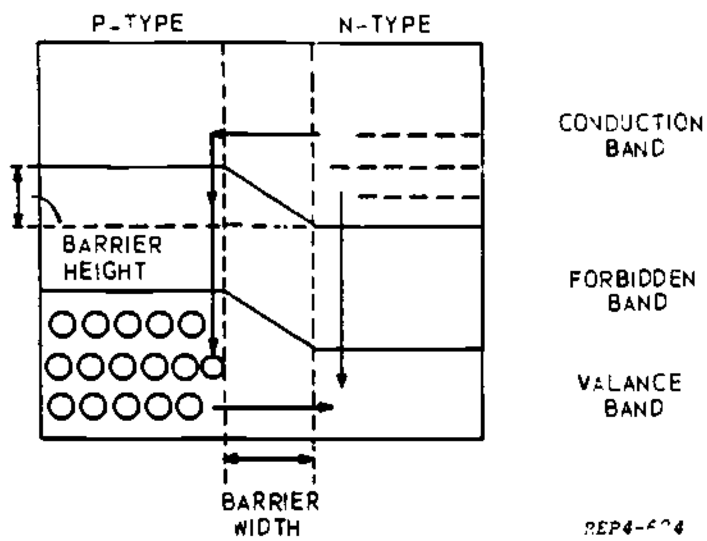

Figure 29-11. Energy Level Diagram of Junction Barrier Formation

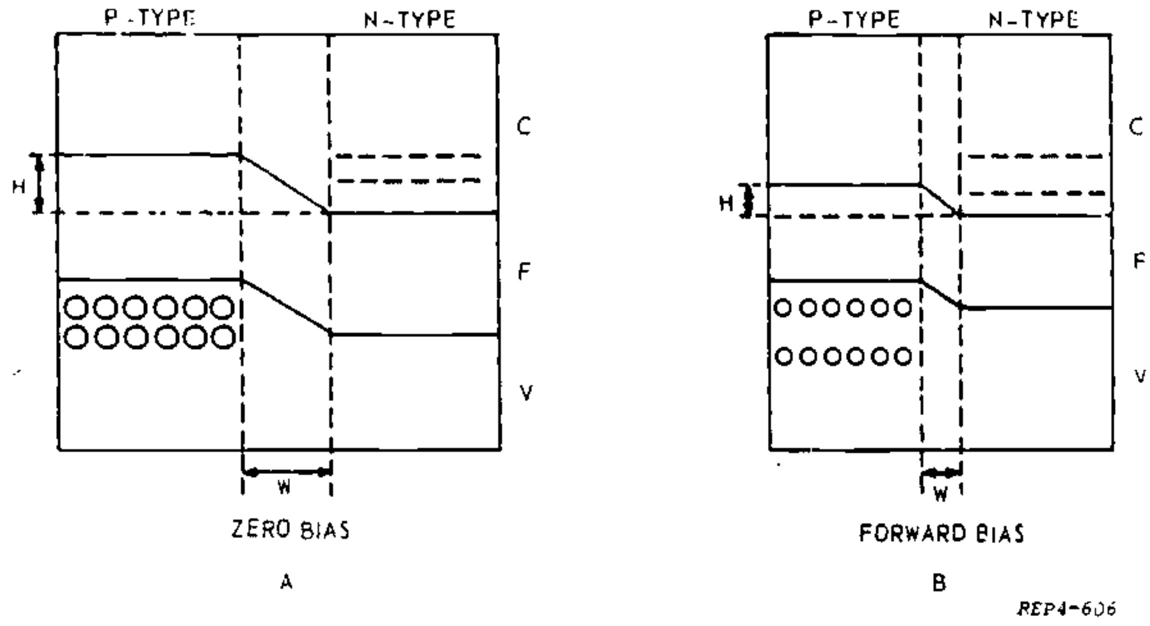

Figure 29-12. Effect of Forward Bias on Barrier Height, Width, and Junction E Field

After junction recombination occurs, the depletion region will act as a barrier to current flow. An external source of EMF can be applied to the PN junction diode so that it either aids or opposes the flow of current through the device. This external EMF is called BIAS which may be qualified as FORWARD or REVERSE. The effect of FORWARD bias on barrier height and width is shown in figure 29-12B.

Forward bias places a positive voltage on the P-type material and a negative voltage on the N-type material. This bias opposes the junction E field and reduces the barrier height and width. Forward bias, therefore, reduces the resistance of the PN junction and allows majority carriers to cross the junction.

Figure 29-13 shows the result of REVERSE bias being applied to a PN junction diode. Reverse bias places a negative voltage on the P-type material and a positive voltage on the N-type material. This bias aids the junction E field and increases the barrier height and width. Notice that the majority carriers in the N and P material are now aligned with the forbidden bands of the adjacent material. This prevents majority carrier current flow. The minority carriers are now properly aligned for conduction and will produce a small current (μA) flow when connected in a circuit. A reverse biased PN junction diode has very high resistance and a small minority carrier current flow.

Figure 29-14 graphically depicts the relationship of forward and reverse bias voltages to current flow in a typical PN junction diode.

In the forward bias portion of the graph, the resistance of the diode can be computed using Ohm's Law. For instance, the resistance at point B would be:

$$R = \frac{E}{I} = \frac{3V}{50\ mA} = 60 \text{ ohms}$$

In the reverse bias area, the resistance of the diode at point C would be:

$$R = \frac{E}{I} = \frac{80V}{100\mu A} = 800 \text{ k ohms}$$

The solutions readily show that a PN junction diode offers very little opposition to current

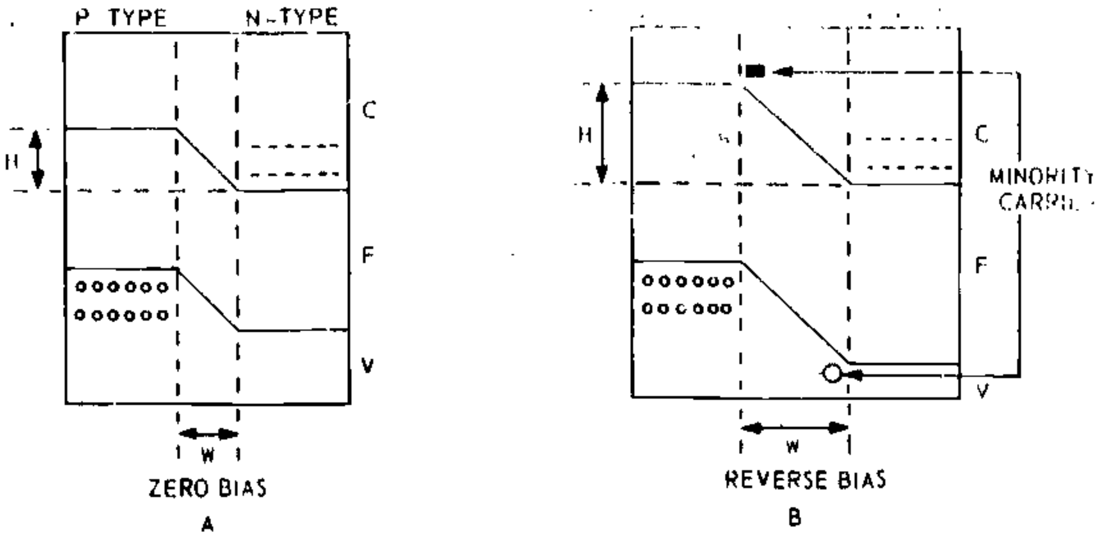

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Figure 29-13. Effect of Reverse Bias on Barrier Height, Width, and Junction E Field

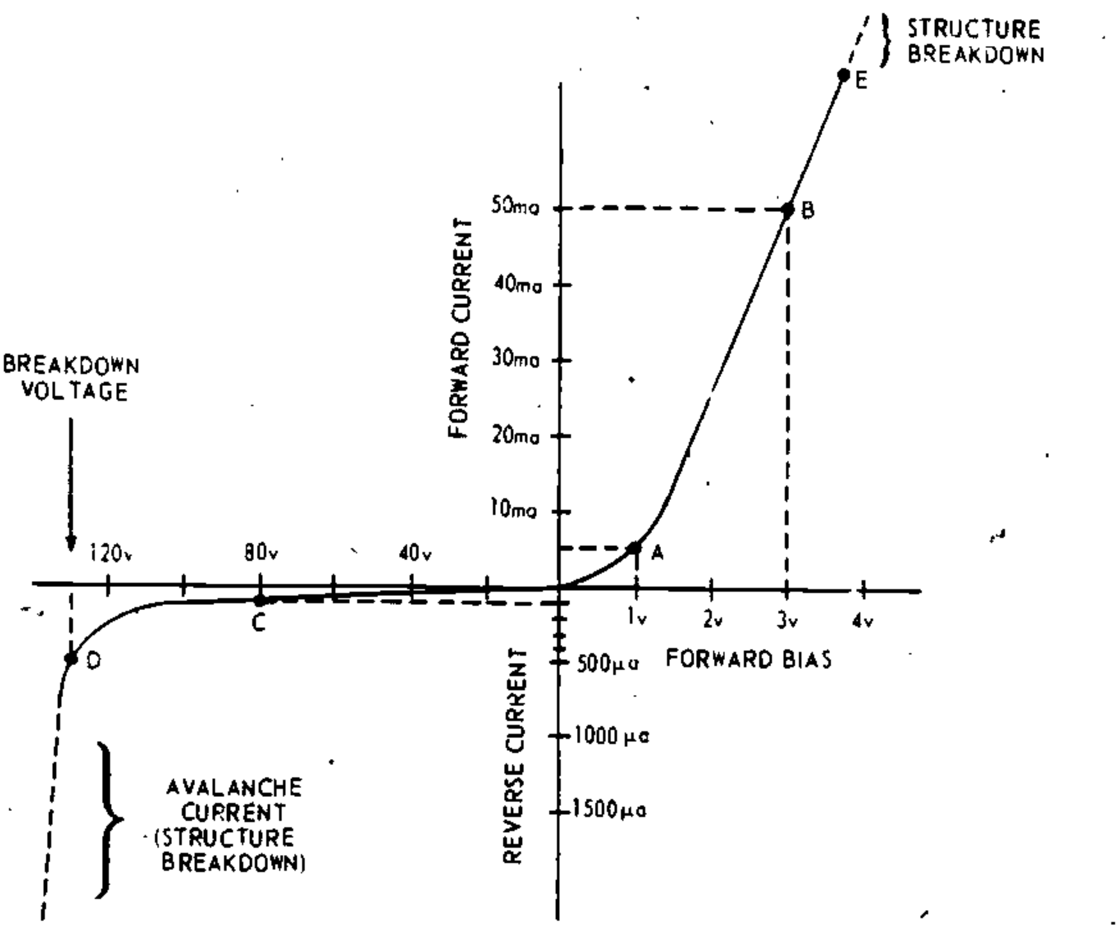

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Figure 29-14. Voltage-Current Characteristics of a Diode

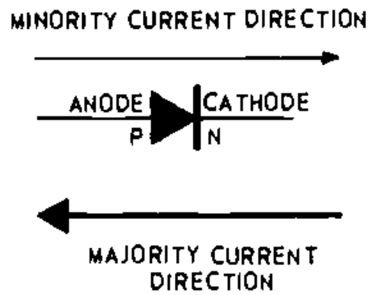


Figure 29-15. Schematic Diagram of a PN Junction Diode Showing Majority and Minority Current Direction

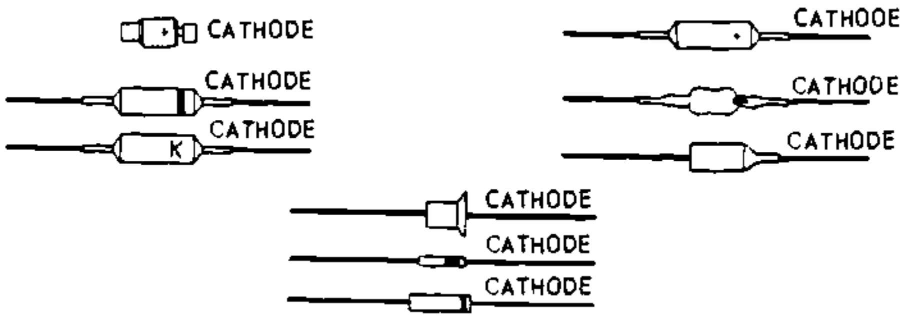


Figure 29-16. Physical Appearance of Semiconductor Diodes

flow in the forward bias direction and an extremely high opposition to current flow in the reverse bias direction.

A PN junction diode can be destroyed if excessive forward or reverse bias voltages are applied. On the graph in figure 29-14, operation of the diode beyond point E will cause excessive heat to be generated (Power = IE). This heat energy will cause an excessive number of electron-hole pairs to be generated and destroy the semiconductor material. In the reverse bias direction, when the voltage becomes excessive (point D), there is sufficient energy supplied to the covalent bonded electrons to cause them to break their bonds and reach the conduction band. This results in avalanche current and causes structural breakdown.

The schematic symbol for a PN junction diode is shown in figure 29-15. The lead connected to the P-type material is called the ANODE and the lead connected to the N-type material is the CATHODE. Majority current direction is from cathode to anode and minority current direction is from anode to cathode.

Figure 29-16 shows some typical PN junction diodes and identifies the cathode lead. Note the distinctive markings or shape of this lead.

MODULE 30

TRANSISTORS

Transistors are manufactured by sandwiching a thin piece of N type material between two pieces of P type material or by sandwiching a thin piece of P type material between two pieces of N type material. This results in the formation of

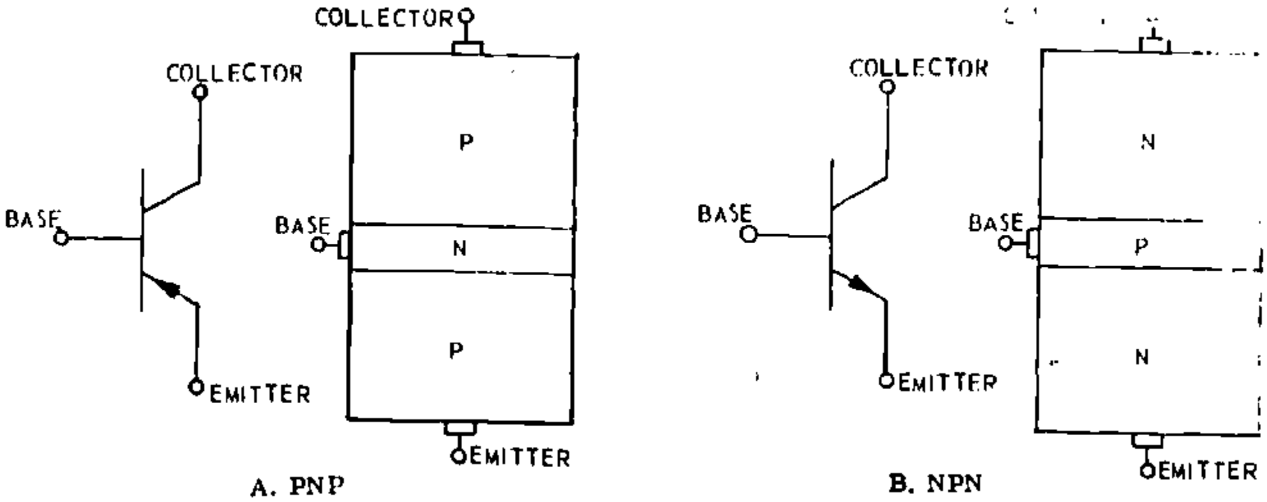


Figure 30-1. Pictorial and Schematic Diagrams of PNP and NPN Transistors

the PNP and NPN transistor as shown in figure 30-1A and B.

Metallic contact points are bonded and leads are attached to each section. The thin region is called the base and the other areas are called the emitter and collector. The emitter is normally smaller and more heavily doped than the collector and the base region is lightly doped. Note that the arrowhead on on the schematic diagram is on the emitter lead and the direction of the arrowhead identifies the type transistor (NPN or PNP).

Transistors have two PN junctions; the emitter/base (EB) junction and the collector/base (CB) junction. For conduction the EB junction is forward biased and the CB junction is reverse biased. Figure 30-2 shows the result of forward biasing a NPN transistor, and figure 30-3 depicts the result of forward biasing a PNP transistor.

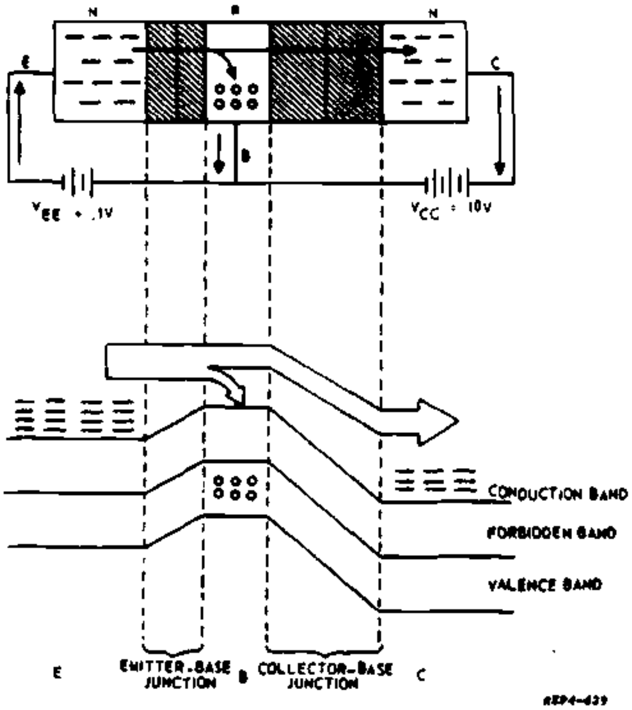


Figure 30-2. Pictorial and Energy Level Diagram of a Biased NPN Transistor

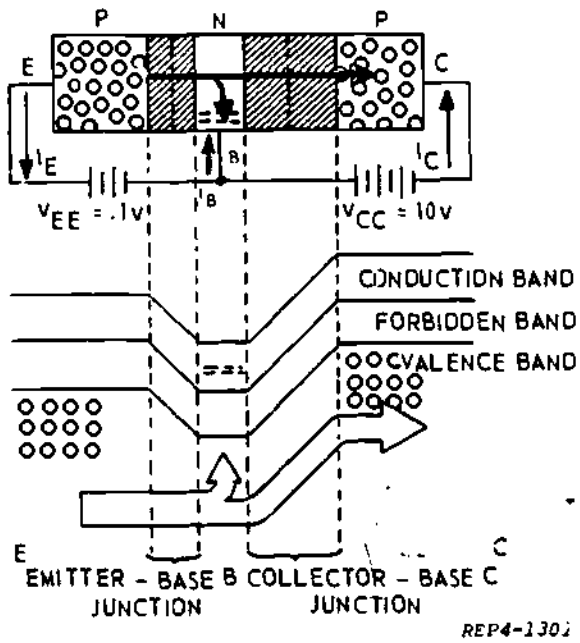


Figure 30-3. Pictorial and Energy Level Diagram of a Biased PNP Transistor

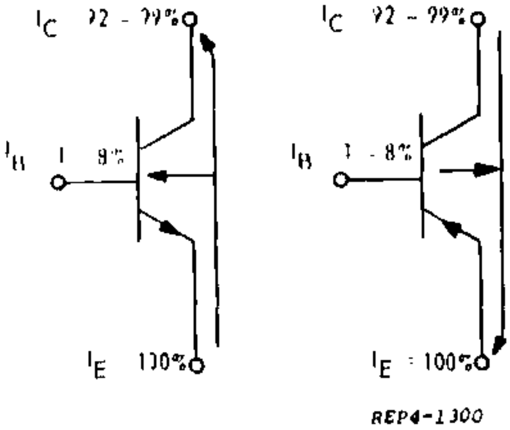


Figure 30-4. Schematic Symbols for NPN and PNP Transistors

The forward bias voltage (V_{EE}) causes an injection of majority carriers from the heavily doped emitter region into the thin, lightly doped base region. Once in the base region, the injected carriers become minority carriers. These minority carriers in the base are subjected to two forces; one is the attraction of the V_{EE} forward bias voltage and the other force is the extremely intense "E" field of the CB junction produced by the large reverse bias voltage (V_{CC}). From 92 to 99% of the injected carriers will move to the collector. From 1 to 8% of the carriers will return to the forward bias source (V_{EE}). The current distribution of transistors is as follows:

Emitter Current (I_E) = 100%
Base Current (I_B) = 1 to 8%
Collector Current (I_C) = 92 to 99%

The only difference in the operation of the NPN and PNP transistors is the voltage polarities and direction of external current flow. The larger the percentage of transfer of majority carriers from the emitter region, through the base region to the collector region, the more efficient the transistor. Figure 30-4 indicates the external circuit current direction and the relative magnitudes of the current for NPN and PNP transistors.

The significant fact that makes transistors useful in electronics is the effect that small forward bias voltage changes have on the transistor currents. Figure 30-5 illustrates the controlling effect that forward bias voltage changes have on transistor currents in relation to barrier heights and widths for

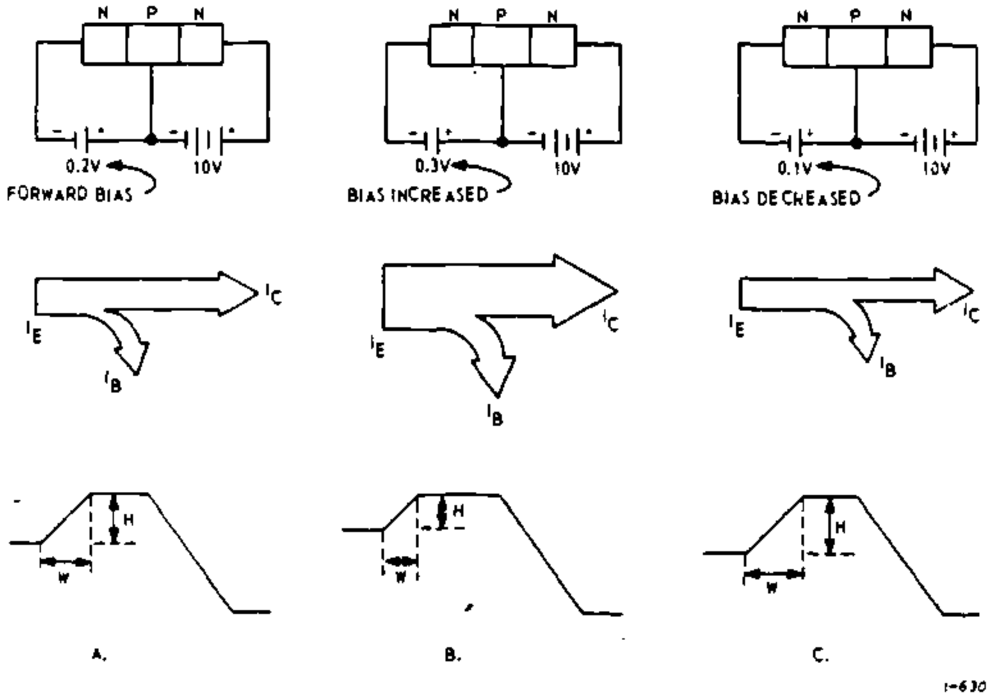


Figure 30-5. Controlling Effect of Varying Forward Bias (NPN, Resulting Electron Flow (center), and Energy Level (bottom)

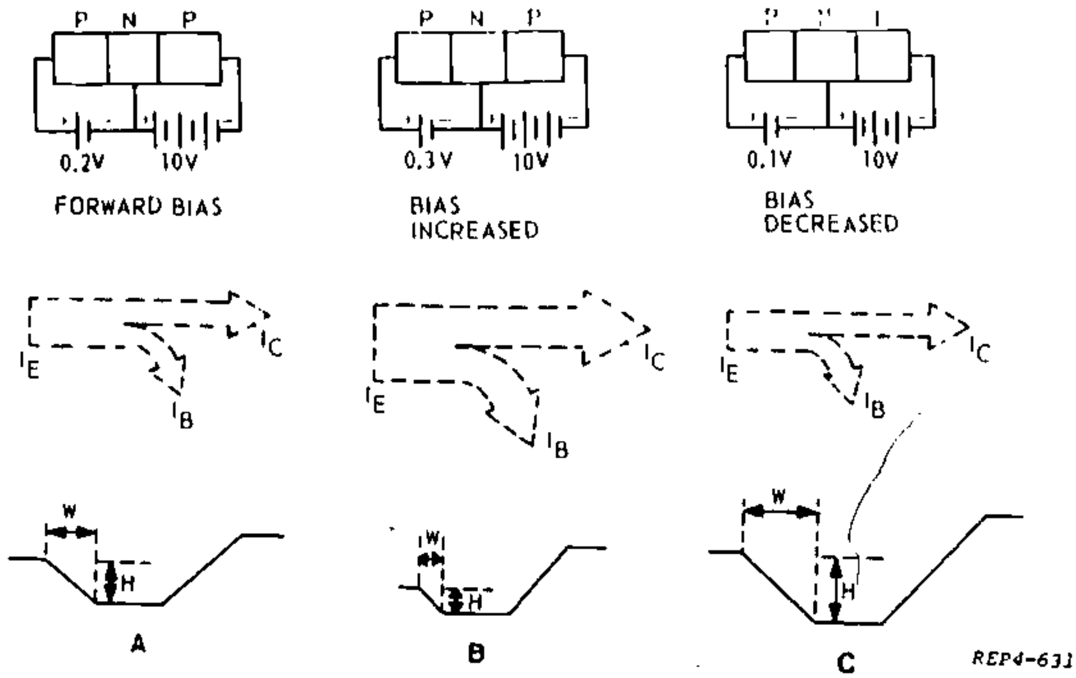


Figure 30-6. Controlling Effect of Forward Bias (PNP), Resulting Hole Flow, (center), and Energy Level Diagram (bottom)

an NPN transistor. Figure 30-6 illustrates the same information for a PNP transistor.

Figure 30-7 diagrams the forward bias voltage relationship with collector current. The graph shows the extremely nonlinear relationship that exists.

Because of this nonlinear relationship, further discussions about forward bias

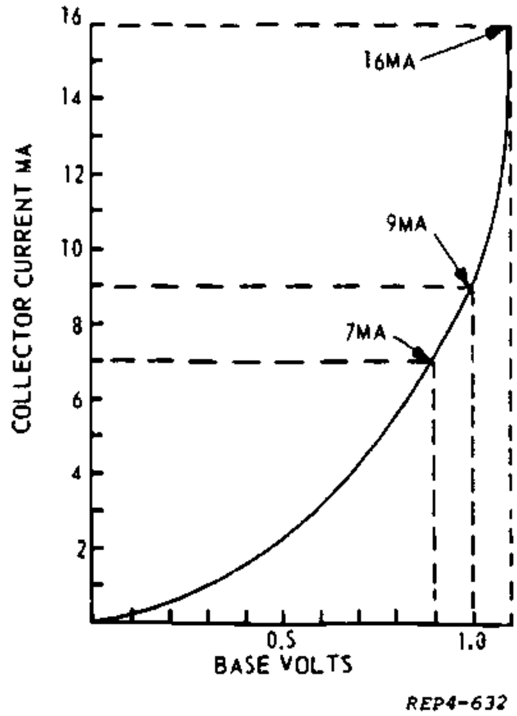


Figure 30-7. Nonlinear Characteristics of Emitter-Base Voltage vs Collector Current

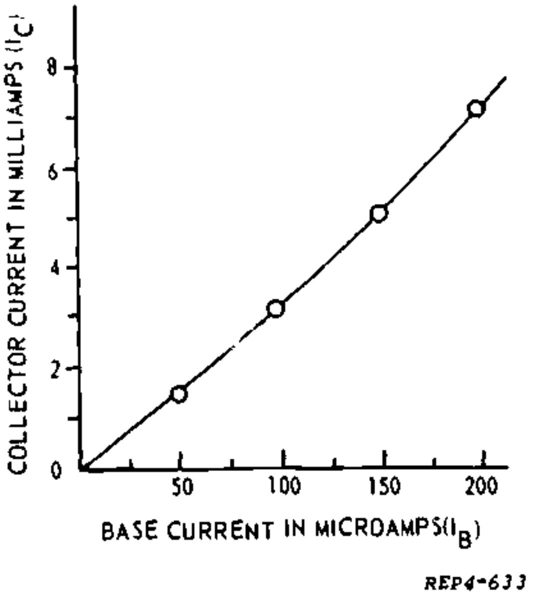


Figure 30-8. Linear Characteristics of Base Current vs Collector Current

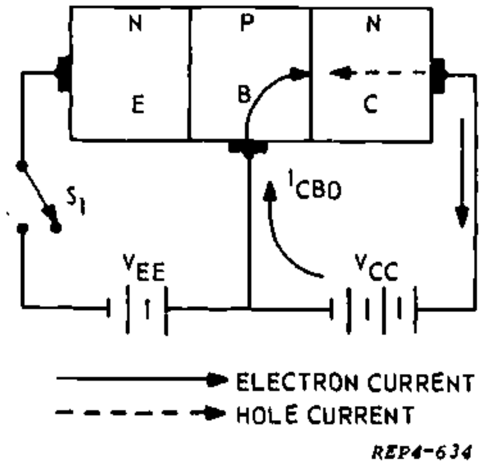


Figure 30-9. I_{CBO} in an NPN Transistor

changes will be referred to as base current changes rather than emitter/base voltage changes. Figure 30-8 shows the linear relationship between base current and collector current changes.

Another transistor current that has not been discussed is the minority current that flows across the reverse biased CB junction. This current is in the order of microamperes and can not be measured when normal transistor currents are present. To measure this current the forward bias is removed and the current observed as illustrated in figure 30-9.

The term I_{CBO} is used to identify this current as the current (I) between the collector/base (CB) junction with the emitter lead open (O). The magnitude of this current is dependent primarily upon temperature. An increase in temperature of 8 to 10° Celsius will double the magnitude of I_{CBO}. Changes in the value of the V_{CC} supply voltage will

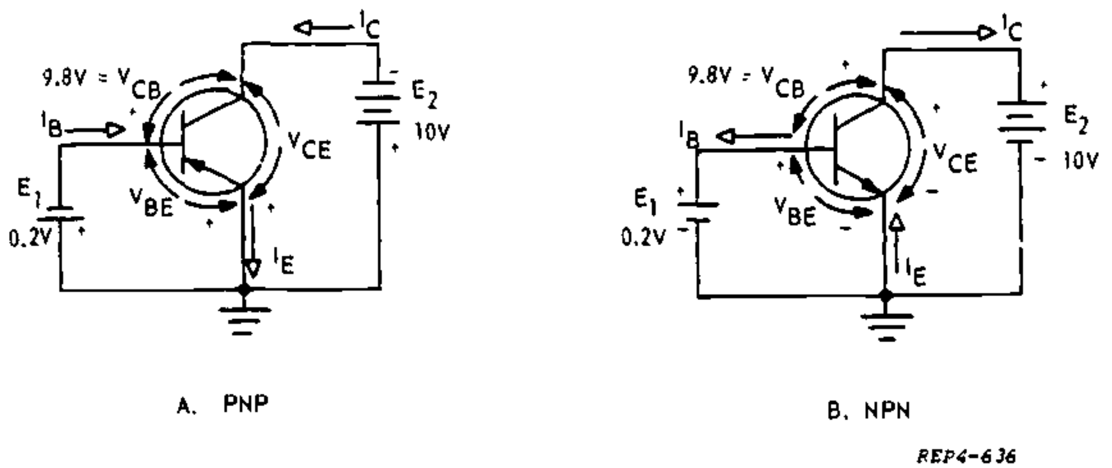


Figure 30-10. Bias Polarities and Current Directions

have little or no effect on the magnitude of I_{CBO}.

Figure 30-10 shows biasing possibilities for NPN and PNP transistors using two voltage sources.

Figure 30-11 illustrates methods of obtaining the same voltage distributions using a single voltage source.

A transistor can be connected in the following three basic configurations:

1. The Common Emitter (CE).

2. The Common Base (CB).

3. The Common Collector (CC).

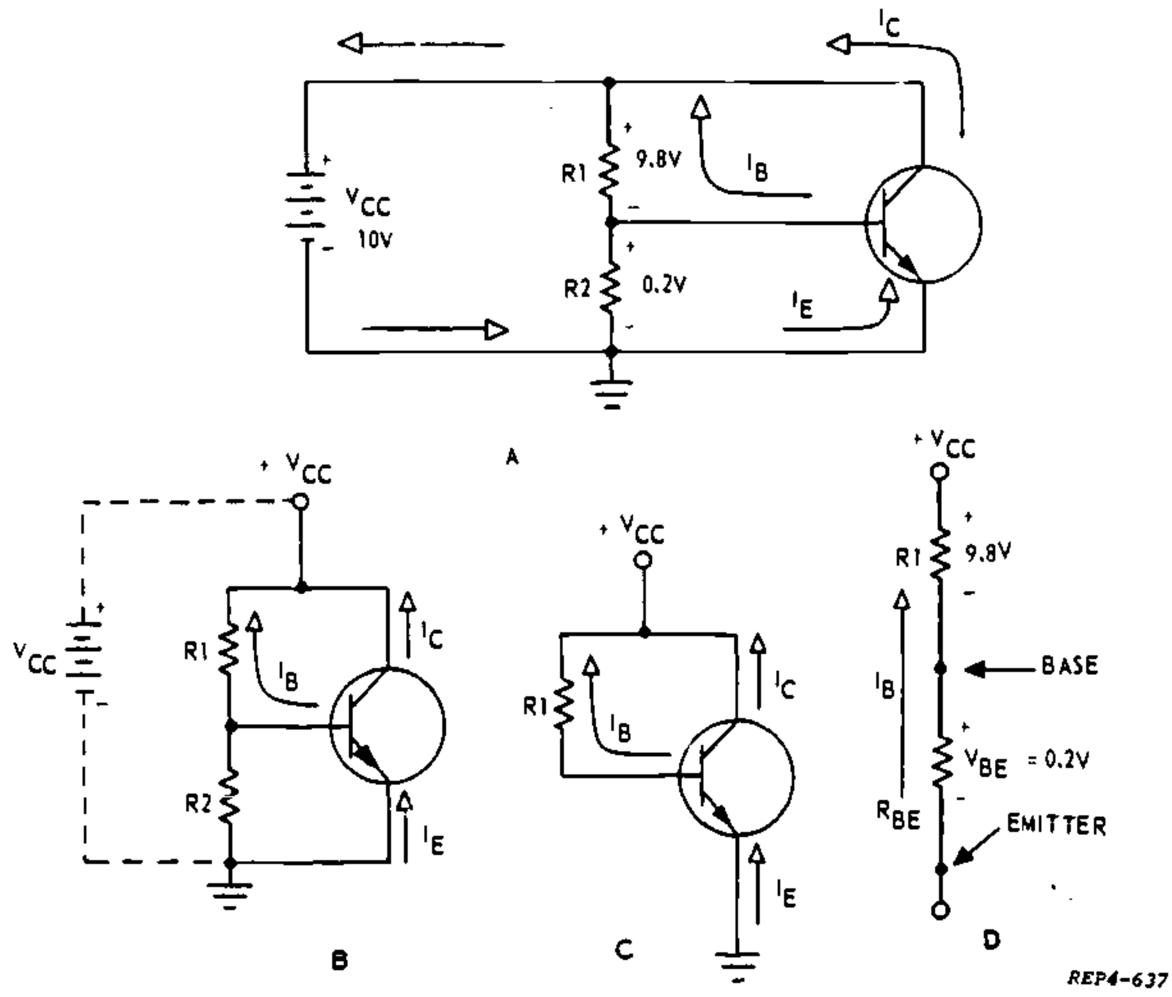


Figure 30-11. Biasing a Transistor from a Voltage Divider

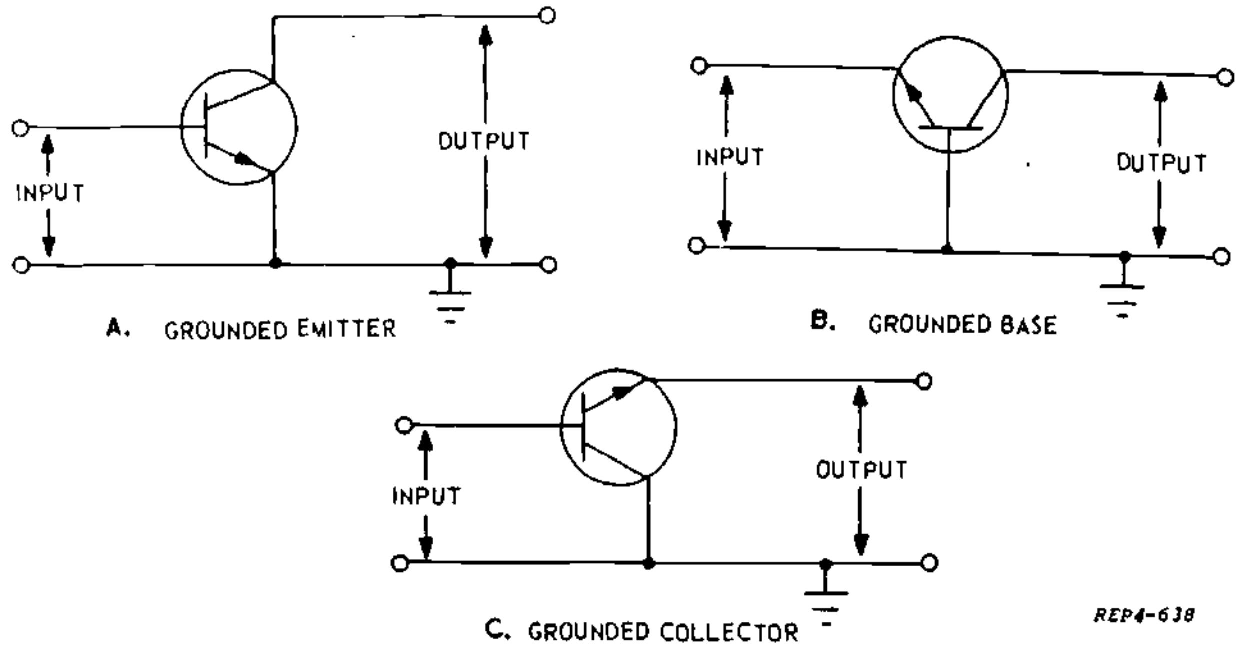


Figure 30-12. Transistor Configurations

Figure 30-12 shows these configurations and their relationships. Notice that the grounded element is being used as the common point of reference in each configuration, thus the terms COMMON or GROUNDED are used to identify each configuration.

The common (grounded) emitter configuration will be discussed first. In this circuit, the control that base current (I_B) maintains over collector current (I_C) is

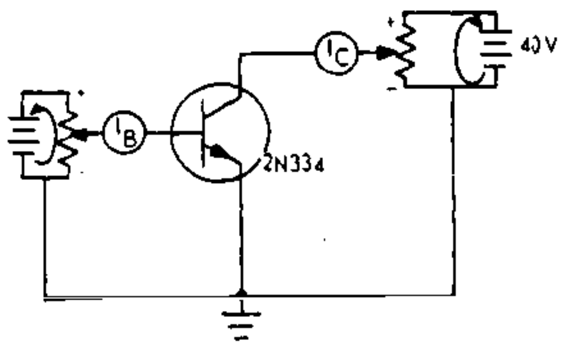


Figure 30-13. Static CE Configuration Test Circuit

called the forward current transfer ratio and is referred to as BETA (β), stated mathematically as:

$$\beta = \frac{\Delta I_C}{\Delta I_B} \text{ with } V_{CE} \text{ constant}$$

The Greek letter Delta (Δ) in the formula is used to indicate a change. The value of beta will be different for each type transistor that is manufactured. Figure 30-13 shows a static CE configuration test circuit and figure 30-14 shows a family of characteristic curves for a 2N334 transistor. The static circuit is used to develop the characteristic curves. The curves are normally developed and provided by the manufacturer. The curves depict the relationship of collector to emitter voltage to collector current for different values of base current.

Using the characteristic curves for a 2N334 transistor (figure 30-14), the control that I_B exhibits over I_C can be computed. With a constant V_{CE} of 20 V, a 25 μA change in I_B (from 75 μA to 100 μA) results in a

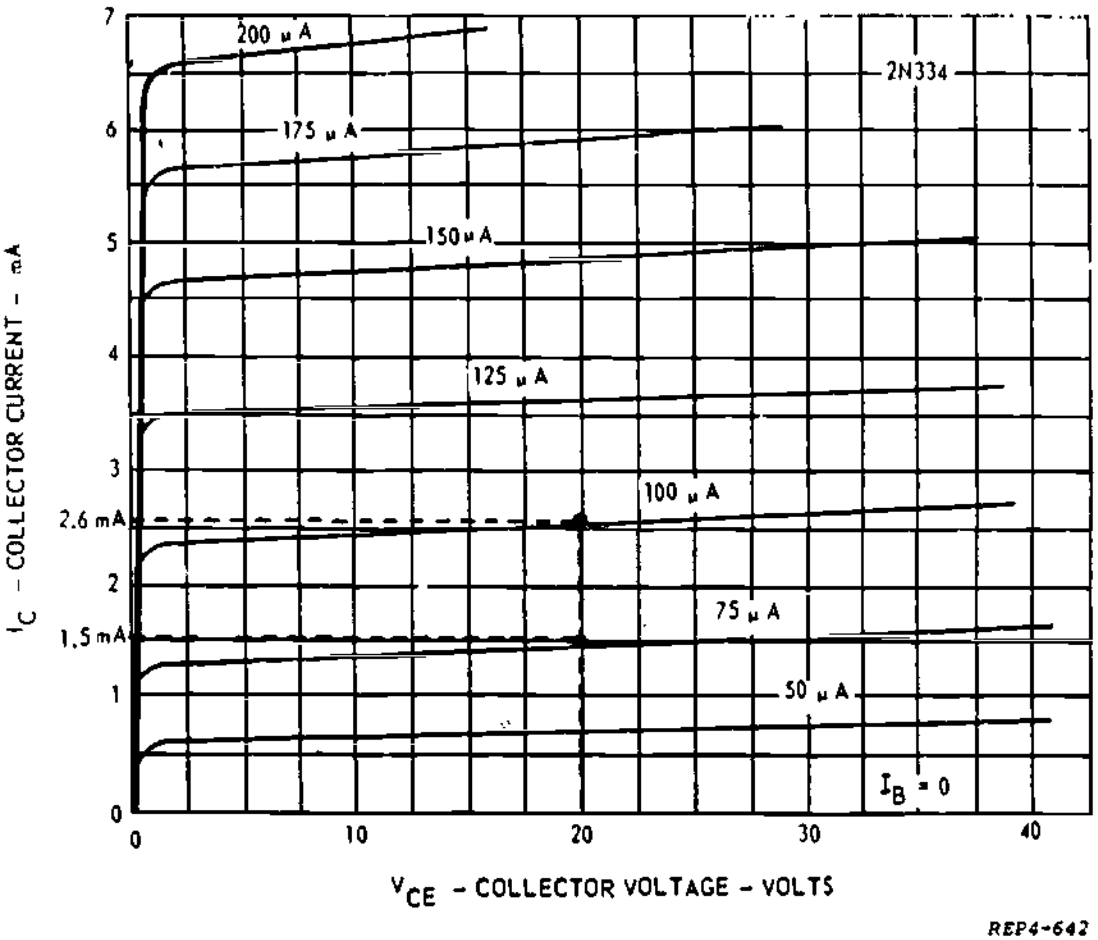


Figure 30-14. CE Characteristic Curve

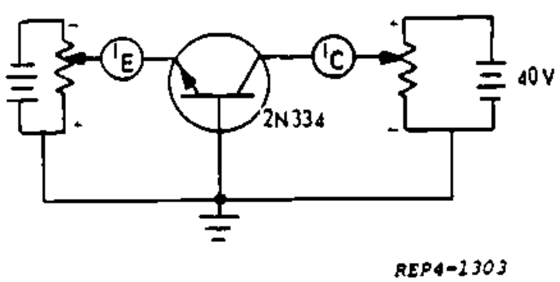


Figure 30-15. Static CB Configuration Test Configuration

change in I_C of 1.1 mA (from 1.5 mA to 2.6 mA). Thus, the forward current transfer ratio (BETA) is 44.

In the common (grounded) base configuration, the control that emitter current (I_E) exhibits over collector current (I_C) is called forward current transfer ratio and is referred to as ALPHA (α). It is stated mathematically as:

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \text{ with } V_{CB} \text{ constant.}$$

As with beta, the value of alpha differs with each type transistor. Figure 30-15 shows a static CB configuration test circuit

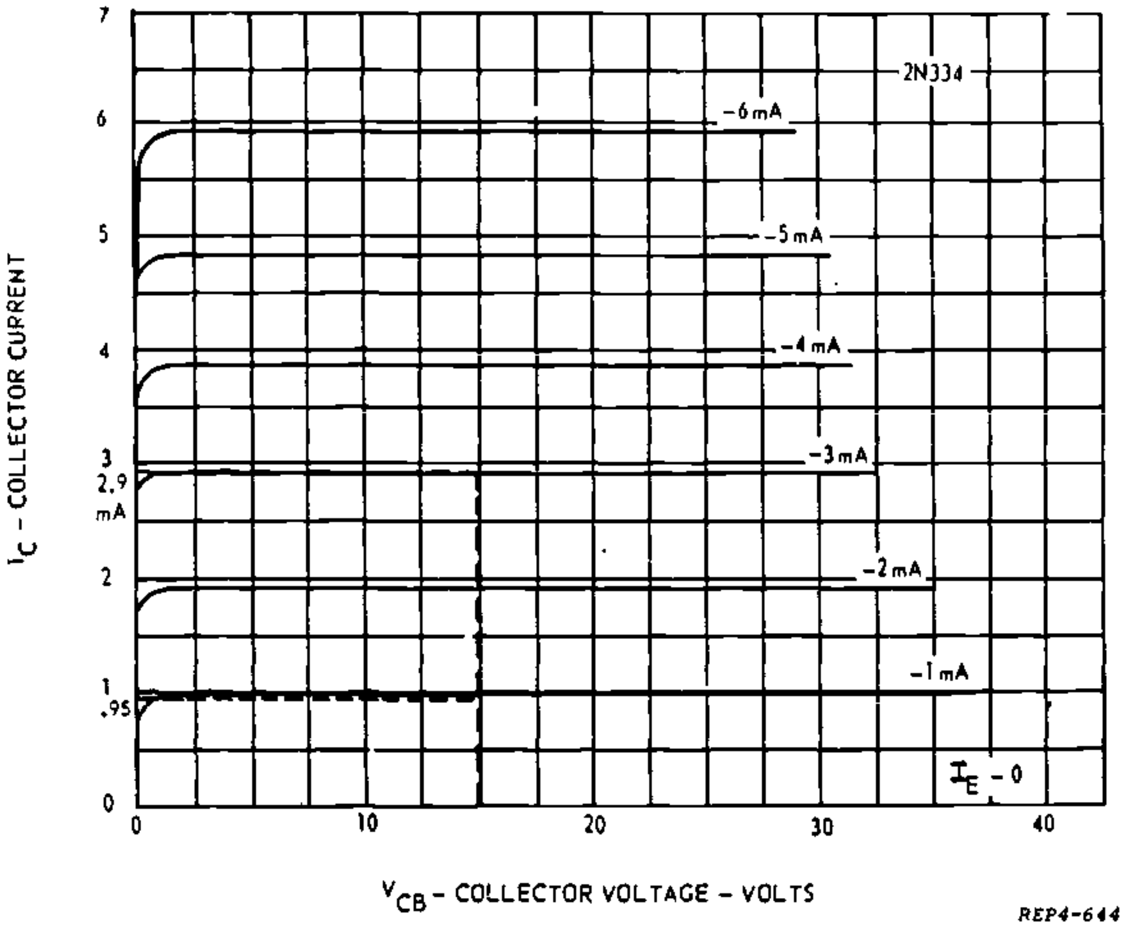


Figure 30-16. CB Characteristic Curves

and figure 30-16 shows a family of characteristic curves for a 2N334 transistor. The curves depict the relationship of V_{CB} to I_C for different values of I_E.

Using the characteristic curves for a 2N334 transistor (figure 30-16), the control that I_E has over I_C can be computed. With a constant V_{CB} of 15 V, a 2 mA change in I_E (from 1 to 3 mA) results in a change in I_C of 1.95 mA (from .95 mA to 2.9 mA). Thus, the forward current transfer ratio (alpha) is .975. Note that alpha is less than one.

In the common (grounded) collector configuration, the control that I_B exerts over I_E is called the forward current transfer ratio and is referred to as GAMMA (γ). It is stated mathematically as:

$$\gamma = \frac{\Delta I_E}{\Delta I_B} \text{ with } V_{CE} \text{ constant.}$$

Output characteristic curves are seldom prepared for the common collector configuration. Gamma is computed by calculating beta, then adding one (1). The formula now becomes:

$$\gamma = \beta + 1$$

For example, gamma for a 2N334 transistor would be beta (44) + 1 or 45.

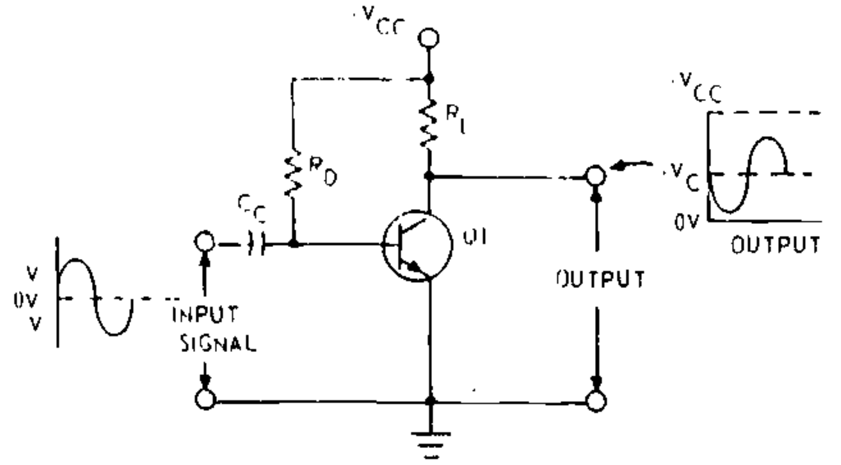


Figure 31-1. Common Emitter Amplifier (NPN)

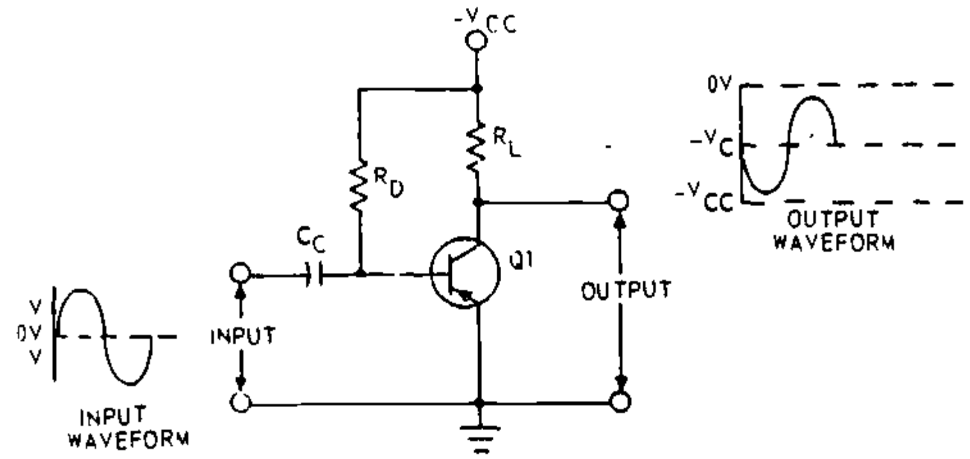


Figure 31-2. Common Emitter Amplifier (PNP)

MODULE 31

AMPLIFIER PRINCIPLES

Amplification factor is the ratio of the output changes to input changes and is called gain. These changes can be in the form of current, voltage, or power. The amount of gain realized in a transistor amplifier is dependent upon the type of configuration and the value of circuit components. Figure 31-1 illustrates a basic common emitter amplifier using an NPN transistor. Components serve the following functions:

Q1 - Amplifying device
R_L - Develop output signal
R_D - Provide bias
C_C - Coupling capacitor

On the positive alternation of the input signal, forward bias is increased, resulting in an increase in I_E, I_B, and I_C. The voltage drop across R_L (E_{RL}) will also increase, causing V_C (the output voltage) to decrease.

On the negative alternation of the input signal, forward bias is decreased, resulting in a decrease in I_E, I_B, and I_C. E_{RL} will decrease, causing V_C to increase. The input and output voltage waveshapes are 180° out of phase.

Figure 31-2 is a common emitter amplifier using a PNP transistor.

The PNP transistor amplifier operates like the NPN transistor amplifier except for the direction of current and the polarity of the

41

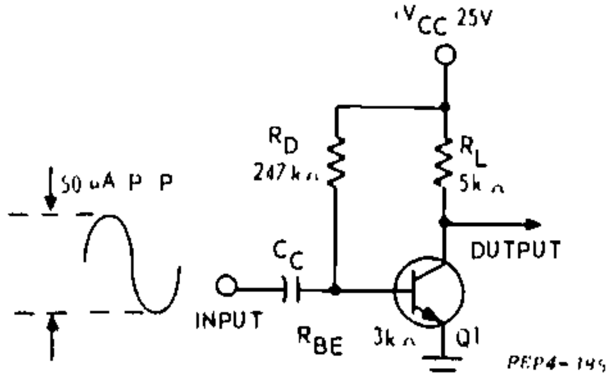


Figure 31-3. Transistor Amplifier Circuit

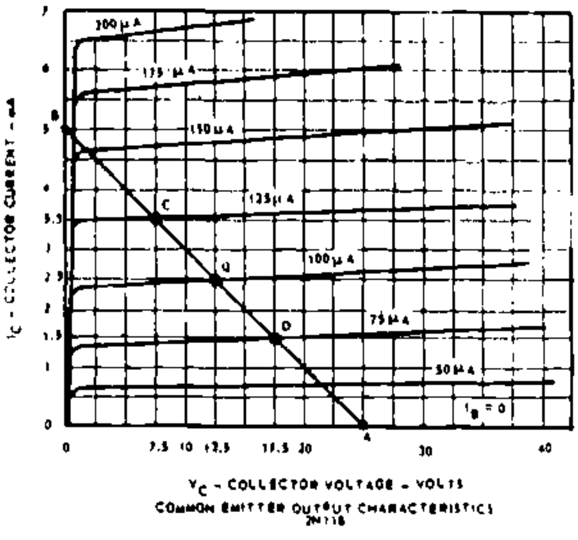


Figure 31-4. Load Line for 2N118 Transistor (Common Emitter Configuration)

voltages. On the positive alternation of the input signal, forward bias is decreased, decreasing I_E, I_C, and I_B. E_{RL} decreases and V_C (output) becomes more negative. On the negative alternation of the input signal, I_E, I_C, and I_B increase. E_{RL} increases and V_C becomes less negative. The input and output voltage waveshapes are 180° out of phase.

The significance of the above changes is their magnitude. In the CE configuration, the output signal voltage, current, and power changes are larger than the input signal changes. The family of characteristic curves will be used to illustrate this fact. Figure 31-3 is a basic transistor amplifier circuit with component values and figure 31-4 is the characteristic curves and load line for this circuit. The load line is the line that extends from point A to point B and represents the relationships between V_C and I_C for specific values of I_B. The load line is constructed by considering the two extreme biasing conditions (cutoff and saturation) for the transistor. At cutoff, no collector current will flow and V_C would be the applied voltage, or 25 V (point A). At saturation, the transistor's resistance is zero and collector current would be 5 mA (point B). Connecting points A and B result in the load line.

The operating point (I_B), often referred to as the QUIESCENT or Q point, is determined by using Ohm's law:

$$I_B = \frac{V_{CC}}{R_D + R_{BE}} = \frac{25V}{250\ k\Omega} = 100\ \mu A$$

Note point Q on figure 31-4. With an I_B of 100 μA, V_{CE} = 12.5 V and I_C = 2.5 mA.

With an input signal of 50 μA Pk-Pk base current will vary from 75 μA to 125 μA (points C and D). On the positive alternation, when I_B increases from 100 μA to 125 μA, I_C increases from 2.5 mA to 3.5 mA and V_C decreases from 12.5 V to 7.5 V. On the negative alternation, when I_B decreases from 100 μA to 75 μA, I_C decreases from 2.5 mA to 1.5 mA, and V_C increases from 12.5 V to 17.5 V. Figure 31-5 summarizes this action.

Actual current gain (A_I) can be computed using the values obtained from the load line. The formula for A_I is:

$$A_I = \frac{\text{Output current change}}{\text{Input current change}} = \frac{\Delta I_C}{\Delta I_B} = \frac{2\ mA}{50\ \mu A} = 40$$

Therefore, the 2N118 transistor in the CE configuration, with a load resistor of 5 k ohms, will have a current gain of 40. Output current changes are 40 times greater than input current changes.

42

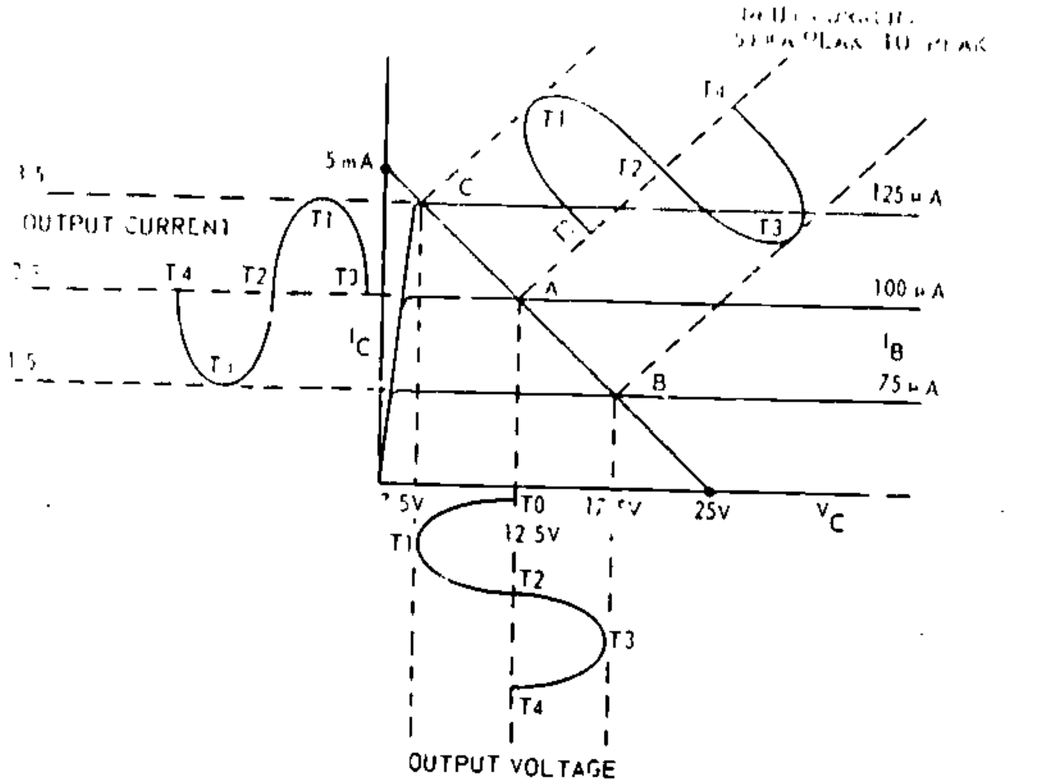


Figure 31-5. Load Line Summary

To determine the actual voltage gain (A_V), the value of the input voltage change (ΔV_{BE}) must be first determined. This can be computed by using the formula:

$$\Delta V_{BE} = \Delta I_B \times R_{EB} = 50\ \mu A \times 3\ k\Omega = .15\ V$$

The voltage gain can now be determined using the formula:

$$A_V = \frac{\text{Output voltage change}}{\text{Input voltage change}} = \frac{\Delta V_{CE}}{\Delta V_{BE}} = \frac{10\ V}{.15\ V}$$

$$= 66.6$$

Therefore a 2N118 transistor in the CE configuration, with a load resistor of 5 k ohms, has a voltage gain of 66.6. Output voltage changes are 66.6 times greater than input voltage changes. The power gain (A_P) can be determined by using either formula:

$$A_P = A_i \times A_V = 40 \times 66.6 = 2666$$

$$A_P = \frac{\text{Output power}}{\text{Input power}} = \frac{P\ out}{P\ in}$$

Output and input power values are determined using the formulas:

$$P\ out = \Delta V_{CE} \times \Delta I_C = 10V \times 2\ mA = 20\ mW$$

$$P\ in = \Delta V_{BE} \times \Delta I_B = .15V \times 50\mu A = 7.5\ \mu W$$

Therefore:

$$A_P = \frac{P\ out}{P\ in} = \frac{20\ mW}{7.5\ \mu W} = 2666$$

The 2N118 transistor in the CE configuration with a 5 k ohm load resistor has 2666 times more output power than input power.

R_L = 4.2k ohms

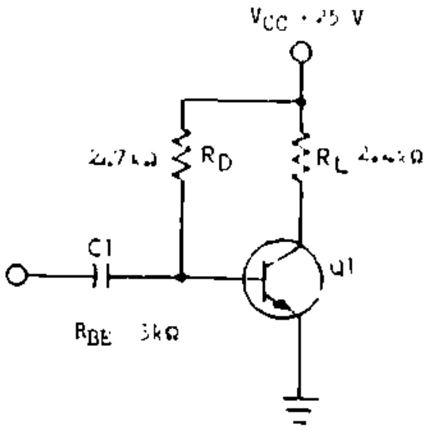
ΔI_C = 2.1 mA P-P

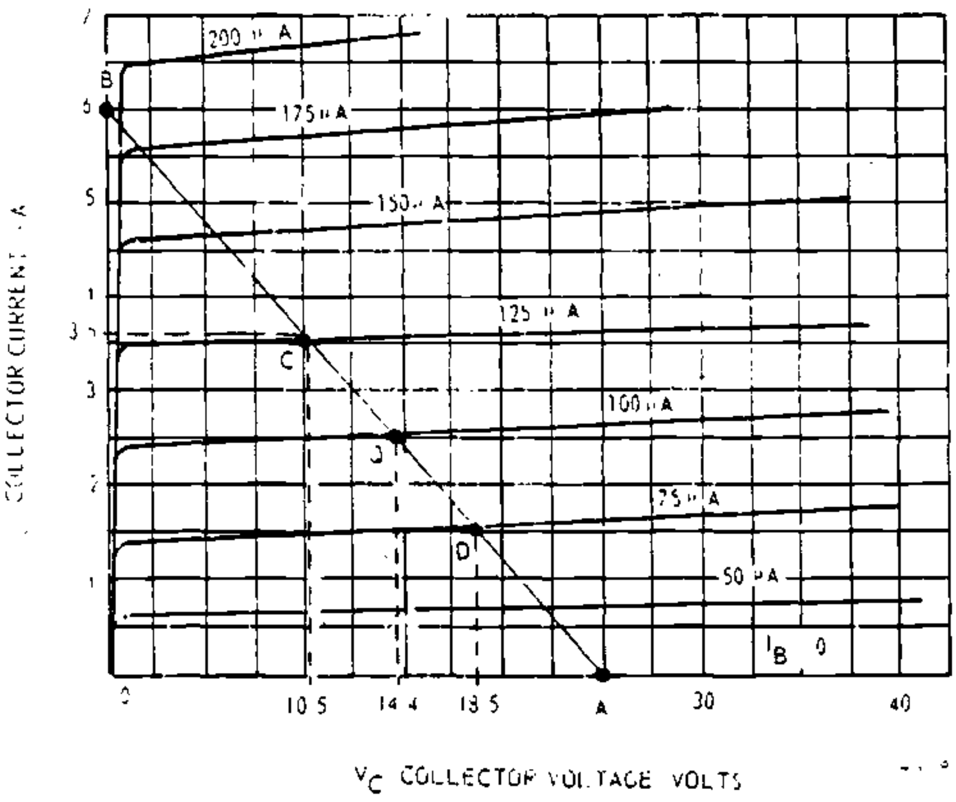
ΔV_C = 8V P-P

Ai = 42

Av = 53.3

Ap = 2238



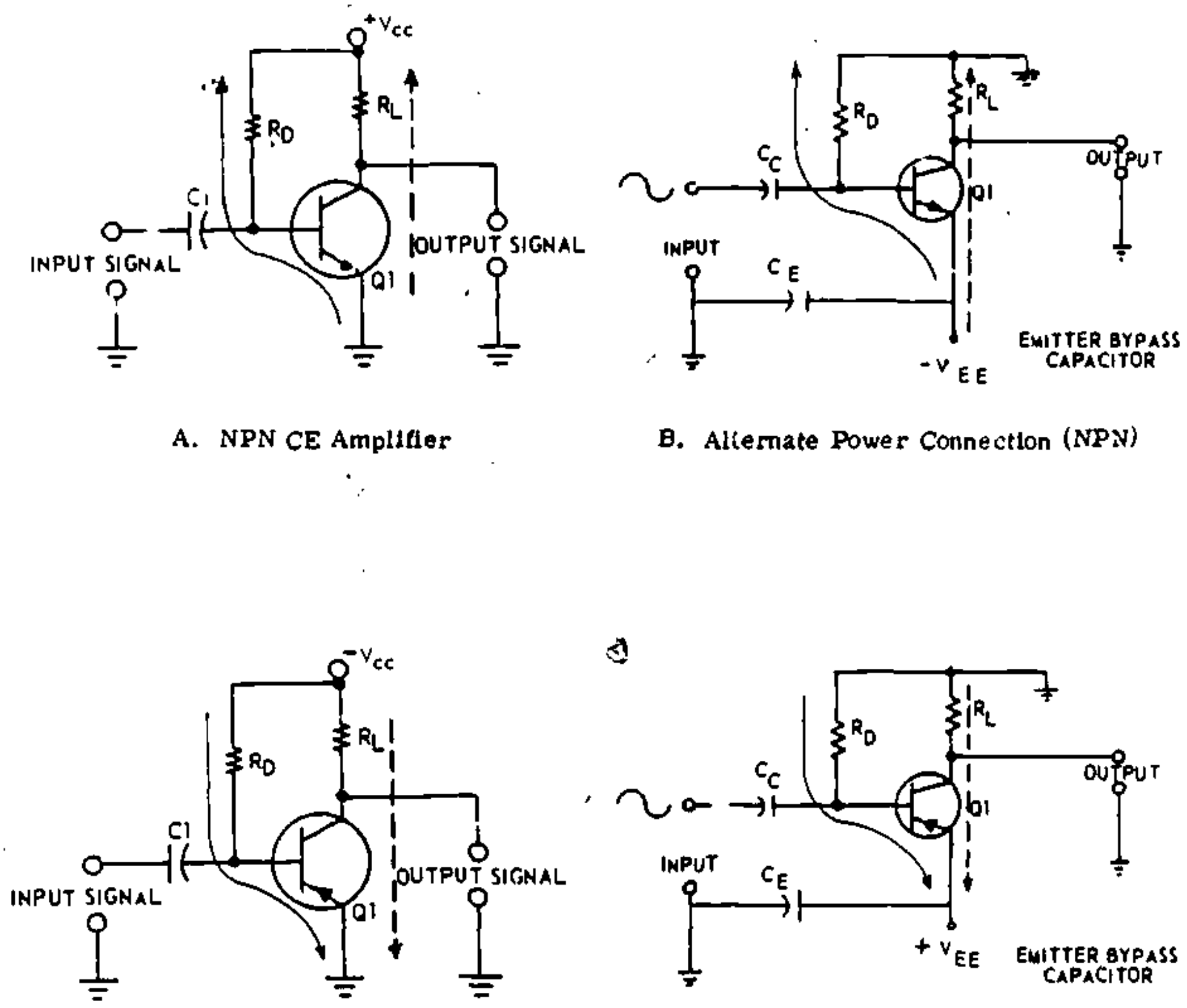


B

Figure 31-6. Common Emitter Amplifier

Figure 31-6 shows the circuit diagram, gain values, characteristic curves and load line for the 2N118 transistor with a load resistor of 4.2 k ohms. Notice that decreasing the resistive load increases the slope of the load line. Comparing the gain values for this circuit with the previous circuit, you should notice that the size of R_L affects amplifier gain and the slope of the load line. The current gain increases with an increase in the slope of the load line (decrease R_L) and the voltage gain and decreasing current gain. The [illegible] not be pr[illegible] R_L caused power gain to decrease. Power gain will be maximum when the impedances are matched. Impedance matching will be discussed later in the course.

Figure 31-7 illustrates methods of arranging the common emitter amplifier and shows current direction for NPN and PNP transistors.



A. NPN CE Amplifier

B. Alternate Power Connection (NPN)

C. PNP CE Amplifier

D. Alternate Circuit (PNP)

Figure 31-7. Common Emitter Amplifier

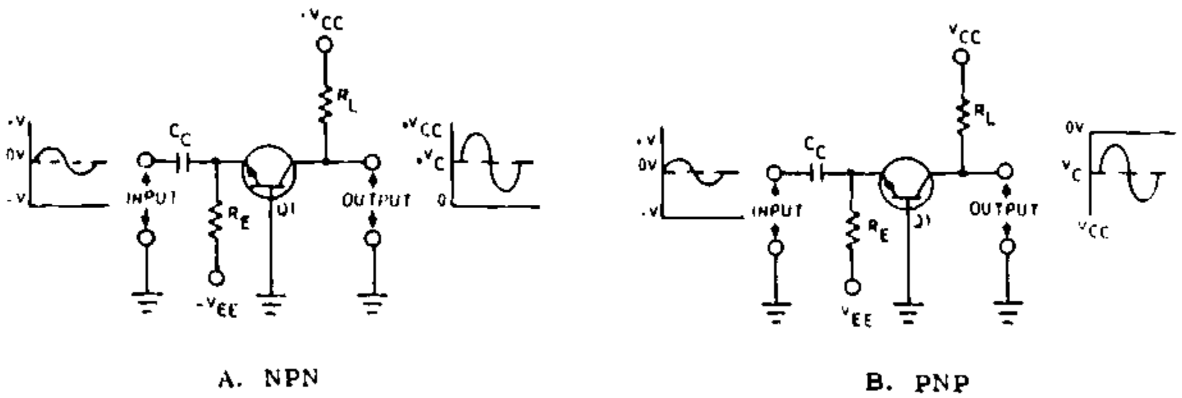


Figure 31-8. Common Base Configuration

Figure 31-8 illustrates the common (grounded) base amplifier using NPN and PNP transistors. It also depicts the input and output waveshapes. Consider the NPN circuit first. On the positive alternation of the input, forward bias decreases, thus decreasing I_E, I_B, and I_C. E_{RL} decreases, increasing the collector (V_C) voltage. On the negative alternation, forward bias is increased, thus increasing I_E, I_B, and I_C. E_{RL} increases which decreases V_C. In the PNP circuit, the positive alternation increases forward bias. I_E, I_C, and I_B increase and decreases V_C. The negative alternation decreases forward bias, thus decreasing I_E, I_B and I_C and increasing V_C. Note that the common base amplifier has no voltage phase shift between input and output.

The magnitude of the voltage and current changes can be analyzed using the characteristic curves and load line. Refer to figure 31-9 and observe the load line for a 2N117 transistor. In the common base configuration with a load resistance (R_L) of 4 k ohms,

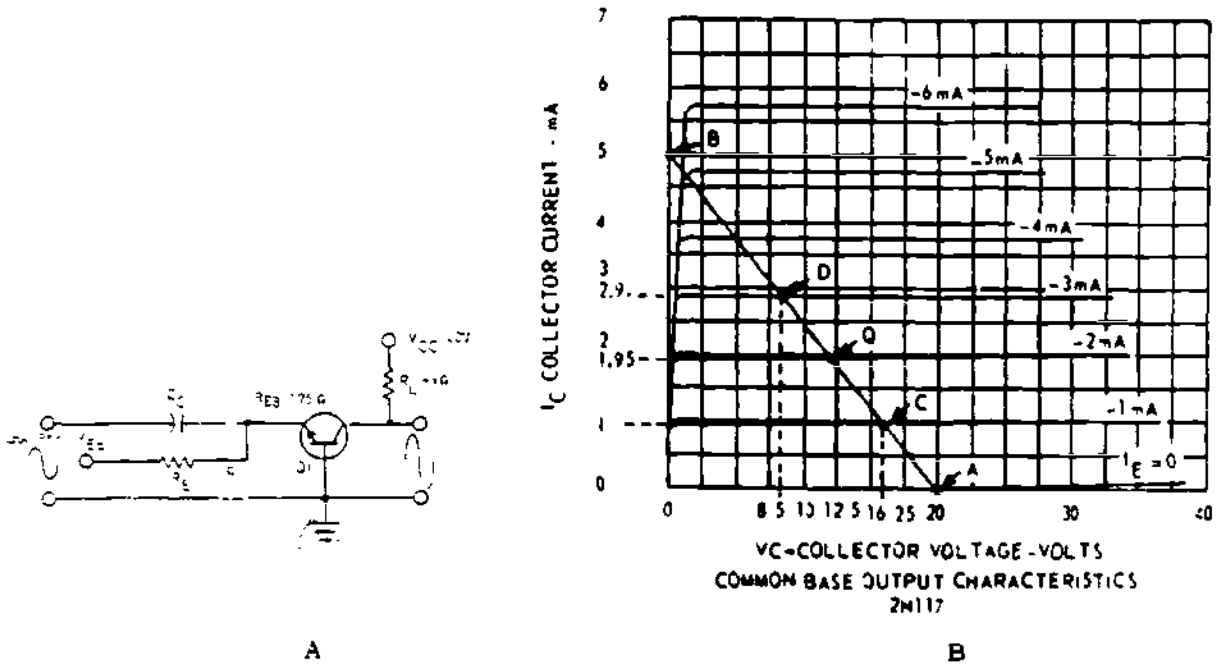


Figure 31-9. Load Line for 2N117 Transistor (Common Base Configuration)

46

the load line falls between 20 V (transistor cut off) to I_C of 5 mA (transistor saturated).

The quiescent (Q) point is determined by Ohm's law using the value of R_E and R_{EB} in the following formula:

$$I_E = \frac{-V_{EE}}{R_E + R_{EB}} = \frac{-1V}{325\Omega + 175\Omega} = \frac{1V}{500} = 2 \text{ mA}$$

At the Q point $I_C = 1.95$ mA and $V_{CB} = 12.5$ V. Figure 31-10 summarizes the effect of a 2 mA Pk-Pk input signal.

Actual current gain (A_i) can be determined using the following:

$$A_i = \frac{\text{output current change}}{\text{input current change}} = \frac{\Delta I_C}{\Delta I_E} = \frac{1.9 \text{ mA}}{2 \text{ mA}}$$

$$= .95$$

Actual current gain for a common base amplifier is always less than one. A common base amplifier does produce a voltage gain (A_v). To compute the A_v, the input voltage change must first be determined using the formula:

$$\Delta V_{EB} = \Delta I_E \times R_{EB} = 2 \text{ mA} \times 175\Omega = .35 \text{ V}$$

Using this value and the output voltage change (ΔV_{CB}) from figure 31-10, actual voltage gain can be determined.

$$A_v = \frac{\text{output voltage change}}{\text{input voltage change}} = \frac{\Delta V_{CB}}{\Delta V_{EB}} = \frac{7.75 \text{ V}}{.35 \text{ V}}$$

$$= 22.1$$

The power gain (A_p) is computed using the formula:

$$A_p = \frac{P \text{ out}}{P \text{ in}} = \frac{\Delta V_{CB} \times \Delta I_C}{\Delta V_{EB} \times \Delta I_E} = \frac{7.75 \text{ V} \times 1.9 \text{ mA}}{.35 \text{ V} \times 2 \text{mA}}$$

$$= \frac{14.725 \text{ mW}}{.7 \text{ mW}} = 21$$

As with the common emitter amplifier, the gain of the common base amplifier is

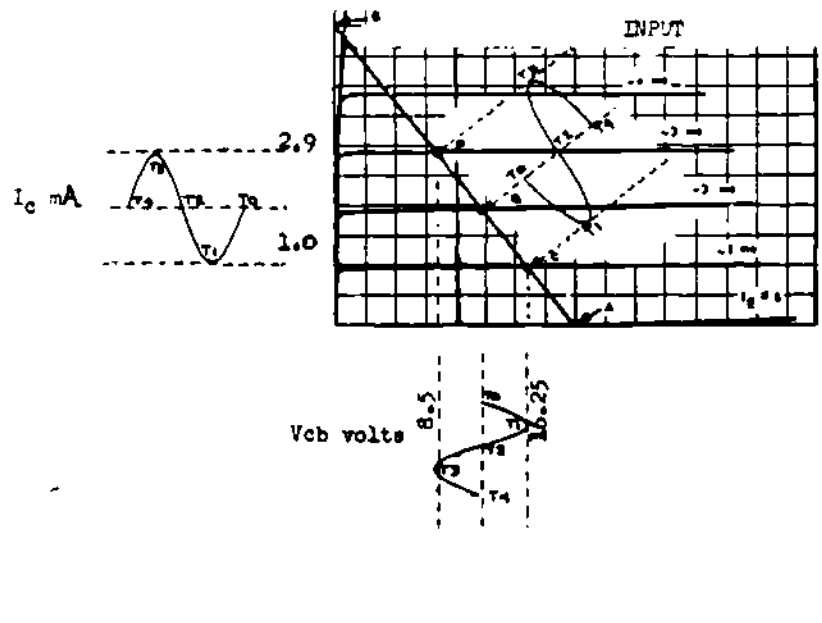


Figure 31-10. Load Line Summary

47

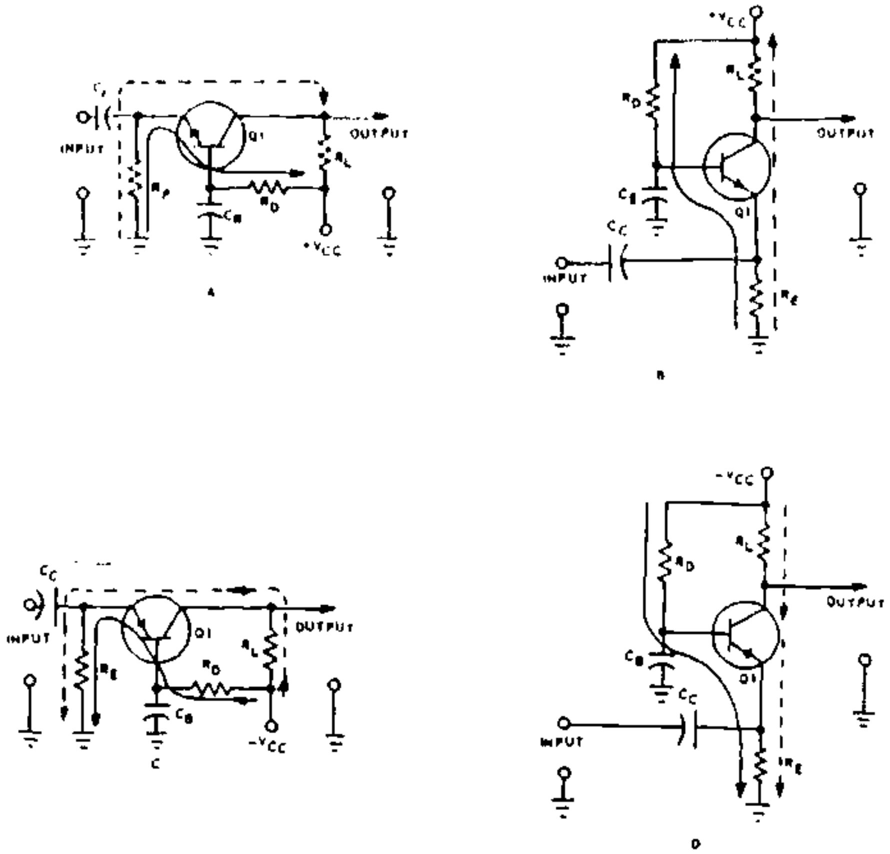


Figure 31-11. Common Base Amplifiers

dependent on the value of the load resistor. Decreasing R_L increases the slope of the load line, increases A_i and decreases A_v. Power gain is dependent on impedance matching.

Figure 31-11 illustrates some typical common base amplifiers and shows current direction for NPN and PNP transistors.

Figure 31-12 illustrates an NPN and a PNP common collector amplifier with current direction. Resistor R_E is the output load resistor.

First, we shall analyze the NPN transistor circuit in figure 31-12A. On the positive alternation, forward bias increases which increases I_E, I_B and I_C. The increased I_E increases the voltage across R_E and causes the output voltage to approach zero. On the negative alternation, I_E, I_B, I_C and E_{RE} decrease and the output voltage approaches $-V_{EE}$.

The PNP transistor circuit decreases in conduction on the positive alternation causing the output voltage to approach $+V_{EE}$. The negative alternation increases conduction which results in the output decreasing toward zero. Because the emitter voltage follows the input voltage changes, the common collector is often referred to as an EMITTER FOLLOWER. The input and output voltage waveshapes are in phase.

Characteristic curves are not normally developed for the common collector amplifier. To determine the output voltage amplitude, consider the 1V pK-Pk input applied to the common collector amplifier in figure 31-13. Assume, for example, that R_{BE} and R_E are equal in resistance and the input signal will be divided equally between them. Because of this, the output voltage can never equal the input voltage and the voltage gain (A_v) is always less than one. Current gain in the common collector amplifier is

48

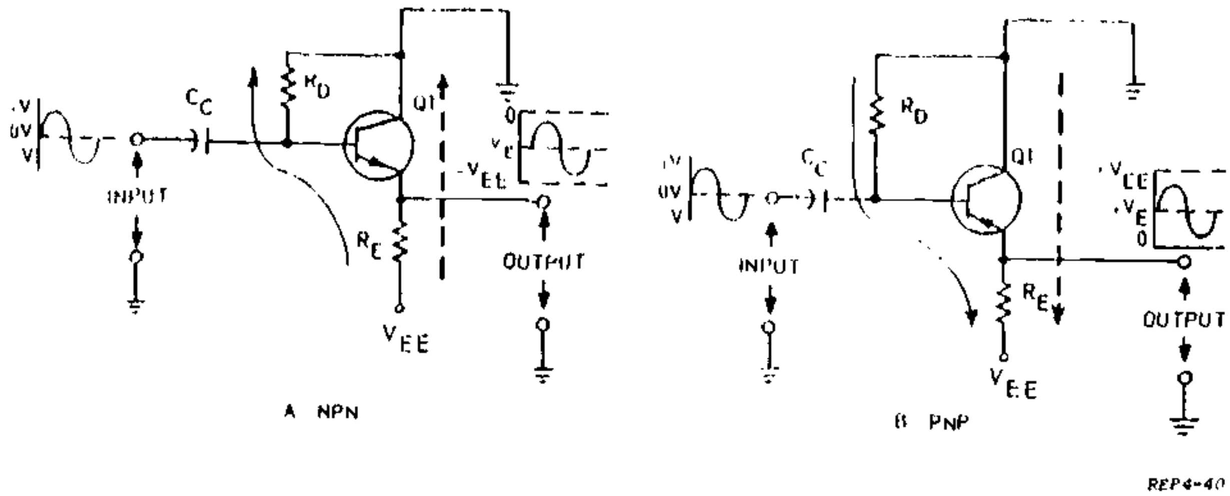


Figure 31-12. Common Collector Configuration

higher than in the common base or common emitter amplifiers. (Gamma = $\beta + 1$).

In a common collector amplifier, the output voltage (V_E) is always opposing the input voltage. For instance, when the input to an NPN amplifier goes positive, forward bias is increased with an accompanying increase in emitter current and voltage. The increased emitter voltage (more positive) will attempt to reduce the forward bias and oppose the action of the input. This action is referred to as DEGENERATION. Degeneration is the process of returning a portion of the output signal back to the input of an amplifier in

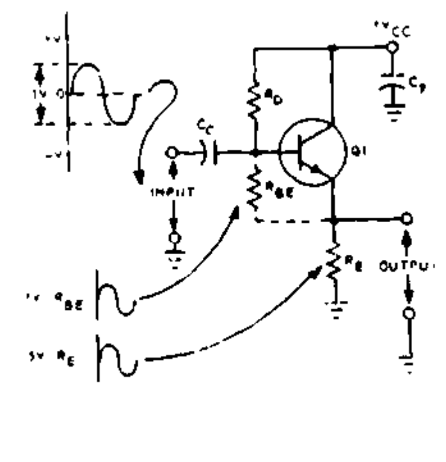


Figure 31-13. Common Collector Amplifier

such a manner that it cancels part of the input signal. This results in a reduced amplifier gain, hence an A_V of less than one in the common collector amplifier.

Increasing the resistive value of the load resistor (within limits) will result in an increased voltage gain (approaching one) and a corresponding decrease in current gain. The power gain is dependent on impedance matching. Maximum power gain is realized when impedances are matched.

DISTORTION results when there is an undesired change in the output waveform of an amplifier. Three types of distortion are frequency, phase, and amplitude. When the output of an amplifier is changed so that its amplitude is no longer proportional to the amplitude of the input signal, amplitude distortion is present. Operating an amplifier in the nonlinear region of the dynamic transfer curve will cause amplitude distortion. When an amplifier is unable to provide equal amplification for all frequencies applied to its input, frequency distortion is present. The primary cause of frequency distortion is the reactive components (inductors and capacitors) in the amplifier circuitry.

When some frequencies applied to an amplifier do not receive the same time delay as other frequencies, then phase

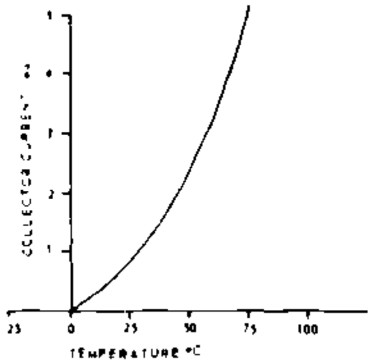


Figure 31-14. I_C Versus Temperature in Nonstabilized Circuits

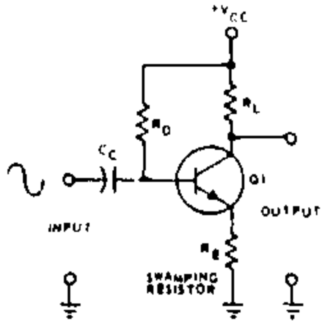


Figure 31-15. Swamping Resistor Stabilization

distortion is present. Phase distortion is also caused by reactive components in the amplifier circuitry.

All semiconductor material is sensitive to temperature changes. An increase in temperature will result in a decrease in the resistance of the material, thus a negative temperature coefficient of resistance. In transistor circuitry, the negative temperature coefficient has a significant effect on the circuit operation. Figure 31-14 illustrates the changes in output current (I_C) of an amplifier resulting from changes in temperature.

In most instances, this change in collector current can not be tolerated, therefore temperature stabilizing circuits have been developed. Collector current variations occur because of emitter/base resistance (R_{EB}) changes and I_{CBO} changes. R_{EB} changes will be considered first. An increase in temperature will decrease R_{EB}, increasing forward bias which results in an increase in I_E, I_B and I_C.

The use of an emitter swamping resistor (figure 31-15) can minimize the change in I_C. Increases in temperature result in an increase in the voltage across R_E (swamping resistor) which will tend to oppose the change in forward bias, thus minimizing the change in I_C. A distinct disadvantage of the swamping resistor is that it will produce degeneration and reduce amplifier gain. This can be prevented by using a capacitor in parallel with R_E which has a low reactance to the input signal frequency. Figure 31-16 illustrates the use of this capacitor.

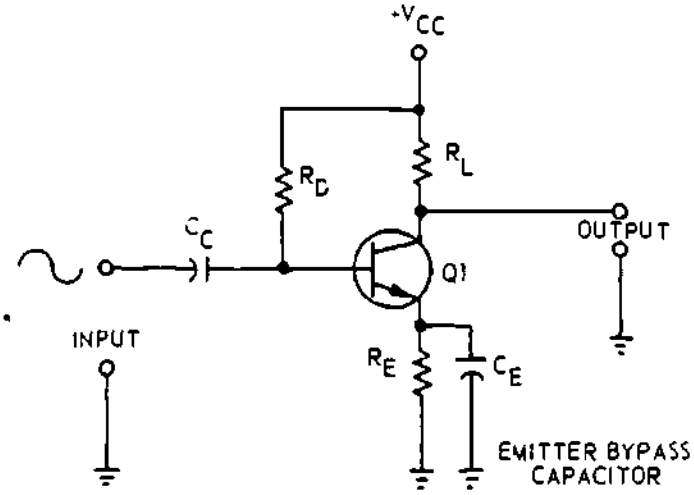


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Figure 31-16. Placing Emitter at AC Ground

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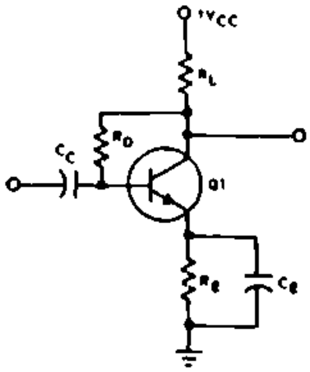

Figure 31-17. Self-Bias Stabilization

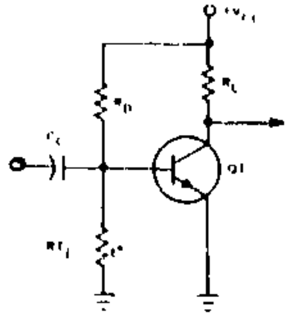

Figure 31-19. Thermistor Stabilization

The circuit now compensates for R_{EB} changes caused by temperature without reducing gain. Figure 31-17 through 31-19 show other methods used to minimize I_C changes caused by temperature.

In the self-bias stabilizing circuit, temperature increase causes I_C to increase and V_{CE} to decrease. This decrease is coupled back through R_D and decreases forward bias. The disadvantage of this arrangment is that R_D also couples back part of the output signal. This degenerative feedback reduces amplifier gain. The use of a low pass filter, R_{D1}, R_{D2} and C_F (figure 31-18) prevents this loss of gain (degeneration), while providing temperature stabilization.

Figure 31-20 illustrates the stabilizing effect that the thermistor, the forward biased diode, and the emitter swamping resistor have on collector current. Notice that stabilization decreases rapidly between 50° and 75° Celsius.

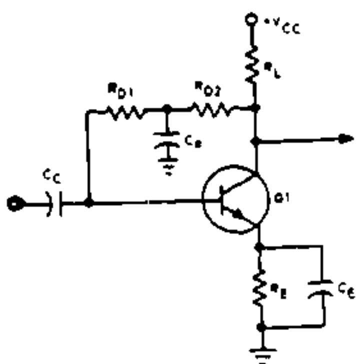

Figure 31-18. Self-Bias Stabilization
(w/o AC Degeneration)

All circuits previously discussed compensate only for R_{EB} changes. The decreased stability above 50° is the result of I_{CBO} changes caused by temperature. Figure 31-21 shows the path for I_{CBO}.

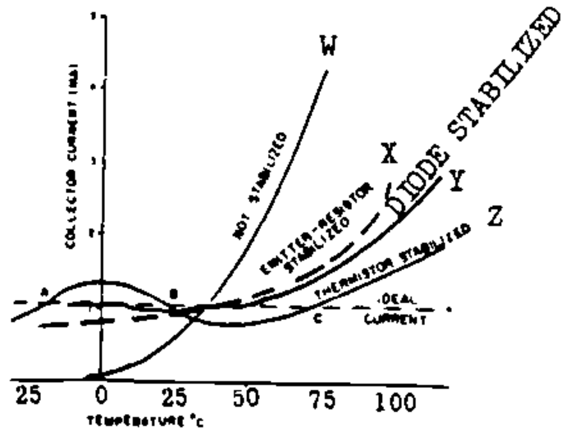

Figure 31-20. I_C vs Temperature

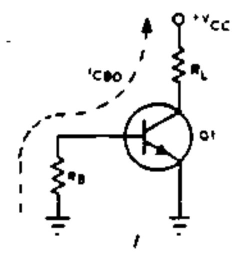

Figure 31-21. Flow of I_{CBO}

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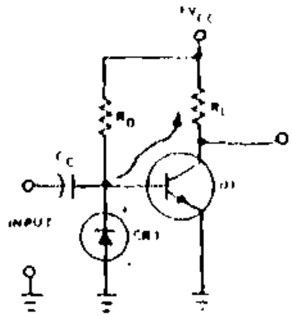


Figure 31-22. Reverse Biased Diode Stabilization

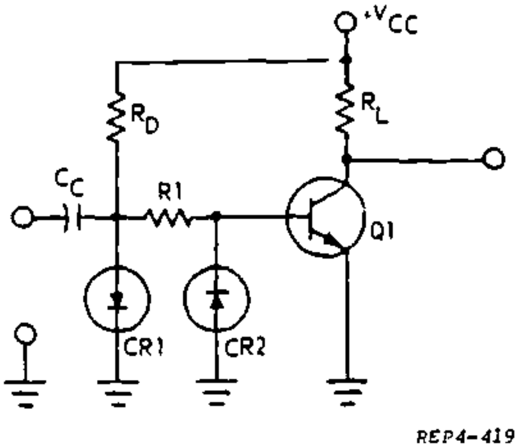
The value of I_{CBO} doubles with an 8 to 10 degree Celsius change in temperature. At 25° C, I_{CBO} is in the order of microamperes and has very little effect on I_C. Above 50° C, I_{CBO} has become larger and will result in a noticeable change in the forward bias voltage across R_B. These forward bias changes will be amplified by the factor beta (β) and will result in a significant change in I_C. Figure 31-22 shows how a reverse biased diode can be used to minimize this change.

Reverse biased diode, CR1, replaces R_B. The magnitude of minority current through CR1 equals I_{CBO} and will change with temperature. Forward bias changes are prevented and the only change in I_C is the additional I_{CBO}. In other words, CR1 prevents I_{CBO} changes from being amplified by the factor BETA.

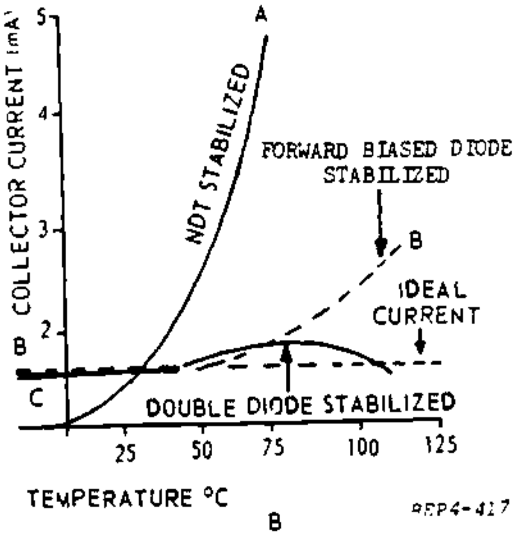
Additional stabilization can be achieved using a combination of forward and reverse biased diodes as illustrated in figure 31-23A. Figure 31-23B graphically illustrates the comparison.

Amplifiers are seldom used alone. Normally two or more of them are connected to achieve desired gain. When the output of an amplifier is applied to the input of the next amplifier, they are said to be CASCADED.

There are four basic methods of coupling the output of one amplifier to the input of the next. They are direct, resistive/capacitive (RC), impedance and transformer. Each type of coupling affects an amplifier's ability to provide equal amplification at all frequencies.



A



B

Figure 31-23. Double Diode Stabilization Circuit and Graph

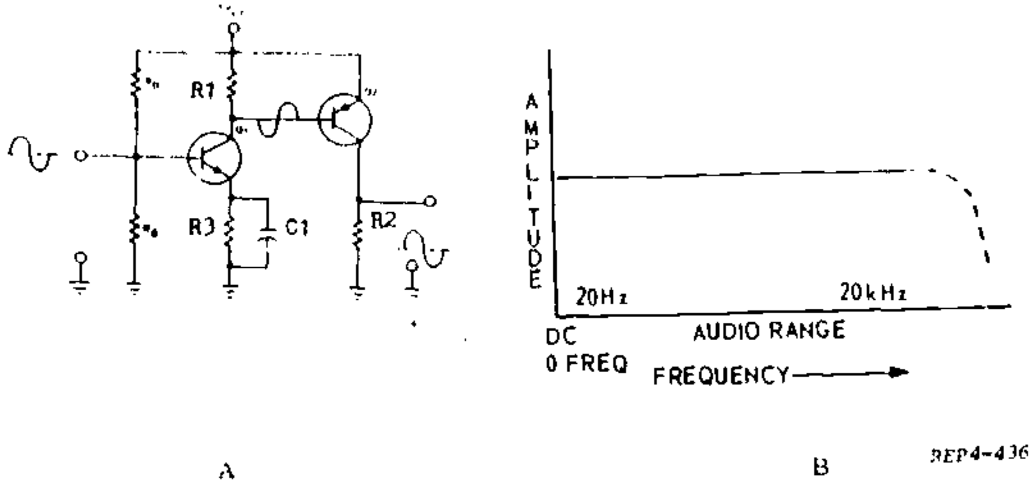


Figure 31-24. Direct Coupling with Frequency Response

Figure 31-24A shows an example of direct coupling and figure 31-24B illustrates the relationship of gain versus frequency for this type coupling.

The loss of gain at high frequencies is caused by the interelement and stray capacitances. Figure 31-25 shows interelement capacitance.

Figure 31-26A shows an RC coupled amplifier and figure 31-26B graphically illustrates the gain versus frequency relationship.

The loss of gain at the low frequencies is due to the reactance of the coupling

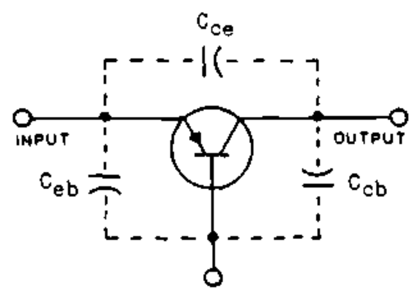


Figure 31-25. Interelement Capacitance of a Transistor

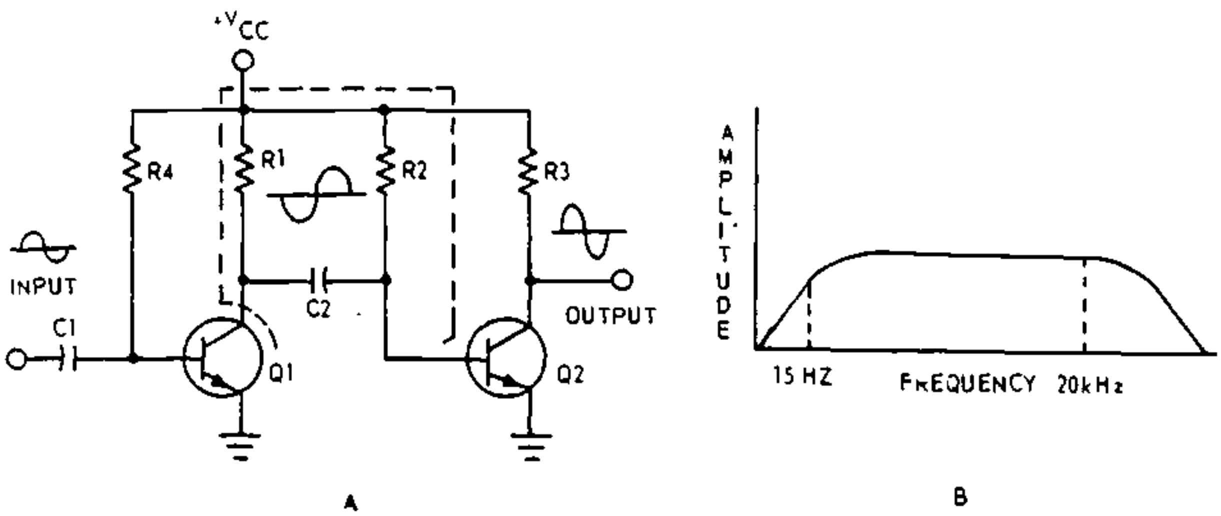


Figure 31-26. RC Coupled Amplifier with Frequency Response Curve

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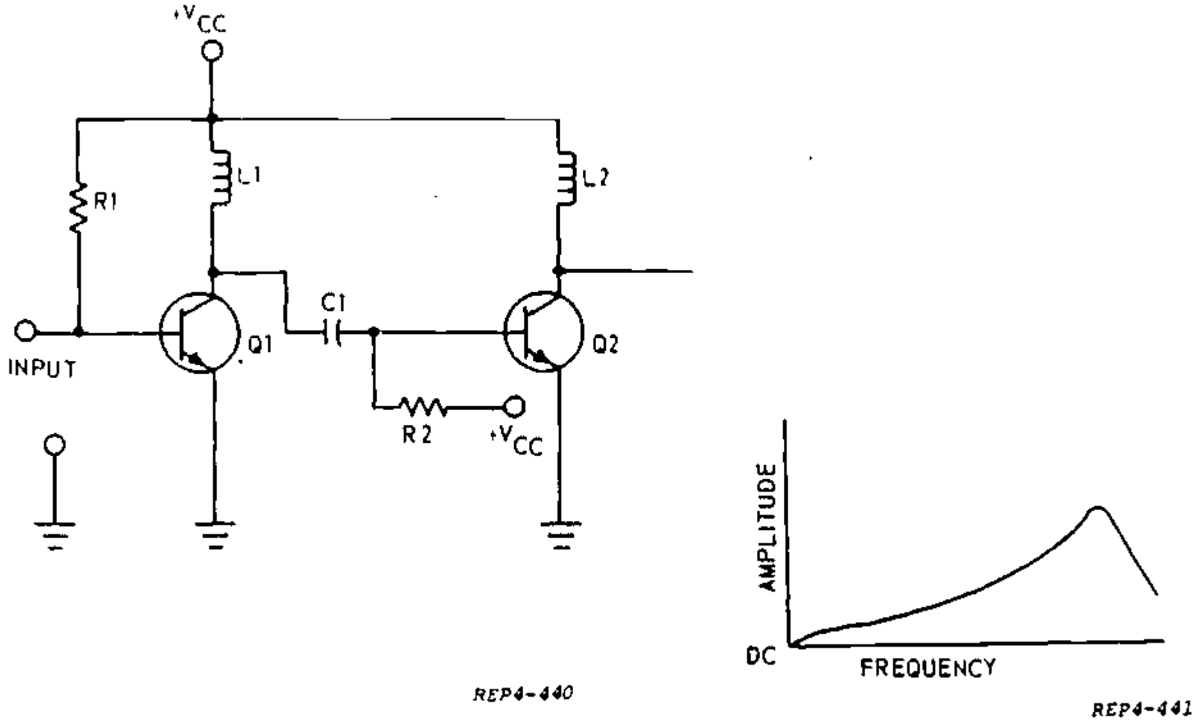
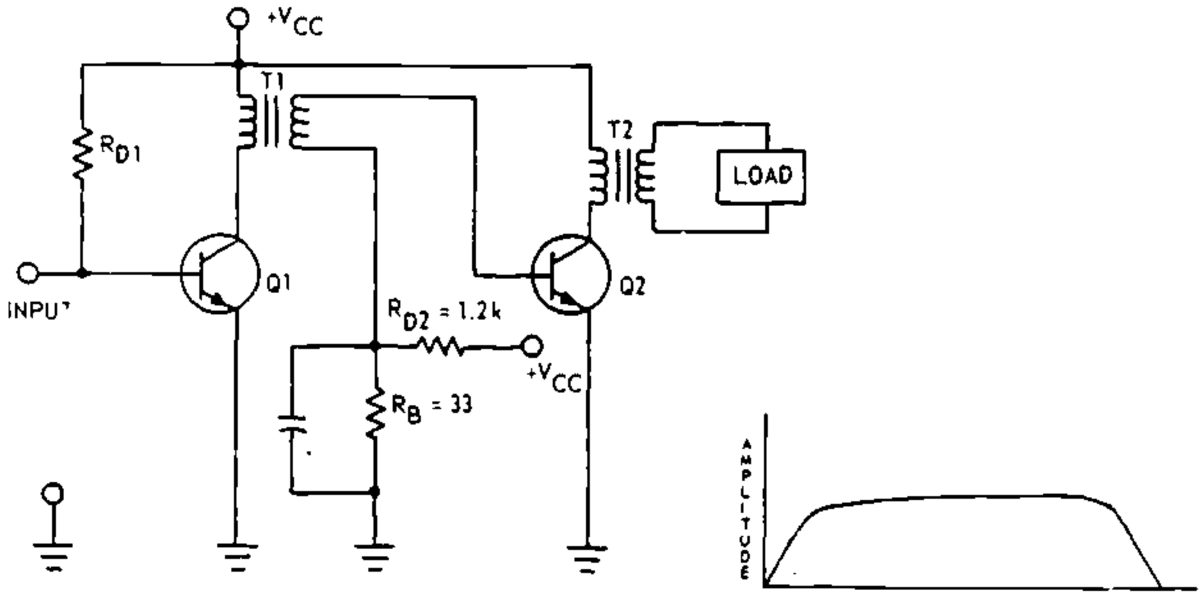


A B

Figure 31-27. Impedance Coupled Amplifier with Frequency Response Curve



A B

Figure 31-28. Transformer-Coupled Amplifier with Frequency Response Curve capacitors, (C1 and C2). As with direct coupling, the loss of gain at high frequencies is due to interelement and stray capacitances.

Figure 31-27 shows an impedance coupled amplifier with the frequency response curve.

In impedance coupling, the amplifier load is an inductor whose reactance is dependent on frequency. Recall that voltage gain is dependent on the value of the collector load. As frequency increases, X_L increases along with the amplifier's gain. The peak-point on the response curve indicates resonance between the transistor's interelement capacitance and the inductive load. Above this frequency, the gain drops off because of the interelement and stray capacitance.

Figure 31-28 represents transformer coupling and the response curve.

The loss of gain at low frequencies is due to the low X_L of the transformer windings. Loss of gain at high frequencies is caused by the circuit capacitances.

MODULE 33

SELECTED SOLID STATE DEVICES

The Unijunction Transistor

The unijunction transistor (UJT) has two conduction conditions and operates similar to a switch. Figure 33-1 shows the basic construction and schematic symbols for the UJT.

When the material between base 1 (B1) and base 2 (B2) is N type material, the emitter (E) will be P material. The opposite is true for the P type UJT. The point where the emitter region is attached to the basic material forms a PN junction. When the PN junction is forward biased, the UJT is in its high conduction or ON state. When the PN junction is reverse biased, the UJT is in its low conduction or OFF state.

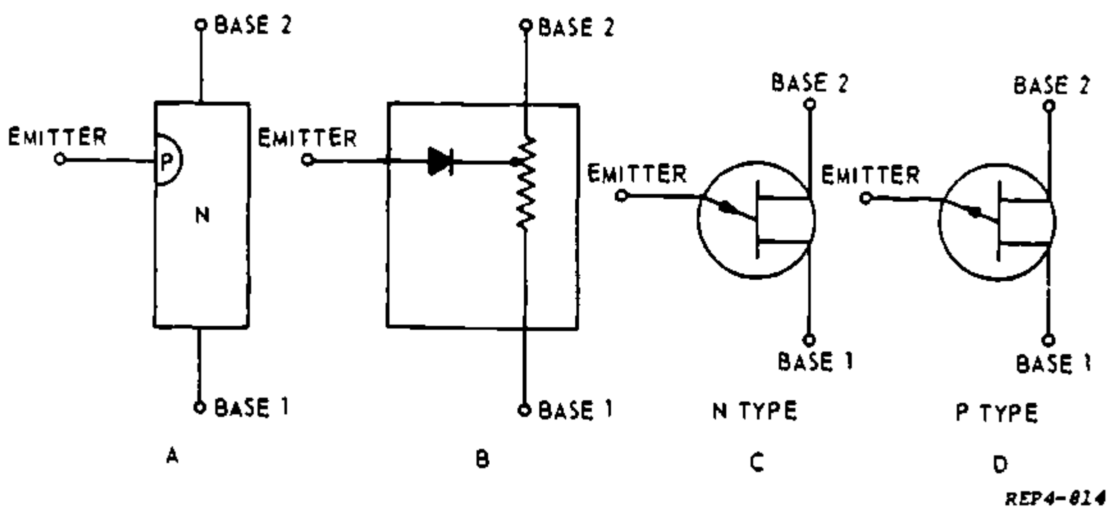


Figure 33-1. Unijunction Transistor

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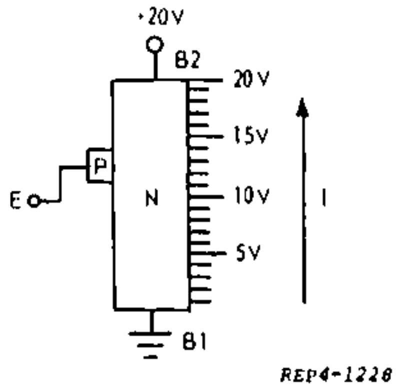

Figure 33-2. Pictorial Diagram of UJT Showing Low Conduction (OFF) Condition

First consider a voltage applied between B1 and B2 as illustrated in figure 33-2.

The applied voltage will be distributed evenly across the N material. The emitter to B1 junction will be reverse biased because the voltage at the point where the emitter material is attached to the N material is at approximately +13 V. The emitter current at this time will be zero and the UJT will be in its low conduction condition. This situation is illustrated as the peak voltage point (B) on figure 33-3.

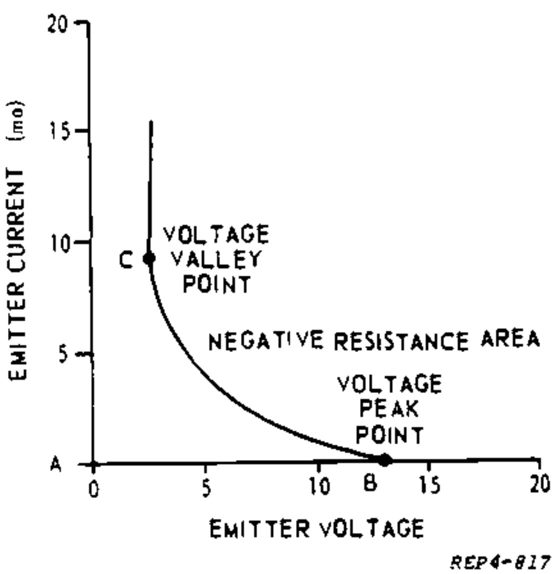

Figure 33-3. UJT Characteristic Curve

Figure 33-4 represents the high conduction (ON) condition of the UJT.

The 15 volts applied to the emitter will forward bias the emitter-base 1 junction and a high emitter current will flow. The high concentration of electrons (carriers) in the area between E and B1 causes the resistivity of the material to decrease and the voltage across the N material to be redistributed, as shown. The emitter current through R1 will drop the emitter voltage from 15 V to 3 V. Referring to figure 33-3, the UJT is now operating at point C on the curve.

The area between points B and C on the curve is referred to as the negative resistance (-R) area because emitter current increases for a decrease in emitter voltage. The time for the UJT to change from its low conduction to its high conduction condition is extremely short and in the order of nanoseconds (10^{-9}). The UJT is utilized in instances where fast switching is required.

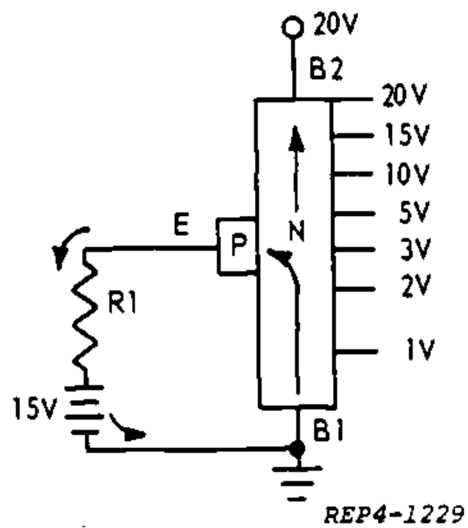

Figure 33-4. Pictorial Diagram of UJT Showing High Conduction (ON) Condition

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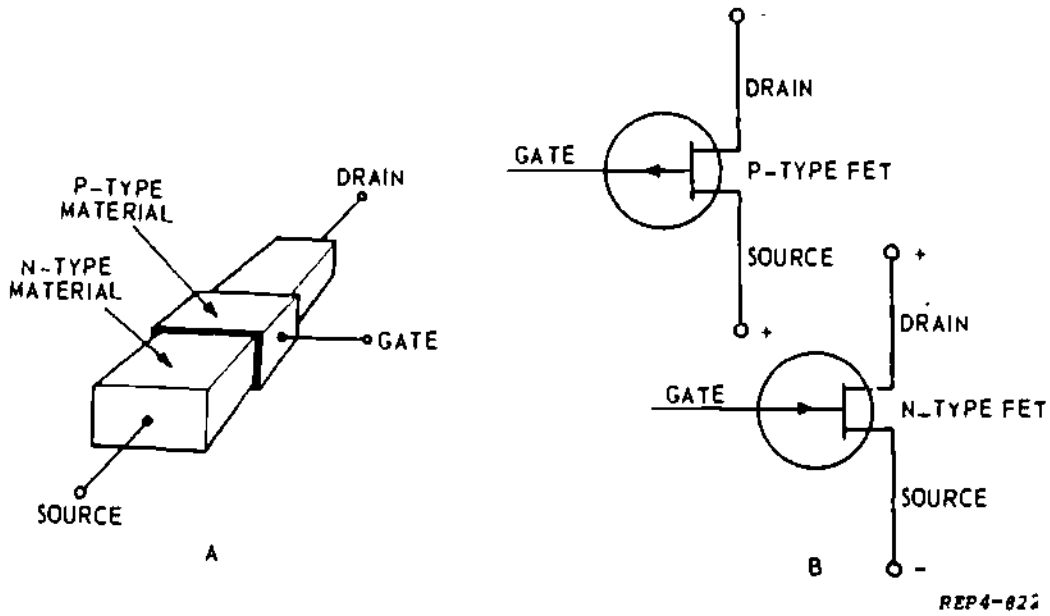

Figure 33-5. Pictorial Diagram and Schematic Symbols for JFETS

The Junction Field Effect Transistor (JFET)

The Junction Field Effect Transistor (JFET) is available in N and P types. Figure 33-5A illustrates the basic construction of an N-type JFET and figure 33-5B shows the schematic symbol for N- and P-type JFETS.

Connecting a voltage between the source and drain as illustrated in figure 33-6 will result in drain current (I_D) and a voltage drop across the bulk N material. The voltage between points A and B results in a reverse-biased PN junction between the gate and the N material, and produces a cone-shaped depletion region between the P-type gate material and the bulk N material. The depletion region completely surrounds the bulk material. The size of the depletion region controls the area (called the channel), through

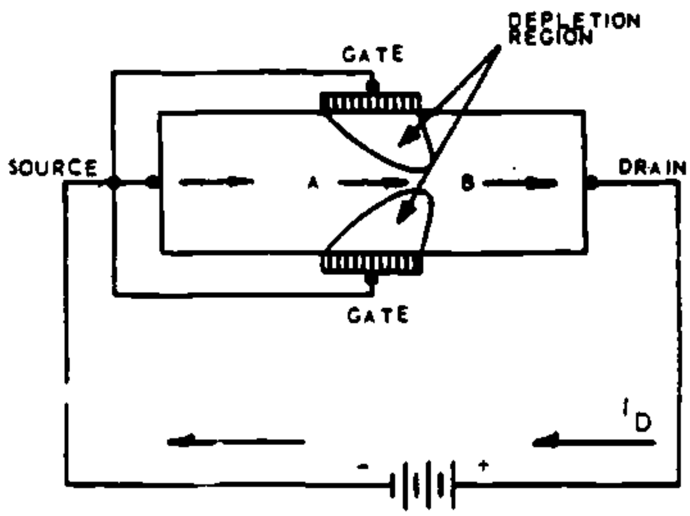

Figure 33-6. Conduction in an N-Type JFET

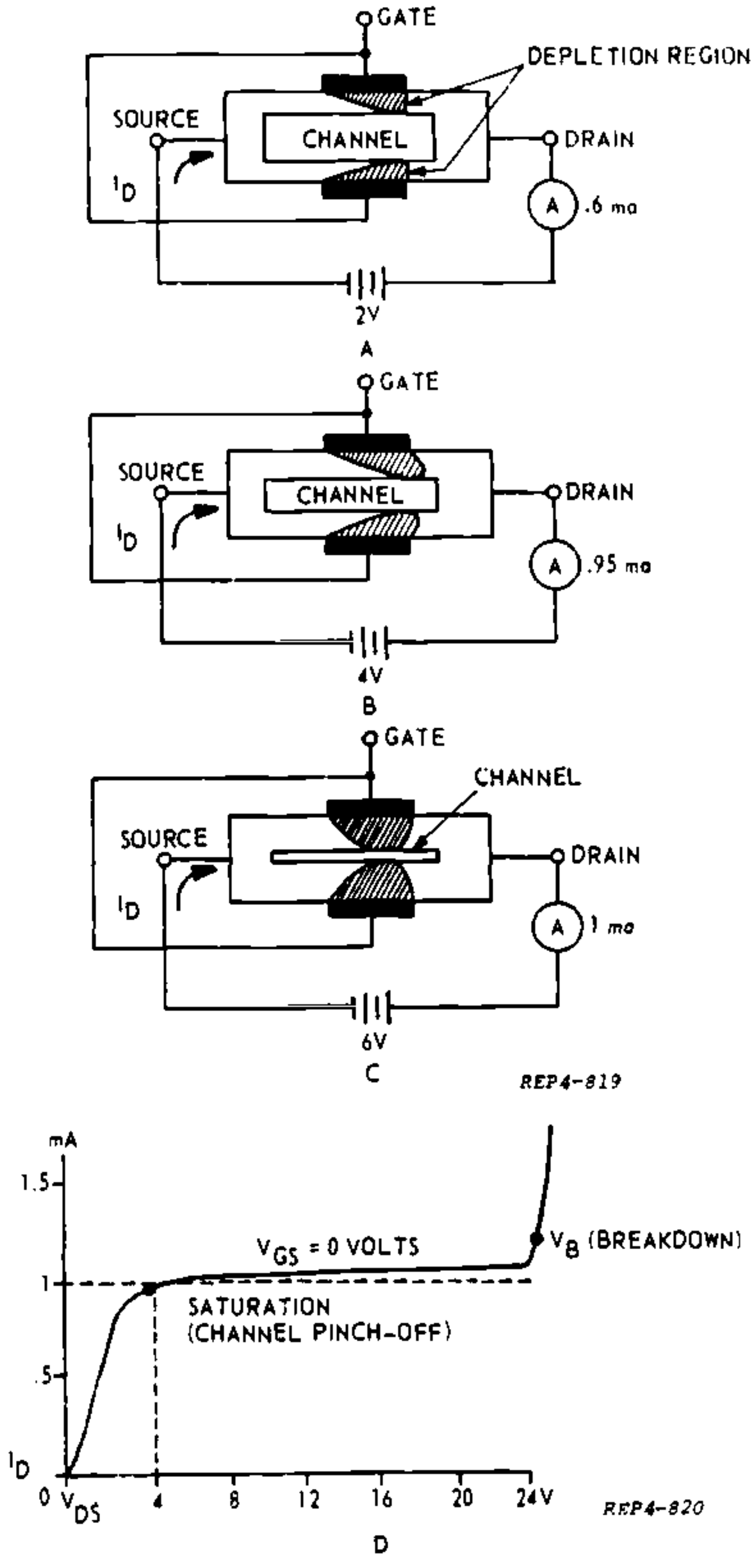

Figure 33-7. Effect of V_{DS} on I_D

which I_D can flow. In other words, controlling the size of the depletion region controls I_D. Increasing the drain to source voltage (V_{DS}) will increase I_D and the size of the depletion region until the depletion region becomes so large that it restricts further increases in I_D. At this point, the device is saturated. This point is referred to as channel pinch-off and further increases in V_{DS} will not produce a noticeable increase in I_D.

The effect of V_{DS} changes is illustrated in figure 33-7. Point V_B on figure 33-7D is where the breakdown voltage of the PN junction is reached.

The size of the depletion region controls drain current. Figure 33-8 graphically illustrates the control that a voltage applied between the gate and source leads (V_{GS}) has on I_D. Note the similarity to the characteristic curves for a transistor.

The significant difference is that with the transistor, the base current (I_B) controls conduction; whereas in the JFET, the gate to source voltage controls the conduction. In other words, the JFET is a voltage-controlled device. Small changes in V_{GS} result in large changes in I_D.

The JFET can be used in three basic configurations. They are the common source, common gate and common drain. Figure 33-9 illustrates a common source amplifier.

Notice that no biasing voltage is required. On the positive alternation, the reverse bias at the gate-to-source junction is decreased. This action decreases the depletion region, increases the channel size and increases drain current (I_D). This results in an increased voltage across the load resistor and a decreased output voltage (V_{DS}). The negative alternation increases the reverse bias, increases the depletion region, decreases I_D and E_{RL} and increases the output (V_{DS}). The output voltage waveshape is larger than the input waveshape, and amplification has occurred. The input and output signal voltages are 180° out of phase. Positive or negative biasing voltages (V_{GS}) can be used with a JFET to move the operating (Q) point.

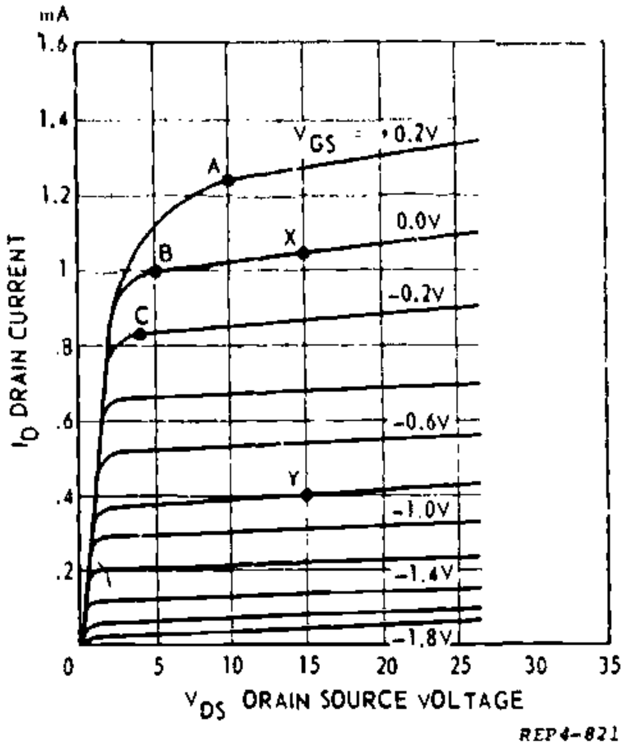

Figure 33-8. N-type JFET Characteristic Curves

The Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

The construction of an "N" Channel Metal Oxide Semiconductor Field Effect Transistor (MOSFET) is illustrated in figure 33-10. The "P" channel MOSFET uses an N type substrate.

MOSFETS can be divided into the enhancement and depletion types. In the depletion MOSFET, the channel is heavily doped and

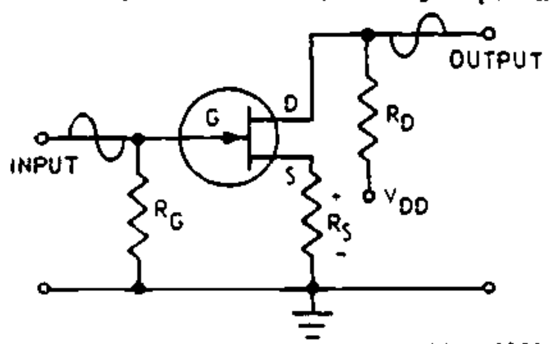

Figure 33-9. JFET Common Source Amplifier

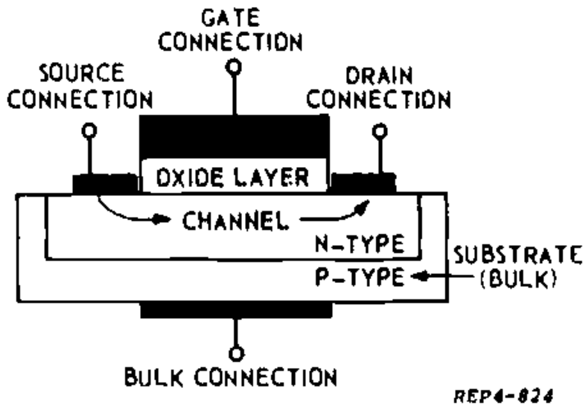

Figure 33-10. Cutaway View of MOSFET N Channel

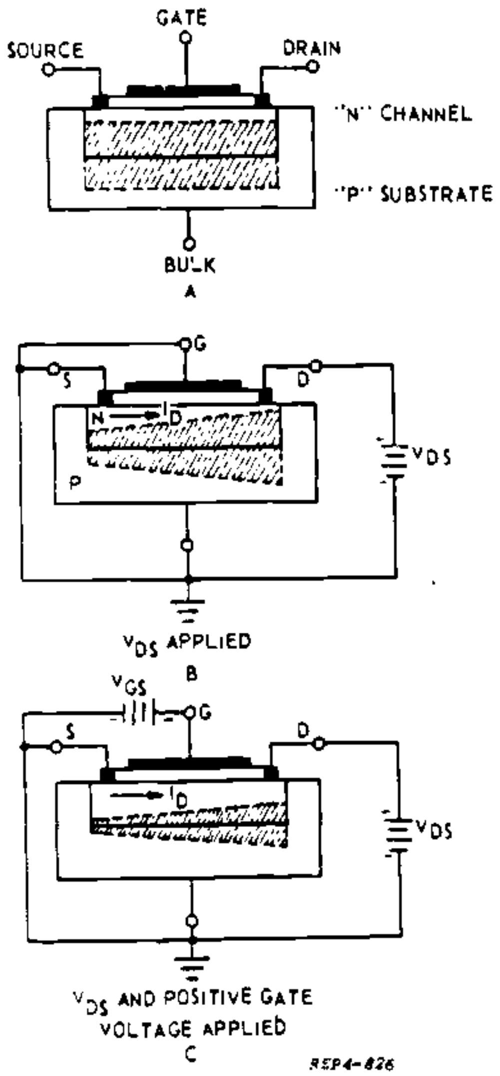

Figure 33-11. N-Channel Enhancement Type MOSFET

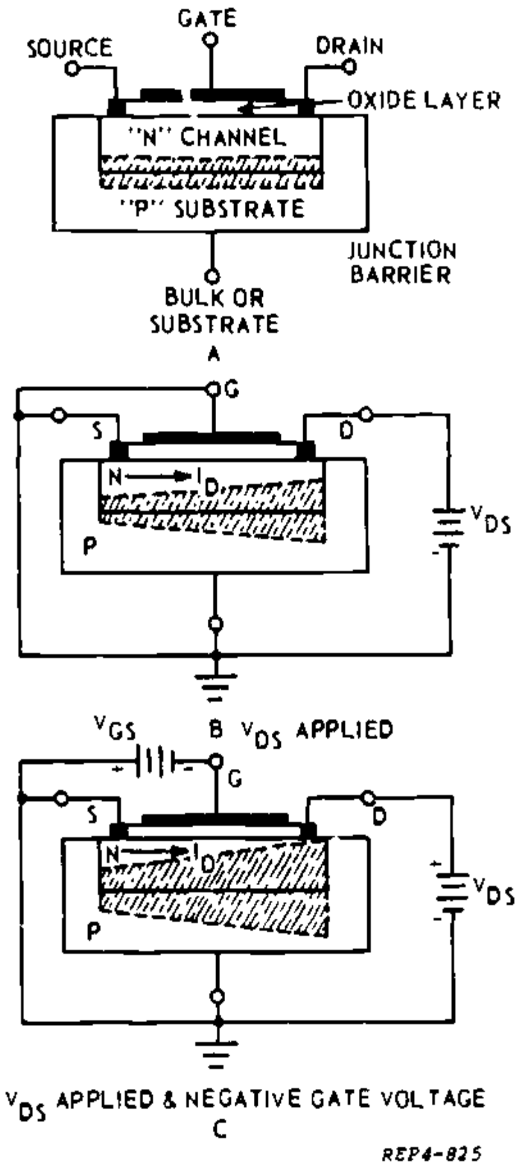

Figure 33-12. N-Channel Depletion Type MOSFET

produces high drain currents for small drain-to-source voltages. The enhancement type MOSFET is lightly doped and I_D is small. Figure 33-11 and 33-12 illustrate the effect of V_{DS} and V_{GS} on the channel and I_D for N channel enhancement and depletion MOSFETS. The lightly doped enhancement type MOSFET has a large depletion region which restricts channel area and produces low drain current. The voltage gradient produced by V_{DS} modifies the channel width. A positive gate-to-source voltage increases or enchnces the channel. I_D increases with an increase in the positive V_{GS} voltage.

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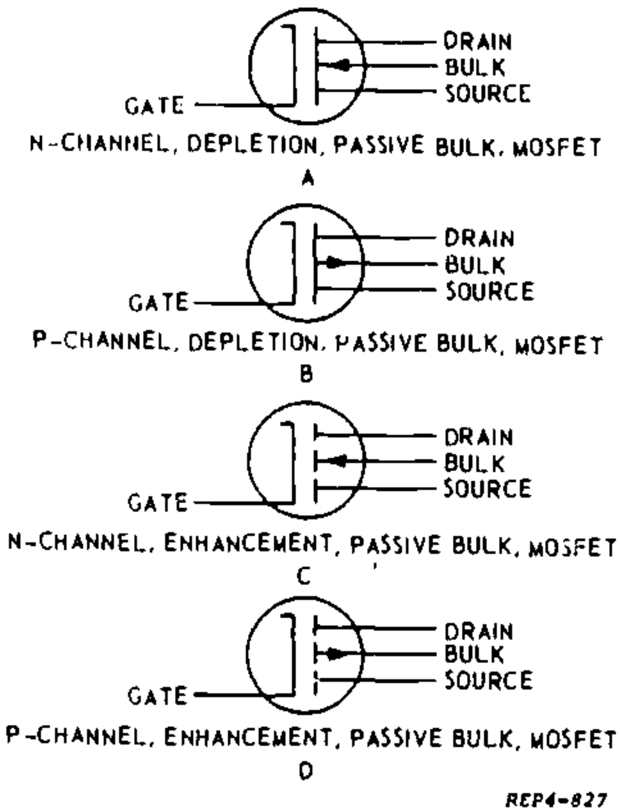

Figure 33-13. MOSFET Symbols

In the heavily doped depletion MOSFET, the depletion region is small, the channel is large and there is a high drain current. The voltage gradient produced by V_{DS} modifies the channel and the negative gate-to-source voltage decreases, or depletes the channel width. I_D decreases with increases in the negative V_{GS} voltage.

Figure 33-13 shows the schematic symbols for MOSFETS.

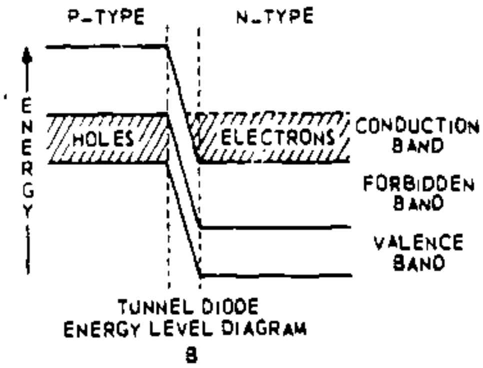

Figure 33-14. Energy Level Diagram of an Unbiased Tunnel Diode

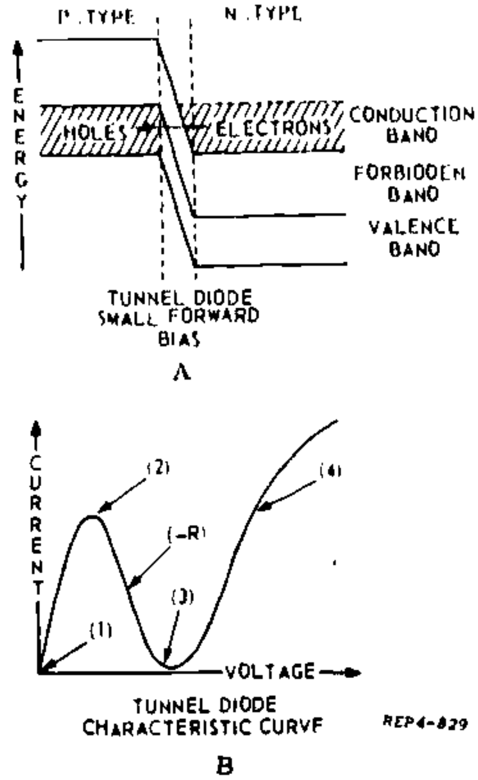

Figure 33-15. Energy Level Diagram and Characteristic Curve for a Tunnel Diode

The Tunnel Diode

A Tunnel Diode is an extremely heavily doped PN junction diode. Figure 33-14 shows the energy level diagram of an unbiased tunnel diode.

Ionization at the junction caused by junction recombination results in the displacement of the energy bands, so that the conduction band electrons in the N material are at the same energy level as the valence band holes in the P material. The depletion region is extremely thin. Applying a small forward bias results in the movement of electrons from the conduction band of the N material directly into the valence band of the P material. Holes in the valence band of the P material move directly into the conduction band of the N material. The carriers pass through, or tunnel under, the forbidden band as they move across the PN junction. Figure 33-15A depicts this movement and figure 33-15B graphs the voltage and current relationship. The current

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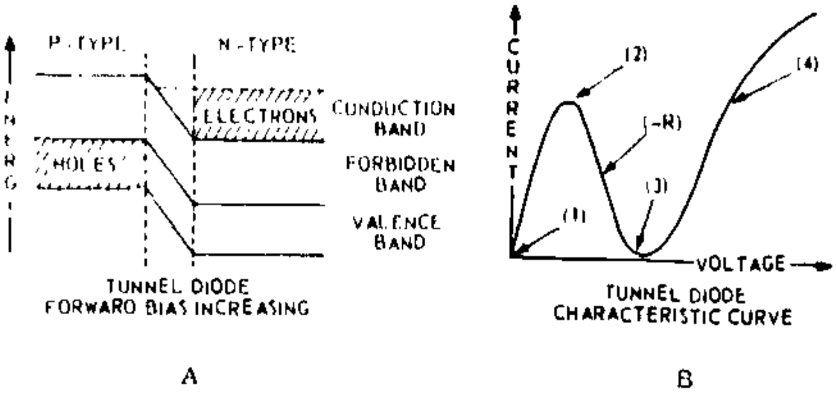

Figure 33-16. Energy Level Diagram and Characteristic Curve for a Tunnel Diode

flow shown on the graph between points 1 and 3, occurs because of this tunneling.

Increasing forward bias changes the relationship between the energy levels of the N and P materials. The N material increases in energy and the P material decreases. The area on the characteristic curve between points 2 and 3 is where the following action takes place. Electrons in the N material become aligned in energy to the forbidden band of the P material and the holes in the P material become the forbidden band of the N material. This action is illustrated in figure 33-16.

This increase in forward bias will result in decreased conduction until the majority carriers are all aligned with the forbidden band and current flow is minimum (point 3 on the curve). Between points 2 and 3 on the curve, the tunnel diode exhibits a negative resistance characteristic (-R). As forward bias is further increased, the electrons in the N material pass into the conduction band of the P material and the holes in the P material pass into the valence band of the N material. This is conventional conduction and it is illustrated in figure 33-17. The area between points 3 and 4 on the characteristic curve represents conventional conduction.

The Varactor Diode

A capacitor is described as two conductors separated by a dielectric. A reverse biased

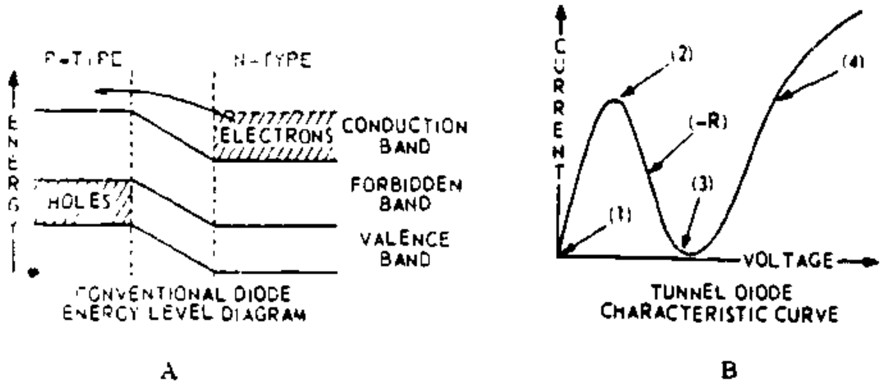

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Figure 33-1.. Tunnel Diode Energy Level Diagram and Characteristic Curve

62

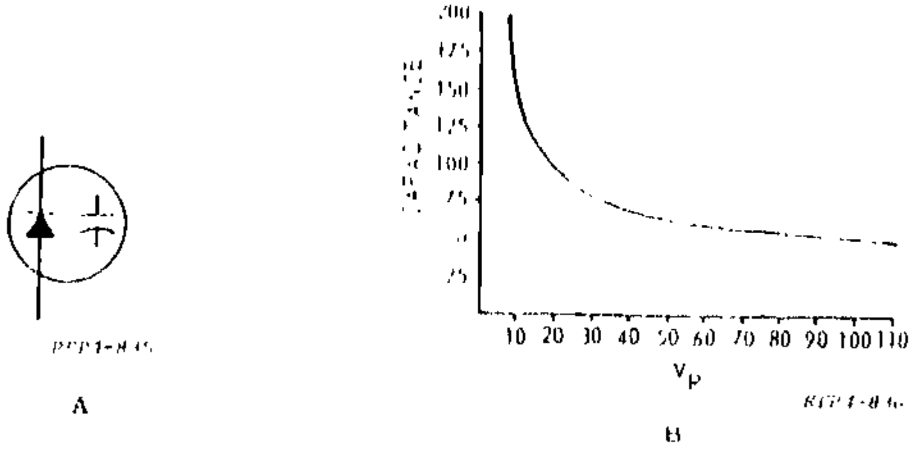


Figure 33-18. Varactor Diode Schematic Symbol and Characteristic Curve

junction diode exhibits the properties of a capacitor. The N and P materials become the conductors separated by the depletion region (the dielectric). Varying the reverse bias changes the width of the depletion region, thus changing the capacitance of the diode. A diode designed to be used as a variable capacitor is called a VARACTOR. Recall the formula for capacitance: $C = K\frac{A}{D}$.

Using the formula, the effect of changing the reverse bias on capacitance can be determined. Increasing reverse bias increases the depletion region (increased distance - D) causing a decrease in capacitance. Conversely, decreasing reverse bias increases capacitance. Figure 33-18 shows the schematic symbol and characteristic curve for a varactor diode.

The Silicon Controlled Rectifier

A Silicon Controlled Rectifier (SCR) is a 4 layer, 3 junction device. Figure 33-19 is the pictorial diagram and schematic symbol for the SCR. Conduction in the SCR can be

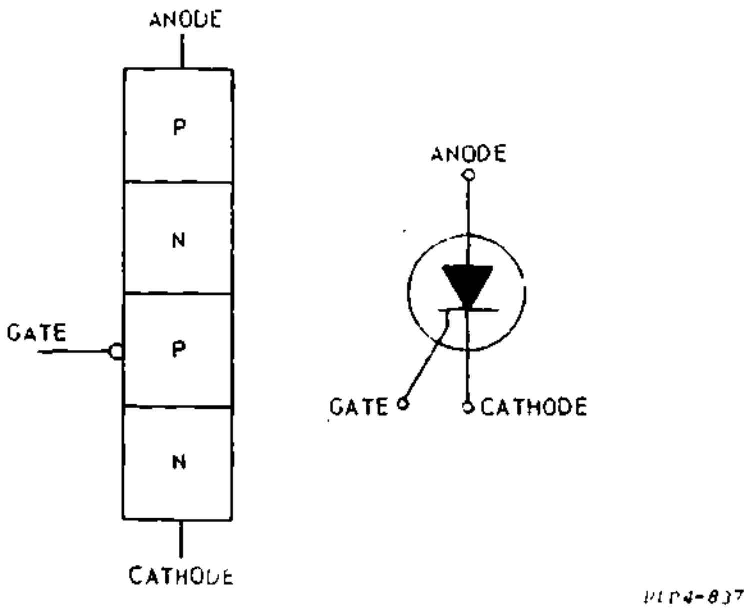


Figure 33-19. Silicon Controlled Rectifier (SCR) Structure and Schematic Symbol

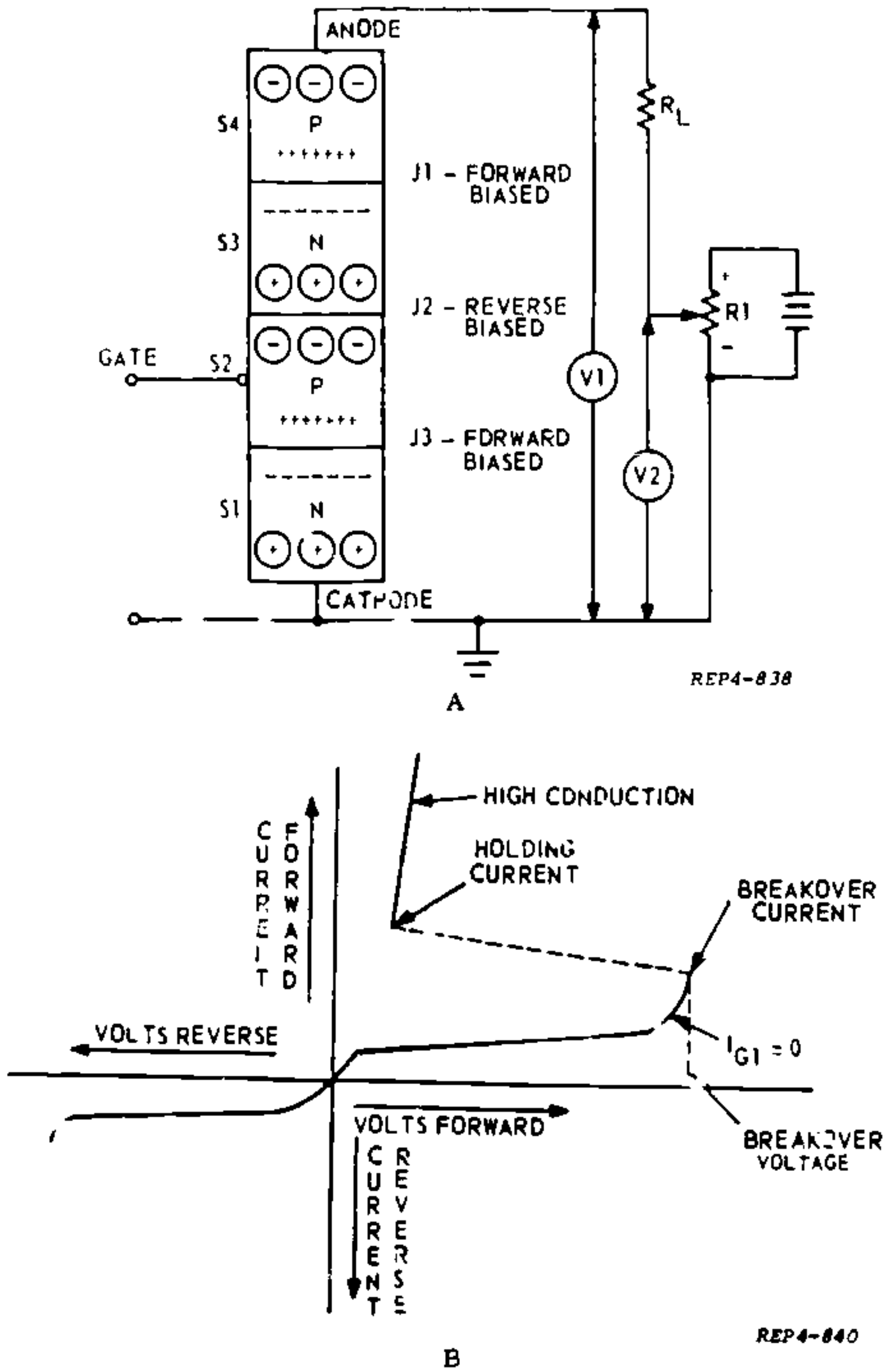


Figure 33-20. Biasing and Characteristic Curve for an SCR

achieved by applying anode to cathode voltage and a gate voltage to this cathode. After conduction is achieved, the anode to cathode voltage and the gate lose control of conduction. Figure 33-20A illustrates how conduction is achieved by the application of an anode to cathode voltage and figure 33-20B is the characteristic curve.

Section 1 (S_1) of the SCR is more heavily doped than section 2 (S_2). Junctions J_1 and J_3 are forward biased and J_2 is reverse

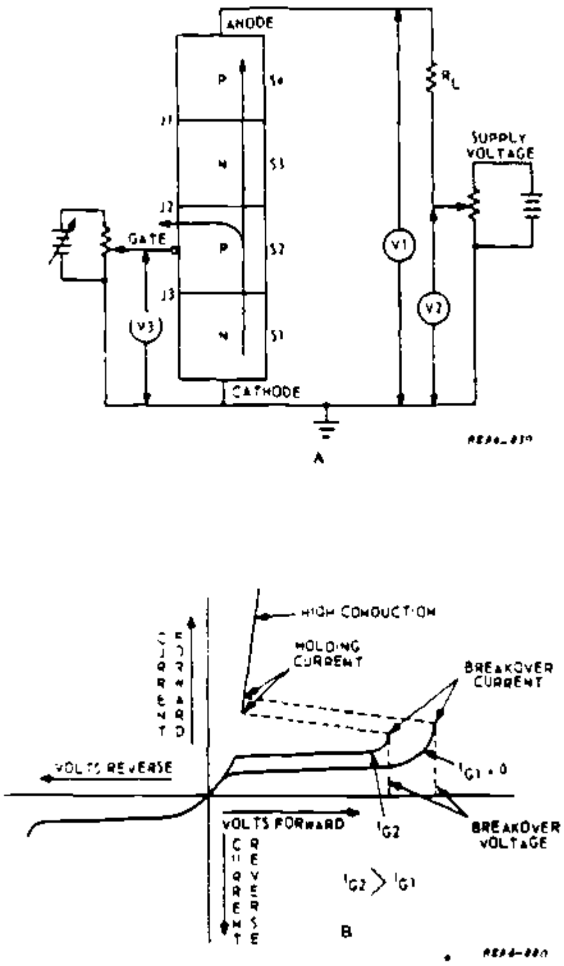


Figure 33-21. Schematic Diagram and Characteristic Curve for a Gated SCR

biased. As the arm of the potentiometer (R1) is moved up (more positive), the anode to cathode voltage is increased. The only conduction is the reverse current across J_2. When the anode-to-cathode voltage reaches the breakover voltage (see curve junction, J_2 goes into reverse breakdown momentarily. This results in the injection of electron carriers from section S_1 to S_2. These electrons, once in S_2, act as minority carriers (electrons in P material) and move easily across the junction (J_2). Once they arrive in S_3, they again become majority carriers and move easily across J_1. The result is high conduction and a large voltage drop across R_L. This immediately reduces the anode-to-cathode voltage and brings J_2 junction out of reverse breakdown. The SCR remains in high conduction because of the continued injection of electron carriers from S_1 to S_2. If the current is allowed to drop below the "holding current" (see chart), then carrier injection into S_2 will not be sufficient to maintain the level of high conduction. Notice that the anode-to-cathode voltage remains relatively constant for large changes in current. Refer to figure 33-21A and 33-21B to determine the effect of the voltage on conduction of an SCR.

The application of a gate voltage will result in gate current and the injection of electron carriers from S_1 and S_2 with no anode-to-cathode voltage applied. The result is that a significantly smaller amount of anode-to-cathode voltage is required to achieve high conduction (see chart). The gate voltage will determine the breakover voltage required to achieve high conduction. The holding current determines when the SCR will drop out of high conduction.

The Zener Diode

A zener diode is a PN junction diode whose doping has been increased so that it can operate in the reverse breakdown, avalanche current area of the characteristic curve without causing structural breakdown. While operating in the avalanche current area, the zener diode will maintain a relatively constant voltage across it for

65

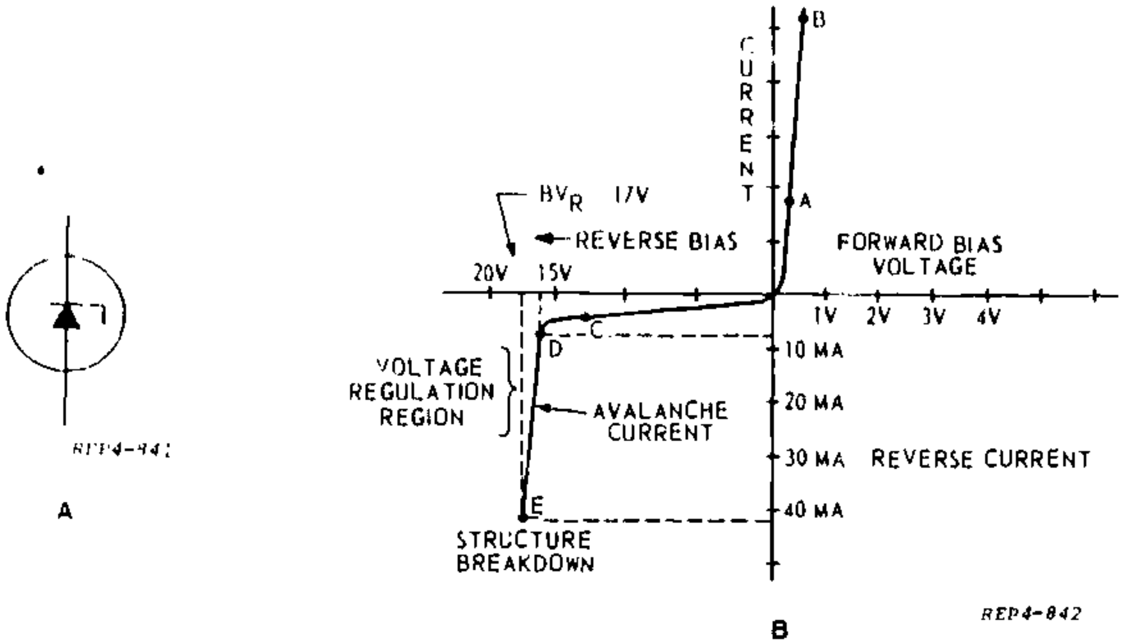


Figure 33-22. Schematic Symbol and Characteristic Curve for a Zener Diode

a wide range of currents. Figure 33-22 shows the schematic symbol and the characteristic curve for a zener diode. By controlling doping, a zener diode can regulate voltage within the range of 3 to 20 volts and may be connected in series if a higher regulated voltage is required.

Integrated Circuits

Integrated circuits are divided into two categories, HYBRID and MONOLITHIC. In the monolithic integrated circuit, all elements (resistors, transistors, diodes, and capacitors are fabricated inseparably within a continuous piece of material called the SUBSTRATE. If the substrate is N material, then controlled amounts of P material will be doped into the substrate to form the components. Metallic contacts are attached to these areas and leads are connected. An entire electronic circuit can be manufactured on a single piece of substrate 40 by 60 thousandths of an inch in size.

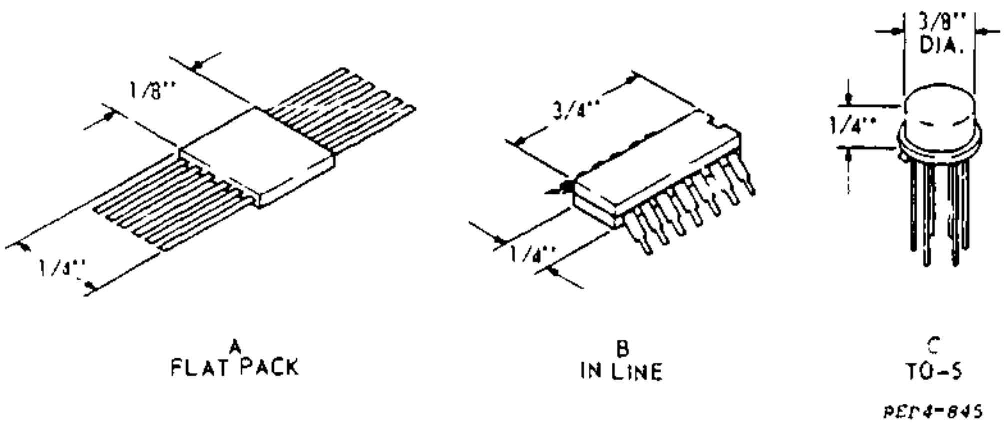


Figure 33-23. Package Styles for Integrated Circuits

75

Hybrid integraded circuits have the passive components (resistors, capacitors) deposited on a substrate made of glass, ceramic, or some other insulating material. The active components (diodes, transistors) are then attached to the substrate. Figure 33-23 shows some typical examples of integrated circuit packages. One of these tiny packages may contain one or several circuits and often have several hundred components.

Integrated circuits are small in size and light in weight. They consume very little power and are highly reliable. This makes them ideally suited for use in airborne equipment, missile systems, computers, spacecraft, and portable equipment. Because of their construction they are not normally repaired. For example, a monolithic integrated circuit cannot be repaired and the entire device is replaced.

NOTES

PREPARE THE MAN

PT 3AQR30020
KEP-420*

6t

Electronic Principles Department

SOLID STATE DEVICES

1 July 1973

7-8

Keesler Technical Training Center
Keesler Air Force Base, Mississippi

Designed For ATC Course Use

*Formerly C857

DO NOT USE ON THE JOB

ATC Keesler 4-33

Electronic Principles Department
KTTC, Mississippi

Programmed Text KEP-420
3AQR30020
1 July 1973*

TABLE OF CONTENTS

NOTE: This workbook is a revision of NAVPERS Training Manual 92903, Transistors.

*This supersedes C857, August 1969. Supplies of C857 on hand will be used.

10

INTRODUCTION

John Bardeen, William Shockley, and W. H. Brattain are credited with having developed the transistor at Bell Telephone Laboratories in June, 1948. Initially the device was referred to as a TRANSFER RESISTOR, but soon the name was shortened to transistor.

Since its introduction the "transistor" has been constantly improved until for many uses it is the most efficient and dependable device available for its field of application. The advantages are that they do not have filaments which require heating, require less power than electron tubes, are rugged, and have a very low failure rate.

Transistors and associated circuits are especially suited for use in equipments which must be miniaturized. This is because the components are small and light, can be operated with light compact power supplies, and are rugged. This last feature permits simpler, more compact shock and vibration-isolation equipment to be used. Also, since the components have a very low failure rate, less storage space for equipment replacement parts is required.

Because of the continuous advance of solid state technology, semiconductor devices and circuits are being used more and more, both in military and commercial electronic equipment.

INSTRUCTIONS

This student workbook is a programmed text. When using this programmed text, you learn by actively responding to each bit of information before proceeding to the next. You are allowed to proceed at your own pace. Don't rush, but don't loaf. THIS IS NOT A TEST.

Each learning step—consisting of the information, plus an instruction on how you are to respond (when needed), and your response—is called a frame. Each frame contains diagonal lines ////////////////////. Use a 5 x 8 card, or heavy paper you can't see through, as a mask. Slide the mask down the page until you expose the first diagonals.

Read the information and either:

a. fill in the blank(s) in a sentence to complete it correctly,
b. follow the instructions in the frame, or
c. go to the next frame. Some frames don't require a response.

After you respond, slide the mask down to the next solid line which runs across the page. The correct response appears above that line. Compare your response with the correct one. If your response is incorrect, reread the information to see why the correct, printed response is really correct. Write that response next to yours, slide the mask down to the next //////, and start the next frame.

Get a mask, slide it to the //////////////////// below and try a practice frame.

---

1. Maine, Virginia and Florida are coastal states. Massachusetts also borders the Atlantic, so it is a (   ).

   (After you have written your answer, move the paper to the solid line and compare your response with the correct one:)

////////////////////

coastal state

Since your learning in every frame usually depends on what you also learned in the preceding frame, DO NOT SKIP ANY FRAME.

TURN THE PAGE AND BEGIN

I. BASIC ATOMIC THEORY

This lesson teaches basic atomic theory. First, you will learn about the structure of matter, including elements, compounds, molecules, and atoms. Then, the structure of the atom will be covered.

Quite possibly, you may have already learned some of this material in a prior course. If so, this part of the program is designed to let you skip the parts you may already know.

STRUCTURE OF MATTER

1. Choose the phrase or phrases in the second column that best describe the word in the first column. If all answers are correct, move on to frame 17; otherwise, proceed with frame 2.

1. compound	a. smallest unit of an element
2. atom	b. combination of elements
3. element	c. smallest unit of a compound
4. molecule	d. made up of atoms

////////////////////

1. b   2. a   3. d   4. c, d

---

2. Matter is any substance that has mass and occupies space. Since water has mass and occupies space, it is an example of (   ).

////////////////////

matter

---

3. Stone is matter because it has (   ) and occupies (   ).

////////////////////

mass   space

---

4. Wood, water, and oxygen are examples of the three states of matter. The three states are:

a. (   )   b. (   )   c. (   )

////////////////////

a. solid   b. liquid   c. gas

---

5. All matter is composed of elements. Elements cannot be reduced into simpler substances nor built up from simpler substances. Oxygen cannot be decomposed or made from other substances, so it is (   ).

////////////////////

an element

---

6. Hydrogen is also an element. It too cannot . . . .

////////////////////

be decomposed nor made from other substances.

7. Water is made with oxygen and hydrogen. Water (is/is not) an element

////////////////////

is not

8. When elements are combined to form another substance, they produce a compound. Water is ( ).

////////////////////

a compound

9. The compound water is made by combining oxygen and hydrogen, which are ( ).

////////////////////

elements

10. The smallest particle of a compound that retains all the properties of the compound is a molecule. A drop of water contains many ( ) of water.

////////////////////

molecules

11. If the compound carbon dioxide was broken down to the smallest particle that could be identified as carbon dioxide, that particle would be a ( ).

////////////////////

molecule (of carbon dioxide)

12. When a molecule of a compound is reduced even further, the compound no longer exists. In its place are the ( ) that were originally combined to form the compound.

////////////////////

elements

13. The smallest unit of an element that can still be identified as that element is called an atom. Since compounds are made of elements, molecules of compounds are made of ( ) of elements.

////////////////////

atoms

14. The smallest units of oxygen and hydrogen are (   ).

////////////////////

atoms

15. If the atoms of oxygen and hydrogen are combined, a (   ) of the compound water is produced.

////////////////////

molecule

16. Choose the phrase or phrases in the second column that best describe the word in the first column.

1. compound	a. smallest unit of an element
2. atom	b. combination of elements
3. element	c. smallest unit of a compound
4. molecule	d. made up of atoms

////////////////////

1. b   2. a   3. d   4. c, d

ATOMIC STRUCTURE

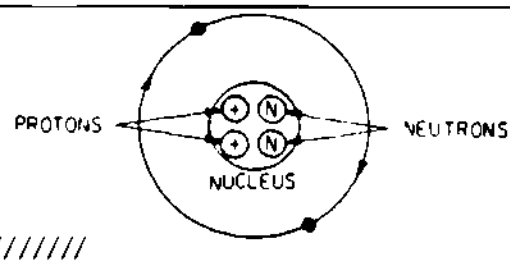
17 Match the word in the second column with the appropriate word in the first column. If all answers are correct. move on to frame 39; otherwise, proceed with frame 18.

1. electron	a. positive
2. proton	b. neutral
3. neutron	c. negative
4. atom	

////////////////////

1. c   2. a   3. b   4. b

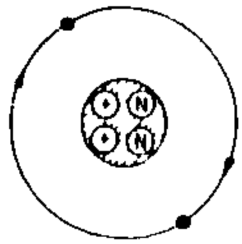
18. Electrons. protons, and neutrons are the most important parts of an atom. In the diagram. the nucleus, or center of the atom, is composed of (   ) and (   ).



////////////////////

protons   neutrons

19. Electrons circle about the nucleus of an atom in paths called orbits. In the diagram, label the parts which represent electrons.



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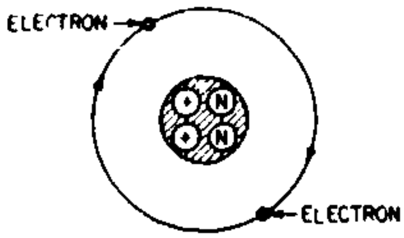


20. Electrons and protons have opposite electrical charges. Electrons have a negative charge. Protons have a (   ) charge.

////////////////////

positive

21. The charges of electrons and protons are represented by signs. A positive (+) sign is used to denote a proton; an electron is represented by a (   ) sign.

////////////////////

negative (-), minus

22. The electrical charges of electrons and protons are EQUAL and OPPOSITE. Because of this, the negative charge of an electron and the positive charge of a proton (   ).

////////////////////

cancel each other.

23. When the electrical charges of an electron and a proton cancel, the resultant charge is (   ).

////////////////////

neutral, zero

24. A neutron can be thought of as a combination of a proton and an electron; therefore, the electral charge of a neutron is (   ).

////////////////////

neutral, zero

25. Protons are ( ) and neutrons are ( ).

////////////////////

positive neutral

26. Because protons and neutrons make up the nucleus of an atom, the overall charge of the nucleus is ( ).

////////////////////

positive

27. Particles with opposite electrical charges attract each other. Particles with the same electrical charge, then, ( ) each other.

////////////////////

repel

28. Two electrons will ( ) each other.

////////////////////

repel

29. A proton will repel a ( ).

////////////////////

proton

30. A proton will attract ( ).

////////////////////

an electron

31. The nucleus has a ( ) charge.

////////////////////

positive

32. The nucleus attracts ( ).

////////////////////

electrons

33. Electrons move at a great speed in their orbits around the (   ).

////////////////////

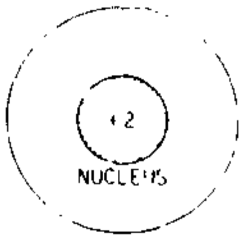
nucleus

34. Because of their great orbital speed, electrons TEND to break away. But, they are kept in orbit by the (   ) of the (   ).

////////////////////

attraction   nucleus

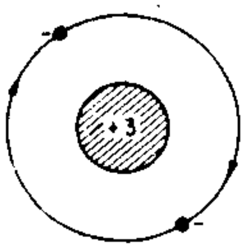
35. Normally, the number of electrons in an atom is equal to the number of protons in the nucleus. In the diagram, the number in the nucleus represents the number of protons. There should be (   ) orbital electrons.



////////////////////

two

36. Since opposite charges cancel out, an atom that has the same number of protons and electrons is electrically neutral. In the diagram, the atom (is/is not) neutral.



////////////////////

is not

37. If an atom has three electrons and three protons, it is electrically (   ).

////////////////////

neutral

38. Match the word in the second column with the appropriate word in the first column.

1. electron	a. positive
2. proton	b. neutral
3. neutron	c. negative
4. atom	

////////////////////

1. c   2. a   3. b   4. b

39. The orbits of electrons may be thought of as being arranged in concentric shells around the ( ) of an atom.

//////////////////////

nucleus, center

40. Each shell has a maximum number of ( ) that it can hold.

//////////////////////

electrons

41.a. The maximum number of electrons that each shell can hold depends upon the "distance" of the shell from the nucleus. Referring to the table listing the "electron structure of atoms" (page 11), what is the MAXIMUM number of electrons that can be held in the first shell, which is the one that is closest to the nucleus?

//////////////////////

2

41.b. What is the MAXIMUM number of electrons that can be contained in the second shell of any atom? In the third shell? In the fourth shell?

//////////////////////

8 18 32

41.c. Based on this, a general rule can be stated as follows: The first shell can hold up to ( ) electrons; the second shell can hold up to ( ) electrons; the third shell can hold up to ( ) electrons; and the fourth shell can hold up to ( ) electrons.

//////////////////////

2 8 18 32

(Although there are atoms with up to 7 shells, these atoms are not important in the study of transistors.)

41.d. Is it necessary for all of the preceding shells to be filled before a new shell can be started?

//////////////////////

No. (In atoms having up to 3 shells all the inner shells ARE filled, but this is not true in atoms having more than 3 shells. The reason for this is believed to be that the further the distance each shell is from the nucleus, the less influence the nucleus has over the electrons in the shell.)

42.a. By studying the table closely, another important rule for the number of electrons in each shell can be derived. What is the maximum number of electrons that can be contained in a shell IF THAT SHELL IS THE OUTERMOST SHELL?

////////////////////

8

42.b. Studying the table again, what is the maximum number of electrons that can be contained IN THE NEXT TO THE OUTERMOST SHELL?

////////////////////

18

42.c. Thus, as another general rule, it can be stated that: The OUTERMOST shell of an atom can hold no more than (   ) electrons and the next to the outermost shell can hold no more than (   ) electrons.

////////////////////

8   18

43.a. In your own words, state the rule defining the MAXIMUM number of electrons that can be contained in each shell (up to 4 shells), and give the EXCEPTIONS to the rule.

////////////////////

The first shell can hold up to 2 electrons, the second shell can hold up to 8 electrons, the third shell can hold up to 18 electrons, and the fourth shell can hold up to 32 electrons. But, whenever a shell is the OUTERMOST shell, it can only hold up to 8 electrons and whenever a shell is the NEXT TO THE OUTERMOST shell, it can only hold up to 18 electrons. (This will become apparent by studying the table.)

43.b. If the atom had four shells, the third shell could hold (   ) electrons.

////////////////////

18

43.c. In an atom with only four shells, the fourth shell could hold up to (   ) electrons.

////////////////////

8

43.d. In an atom with five shells, the fourth shell could hold (   ) electrons.

////////////////////

18

43.e. In an atom with six shells, the fourth shell could hold (   ) electrons, and the third shell (   ) electrons.

////////////////////

32   18

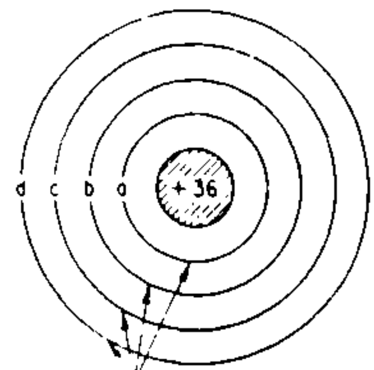
43.f. In an atom with seven shells, the third and fourth shells could still only hold (   ) and (   ) electrons, respectively.

////////////////////

18   32

44. Although there are some atoms with up to 7 shells, this transistor course only covers materials whose atoms have up to 4 shells. Such an atom could have at the most 36 electrons. List the correct number of electrons per shell for the atom in the diagram.

a. (   )
b. (   )
c. (   )
d. (   )



////////////////////

a. 2   b. 8   c. 18   d. 8

45. Each shell must be filled to capacity before the next shell can contain any electrons. If the first shell is incomplete, there (might/cannot) be electrons in the second shell.

////////////////////

cannot

46. When an atom has 36 electrons, how many protons must it contain for the atom to be neutral?

////////////////////

36

47. If an atom was electrically neutral and had 18 protons in its nucleus, how many electrons would it have in its first, second, and third shells?

////////////////////

first shell: 2   second shell: 8   third shell: 8

SUMMARY

1. Matter is any substance that has mass and occupies space.

2. Matter exists in three states: solid, liquid, and gas.

3. Elements cannot be decomposed into simpler substances nor built up from simpler substances.

4. Compounds contain two or more different elements in chemical combination.

5. A molecule is the smallest particle of a compound that retains all the properties of the compound.

6. An atom is the smallest part of an element that can still be identified as that element.

7. An atom is composed primarily of electrons, protons, and neutrons.

8. At the center of an atom is the nucleus, which contains protons and neutrons.

9. Electrons circle about the nucleus in paths called orbits.

10. Electrons have a negative electrical charge.

11. Protons have a positive electrical charge.

12. Neutrons are electrically neutral.

13. The nucleus of an atom has a positive electrical charge.

14. Like charges repel and opposite charges attract.

15. Electrons tend to break away from atoms because of their orbital speed.

16. Electrons are kept in orbit by the attraction of the nucleus.

17. Normally, the number of electrons in an atom is equal to the number of protons in the nucleus.

18. An atom with the same number of protons and electrons is electrically neutral. If it has more electrons than protons, the atom has a negative charge. If there are more protons than electrons, the atom has a positive charge.

19. The orbits of electrons may be thought of as being arranged in concentric shells around the nucleus of an atom.

20. No atom has more than seven shells.

21. There is a maximum number of electrons for each shell.

22. The first shell can hold up to 2 electrons, the second, 8; the third, 18; the fourth, 32.

23. However, the outermost shell, regardless of whether it is the third, fourth, etc., can hold no more than 8 electrons.

24. The shell next to the outermost shell can only hold up to 18 electrons.

ELECTRON STRUCTURE OF ATOMS*

ATOMIC NUMBER	ATOM	SHELL 1	2	3	4	5	ATOMIC NUMBER	ATOM	SHELL 1	2	3	4	5	6	7
1	Hydrogen H	1					50	Tin Sn	2	8	18	18	4	0	0
2	Helium He	2					51	Antimony Sb	2	8	18	18	5		
3	Lithium Li	2	1				52	Tellurium Te	2	8	18	18	6		
4	Beryllium Be	2	2				53	Iodine I	2	8	18	18	7		
5	Boron B	2	3				54	Xenon Xe	2	8	18	18	8		
6	Carbon C	2	4				55	Cesium Cs	2	8	18	18	8	1	
7	Nitrogen N	2	5				56	Barium Ba	2	8	18	18	8	2	
8	Oxygen O	2	6				57	Lanthunum La	2	8	18	18	9	2	
9	Fluorine F	2	7				58	Cerium Ce	2	8	18	19	9	2	
10	Neon Ne	2	8				59	Praseodymium Pr	2	8	18	20	9	2	
11	Sodium Na	2	8	1			60	Neodymium Nd	2	8	18	21	9	2	
12	Magnesium Mg	2	8	2			61	Promethium Pm	2	8	18	22	9	[illegible]	
13	Aluminum Al	2	8	3			62	Samarium Sm	2	8	18	23	9	2	
14	Silicon Si	2	8	4			63	Europium Eu	2	8	18	24	9	2	
15	Phosphorous P	2	8	5			64	Gadolinium Gd	2	8	18	25	9	2	
16	Sulphur S	2	8	6			65	Terbium Tb	2	8	18	26	9	2	
17	Chlorine Cl	2	8	7			66	Dysprosium Dy	2	8	18	27	9	2	
18	Argon A	2	8	8			67	Holmium Ho	2	8	18	28	9	2	
19	Potassium K	2	8	8	1		68	Erbium Er	2	8	18	29	9	2	
20	Calcium Ca	2	8	8	2		69	Thulium Tm	2	8	18	30	9	2	
21	Scandium Sc	2	8	9	2		70	Ytterbium Yb	2	8	18	31	9	2	
22	Titanium Ti	2	8	10	2		71	Lutetium Lu	2	8	18	32	9	2	
23	Vanadium V	2	8	11	2		72	Hafnium Hf	2	8	18	32	10	2	
24	Chromium Cr	2	8	13	1		73	Tantalum Ta	2	8	18	32	11	2	
25	Manganese Mn	2	8	13	2		74	Tungsten W	2	8	18	32	12	2	
26	Iron Fe	2	8	14	2		75	Rhenium Re	2	8	18	32	13	2	
27	Cobalt Co	2	8	15	2		76	Osmium Os	2	8	18	32	14	2	
28	Nickel Ni	2	8	16	2		77	Iridium Ir	2	8	18	32	15	2	
29	Copper Cu	2	8	18	1		78	Platinum Pt	2	8	18	32	16	2	
30	Zinc Zn	2	8	18	2		79	Gold Au	2	8	18	32	18	1	
31	Gallium Ga	2	8	18	3		80	Mercury Hg	2	8	18	32	18	2	
32	Germanium Ge	2	8	18	4		81	Thallium Tl	2	8	18	32	18	3	
33	Arsenic As	2	8	18	5		82	Lead Pb	2	8	18	32	18	4	
34	Selenium Se	2	8	18	6		83	Bismuth Bi	2	8	18	32	18	5	
35	Bromine Br	2	8	18	7		84	Polonium Po	2	8	18	32	18	6	
36	Krypton Kr	2	8	18	8		85	Astitine At	2	8	18	32	18	7	
37	Rubidium Rb	2	8	18	8	1	86	Radon Rn	2	8	18	32	18	8	
38	Strontium Sr	2	8	18	8	2	87	Francium Fr	2	8	18	32	18	8	1
39	Yttrium Y	2	8	18	9	2	88	Radium Ra	2	8	18	32	18	8	2
40	Zirconium Zr	2	8	18	10	2	89	Actinium Ac	2	8	18	32	18	9	2
41	Niobium Nb	2	8	18	12	1	90	Thorium Th	2	8	18	32	19	9	2
42	Molybdenum Mo	2	8	18	13	1	91	Protactinium Pa	2	8	18	32	20	9	2
43	Technetium Te	2	8	18	14	1	92	Uranium U	2	8	18	32	21	9	2
44	Ruthenium Ru	2	8	18	15	1	93	Neptunium Np	2	8	18	32	22	9	2
45	Rhodium Rh	2	8	18	16	1	94	Plutonium Pu	2	8	18	32	23	9	2
46	Palladium Pd	2	8	18	18	0	95	Americium Am	2	8	18	32	24	9	2
47	Silver Ag	2	8	18	18	1	96	Curium Cm	2	8	18	32	25	9	2
48	Cadmium Cd	2	8	18	18	2	97	Berkelium Bk	2	8	18	32	26	9	2
49	Indium In	2	8	18	18	3	98	Californium Cf	2	8	18	32	27	9	2

*This table is used solely as an example and is not complete. There are actually 106 known elements.

II. BASIC ELECTRON THEORY

In the first lesson, you learned that atoms are made up of electrons, protons, and neutrons and that electrons are in motion and tend to break away from the atoms. This lesson will teach you about energy levels of electrons according to quantum theory, and how electrons can be moved. Then you will learn what valence electrons are and how they act in electrical conductors, insulators, and semiconductors.

QUANTUM THEORY

1. The quantum theory states that an electron can be moved out of its shell if enough energy (in the form of light, heat, magnetic fields, etc.) is applied to or lost by the electron. That electron can move to a (   ) that is closer to or further from the nucleus.

////////////////////

shell

---

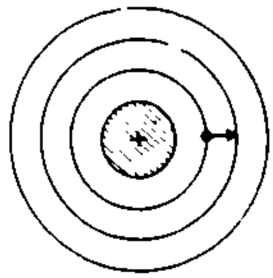
2. If the electron loses enough energy, it will move to a lower shell. If it gains enough energy, it will move to a (   ).

////////////////////

higher shell

---

3. What would have to be done to the electron shown in the diagram to move it to the shell indicated?

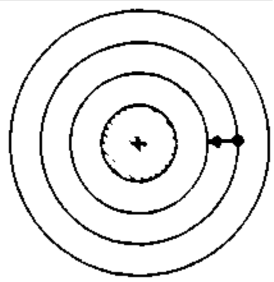


////////////////////

Add enough energy to it.

---

4. What would have to be done to the electron shown in this diagram to move it to the shell indicated?



////////////////////

Take enough energy away from it.

---

5. To move an electron to a higher shell, its energy level must be (increased/decreased); to move it to a lower shell, its energy level must be (increased/decreased).

////////////////////

increased decreased

6. The units of energy contained by an electron are called quanta. If we add two quanta of energy to an electron, it might move to a ( ).

////////////////////

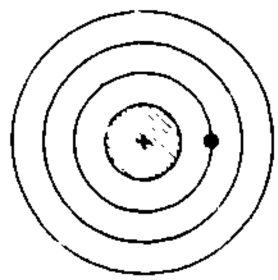
higher shell

7. A certain amount of energy must be added to or taken from an electron's energy level for that electron to move out of its shell. If the energy level does not change enough, the electron will ( ).

////////////////////

stay in its shell

8. Assume 3 quanta must be ADDED to the electron shown in the diagram to move it to the next shell. Indicate the new position of the electron if 2 quanta are imparted to it.



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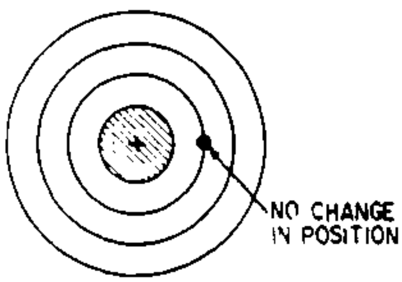


9.a. If more than enough energy is added, the extra energy will have no further effect unless it is enough to move the electron to a higher shell.

If 3 quanta had to be added to an electron to move it to the next higher shell, and 4 quanta were added to it, would the electron move to the higher shell?

////////////////////

Yes

9.b. How much of the 4 quanta was actually used by the electron?

//////////////////////

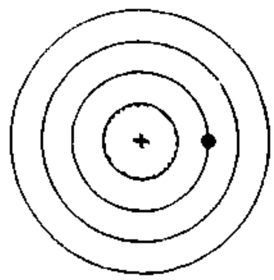
3

9.c. What effect did the extra quantum have?

//////////////////////

none

10.a. Assume that an electron in the first shell of an atom has a particular energy level. Assume further that 2 quanta must be ADDED to the electron to move it from the FIRST to the SECOND shell, and that 4 quanta must be ADDED to move it from the FIRST to the THIRD shell. Indicate the new position of the electron if 3 quanta are added to it.



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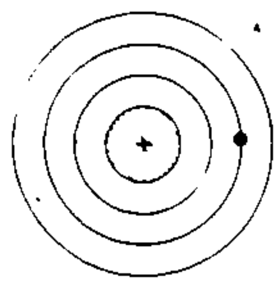


10.b. What if the electron were in the third shell and 4 quanta were taken away from it?

//////////////////////

The electron would move to the first shell.

11. Since energy must be added to an electron to move it to a higher shell, the electrons in the higher shells have (higher/lower) energy levels than those in the lower shells.

//////////////////////

higher

12. Which shell has the highest energy level?

//////////////////////

The outermost or highest shell.

13. The outermost shell of an atom is called the valence shell. Electrons in this shell are known as valence electrons. Since they are in the outermost shell, valence electrons have the (   ) energy levels.

////////////////////

highest

14. If enough energy is added to a valence electron, it will move out of the valence shell. Since there is no next higher shell, this freed valence electron will move out of the (   ).

////////////////////

atom

The tendency of atoms to give up their valence electrons depends upon a characteristic called "chemical stability." An atom is said to be stable if its valence shell is full; that is, when the valence shell contains eight valence electrons. When the valence shell of an atom is more than half full, the atom tends to take on electrons to complete its valence shell. When an atom's valence shell is less that half full, the atom tends to give up electrons.

15. The less valence electrons there are in the valence shell, the easier it is to free them. Which atoms would more readily give up their valence electrons: atoms with one valence electron or atoms with five valence electrons?

////////////////////

Atoms with one valence electron.

16. [illegible] electrons that are freed are called free electrons. When free electrons leave atc... they can take part in the flow of electric current. Therefore, the fewer the valence electrons in a material, the easier it is for the material to conduct (   ).

////////////////////

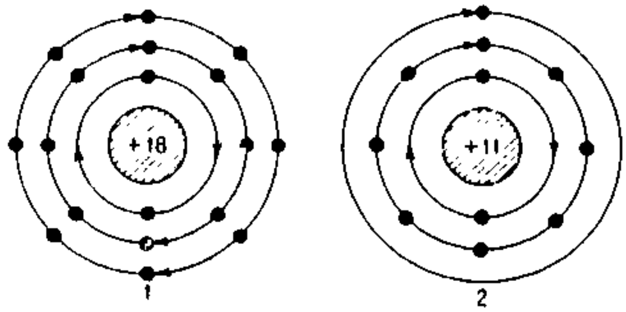
electric current

17. Since the outermost shell can only have up to 8 electrons, an atom that has 8 valence electrons is considered stable. This means that its valence electrons are difficult to (   ).

////////////////////

free

18.a. Choose the atom which would more easily release its valence electrons.



////////////////////

2

18.b. Which atom would not easily give up electrons?

////////////////////

1

19. Electric current is composed of free electrons that were removed from the ( ) shell.

////////////////////

valence

CONDUCTORS, INSULATORS AND SEMICONDUCTORS

20.a. Materials that easily conduct electric current are called conductors. Conductors have many ( ) electrons.

////////////////////

free

20.b. The valence shells in the atoms of conductors have only a few ( ) electrons.

////////////////////

valence

21. Most metals have a large number of free electrons, which makes them good ( ).

////////////////////

conductors

22.a. A material that cannot conduct electric current is called an insulator. An insulator has few or no (   ).

////////////////////

free electrons

22.b. The valence shells in the atoms of insulators have many (   ).

////////////////////

valence electrons

23. Glass, rubber, and mica have very few free electrons, and so are good (   ).

////////////////////

insulators

24.a. Some materials can provide enough free electrons to conduct current, but not enough to be called good conductors. These materials are known as semiconductors. Which of the following conducts more current?

1. conductors   2. semiconductors

////////////////////

1. conductors

24.b. Which of these conducts more current?

1. insulators   2. semiconductors

////////////////////

2. semiconductors

25.a. The manner in which materials conduct electric current can also be described in terms of resistance.

Conductors offer a (high/low) resistance to current flow.

////////////////////

low

25.b. Insulators offer a (high/low) resistance to current flow.

////////////////////

high

25.c. Semiconductors have (more/less) resistance than conductors, but (more/less) than insulators.

////////////////////

more less

25.d. Metals offer a ( ) to current flow.

////////////////////

low resistance

26. In contrast to low-resistance materials, high-resistance materials have very few ( ). But the outermost shells of their atoms have many ( ).

////////////////////

free electrons valence electrons

27. Semiconductors are neither good ( ) nor good ( ).

////////////////////

conductors insulators

28. Very little energy has to be applied to a conductor to free its valence electrons and cause the flow of ( ).

////////////////////

current

29. A great deal of energy is needed to cause current flow in ( ).

////////////////////

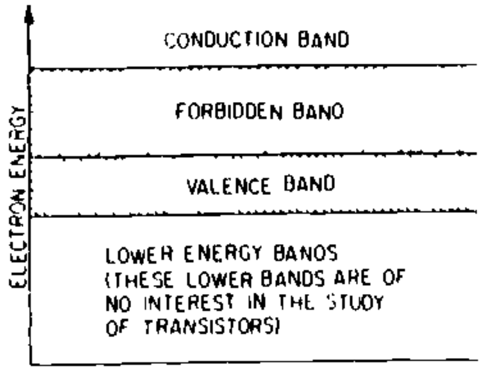
insulators

30. Semiconductors require more energy for current flow than ( ), but less than ( ).

////////////////////

conductors insulators

31. The amount of energy needed to cause current flow in any material can be represented by an energy-band diagram. The conduction band represents the level of energy that must be reached by an electron for it to be freed. Therefore, it represents the energy level at which (   ) will flow.



////////////////////

current

32. The valence band in the diagram corresponds to an atom's highest (   ) level.

////////////////////

energy

33. The forbidden band represents the amount of energy that must be added to an electron's energy level to reach the conduction band. The wider the forbidden band, the (   ) the energy required.

////////////////////

greater, more

34. If energy is added to the valence electrons, but the total energy still does not reach the conduction band, there will be no (   ).

////////////////////

current flow

35. The width of the forbidden band determines how easily a substance will conduct. The wider the forbidden band, the (   ) easily a substance conducts.

////////////////////

less

36. The wider the forbidden band, the greater the energy that must be added to the (   ) electrons for conduction to take place.

////////////////////

valence

37. An insulator would have a very wide (   ) band.

//////////////////////

forbidden

---

38. The forbidden band of semiconductors is narrower than that of (   ), but wider than that of (   ).

//////////////////////

insulators   conductors

---

39. In a conductor, the valence and conduction bands overlap so that no (   ) band exists.

//////////////////////

forbidden

---

40. The forbidden band of a semiconductor represents less required energy than the forbidden band of (   ).

//////////////////////

an insulator

---

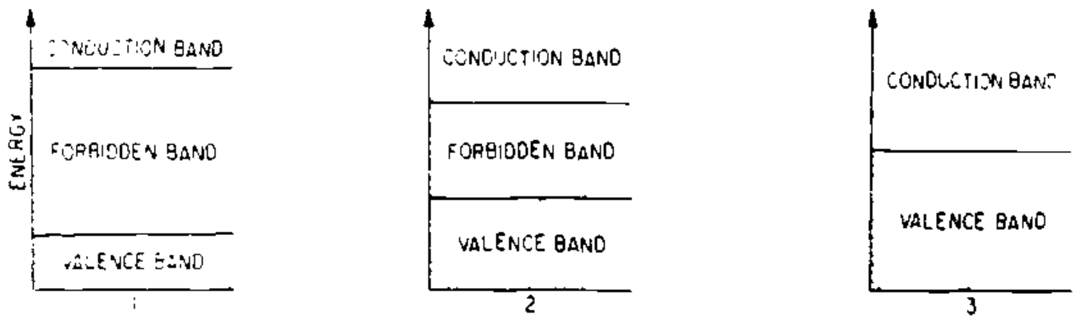
41. The conduction band of a conductor represents a slight increase of energy above the (   ) band.

//////////////////////

valence

---

42. Match the energy level diagrams with the appropriate substances.



a. conductor   b. insulator   c. semiconductor

//////////////////////

1. b.   2. c.   3. a.

---

43. The energy needed by an electron to cross the forbidden band is expressed in electron volts. Therefore, the width of the forbidden band can be measured in ( ).

////////////////////

electron volts

An electron volt is a unit of ENERGY. One electron volt is the ENERGY acquired by an electron after it has been accelerated through a potential of 1 volt. Do not confuse an electron volt with a volt, which is a unit of electromotive force (EMF).

44. If, to go from the valence to the conduction band, an electron must acquire 3 electron volts of energy, then the width of the forbidden band is ( ).

////////////////////

3 electron volts

45. In insulators, at least 4 ev (electron volts) have to be imparted to an electron to move it from the valence band to the conduction band. Therefore, the width of the forbidden band in insulators is ( ) ev or more.

////////////////////

4

46. For semiconductors, from 0.7 ev to 1.1 ev must be imparted to an electron to move it from the valence to the conduction band. This means that the width of the forbidden band in semiconductors is at least ( ).

////////////////////

0.7 ev

47. For conductors, as little as 0.01 ev is needed to move an electron into the ( ). band.

////////////////////

conduction

48. If the width of the forbidden band of a substance is between 0.7 ev and 1.1 ev, that substance is ( ).

////////////////////

a semiconductor

SUMMARY

1. An electron can be moved to a higher shell if enough energy is applied to it.

2. An electron can be moved to a lower shell if enough energy is lost by it.

3. The units of energy contained by an electron are called quanta.

4. In the higher shells, the electrons have higher energy levels.

5. Valence electrons are in the outermost, or valence, shell of an atom.

6. Valence electrons have the highest energy levels.

7. If enough energy is applied to a valence electron, it can be freed from the atom.

8. The fewer the valence electrons in the valence shell, the easier it is to free them.

9. Free electrons are those which have been removed from the valence shell.

10. Free electrons take part in electric current flow.

11. Conductors have a large number of free electrons.

12. Most metals are good conductors.

13. Insulators have very few free electrons.

14. Glass, rubber, and mica are good insulators.

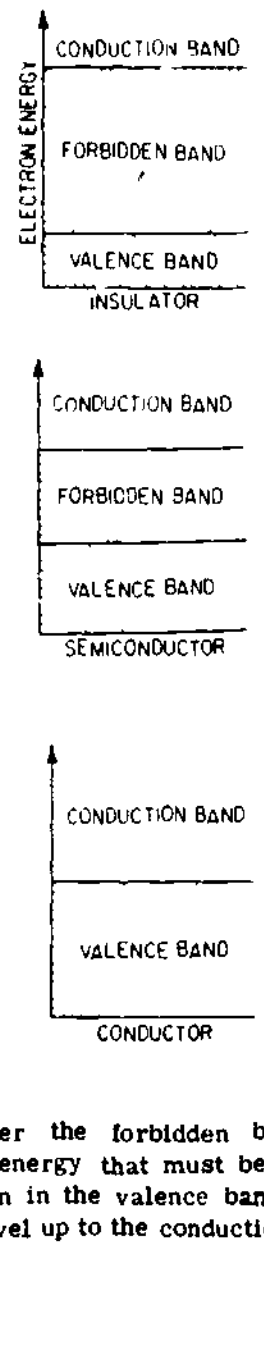
15. Semiconductors are neither good conductors nor good insulators.

16. Very little energy is needed to cause current flow in conductors.

17. A great deal of energy is needed to cause current flow in insulators.

18. Semiconductors require more energy for current flow than conductors, but less than insulators.

19. The amount of energy needed to cause current flow in any material can be represented by an energy-level diagram.



20. The wider the forbidden band, the greater the energy that must be imparted to an electron in the valence band to raise its energy level up to the conduction band.

21. Insulators have a very wide forbidden band.

22. Semiconductors have narrower forbidden bands than insulators.

23. Conductors have no forbidden band.

24. Electron energy is expressed in electron volts.

25. The width of the forbidden band can be measured in electron volts.

26. The width of the forbidden band in insulators is 4 or more electron volts.

27. The width of the forbidden band in semiconductors is 0.7 to 1.1 electron volts.

28. Conductors need as little as 0.01 electron volts to raise the energy level of a valence electron into the conduction band.

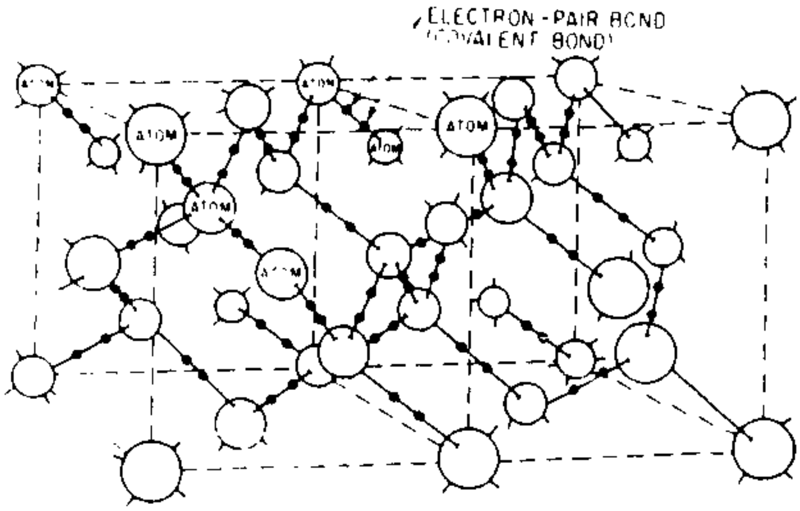
95

III. SEMICONDUCTOR THEORY

In the previous lesson, you learned how electrons are freed to produce current flow, and how some materials can conduct current more easily than others. You also learned that semiconductors are neither good conductors nor good insulators. This lesson will cover the structure of semiconductor materials and will teach you some facts about semiconductor characteristics. Then you will learn about how certain impurities can be added to semiconductor materials so that they can conduct current more freely.

SEMICONDUCTOR CHARACTERISTICS

1 The atoms in a semiconductor material are arranged in a CRYSTAL LATTICE structure. This structure is maintained by a condition called COVALENT BONDING; covalent bonding is brought about by the sharing of valence electrons between two or more adjacent ( ).



CRYSTAL LATTICE STRUCTURE

atoms

---

2. Germanium and silicon are the most commonly used semiconductors in electronics. Their atoms are arranged in a ( ) structure.

crystal lattice

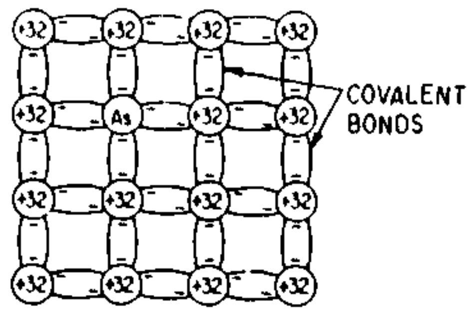
105

3. The valence electrons of adjacent germanium and silicon semiconductor atoms are shared to form a common bond. This is knows as (   ) bonding.

////////////////////

covalent

4. Germanium and silicon atoms have four valence electrons. To form a covalent bond, these atoms share their (   ).



////////////////////

valence electrons

5. This covalent bonding or sharing process effectively gives each atom a total of eight electrons in its (   ) shell.

////////////////////

valence, outermost

6. In each atom, four of the shared electrons are its own and four are borrowed from adjacent (   ).

////////////////////

atoms

7. Since covalent bonding results in each atom seeing eight electrons in its valence shell, a semiconductor crystal is (stable/unstable).

////////////////////

stable

8. Because electron sharing forms stable valence rings, pure germanium and pure silicon might seem to be fairly good (conductors/insulators).

////////////////////

insulators

9 But, because of thermal agitation, the valence electrons can break their ( ) bonds

covalent

---

10 With thermal energy imparted to them, electrons can move from the valence band into the ( ) band.

conduction

---

11 When an electron has moved into the conduction band, it can take part in ( ) flow.

current

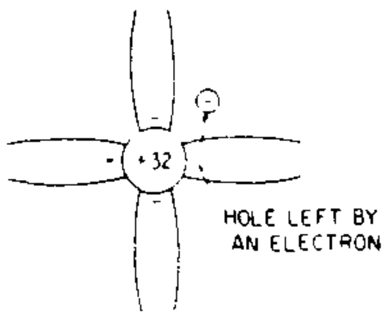
---

12. For an electron to take part in current flow, it must first break the ( ) bond and leave the ( ) band.

covalent valence

---

13. The vacancy in the crystal lattice structure, which is created by an electron leaving a covalent bond, is called a "hole." Therefore, the loss of an electron by an atom creates a ( ).



hole

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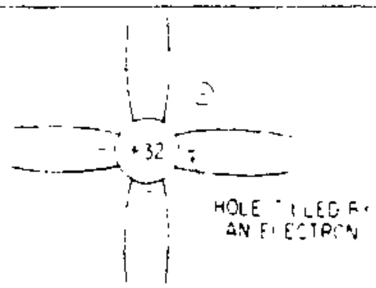
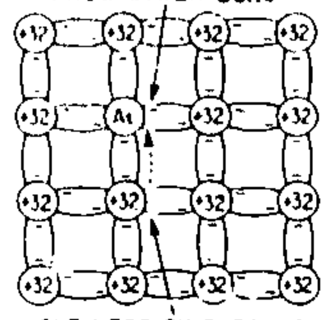
14 The hole in a covalent bond will be eliminated if it is filled with an ( )



electron

---

15 The electron that filled the hole in the covalent bond left a hole in another covalent bond. Therefore, both the ( ) and the ( ) moved.



//////////////////

electron hole

---

16. At normal temperatures, thermal agitation causes electrons to leave their covalent bonds in a random manner. Therefore, holes are also produced in a ( ) way.

//////////////////

random

---

17. The electrons that are released at random, because of thermal agitation, may drift from covalent bond to covalent bond. Holes also ( ) at random.

//////////////////

drift

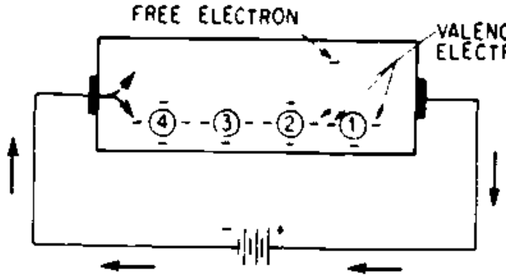
---

18. Semiconductors have electrons and holes that ( ) about at ( ).

//////////////////

drift, move random

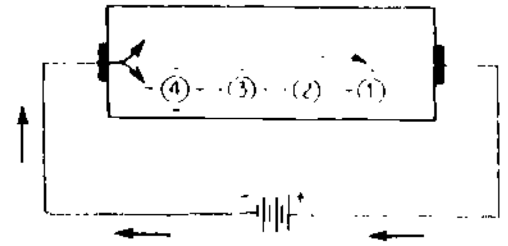
19.a. However, under the effects of an electrical field, such as the field produced by a battery, the free electrons and the holes will no longer drift in a random manner.



(Continued on next page)

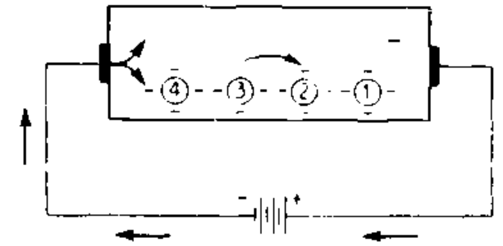
Assume that a valence electron from atom 1 acquires sufficient energy (thermally, or in some other way) to leave the valence band and move into the conduction band. This FREE electron, under the influence of the electric field will move towards the positive battery terminal. When a free electron leaves the positive side of the semiconductor material and enters the external circuit, another free electron enters the negative side of the material from the external circuit.

Notice that a vacancy (hole) has been left in the valence band of atom 1 because one of its valence electrons moved into the conducttion band. Under the influence of the external field, a VALENCE electron from atom 2 may acquire enough energy to leave atom 2 and fill the hole in the valence band of atom 1.



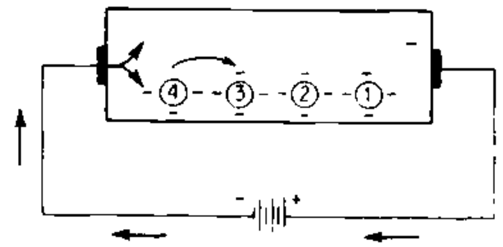
FREE ELECTRONS

Similarly, a valence electron from atom 3 may fill the hole in the valence band of atom 2, and a valence electron from atom 4 may fill the hole in the valence band of atom 3.



FREE ELECTRONS

The vacancy, or hole in the valence band of atom 4 may then be filled by a FREE electron from the external circuit.



FREE ELECTRONS

This discussion described the action of a single electron and hole under the influence of an external field. In an actual semiconductor crystal, many free electrons and holes would be present to support current flow.

In a semiconductor crystal, conduction is by (   ) electrons and (   ) electrons.

//////////////////////

free   valence

19.b. The movement of FREE electrons in a semiconductor is identical to the movement of free electrons in a metallic conductor such as copper. (True/False)

//////////////////////

True

107

19.c. When a valence electron acquires enough energy to leave the valence band and enter the conduction band, it leaves a vacancy in the valence band called a (   ).

////////////////////

hole

19.d. The absence of an electron from a normal covalent bond represents a localized positive charge. Therefore a hole may be considered as a particle similar to an electron but having a (   ) charge.

////////////////////

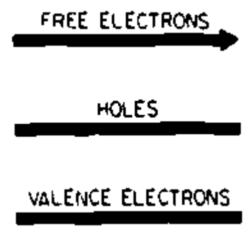
positive

19.e. Furthermore, the hole can be THOUGHT OF as a particle that moves much like an electron under the influence of an electric field, BUT IN THE OPPOSITE DIRECTION to that of an electron. However, it is very important to remember that a hole is simply a CONVENIENT device for describing. . . .

////////////////////

the MOVEMENT OF VALENCE ELECTRONS from covalent bond to covalent bond.

19.f. If the polarity of an electric field is such that free electrons are moving in the direction of the arrow, indicate by arrows the direction of hole current flow and valence electron flow.



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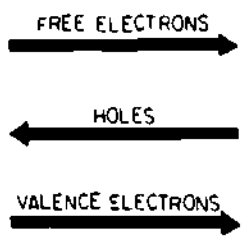


19.g. Since electrons are negative current carriers, holes may be considered (   ) current carriers.

////////////////////

positive

DOPING

20. Pure germanium and silicon materials have only a few current carriers, so that they can provide only a small amount of (   ) flow.

////////////////////

current

---

21. In order to be more useful in electronic circuits, the current carriers in semiconductors must be (increased/decreased).

////////////////////

increased

---

22. Current carriers in semiconductors can be increased by the addition of certain impurities. Germanium and silicon have impurities added to them so that the number of free electrons or (   ) is increased.

////////////////////

holes

---

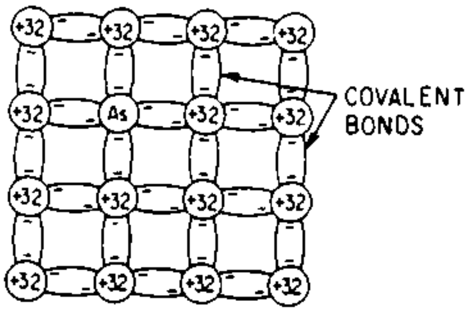
23. Germanium and silicon atoms have (   ) valence electrons.

////////////////////

four

---

24. Each germanium or silicon atom shares its valence electrons with (   ) other atoms.



////////////////////

four

---

25. This sharing effectively gives each atom (   ) valence electrons.

////////////////////

eight

---

26. Each atom with eight valence electrons tends to be (   ).

////////////////////

stable

27. If any of the atoms which are sharing valence electrons have less than eight valence electrons, the CRYSTAL LATTICE STRUCTURE will have (a deficiency/an excess) of electrons.

////////////////////

a deficiency

28. If any of the atoms have more than eight valence electrons, the CRYSTAL LATTICE STRUCTURE will have (a deficiency/an excess) of electrons.

////////////////////

an excess

29. If a pentavalent impurity such as arsenic, whose atoms have five valence electrons, is added to a germanium crystal, each of the arsenic atoms becomes a part of the semiconductor (   ) structure.

////////////////////

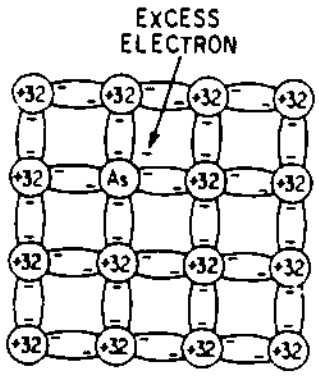
crystal lattice

30. In order to maintain covalent bonding of the crystal lattice, only four of the five valence electrons of the (   ) atom are required.

////////////////////

arsenic, impurity

31.a. Because of this, the germanium crystal lattice structure will contain an excess (   ).



////////////////////

electron

31.b. When a semiconductor material contains an excess of electrons it is called N-type material. Doping a semiconductor material with a pentavalent impurity results in ( ) material because. . . .

////////////////////

N-type

the material contains an excess of electrons.

32. If a trivalent impurity such as indium, whose atoms contain three valence electrons, is added to germanium, each of the indium atoms becomes a part of the semiconductor ( ) structure.

////////////////////

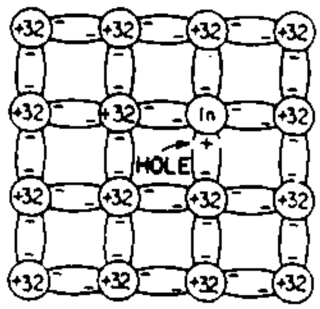
crystal lattice

33. Since an indium atom has only three valence electrons, the covalent bonds created will lack ( ).

////////////////////

one electron

34.a. This lack of one electron produces a ( ).



////////////////////

hole

34.b. Since a hole can be considered a positive charge, semiconductor material that contains an excess of holes is called ( ) material.

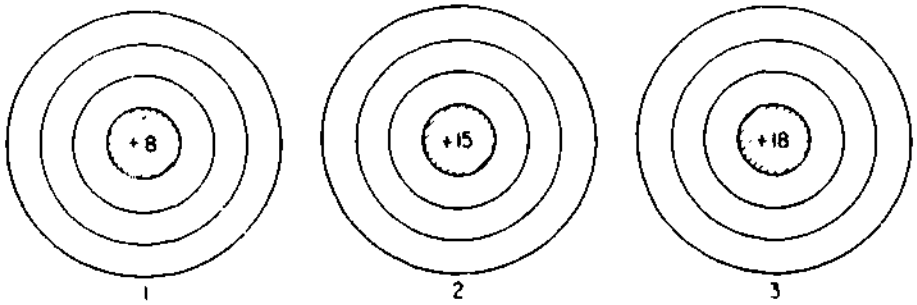
////////////////////

P-type

104

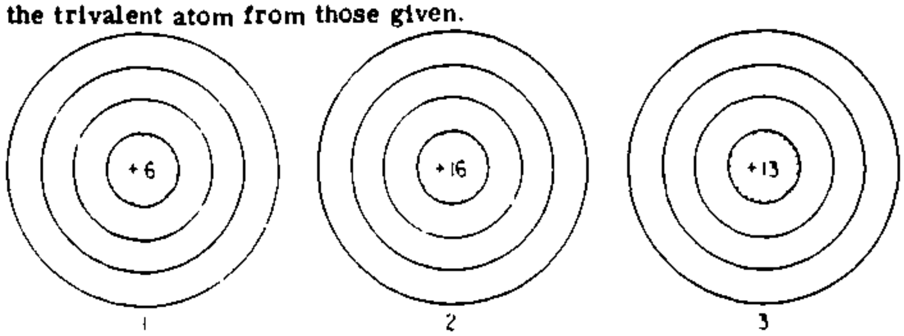
35. An element whose atoms have five valence electrons is called a pe tavalent impurity. Using the table giving the maximum number of electrons per shell, choose the pentavalent atom from those shown.

SHELL	1	2	3	4
MAXIMUM NUMBER OF ELECTRONS	2	8	18	32



2

36. An element whose atoms have three valence electrons is called a trivalent impurity. Choose the trivalent atom from those given.

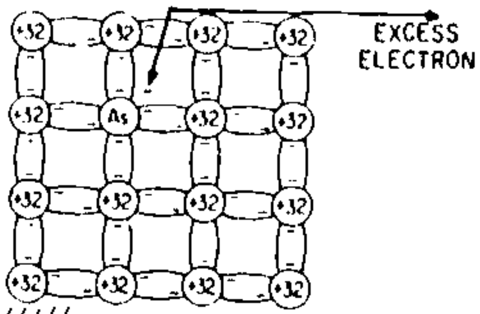


3

37. Elements which provide excess electrons are called donor impurities because they donate excess electrons to the semiconductor. Pentavalent elements such as arsenic, phosphorus, and antimony are (   ).

donor impurities

38. The nucleus of the pentavalent atom exerts only a very weak influence over the excess (   ).



////////////////////

electron

39. At normal room temperature, enough thermal energy is available to cause the excess electron to break away from the (   ) atom.

////////////////////

donor, pentavalent, impurity

40. The free electron then drifts through the (   ) structure of the germanium.

////////////////////

crystal lattice

41. Germanium or silicon crystals containing excess electrons, which are negative carriers, are called (N/P)-type semiconductors.

////////////////////

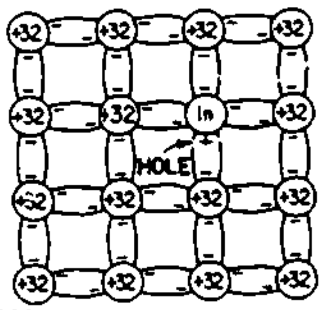
N

42. Elements which create holes are called acceptor impurities. Trivalent elements such as indium, galium, and boron are (   ).

////////////////////

acceptor impurities

43. When a trivalent or acceptor impurity is added to a semiconductor, a deficiency of (   ) is created.



////////////////////

electrons

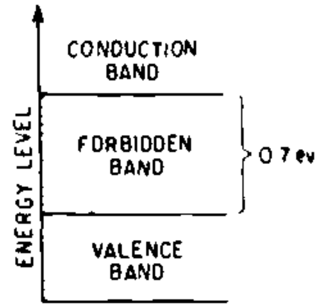
44. Germanium or silicon crystals with an excess of holes, which are positive carriers, are called (   )-type semiconductors.

////////////////////

P

45.a. The effect of creating excess electrons in semiconductors can be examined in terms of energy-level diagrams.

Without the pentavalent impurity, the width of the forbidden band is (   ) electron volts.

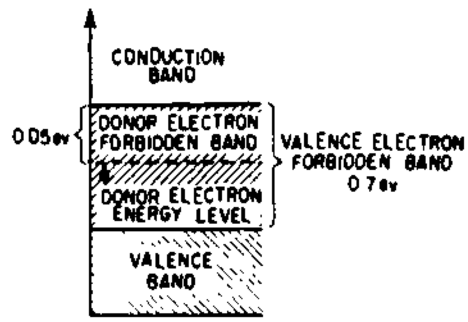


PURE GERMANIUM SEMICONDUCTOR

////////////////////

0.7

45.b. With the pentavalent impurity, the overall width of the forbidden band for the valence electron is (   ) electron volts.



DOPED GERMANIUM SEMICONDUCTOR

////////////////////

0.7

45.c. Only four electrons from the pentavalent impurity atom are needed to take part in covalent bonding, and the fifth electron in the crystal structure is only loosely bound to its parent atom (impurity atom). Therefore, the energy level of the free donor electron is higher than that of the electrons held in covalent bonds, so that the forbidden band for donor electrons is (   ) ev.

////////////////////

0.05

45.d. In N-type semiconductors, the free donor electrons become the main current carriers: therefore, the effective forbidden band is reduced from ( ) to ( ) by the addition of impurities.

////////////////////

0.7 ev 0.05 ev

46.a. Creating holes in semiconductors similarly affects the ( ) level distribution.

////////////////////

energy

46.b. in P-type material, the trivalent impurity effectively decreases the width of the ( ) band.

////////////////////

forbidden

46.c. This occurs becuase the attraction of the holes effectively increases the energy level of surrounding ( ).

////////////////////

electrons

47. This addition of a donor or pentavalent impurity to germanium or silicon produces ( )-type semiconductors.

////////////////////

N

48. N-type semiconductors have an excess of ( ), which drift freely in the crystal lattice structure.

////////////////////

electrons

49. When an EMF (electromotive force) energy is applied to an N-type semiconductor, the free electrons can take part in ( ) flow.

////////////////////

current

50.a. Although N-type semiconductors are made to have no holes, thermal energy causes some valence electrons to break their bonds, leaving some holes. Then, when enough energy is applied, other ( ) will be freed to fill these holes.

////////////////////

valence electrons

50.b. As these valence electrons move from one covalent bond to another, they will cause ( ) current to flow.

////////////////////

hole

51.a. But, in N-type material, there are many more free electrons then there are thermally-produced holes. Therefore, the electrons in N-type material are called the (majority/minority) carriers.

////////////////////

majority

51.b. The holes in N-type material, then, would be called ( ) carriers.

////////////////////

minority

---

52. The addition of acceptor or trivalent impurities to germanium or silicon produces ( )-type semiconductors.

////////////////////

P

---

53. P-type semiconductors have a deficiency of valence electrons, which produces an excess of ( ) in the covalent bonds.

////////////////////

holes

---

54. When energy is applied to a P-type semiconductor, valence electrons will leave their covalent bonds to fill holes. But in doing so, they leave new holes in their wake. This causes an apparent movement of the holes, which is known as ( ) flow.

////////////////////

hole current

---

55. Although P-type semiconductors are made to have no free electrons, thermal energy causes some valence electrons to break their bonds and drift through the crystal lattice structure. Then, when energy is applied to the semiconductor, these free electrons form ( ) current flow.

////////////////////

electron

56.a. But, holes produced by doping are much more numerous than electrons freed by thermal agitation. Therefore, in P-type material, holes are the ( ) carriers

////////////////////

majority

56.b. The minority carriers in P-type material are ( )

////////////////////

electrons

SUMMARY

1. The atoms in a semiconductor form a CRYSTAL LATTICE structure.

2. The crystal lattice structure is maintained by COVALENT BONDING.

3. Covalent bonding is the sharing of valence electrons between adjacent atoms.

4. Germanium and silicon atoms have four valence electrons.

5. Covalent bonding effectively gives each atom eight valence electrons, making a pure semiconductor stable.

6. Because of THERMAL AGITATION, some valence electrons break their covalent bonds and become available for current flow.

7. A HOLE is a location in a covalent bond that has been vacated by a VALENCE electron.

8 A hole is simply a convenient device for expressing the motion of valence electrons.

9. Holes and electrons can move about and recombine in a random manner.

10. Holes and electrons are called CURRENT CARRIERS. Holes are positive carriers and electrons are negative carriers.

11. Impurities are added to semiconductors to increase the number of current carriers. This process is called DOPING.

12. Impurities can be PENTAVALENT or TRIVALENT elements.

13. Pentavalent atoms have five valence electrons.

14. Trivalent atoms have three valence electrons.

15. Pentavalent elements, which produce free electrons, are called DONOR impurities.

16. Trivalent elements, which create holes, are called ACCEPTOR impurities.

17. In terms of energy-level diagrams, adding impurities to semiconductors effectively decreases the width of the forbidden band.

18. A P-TYPE semiconductor contains many holes.

19. A N-TYPE semiconductor contains many free electrons.

20 The MAJORITY CARRIERS in P-type material are holes.

21. The majority carriers in N-type material are electrons.

22. In P-type material, thermal agitation produces a few free electrons.

23. In N-type material, thermal agitation produces a few holes.

24. The MINORITY CARRIERS in P-type material are electrons.

25. The minority carriers in N-type material are holes.

IV. SEMICONDUCTOR DIODES

In the previous lesson, you learned about P- and N-type semiconductors, and how holes and free electrons can move about in these materials. In this lesson, you will learn how a semiconductor diode can be formed by combining a P- and an N-type semiconductor, and how this diode works with different types of bias voltages. Then, the application of a specific type of diode, know as a Zener (reference) diode, will will be covered.

PN CHARACTERISTICS

1. The trivalent acceptor impurity atoms that are added to P-type semiconductors have (   ) valence electrons.

////////////////////

three

---

2. Before the trivalent acceptor atoms are added to a semiconductor, they are electrically neutral; they have the same number of (   ) and (   ).

////////////////////

electrons   protons

---

3. When a pentavalent donor atom becomes part of the semiconductor crystal lattice structure, it gives up an (   ).

////////////////////

electron

---

4. When a trivalent acceptor atom becomes part of the semiconductor structure, it can create a hole in an adjacent semiconductor atom by taking on an (   ) from the adjacent atom.

////////////////////

electron

---

5. Since the acceptor impurity atom originally had the same number of protons and electrons, the extra electron causes the acceptor atom to become (   ) charged.

////////////////////

negatively

6.a. The semiconductor atom that gave up the electron to the impurity atom takes on a (   ) charge.

////////////////////

positive

112

6.b. The space left by the electron is called a (   ).

////////////////////

hole

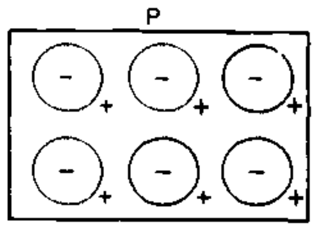
6.c. The hole represents the (   ) charge.

////////////////////

positive

7.a. P-type semiconductors, then, have two types of charged atoms: negative impurity atoms, and positive semiconductor atoms (holes).

In the diagram, a negative sign in a circle represents a (   ).



////////////////////

negative atom (ion)

7.b. The positive atoms, or holes, are shown as:

////////////////////

a plus sign.

7.c. The circles around the negative sign indicate that the negative charge is less apt to move. The majority current carrier, then is made up of (   ).

////////////////////

holes

7.d. However, it is important to keep in mind that THE OVERALL CHARGE of the P-type material remains neutral because the negative charge of the acceptor atoms is balanced by the positive charge of the (   ) created in the material.

////////////////////

holes

8. The pentavalent donor impurity atoms that are added to N-type semiconductors have (   ) valence electrons.

////////////////////

five

9. Before the pentavalent donor atoms are added to a semiconductor, they are also electrically (   ).

////////////////////

neutral

---

10. Since the donor impurity atom gives up an electron, the donor atom becomes (   ) charged.

////////////////////

positively

---

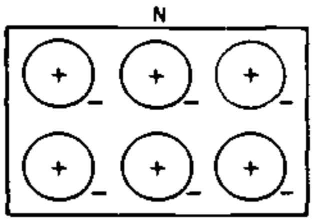
11. However, the OVERALL CHARGE of the N-type material remains NEUTRAL because the positive charge of the donor atoms is balanced by the negative charge of the (   ) created in the material.

////////////////////

free electrons

12.a. N-type semiconductors, then, have two types of charged particles: positive impurity atoms, and free electrons.

In the diagram, the positive atoms are shown as:



////////////////////

plus signs in circles

12.b. The free electrons are shown as:

////////////////////

negative signs

12.c. The circle around the plus sign indicates that the positive charge is less apt to move. The majority current carrier, then, is made up of (   ).

////////////////////

electrons

---

13. The majority carriers in P-type material are (   ).

////////////////////

holes

---

14. The majority carriers in N-type material are ( ).

////////////////////

electrons

15. Although both N- and P-type materials are electrically neutral overall, when they are "joined" together, there is some attraction in the immediate area of the junction. The holes on one side of the junction attract some free electrons from the other side of the junction. The free electrons cross from the N section to the P section and fill ( ).

////////////////////

holes

It is convenient to speak of PN junctions as being "joined" together. Actually, however, a PN junction can be formed only by a chemical process in which the P-type and the N-type material form a single crystal. In fact, a PN junction diode or a transistor would not work if the junctions were mechanically joined.

16. Since the N section was initially neutral, loss of some of its electrons leaves it with a ( ) charge.

////////////////////

positive

17. The positive charge of the N section increases as the number of departed ( ) increases.

////////////////////

electrons

18. Eventually, the positive charge of the N section will be enough to prevent additional electrons from leaving because of the force of ( ).

////////////////////

attraction

19. The P section was initially neutral. But, because some of its holes have been filled with electrons from the N section, the P section becomes ( ) charged.

////////////////////

negatively

20. When additional electrons from the N section attempt to approach the junction, not only are they restrained by the attraction of the positive charge in the N section, but they are also ( ) by the ( ) charge of the P section.

////////////////////

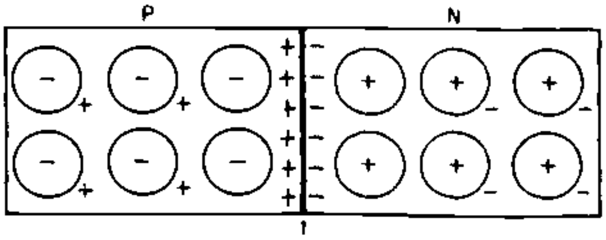
repelled negative

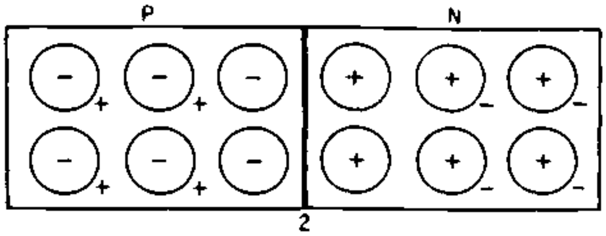
21. Because current carriers have combined, the area around the junction will have an absence of (   ) and (   ).

////////////////////

holes   free electrons

22. This area around the junction is called the DEPLETION REGION because of the lack of holes and electrons. Choose the diagram which most accurately represents this condition.





////////////////////

2

23. Because of the depletion region, restraining forces are set up at the (   ) of the two sections.

////////////////////

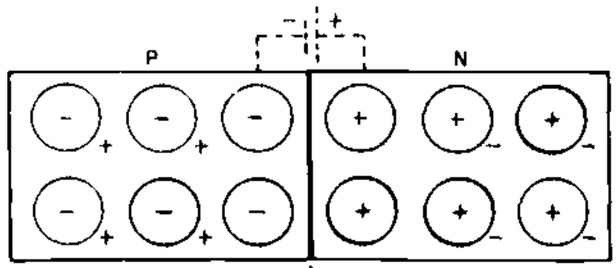
junction

24. The restraining force present at the junction may be REPRESENTED by a battery. Since the P section has a negative charge and the N section a positive charge, a battery that represents these forces would have its negative terminal connected to the (   ) section and its positive terminal connected to the (   ) section.

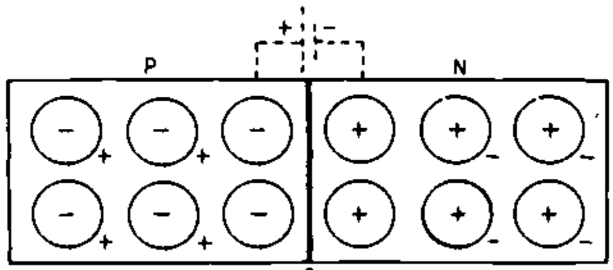
////////////////////

P   N

25.a. Choose the diagram which correctly represents the restraining force present at the junction.



1



2

////////////////////

1

25.b. This force is due to the ( ) region.

////////////////////

depletion

---

26. By representing the restraining forces with a battery, it is shown that electrons attempting to travel from the N section to the P section encounter the opposition of the battery and are ( ).

////////////////////

repelled

---

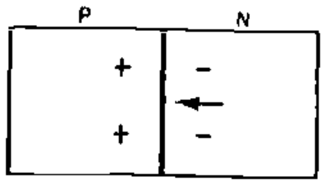
27. Also, the effective battery at the junction also repels the ( ) that might come from the P section.

////////////////////

holes

BIAS

28. In a PN diode, the electrons in the N section have a tendency to move over the junction and combine with ( ).



//////////////////////

holes

29. However, this tendency is opposed by the restraining potential built up across the ( ) region.

//////////////////////

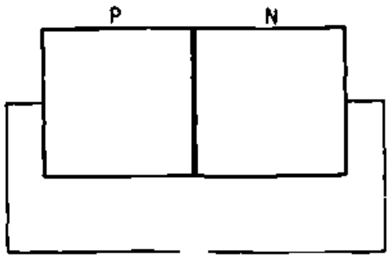
depletion

30. To aid the flow of current through a PN junction diode, an external battery can be connected across the diode to move the electrons in the N section toward the ( ).

//////////////////////

junction, P section

31. Add a battery to the PN diode in the diagram so that the electrons in the N section will cross the junction.



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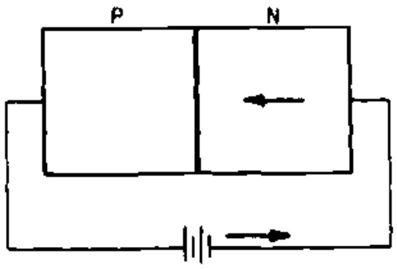
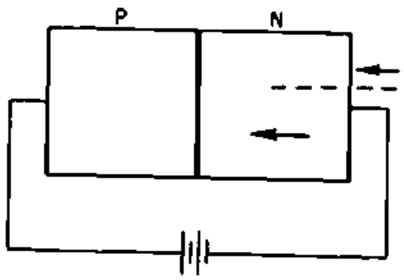


32. However, a significant amount of current will not flow unless the battery potential exceeds that of the restraining potential across the ( ).

////////////////////

junction

33. Electrons from the negative terminal of the battery enter the ( ) section of the diode and cause free electrons to move toward the ( ).



////////////////////

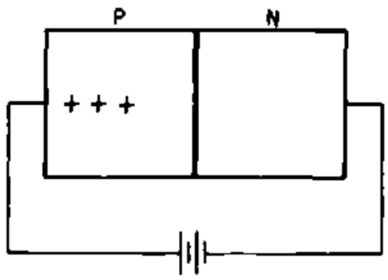
N junction

34. In the N section, the free electrons are called the ( ) carriers.

////////////////////

majority

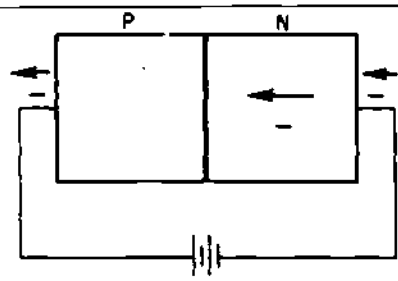
35. In the P section, the battery potential must also get the holes to overcome the ( ) at the junction.



////////////////////

restraining potential

36.a. The positive voltage of the battery causes a ( ) electron to break its bond and leave the P section.



////////////////////

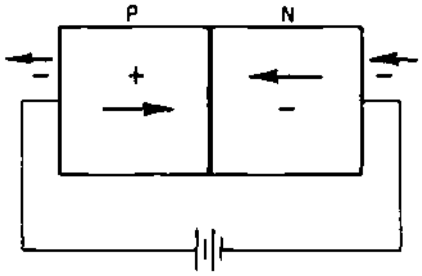
valence

36.b. The valence electron leaves a ( ) in a covalent bond.

////////////////////

hole

36.c. This hole then attracts an electron from another covalent bond, leaving a hole in that bond. This process continues, and the hole apparently flows toward the ( ).



////////////////////

junction

36.d. In the P section, the holes make up the ( ) carrier.

////////////////////

majority

37. When the battery potential is higher than the restraining potential, free electrons and holes cross the ( ).

////////////////////

junction

38. After they cross the junction, some of the holes and free electrons ( ).

////////////////////

combine

39.a. When holes and free electrons combine at the junction, they are "lost."

However, for each combination that occurs, an electron leaves the P section and enters the ( ) battery terminal.

////////////////////

positive

39.b. The electron that leaves the P section starts another (   ) in motion toward the junction.

////////////////////

hole

39.c. Also, for each electron-hole combination at the junction, an electron from the negative battery terminal enters the (   ) section.

////////////////////

N

39.d. This free electron then flows toward the (   ).

////////////////////

junction

39.e. The free electrons from the N section that combine with holes in the P section become valence electrons caught in a covalent bond. They therefore replace the (   ) electrons that leave the (   ) section.

////////////////////

valance   P

39.f. The free electrons that enter the N section (   ) those that fill holes in the covalent bonds in the P section.

////////////////////

replace

40. Free electrons in the N section are (   ) current carriers.

////////////////////

majority

41. Holes in the P section are (   ) current carriers.

////////////////////

majority

42. Since the free electrons in the N section and the holes in the P section are replaced as they flow through the diode, the current is carried by (   ) current carriers.

////////////////////

majority

43. When a diode is biased so that it allows majority carriers to flow, it is said to be biased in the FORWARD direction. Forward bias overcomes the (   ) at the junction to allow current flow.

////////////////////

restraining potential

---

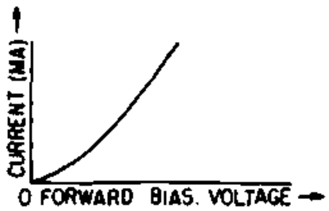
44. The restraining potential is more easily overcome with higher (   ) bias.

////////////////////

forward

---

45. The curve shows that as the forward bias voltage is increased, the forward current through the PN diode is (   ).



////////////////////

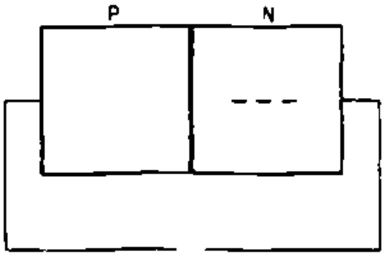
increased

46.a. When the battery potential to the diode is reversed, the voltage applied to the diode is called (   ) bias.

////////////////////

reverse

46.b. Add a battery to the diagram showing reverse bias.



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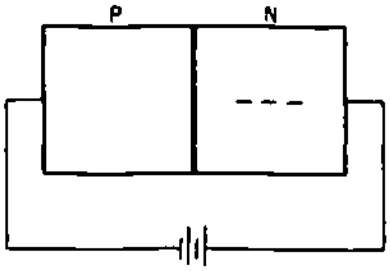
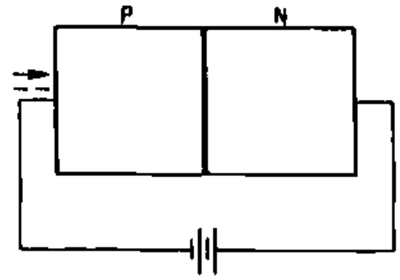


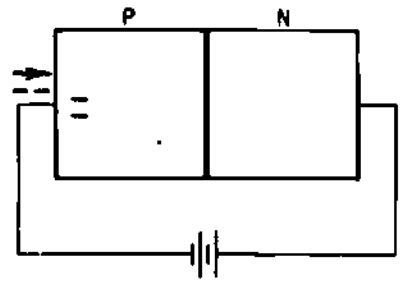
47.a. Electrons from the negative terminal of the battery enter the (   ) section of the diode.



////////////////////

P

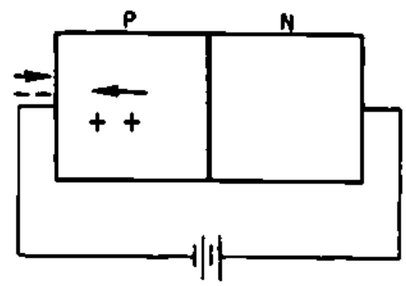
47.b. These electrons fill (   ) in covalent bonds in the P section.



////////////////////

holes

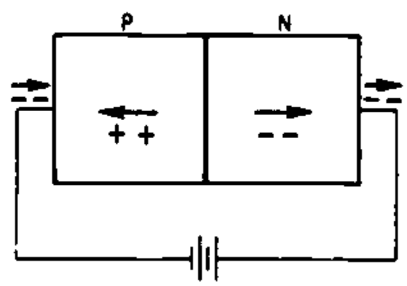
47.c. The negative voltage of the battery repels the electrons from one hole to another toward the junction. This causes the holes to move away from the (   ).



////////////////////

junction

48. The positive voltage of the battery attracts free electrons out of the (   ) section and away from the (   ).



////////////////////

N   junction

49.a. With reverse bias, the holes in the P section and the free electrons in the N section are attracted (away from/toward) the junction.

////////////////////

away from

49.b. These majority current carriers cannot ( ) at the junction; and majority current cannot ( ).

////////////////////

combine flow

50. However, you will recall that there are some free electrons in the P section because of thermal agitation. These free electrons in the P section are ( ) current carriers.

////////////////////

minority

51. Also, there are some holes in the N section because of thermal agitation. These holes in the N section are ( ) current carriers.

////////////////////

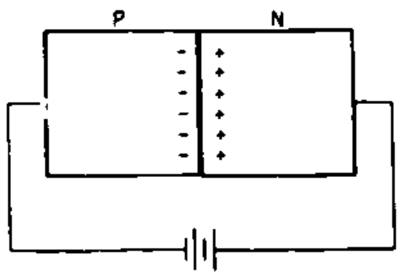
minority

52.a. With reverse bias, the ( ) carriers act similar to the majority carriers with forward bias.

////////////////////

minority

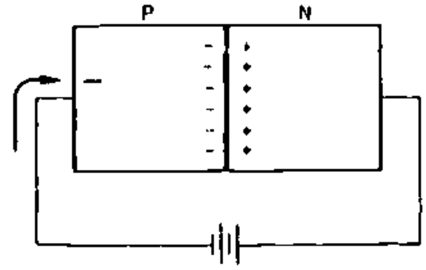
52.b. Due to the battery potential, the minority carriers (free electrons in the P section and holes in the N section) accumulate at the ( ).



////////////////

junction

52.c. The negative terminal of the battery tends to move an electron into and through the ( ) section.



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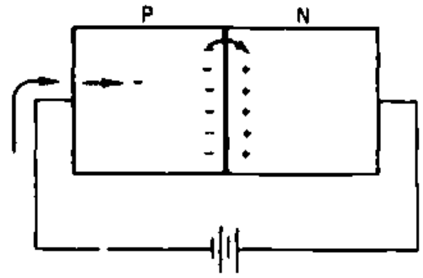
P

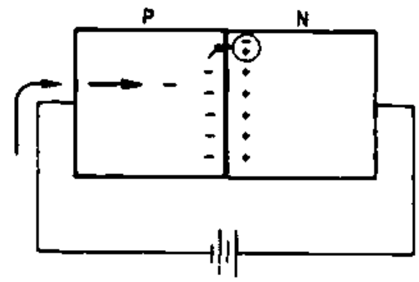
52.d. When an electron flows into the P section, a free electron from the P section crosses the ( ).



////////////////////

junction

52.e. When the free electron crosses the junction, it encounters a ( ) in the N section.



////////////////////

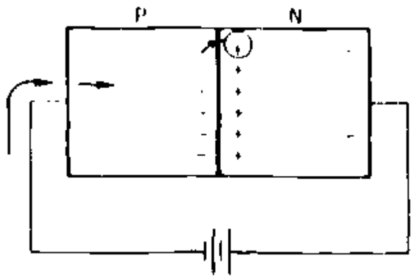
hole

52. f. The free electron fills the hole. For current to continue to flow, an electron must then leave the ( ) section, and a new hole must be ( ).

////////////////////

N created, produced

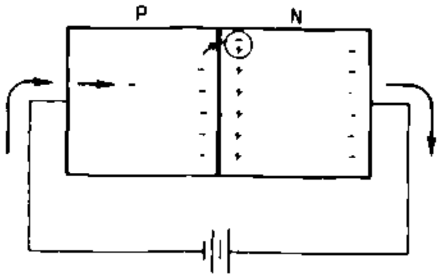
52.g. The positive terminal of the battery tends to pull a free electron out of the N section, and also applies a force of (attraction/repulsion) on the valence electrons at that end of the N section.



///////////////////

attraction

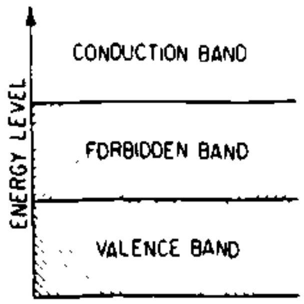
52.h. The free electron from the P section that crossed the junction allows a free electron to flow out of the (   ) section.



///////////////////

N

52.i. The free electron from the P section that filled the hole in the N section became a valence electron. Its energy level went down from the conduction band to the valence band. It therefore had to give up (   ).



///////////////////

energy

52.j. The energy given up by the electron is transmitted through the crystal structure and aids the positive battery potential to free a (   ) electron at the other end of the N section.

///////////////////

valence

126

52.k. This produces a ( ) there.

////////////////////

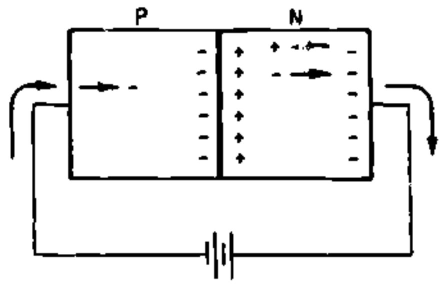
hole

52.l. That hole is filled by another ( ) electron, which creates a ( ).

////////////////////

valence hole

52.m. The hole, then, apparently moves toward the ( ).



////////////////////

junction

52.n. At the junction, the process continues. A ( ) from the P section crosses over to fill a ( ) in the N section.

////////////////////

free electron hole

53.a. The minority carriers are "lost" when they combine at the junction.

But for each combination, a free electron left the N section, and a valence electron was freed to produce a new ( ).

////////////////////

hole

53.b. Also, an electron from the negative battery terminal enters the ( ) section for each combination.

////////////////////

P

136

53.c. Since the free electron that enters the P section and the new hole produced in the N section replace the minority carriers that combined at the junction, ( ) current flows.

minority

54. Therefore, current through a diode connected to reverse bias is controlled by ( ) current carriers.

minority

55. At normal operating temperatures there are much (more/less) minority carriers than majority carriers.

less

56. Therefore, minority carrier current is much (more/less) than majority carriers.

less

57. Reverse bias gives much (more/less) diode current than ( ) bias.

less forward

58. Since with forward bias majority current flows, and with reverse bias minority current flows, a PN diode will conduct less current with ( ) bias.

reverse

Actually, minority carrier current flow exists whether the diode is reverse biased or forward biased. However, with forward bias the majority carrier current flow is so much greater than the minority carrier current flow that minority carrier current flow can usually be ignored. With reverse bias there is no majority carrier current flow so that minority current is the only current that flows. And, in many cases it is so small that it can be ignored.

Since there are so few minority carriers in a junction diode, the level of the bias voltage has very little affect on the amount of reverse current that flows. However, since the NUMBER of minority carriers INCREASES as TEMPERATURE INCREASES, the amount of reverse current will increase as temperature increases.

59. Choose the phrases in the second column that match those in the first column.

1. forward bias
2. reverse bias

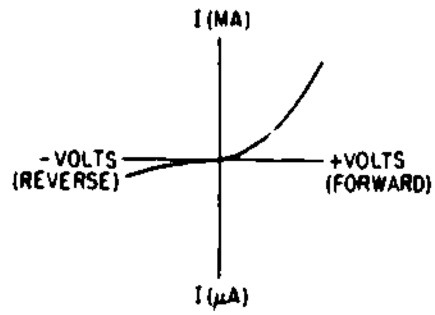
a. low current
b. majority current
c. high current
d. minority current

////////////////////

1. b., c. 2. a., d.

---

60. A comparison of forward and reverse bias can be made with a diode characteristic curve. The diagram shows that for equivalent values of voltage, forward bias provides more ( ) than reverse bias.



////////////////////

current

---

61. A sharp increase in current occurs where the forward bias overcomes the restraining potential at the ( ).

////////////////////

junction

---

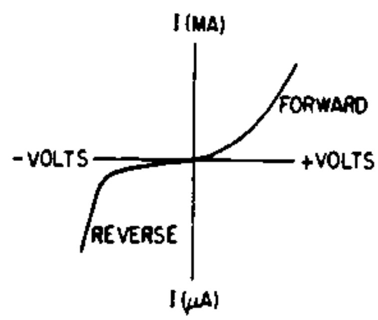
62. Reverse-bias current flow is due to (majority/minority) carriers.

////////////////////

minority

---

63. However, as the value of reverse bias voltage applied to a PN diode is increased, a point is reached at which there is a sharp increase in reverse ( ).



////////////////////

current

---

64. This sharp increase in reverse current occurs when minority electrons, passing through the PN junction, gain sufficient energy to knock off many valence (   ) bound to the crystal lattice structure.

//////////////////////

electrons

65. Electrons removed from the crystal lattice structure have their energy levels raised from the valence band to the (   ) band.

//////////////////////

conduction

66. The energy levels of several valence electrons may be raised to the conduction band from the energy imparted by the collision of one (   ) electron.

//////////////////////////

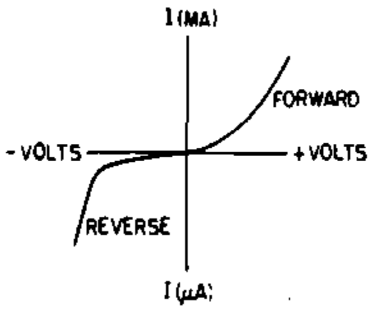
minority

67. With high reverse bias voltages, each valence electron may in turn free several more electrons, until a considerable (   ) results.

//////////////////////

current

68. This sharp increase in reverse current is called avalanche breakdown. Label the portion of the curve representing where avalanche breakdown starts.



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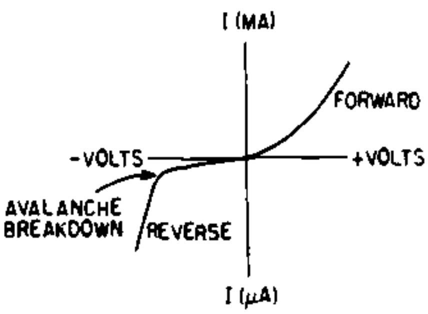
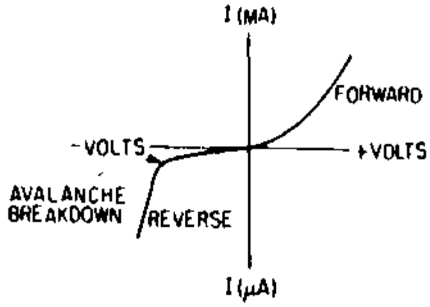


69. The voltage at which avalanche breakdown occurs is called the breakdown voltage. Label the point indicating the breakdown voltage.



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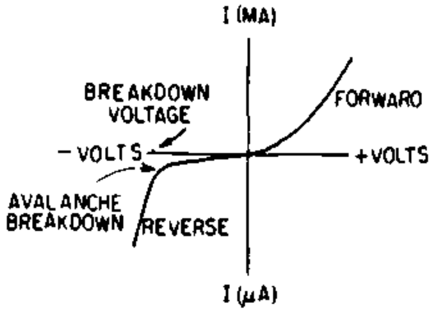


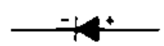
70. A high reverse current would damage an ordinary diode; but, because of special construction techniques, certain diodes are not damaged when the breakdown voltage is exceeded and ( ) occurs.

////////////////////

avalanche breakdown

71.a. This symbol is the schematic representation of a diode:

When the diode is forward biased, electron current flows "against" the arrow:

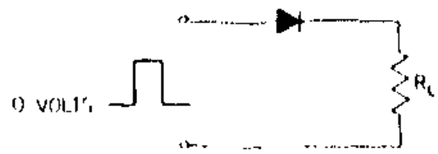


When the diode is reverse biased, ... electron current flows:

////////////////////

very little, no

71.b. DRAW the output voltage waveform that will appear across load resistor RL.



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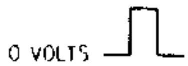
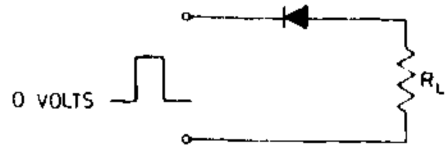


71.c. DRAW the output voltage waveform that will appear across RL.



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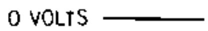
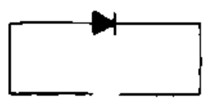


71.d. With the voltage polarities indicated, is this diode forward or reverse biased?

////////////////////

forward

71.e. On this diagram, draw a battery that will reverse bias the diode.



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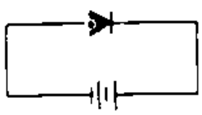
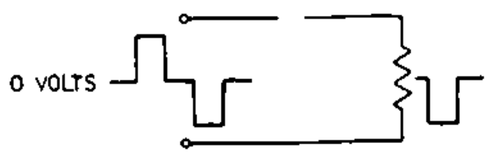


71.f. Add a diode to this circuit that will result in the output shown. Draw polarities (-+) on the diode.



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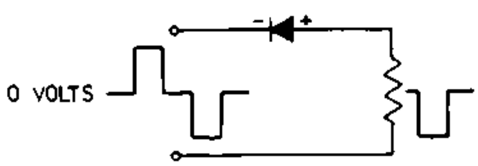
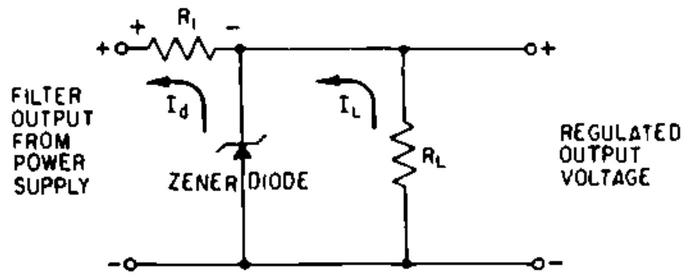


72. Diodes that are made to operate in the breakdown reginn are called Zener diodes; they are also known as reference diodes, avalanche diodes, and breakdown diodes. Zener diodes, then are used in ( ) bias applications.

////////////////////

reverse

73. The Zener breakdown region can be used in certain circuits for voltage regulating, clipping, and limiting. In the schematic, the Zener diode is being used as a ( ).



////////////////////

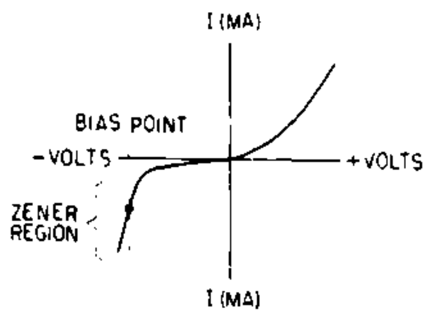
voltage regulator

74. The output voltage is also the ( ) voltage for the Zener diode.

////////////////////

bias

75. The curve shows that the Zener diode is biased by the output voltage in the center of the ( ) region.



////////////////////

Zener

76. If the output or bias voltage increases, the current through the diode will (increase/decrease) sharply.

////////////////////

increase

77. This diode current and the load current flow through the series ( ).

////////////////////

resistor (R1)

78. The increase in current will cause an ( ) in the voltage drop across R1.

////////////////////

increase

79. A bigger voltage drop across R1 means that the voltage will be decreased to its normal value at the ( ).

////////////////////

output

80. If the output voltage decreases, the current through the ( ) will decrease.

////////////////////

diode

81. Since the current decreases, the voltage drop across the ( ) will decrease.

/////////////////////

series resistor (R1)

82. Because of the smaller voltage drop across the series resistor, the voltage will increase to its normal value at the ( ).

////////////////////

output

83.a. Thus, a Zener diode used as a voltage regulator tends to maintain a steady output voltage by varying the ( ) through the series resistor.

////////////////////

current

83.b. A Zener diode operating with avalanche current works well as a regulator because small changes in voltage cause ( ) changes in current.

////////////////////

large

SUMMARY

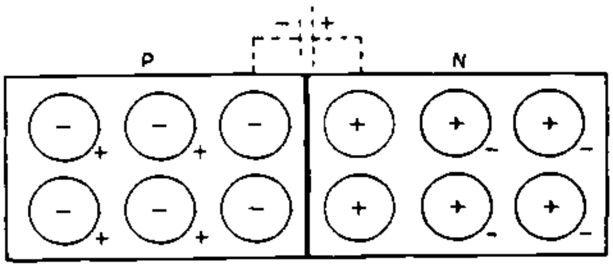
1. When a PN junction diode is formed, some of the electrons in the N section cross the junction and combine with holes in the P section.

2. A loss of electrons leaves the N section with a positive charge, which prevents further electrons from crossing the junction by the force of attraction.

3. A loss of holes through combination with electrons from the N section leaves the P section with a negative charge, which also prevents further electrons from crossing the junction by the force of repulsion.

4. The area around the junction is called the DEPLETION REGION because of the absence of free electrons and holes.

5. The restraining force at a junction can be represented by a battery. Electrons are repelled by the negative potential and holes are repelled by the positive potential.



6. FORWARD BIAS of a PN diode allows the majority carriers to flow. This is accomplished with the application of a positive potential to the P section and a negative potential to the N section.

7. The negative potential repels electrons toward the junction and the positive potential repels holes toward the junction.

8. When the external potential exceeds that of the restraining potential, electrons and holes combine at the junction.

9. For each combination, an electron enters the N section from the negative battery terminal and an electron reaches the P section and goes to the positive battery terminal.

10. Current is carried by electrons in the N section and by holes in the P section.

11. As the forward bias voltage increases, the current through the diode increases.

12. A forward-biased diode is biased in the low resistance direction.

13. Reverse bias inhibits the majority carriers from flowing. This is accomplished with the application of a positive potential to the N section and a negative potential to the P section.

14. The negative potential attracts holes away from the junction and the positive potential attracts electrons away from the junction, preventing majority carriers from flowing.

15. Minority electrons in the P section and minority holes in the N section are repelled toward the junction where they combine to form minority current.

16. At normal operating temperatures, minority or reverse current is very small, so that a reverse biased diode is said to be biased in the high resistance direction.

17. If the value of reverse bias voltage is increased, a point will be reached at which there is a sharp increase in reverse current. This is called AVALANCHE BREAKDOWN.

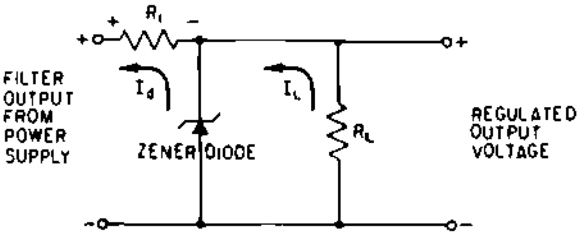
18. Avalanche breakdown occurs when minority electrons gain enough energy to free valence electrons by collision.

19. The voltage at which avalanche breakdown occurs is called the BREAKDOWN VOLTAGE.

20. A Zener (reference) diode is constructed so that the breakdown voltage can be exceeded without damaging the diode.

21. Once avalanche breakdown occurs, a small change in voltage causes a comparatively large change in current. This characteristic is made use of in voltage regulation.

22. In a typical voltage regulator circuit, if the output voltage increases, the current through the Zener diode increases sharply. This increases the voltage drop across a series resistor, thereby decreasing the output voltage to its normal value. The reverse action occurs when the output voltage decreases.



V. TRANSISTOR FUNDAMENTALS

In the preceding section, the operation of semiconductor diodes was explained. Now, another element is added to the diode to form a transistor. It is shown how P and N materials are combined in forming PNP and NPN transistors, and how the schematic symbols represent them. Finally, the basic operation of PNP and NPN transistors is analyzed, with reference to biasing, current flow, gain, and the effects of an input signal.

TRANSISTOR CLASSIFICATIONS

1. The two most common transistors are the PNP and NPN types. There are other classifications, such as PNPN and NPNP, but the three-element (   ) and (   ) are used most often.

////////////////////

PNP NPN

2.a. A PNP transistor consists of an extremely thin strip of N-type material between two relatively wide strips of (   )-type material.

////////////////////

P

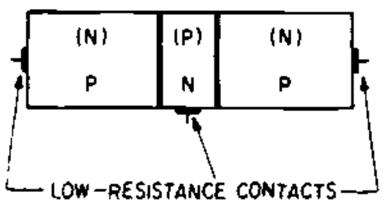
2.b. An NPN transistor consists of . . . .

////////////////////

a thin strip of P-type material between two wider N-type sections.

---

3. A low resistance contact is attached to each (   ) of the transistor for circuit connections.



////////////////////

section, strip, element

---

4. The sections of NPN and PNP transistors are joined so that the two similar sections are (adjacent/separated).

////////////////////

separated

(Continued on next page)

Keep in mind an important point that was mentioned in the previous section: junctions are not physically "joined" or "butted" together.

It is convenient to speak of a PN junction as being "joined" together, but diode or transistor junctions can be formed only by a chemical process.

5.a. The three basic elements of transistors are known as: (1) emitter, (2) base, and (3) collector. The base is the center element; it is always a (   ) strip of material.

////////////////////

thin

5.b. The element that sends the current carriers into the base is called the (   ).

////////////////////

emitter

5.c. The element that ultimately collects the current carriers is known as the (   ).

////////////////////

collector

---

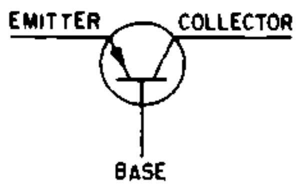
6. The base is always between the (   ) and (   ) elements.

////////////////////

emitter   collector

---

7. This is the circuit symbol for a transistor. The element indicated by an arrow is the (   ).

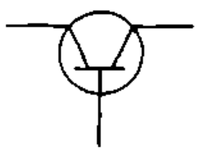


////////////////////

emitter

---

8. Label the three elements of a transistor.



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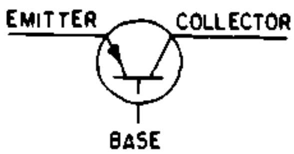

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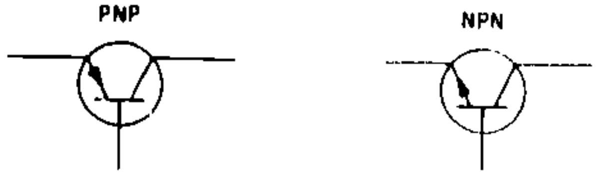
9. The direction of the emitter arrow on the circuit symbol indicates whether the transistor is a PNP or NPN type.



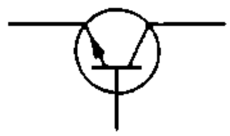
The arrow always points towards the ( )-type material.

////////////////////

N

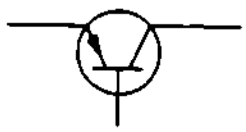
10. Draw a circuit symbol for an NPN transistor.

////////////////////



11. Draw a circuit symbol for a PNP transistor.

////////////////////



12. Transistors are made so that the ( ) and ( ) elements use the same type of material.

////////////////////

emitter collector

13.a. If the emitter is P-type material, the collector must be ( )-type material.

////////////////////

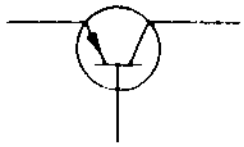
P

13.b. If the emitter is N-type material, the ( ) must be P-type material.

////////////////////

base

13.c. In the transistor represented by the circuit symbol, what material is used in the base?

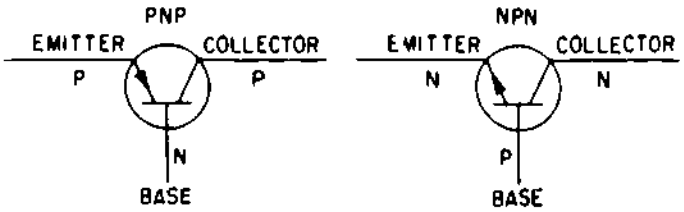


////////////////////

N

14. Draw two transistor circuit symbols: one for the NPN type, and one for the PNP type. Give the name of each element and label each element with the type of material it uses.

////////////////////



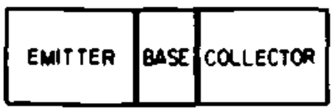
NPN OPERATION

15. For the transistor to work as an amplifier, it must be connected so that it has an input circuit and an output circuit. The amount of current in the input circuit should control the amount of current in the (   ).

////////////////////

output circuit

16.a. In a transistor, the emitter and base form one junction, and the base and (   ) form another junction.



////////////////////

collector

16.b. The (   ) would then be common to both the emitter and collector.

////////////////////

base

17. If the emitter-base section were connected as the input circuit, the (   ) section would form the output circuit.

////////////////////

base-collector

18.a. The amount of current that flows in the base-collector section should be controlled by the amount of current that flows in the (   ).

////////////////////

emitter-base section

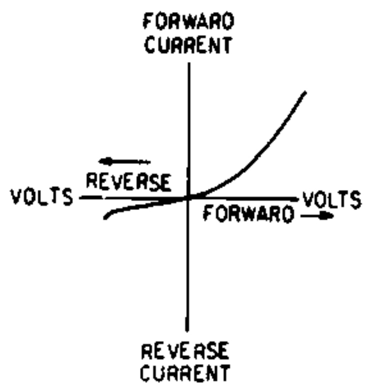
18.b. Then, if a circuit is set up so that a signal voltage will change the emitter-base current, the (   ) current would also change.

////////////////////

base-collector

19. If the base-collector junction were forward biased, it would conduct current in the low resistance direction. The amount of current that would flow would depend mostly on the collector bias battery.

To make the base-collector current relatively independent of collector bias, the base-collector junction should be (   ).



////////////////////

reverse biased

20. The emitter-base current should not be independent of bias voltage since it must be varied by a signal voltage. The emitter-base junction, then, should be (   ).

////////////////////

forward biased

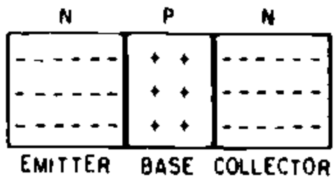
21. The base-collector junction is (   ) biased, and the emitter-base junction is (   ) biased.

////////////////////

reverse   forward

22.a. In an NPN transistor, in order to bias the emitter-base junction in the forward direction, the free electrons in the emitter and the holes in the base should be forced toward the junction.

The emitter should be connected to the (   ) battery terminal.



////////////////////

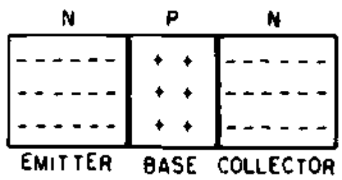
negative

22.b. The base should be connected to the (   ) battery terminal.

////////////////////

positive

23.a. In an NPN transistor, in order to bias the base-collector junction in the reverse direction, the free electrons in the collector and the holes in the base must be forced (   ) the junction.



////////////////////

away from

23.b. The collector is connected to the (   ) battery terminal.

////////////////////

positive

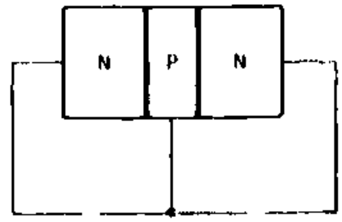
23.c. The base is connected to the (   ) battery terminal.

////////////////////

negative

---

24. Show how the bias batteries should be connected to this transistor.



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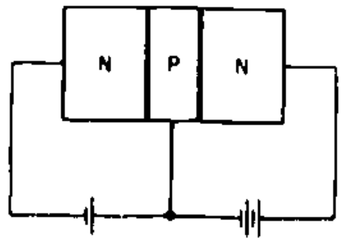
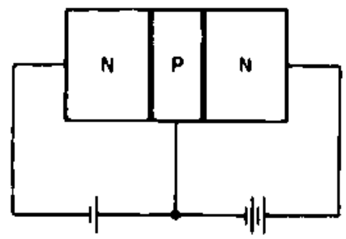


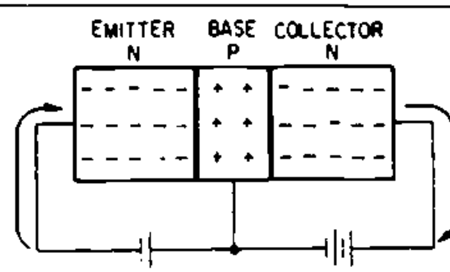
25. Since the emitter-base junction is forward biased, the battery needed in that circuit can be (   ) than the one used with the base-collector to get the needed current flow.



////////////////////

smaller

26.a. The emitter and base are forward biased. If the emitter and base had the same amount of current carriers, the free electrons from the emitter would cross the junction and fill (   ) in the base.



////////////////////

holes

26.b. For each combination that would occur, an electron would enter the (   ) and leave the (   ).

////////////////////

emitter base

26.c. This would produce emitter-base (   ) flow.

////////////////////

current

26.d. However, in the transistor, the base is doped less than the emitter and is much thinner than the emitter. Therefore, there are fewer (   ) in the base than there are (   ) in the emitter.

////////////////////

holes   free electrons

26.e. As a result, MOST of the free electrons that cross the junction (   ) combine with holes.

////////////////////

cannot, do not

26.f. The free electrons from the emitter become (majority/minority) carriers in the base region.

////////////////////

minority

26.g. As these minority electrons diffuse through the base, they will be (attracted into/ repelled away from) the collector region by the influence of the collector battery.

////////////////////

attracted into

26.h. In the section on PN junction diodes, it was shown that under reverse bias conditions, current is carried by (   ) carriers and is very (   ).

////////////////////

minority   very low, small

26.i. But, in the case of a transistor, the emitter acts as a continuous source of (   ) carriers for the collector junction.

////////////////////

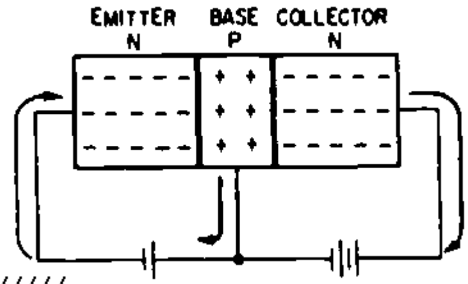
minority

26.j. Therefore, even though the collector junction is reverse biased, a relatively (   ) current flows.

////////////////////

large, high

27.a. To sum up, the emitter-base diode is (   ) biased.



////////////////////

forward

27.b. Many free electrons cross the junction from the (   ) to the (   ).

////////////////////

emitter   base

27.c. Since the base has relatively few (   ) to combine with the emitter electrons, only a few electrons flow out of the (   ) to the battery.

////////////////////

holes   base

27.d. The base-collector is (   ) biased.

////////////////////

reverse

27.e. The electron current flowing out of the collector to the battery would usually be limited by the few free electrons the base would normally have. But, many (   ) from the (   ) have accumulated there.

////////////////////

free electrons   emitter

27.f. The (   ) in the base cross the junction into the (   ) to allow collector current to flow.

////////////////////

free electrons   collector

28.a. Most of the electrons that pass through the collector ORIGINALLY come from the ( ).

////////////////////

emitter

28.b. Therefore, the amount of collector current that flows depends on the amount of ( ).

////////////////////

emitter current

29.a. Ordinarily, with a diode biased in the reverse direction, the reverse current is small because of the ( ) amount of minority carriers.

////////////////////

low, small

29.b. In an NPN transistor, free electrons in the base are ( ) carriers.

////////////////////

minority

29.c. During operation, most free electrons in the base are supplied by the emitter biased in the ( ) direction; these ( ) carriers, then, become plentiful in the ( ).

////////////////////

forward minority base

29.d. As a result, collector current, is relatively ( ).

////////////////////

high

29 e. Since the collector bias is larger than the emitter bias, the collector demands more current than the ( ) can supply.

////////////////////

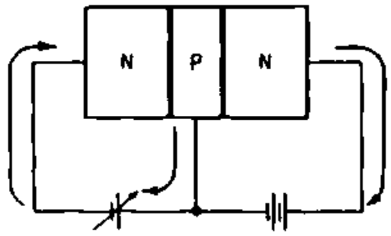
emitter

29.f. Emitter current, then, controls ( ) current.

////////////////////

collector

30.a. If the emitter-base bias battery is variable, and the bias voltage is increased, emitter current would (   ).



////////////////////

increase

30.b. As a result, collector current would (   ).

////////////////////

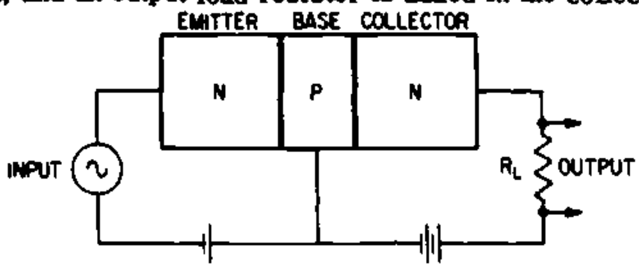
increase

31. If the emitter-base bias voltage is decreased, both (   ) and (   ) current would go down.

////////////////////

emitter   collector

32.a. To make the NPN transistor work as an amplifier, a signal input is added in the emitter circuit, and an output load resistor is added in the collector circuit.



The input signal voltage either aids or opposes the emitter battery voltage. This varies the (   ) bias.

////////////////////

emitter

32.b. When the emitter bias varies, the emitter (   ) varies.

////////////////////

current

32.c. When the emitter current varies, the (   ) varies.

////////////////////

collector current

32.d. The varying collector current produces a varying (   ) drop across load resistor RL.

////////////////////

voltage

32.e. Although the emitter and collector current variations are almost the same, there is a relatively large size load resistor in the output circuit. Therefore, the output voltage variations are (   ) than the signal voltage variations.

////////////////////

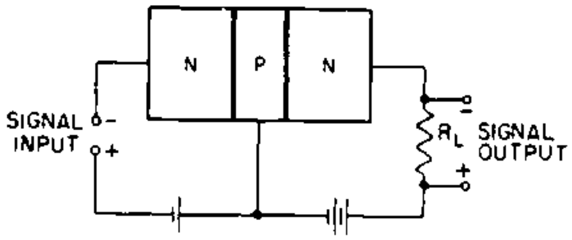
larger, greater

33. Since the output voltage variations are greater than the input voltage variations, the transistor provides a (   ) gain.

////////////////////

voltage

34.a.



When the signal input goes NEGATIVE, it (aids/opposes) the bias battery.

////////////////////

aids

34.b. When the signal aids the bias battery, emitter and collector currents go (   ).

////////////////////

up

1450

34.c. The increased collector-current causes a greater voltage drop across (   ).

////////////////////

load resistor RL

34.d. The signal output, then, goes more (   ).

////////////////////

negative

34.e. Since the input and output signal both went more negative, there (is/is no) phase reversal in this circuit.

////////////////////

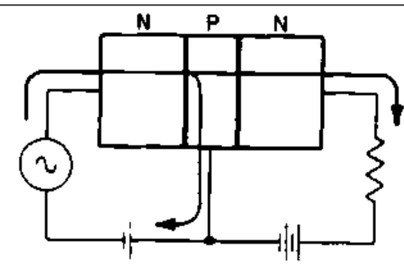
is no

34.f. The output phase is (the same as/different from) the input phase.

////////////////////

the same as

35.a. The current from the emitter follows two paths: down through the base, and through the (   ).



////////////////////

collector

35.b. Only about 2 percent of the emitter current goes down through the (   ).

////////////////////

base

35.c. About (   ) percent of the emitter current goes through the collector.

////////////////////

98

35.d. The percentage of emitter electrons that flows through the external base circuit is ( ) percent.

////////////////////

2

35.e. The emitter current represents ( ) percent of the current.

////////////////////

100

35.f. The collector current is about ( ) percent of the emitter current.

////////////////////

98

36.a. The emitter current is the input current of the circuit, and the collector current is the ( ) current.

////////////////////

output

36.b. The current gain of the transistor circuit is computed with: $\frac{\text{output current}}{\text{input current}}$

What is a typical current gain for this type of transistor circuit?

////////////////////

.98

36.c. There is also a resistance gain because the resistance of the emitter-base junction is much lower than the resistance of the ( ) junction.

////////////////////

collector-base

36.d. $\frac{\text{output resistance}}{\text{input resistance}}$ = ( ) gain.

////////////////////

resistance

150

36.e. Using Ohm's law, current gain x resistance gain = (   ) gain.

////////////////////

voltage

37. Given: (a) Emitter-to-base resistance of 100 ohms.
(b) Collector-to-base resistance of 10,000 ohms.
(c) Assume 98 percent of the current leaving the emitter reaches the collector.

Find voltage gain.

////////////////////

$$\text{resistance gain} = \frac{10{,}000}{100} = 100$$

current gain = .98

voltage gain = 100 x .98 = 98

38. Power gain can also be found by multiplying the voltage gain by the (   ) gain.

////////////////////

current

39. Given: (a) Current gain = .98
(b) Voltage gain = 98

Find power gain.

////////////////////

power gain = 98 x .98 = 96

PNP OPERATION

40. The PNP transistor works essentially the same as the NPN transistor. However, since the emitter, base, and collector in the PNP transistor are made of materials that are different from those used in the NPN transistor, different current carriers flow in the PNP unit. In any event, the amount of current that flows in the base-collector section of a PNP transistor should also be controlled by the amount of current that flows in the (   ).

////////////////////

emitter-base section

160

41. As with the NPN transistor, the collector-base junction of the PNP transistor is biased so that the output current is relatively independent of collector-base voltage. This means that the collector-base junction is (   ) biased.

////////////////////

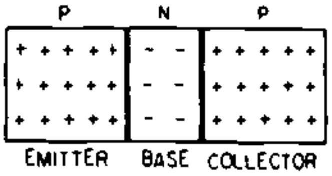
reverse

42. The emitter-base junction of a PNP transistor is biased so that input current is easily varied. In other words, the emitter-base junction is (   ) biased.

////////////////////

forward

43.a. In a PNP transistor, to forward bias the emitter-base junction, the holes in the emitter and the free electron in the base should be forced toward the (   ).



////////////////////

junction

43.b. The negative battery terminal should be connected to the (   ).

////////////////////

base

43.c. The positive battery terminal should be connected to the (   ).

////////////////////

emitter

44.a. To reverse bias the collector-base junction, the holes in the collector and the free electrons in the base should be moved (toward/away from) the junction.

////////////////////

away from

44.b. The collector is connected to the (   ) battery terminal.

////////////////////

negative

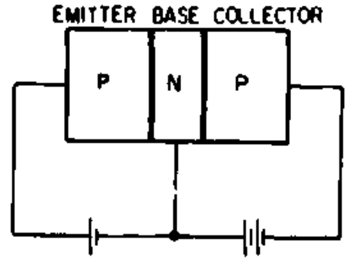
44.c. The base is connected to the ( ) battery terminal.

////////////////////

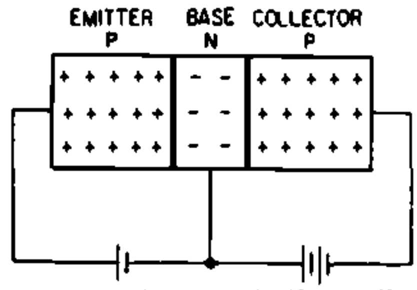
positive

45. Draw a properly biased PNP transistor.

////////////////////



46.a.



The operation of a PNP transistor is very similar to that of an NPN transistor. Since the emitter-base junction is forward biased, emitter holes and free base electrons (combine/separate) at the junction.

////////////////////

combine

46.b. When a combination takes place, an electron enters the ( ) and leaves the ( ).

////////////////////

base emitter

46.c. This produces emitter-base (majority/minority) current flow.

////////////////////

majority

46.d. The base is not as thick and as heavily doped as the emitter. Therefore, there are fewer ( ) in the base than there are ( ) in the emitter.

////////////////////

free electrons holes

46.e. As a result, most of the holes at the junction ( ) combine with free electrons from the base.

////////////////////

do not

46.f. However, the holes at the junction attract valence electrons from the ( ).

////////////////////

base

46.g. When a valence electron from the base is freed and combines with a hole from the emitter, a ( ) is produced in the base.

////////////////////

hole

46.h. Thus, holes are effectively transmitted to the base from the ( ).

////////////////////

emitter

46.i. As a result, the number of MINORITY carriers in the base is increased. This allows more valence electrons from the collector to cross the base-collector junction to fill holes in the base and, therefore, a (higher/lower) collector current can flow.

////////////////////

higher

47.a. To sum up, the emitter-base junction is ( ) biased.

////////////////////

forward

47.b. The base-collector junction is ( ) biased.

////////////////////

reverse

154

47.c. Collector-base current is limited by the few (   ) in the base.

////////////////////

holes

47.d. However, the forward current of the emitter-base section causes extra (   ) to be produced in the base.

////////////////////

holes

47.e. This allows a higher (   ) current to flow.

////////////////////

collector

48.a. Most of the electrons that flow through the collector combine with holes in the base that originally were supplied by the (   ).

////////////////////

emitter

48.b. Therefore, the amount of collector current that flows depends on the amount of (   ).

////////////////////

emitter current

49.a. Normally, a reverse biased diode produces little reverse current because of relatively few (   ) carriers.

////////////////////

minority

49.b. In a PNP transistor, minority carriers in the base are (   ).

////////////////////

holes

49.c. Holes become plentiful in the base because they are effectively transmitted from the (   ).

////////////////////

emitter

49.d. As a result, collector current is relatively high, even though it is ( ) current.

////////////////////

reverse

49.e. Because the collector bias is larger than the emitter bias, the collector demands more current than the ( ) can supply.

////////////////////

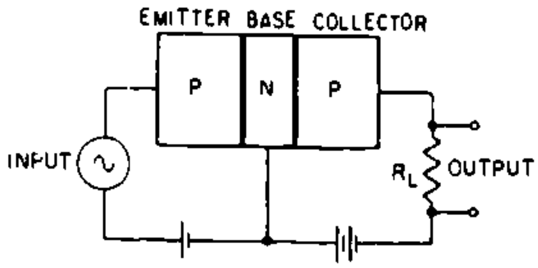
emitter

49.f. Therefore, emitter current controls ( ) current.

////////////////////

collector

50.a. As with the NPN transistor, the PNP transistor can be used as an amplifier by adding a signal input in the ( ) circuit, and a load resistor in the ( ).



////////////////////

emitter collector

50.b. The input signal varies the emitter bias, thus varying the emitter ( ).

////////////////////

current

50.c. This varies the collector current and produces a varying ( ) voltage.

////////////////////

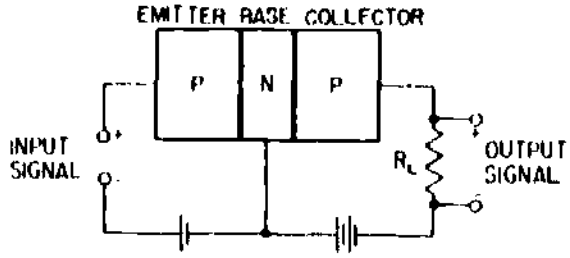
output

50.d. The output voltage variations are greater than the input voltage variations because of the relatively large ( ).

////////////////////

load resistor

51.a. A positive-going input signal aids the forward bias, (increasing/decreasing) the emitter and collector currents.



////////////////////

increasing

51.b. The increased collector current causes a greater voltage drop across RL, making the output signal more (   ).

////////////////////

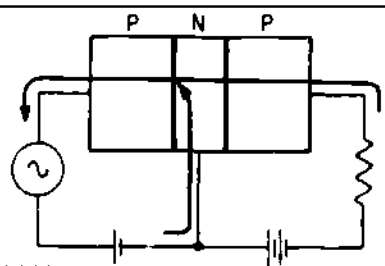
positive

51.c. Since the input and output signals go positive simultaneously, they are (in/out of) phase.

////////////////////

in

52.a. Total current flows through the (   ).



////////////////////

emitter

52.b. About 2 percent of the total current flows through the base; therefore, about 98 percent of the total current flows through the (   ).

////////////////////

collector

52.c. The emitter current is the (input/output) current of the circuit, and the collector current is the (   ) current.

////////////////////

input output

52.d. Current gain = ( ) current divided by ( ) current.

////////////////////

output input

52.e. If about 98 percent of the emitter current flows through the collector, the current gain is about ( ).

////////////////////

.98

53.a. The input resistance is (higher/lower) than the output resistance.

////////////////////

lower

53.b. $\frac{\text{output resistance}}{\text{input resistance}}$ = ( ) gain.

////////////////////

resistance

54.a. Voltage gain = ( ) gain x ( ) gain.

////////////////////

current resistance

54.b. Voltage gain can also be expressed as:

Voltage gain = $\frac{(\quad\quad) \text{ voltage}}{(\quad\quad) \text{ voltage}}$

////////////////////

output input

55. Power gain = ( ) gain x ( ) gain.

////////////////////

voltage current

56.a. Given: 1. Emitter-base resistance = 200 ohms.
2. Collector-base resistance = 9.000 ohms.
3. Assume 97 percent of the total current flows through the collector.

Find voltage gain.

////////////////////

$$\text{resistance gain} = \frac{9,000}{200} = 45$$

$$\text{current gain} = \frac{97}{100} = .97$$

$$\text{voltage gain} = .97 \times 45 = 43.65$$

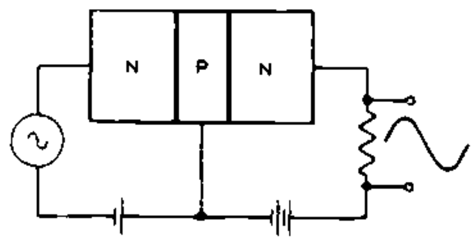
56.b. Find power gain.

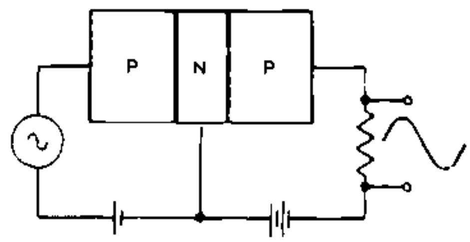
////////////////////

$$\text{power gain} = 43.65 \times .97 = 42.34$$

REVIEW

57. In the transistor amplifier circuits you have been studying up to now, the base of the transistor is used in both the emitter and collector circuits. The circuits are therefore called common ( ) circuits.





////////////////////

base

The common base circuit is seldom used in Polaris equipments. However, it is being taught in this course because you must learn how the common base circuit works before the other types of circuits can be understood.

58a. Does the common base amplifier actually provide a current gain?

////////////////////

No. The gain is about .98. The output current changes are slightly less than the input current changes. But, it is still common practice to refer to this as current GAIN.

58.b. Does it provide voltage gain?

////////////////////

Yes, because although there is a slight current loss, the large load resistor permits a greater output voltage variation. (E = IR)

58.c. Does it provide power gain?

////////////////////

Yes, because the voltage gain is much greater than the slight current loss. (P = EI)

59. In the common-base transistor circuit, what kind of bias is used for the emitter-base input circuit?

////////////////////

forward bias

60. What kind of bias is used for the base-collector output circuit?

////////////////////

reverse bias

61. When the input signal varies, how does it affect the emitter-base bias?

////////////////////

It varies the bias; or, aids or opposes it.

62. What does this bias variation do to the emitter current?

////////////////////

It varies the emitter current.

63. How does this affect the collector current?

////////////////////

The collector current changes in almost the same way.

64. How does this changing collector current produce an a-c output voltage?

////////////////////

It causes a varying voltage drop across the output load resistor in the collector circuit.

65. How is voltage gain computed?

////////////////////

$\frac{\text{output voltage}}{\text{input voltage}}$, or current gain x resistance gain

66. How is current gain computed?

////////////////////

$\frac{\text{output (collector current)}}{\text{input (emitter) current}}$

67. How is power gain computed?

////////////////////

current gain x voltage gain

68. How much of the emitter current flows out of the base?

////////////////////

about 2 percent

69. What is the circuit you have been studying called?

////////////////////

common base

70. Why is it called the common base circuit?

////////////////////

Because the base is common to both the input (emitter) and the output (collector) circuits.

71. Why do most of the free electrons that go from the emitter to the base continue to the collector?

////////////////////

Because the base is doped less and is thin, it does not have enough holes to combine with the electrons; and so the attraction of the collector bias draws them to the collector circuit.

72. Does the common-base transistor circuit cause any signal phase reversal?

////////////////////

No

73. In a junction transistor, which section is thinnest?

////////////////////

base

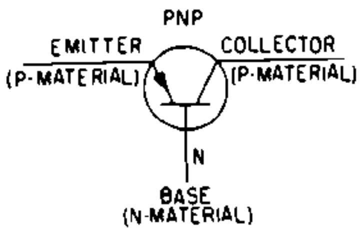
SUMMARY

1. A PNP transistor consists of an extremely thin strip of N-type material between two relatively wide sections of P-type material.

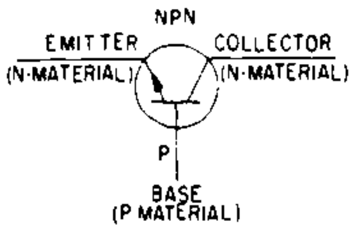
2. An NPN transistor consists of an extremely thin strip of P-type material between two relatively wide sections of N-type material.

3. The three elements of a transistor are: (1) emitter; (2) base; (3) collector. The base is always the thin strip of material between the relatively wide emitter and collector sections. The base is also doped less than the other sections, and so the base has less carriers.

4. In the schematic symbols for transistors, the arrow points towards the N-type material.



PNP SYMBOL

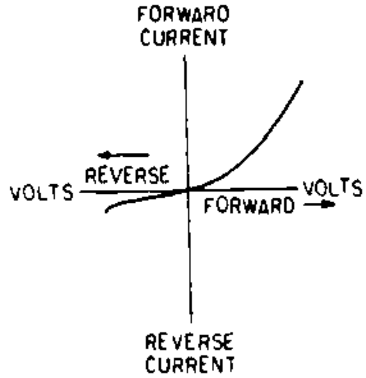


NPN SYMBOL

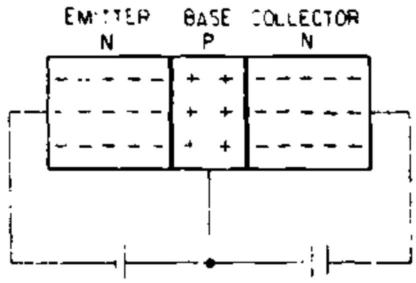
5. In a transistor amplifier, the current in the input circuit controls the current in the output circuit.

6. The input circuit of the common base amplifier is the emitter-to-base section; the output circuit is the collector-to-base section.

7. Since the emitter-base is forward biased, input current depends on the emitter-base voltage. Since the collector-base is reverse biased, output current is relatively independent of the collector-base voltage.



8. In an NPN transistor, the emitter-base junction is forward biased by connecting the negative battery terminal to the emitter and the positive battery terminal to the base. The collector-base junction is reverse biased by connecting the positive battery terminal to the collector and the negative battery terminal to the base.



9. Because the emitter-base is forward biased, free electrons from the emitter cross the junction to fill holes in the base.

163

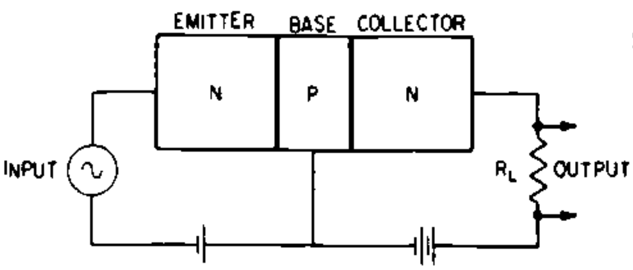
10. For each combination, an electron from the battery enters the emitter and one leaves the base to go to the battery. This produces emitter-base majority current flow.

11. Because the base is doped less and is much thinner than the emitter, there are fewer holes in the base than there are free electrons in the emitter. Therefore, most of the emitter free electrons do not combine with base holes.

12. The free electrons that do not combine with base holes cross the junction into the collector. For each electron that cross the collector-base junction from the base, an electron leaves the collector to go to the battery.

13. Since the electrons that flow through the collector come from the emitter, the amount of collector current that flows depends on the amount of emitter current.

14. To make a transistor work as an amplifier, a signal input is added in the emitter circuit and an output load resistor is added in the collector circuit.

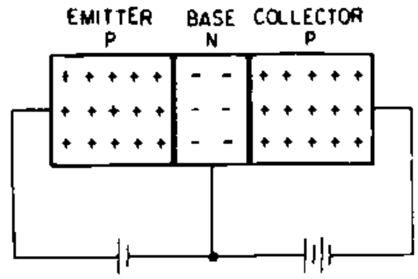


15. The input signal varies the forward bias, thus varying the emitter current.

16. When the emitter current varies, the collector current varies. The varying collector current produces a varying voltage drop across the load resistor.

17. The relatively high value of the load resistor produces an output voltage variation that is considerably greater than the signal input voltage.

18. When a PNP transistor is used, the emitter-base is forward biased by connecting the positive battery terminal to the emitter and the negative battery terminal to the base. The collector-base is reverse biased by connecting the negative battery terminal to the collector and the positive battery terminal to the base.



19. The emitter-base junction is forward biased; free base electrons cross the junction to fill emitter holes.

20. For each combination, an electron from the battery enters the base and one leaves the emitter to go to the battery. This allows majority current to flow.

21. Since there are fewer free electrons in the base than holes in the emitter, most of the holes in the emitter cannot combine with the free electrons from the base.

22. The holes that do not combine with free electrons attract valence electrons from the base. Thus, many of the emitter holes are effectively transmitted to the base.

23. This provides more base holes to combine with electrons from the collector. This allows higher current to flow in the collector.

24. Since the electrons that flow through the collector combine with holes that are originally supplied by the emitter, the amount of collector current that flows depends on the amount of emitter current.

25. The NPN and PNP circuits just described are called common-base circuits. because the base is common to both the input and output.

26. The common-base circuit amplifies the input signal, but does not change its phase.

27. In the common base circuit, the output (collector) current is about 98% of the input (emitter) current. Current gain is output current divided by input current. A typical current gain for a common-base amplifier is .98. It is always less than 1 for a common-base amplifier.

28. The common-base circuit provides resistance, voltage, and power gain.

29. resistance gain = $\frac{\text{output resistance}}{\text{input resistance}}$.

30. voltage gain = $\frac{\text{output voltage}}{\text{input voltage}}$ = current gain x resistance gain.

31. power gain - current gain x voltage gain.

32. In a junction transistor, the base section is very thin, so that it has very few majority and minority carriers of its own.

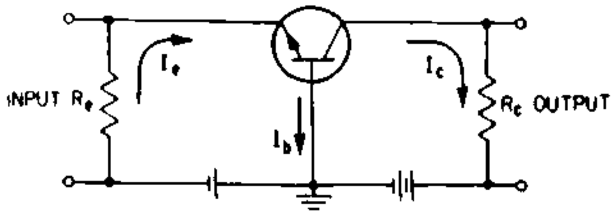
165

VI. TRANSISTOR AMPLIFIERS

The previous lesson covered the basic theory of the transistor, and how it provides amplification. This lesson analyzes in detail, and compares, the three common types of transistor circuits: common base, common emitter, and common collector.

COMMON BASE

1.



This transistor circuit is called a ( ) ( ) amplifier.

////////////////////

common base

---

2. In the common base amplifier, the input signal is applied to the ( ).

////////////////////

emitter

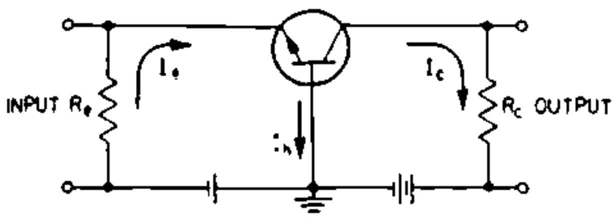
---

3. The output signal appears across load resistor Rc in the ( ) circuit.

////////////////////

collector

4.a.



In an NPN common-base amplifier, a positive going input signal applied to the emitter (increases/decreases) emitter bias.

////////////////////

decreases

4.b. Decreased emitter bias reduces emitter and, therefore, (   ) current.

////////////////////

collector

4.c. With reduced collector current, the drop across the collector load resistor goes (   ).

////////////////////

down

4.d. This causes the collector voltage, or output, to go up, or in the (   ) direction.

////////////////////

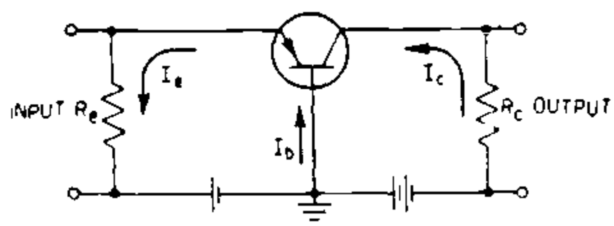
positive

4.e. Therefore, in an NPN common-base amplifier, a positive going input signal produces a (   ) going output signal.

////////////////////

positive

5.a.



In a PNP common-base amplifier, the collector voltage is (   ).

////////////////////

negative

5.b. The actual negative voltage that is at the collector depends on how much voltage is dropped by the (   ) Rc.

////////////////////

load resistor

16

5.c. If the load resistor drops less voltage, more of the collector bias voltage is applied to the collector. The collector then would be more (   ).

////////////////////

negative

5.d. If the load resistor dropped more voltage, the collector would be (   ) negative. It would go in a (   ) direction.

////////////////////

less   positive

5.e. With a PNP common-base amplifier, a positive going input signal applied to the emitter (increases/decreases) emitter bias.

////////////////////

increases

5.f. This increases emitter and, therefore, (   ) current.

////////////////////

collector

5.g. With increased collector current, the drop across the collector load resistor (increases/decreases).

////////////////////

increases

5.h. This makes the collector voltage (   ) negative.

////////////////////

less

5.i. The collector voltage, or output, then, goes in a (   ) direction.

////////////////////

positive

5.j. Therefore, in a PNP common-base amplifier, a positive going input signal produces a (   ) going output signal.

////////////////////

positive

6.a. PNP and NPN amplifier circuits use opposite emitter bias polarities. Therefore, the same phase input signals affect the emitter bias voltages in both circuits differently. If a signal aids the bias in the NPN, the same signal will ( ) the bias in the PNP.

////////////////////

oppose

6.b. However, since the NPN and PNP circuits also use opposite collector bias polarities, the same phase input signals will produce ( ) phase output signals in both circuits.

////////////////////

the same

---

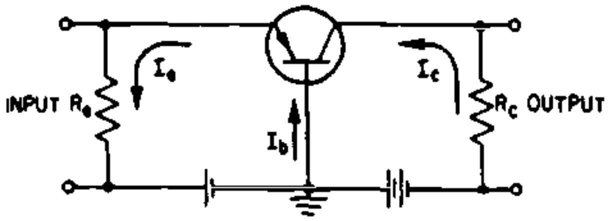
7. Therefore, in the common-base amplifier, there is no ( ) reversal between the input and output signals.

////////////////////

phase

---

8. In the common-base amplifier, output current (Ic) is ( ) current. Input current (Ie) is ( ) current.



////////////////////

collector emitter

9.a. Current gain in a common base circuit is output current divided by input current.

The output current is the ( ) current, and the input current is the ( ) current.

////////////////////

collector emitter

9.b. Therefore, the formula for gain can also be written as . . . .

////////////////////

$$\text{gain} = \frac{\text{collector current}}{\text{emitter current}}$$

169

9.c. The symbol for collector current is (   ).

////////////////////

Ic

9.d. The symbol for emitter current is (   ).

////////////////////

Ie

9.e. The symbol for CURRENT GAIN in a common base circuit is α (alpha). Using the SYMBOLS, the formula for alpha can also be written as . . . .

////////////////////

$$\alpha = \frac{Ic}{Ie}$$

10. Given, emitter current (Ie) = 12 MA
collector current (Ic) = 11.4 MA

Find a... a.

////////////////////

$$\alpha = \frac{Ic}{Ie} = \frac{11.4}{12} = .95$$

11. In the common-base amplifier. Ic is originally supplied by Ie; and Ic is always slightly less than Ie. Therefore, the formula for alpha (α) shows that the current gain of a common-base amplifier is always less than (   ).

////////////////////

1, unity

12. The current gain is less than 1 because part of the emitter current enters the base and does not reach the (   ).

////////////////////

collector

13. Although the current gain is less than 1. the common base circuit provides a resistance gain because the output resistance is much (   ) than the input resistance.

////////////////////

higher

14. E = IR.

The high RESISTANCE gain, together with a CURRENT gain of close to 1, results in a ( ) gain.

////////////////////

voltage

15. P = EI.

Since there is a VOLTAGE gain, and a CURRENT gain close to 1, the circuit also provides a ( ) gain.

////////////////////

power

16. E = IR

$P = I^2\underline{R}$

Basically, the voltage and power gains are due to the ( ) gain.

////////////////////

resistance

17. There is a r e s i s t a n c e gain because the output resistance is much higher than the ( ).

////////////////////

input resistance

18. The input resistance of the common base circuit is usually between 30 and 100 ohms. Therefore, the output resistance must be much ( ) than this.

////////////////////

higher

19.a. The output resistance of the common base circuit is generally about 1 or 2 megohms. However, if a load resistor of this size were used, an unusually large collector battery would be needed. The value of the load resistor, then, is ( ) than the output resistance.

////////////////////

smaller, less

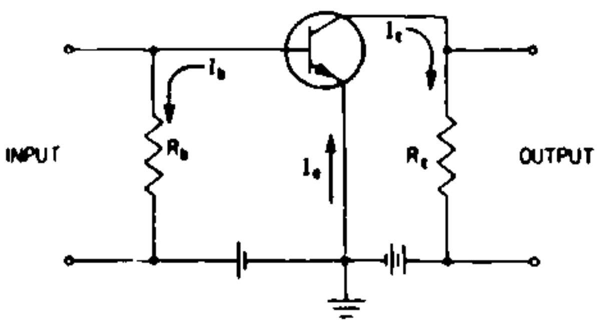
19.b. The size of the load resistor, though, is still much greater than the circuit's ( ) resistance.

////////////////////

input

COMMON EMITTER

20.



The transistor circuit shown is called a ( ) amplifier.

////////////////////

common emitter

21. In the common emitter amplifier, the input signal is applied to the ( ).

////////////////////

base

22. The output signal appears across the load resistor Rc in the ( ) circuit.

////////////////////

collector

23.a. In the NPN common emitter amplifier, a positive going input signal (increases/decreases) base-emitter bias.

////////////////////

increases

172

23.b. Aiding the forward bias (increases/decreases) the collector current through the load resistor.

////////////////////

increases

23.c. Increased collector current results in a larger voltage drop across the load resistor. This causes the collector voltage, or output to go down, or in a ( ) direction.

////////////////////

negative

23.d. In the common emitter amplifier, then, a positive going input signal causes a ( ) going output signal.

////////////////////

negative

23.e. Therefore, in the common emitter circuit there (is/is not) a 180° phase reversal between the input and output signals.

////////////////////

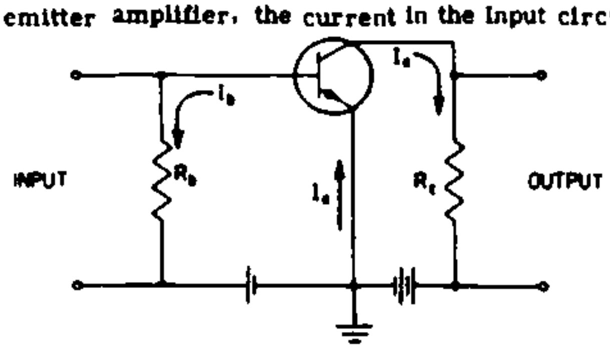
is

24. Since PNP and NPN common emitter circuits use opposite base-emitter bias polarities, a certain phase input signal has opposite effects on the base-emitter bias in these circuits. However, since these circuits also use opposite collector bias polarities, the phase of the output signal in both circuits is ( ).

////////////////////

the same

25. In the common emitter amplifier, the current in the input circuit is ( ) current.



////////////////////

base

152

173

26. Base current is very small in comparison to (   ) or (   ) currents.

////////////////////

emitter   collector

27. The output current is the (   ) current.

////////////////////

collector

28. Collector current is much greater than (   ) current.

////////////////////

base, input

29. Current gain = $\frac{\text{output current}}{\text{input current}}$

Therefore, the common emitter circuit produces a considerable (   ) gain.

////////////////////

current

30.a. The symbol for collector current is (   ).

////////////////////

Ic

30.b. The symbol for base current is (   ).

////////////////////

Ib

30.c. The symbol for current gain in a common emitter circuit is β (beta). Using the SYMBOLS, the formula for beta can be written as . . . .

////////////////////

$$\beta = \frac{Ic}{Ib}$$

31.a. What is the formula for alpha? Use the symbols.

////////////////////

$$\alpha = \frac{Ic}{Ie}$$

31.b. The formulas for alpha and beta might at first seem to be the same because they both divide output current by input current. Are they actually the same?

////////////////////

No.

31.c. What is the difference between alpha and beta?

////////////////////

To find alpha, the input current is emitter current; but to find beta, the input current is base current.

32. Since the emitter current is the total current in the transistor circuit, find the collector current (Ic) and then find β in a common emitter circuit that has an emitter current (Ie) of 5 MA and a base current (Ib) of 0.1 MA.

////////////////////

$$Ib + Ic = Ie$$

$$Ie - Ib = Ic$$

$$Ic = 5 - .1 = 4.9 \text{ MA}$$

$$\beta = \frac{Ic}{Ib} = \frac{4.9}{.1} = 49$$

33. The base-emitter junction is ( ) biased.

////////////////////

forward

34. Therefore, the input circuit is biased in the forward or ( ) resistance direction.

////////////////////

low

35. The base-collector junction is ( ) biased.

////////////////////

reverse

36. Therefore, the output circuit is biased in the ( ) resistance direction.

////////////////////

high

37. Besides having a high current gain, a common emitter also has a (   ) gain.

////////////////////

resistance

38. With high current and resistance gains, the common emitter will have a large (   ) gain.

////////////////////

voltage

39. Given: input resistance = 2,000 ohms
output resistance = 10,000 ohms
β = 49

Find voltage gain.

////////////////////

resistance gain = $\frac{10,000}{2,000} = 5$

voltage gain = current gain x resistance gain = 49 x 5 = 245

40. P = EI

Since the common emitter circuit has high current and voltage gains, there will also be a very high (   ) gain.

////////////////////

power

41. Given: β = 49
voltage gain = 245

Find power gain.

////////////////////

power gain = voltage gain x current gain = 245 x 49 = 12,005

42. In a common emitter circuit, there are high voltage and power gains because of high (   ) and (   ) gains.

////////////////////

current   resistance

174

43. The input resistance of a common emitter circuit is typically 800 to 2,000 ohms. Therefore, the output resistance must be more than (   ) ohms.

////////////////////

2,000

44. A typical output resistance of the common emitter circuit is about 500,000 ohms. As with the common base circuit, the actual load resistor would be considerably (lower/higher).

////////////////////

lower

45.a. What is the input current in the common emitter circuit?

////////////////////

base current (Ib)

45.b. What is the input current in the common base circuit?

////////////////////

emitter current (Ie)

45.c. What are the output currents in both of these circuits?

////////////////////

collector current (Ic)

45.d. Why is the base current (Ib) so small?

////////////////////

Because most of the emitter current (Ie) goes to the collector.

46.a. Current gain in a common emitter circuit is called beta (B). What is it called in a common base circuit?

////////////////////

alpha (α)

46.b. What are the formulas for α and β ?

////////////////////

$\alpha = \frac{Ic}{Ie} \quad \beta = \frac{Ic}{Ib}$

46.c. Which would always be greater, α or β ?

//////////////////////

β (beta)

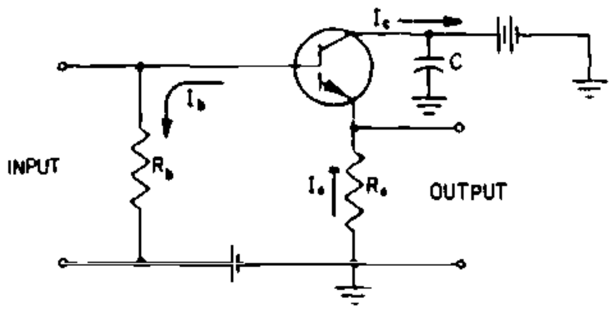
47. Which type of transistor circuit does not reverse the signal phase?

//////////////////////

common base

COMMON COLLECTOR (EMITTER FOLLOWER)

48. This transistor amplifier is called a (   ) amplifier.



//////////////////////

common collector

The common collector amplifier is usually referred to as an "emitter follower." Therefore, it will be called an emitter follower in this section. Keep in mind, however, that the collector is common to both the input and output circuits just as the base is common to the input and output circuits of the common base amplifier and the emitter to the input and output circuits of the common emitter amplifier.

49.a. In the emitter follower (common collector) circuit, the input signal is applied to the (   ).

//////////////////////

base

49.b. The output signal appears across the load resistor (Re) in the (   ) circuit.

//////////////////////

emitter

49.c. Bypass capacitor C places the ( ) at A-C ground potential.

////////////////////

collector

50.a. In the NPN emitter follower, a positive going input signal (aids/opposes) the forward bias.

////////////////////

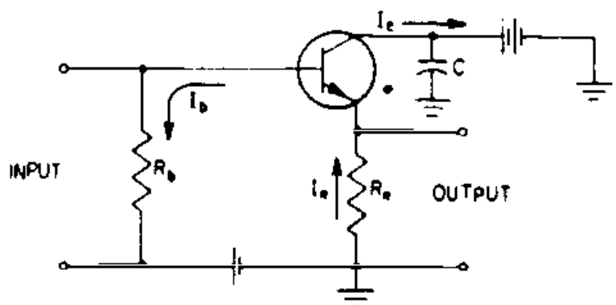
aids

50.b. Aiding the forward bias (increases/decreases) the current through the load resistor.

////////////////////

increases

51.a. The increase in current flow through load resistor Re makes the output voltage more ( ).



////////////////////

positive

51.b. Thus, in the emitter follower circuit, there (is/is not) a 180° phase shift between the input and output circuits.

////////////////////

is not

---

52. In any circuit, current gain equals ( ) current divided by ( ) current.

////////////////////

output input

---

53. In the emitter follower, the current in the input circuit is (   ) current.

////////////////////

base (Ib)

54. Current in the output circuit is (   ) current.

////////////////////

emitter (Ie)

55.a. In the emitter follower circuit, current gain equals (   ) current divided by (   ) current.

////////////////////

emitter   base

55.b. Using SYMBOLS, the formula for current gain in an emitter follower is:

////////////////////

$$\text{current gain} = \frac{Ie}{Ib}$$

Although alpha (α) is used to denote the current gain in a common base circuit, and beta (β) is used for the common emitter circuit, THERE IS NO SPECIAL LETTER USED TO DENOTE THE CURRENT GAIN OF THE EMITTER FOLLOWER CIRCUIT. Instead, a special formula using β is used. This is done because the common emitter circuit is the one that is most widely used in the electronics industry, and so β is of most interest to design engineers. As a result, the transistor manufacturers usually include β in their typical characteristics for the transistors they make. Occasionally, α is also given. The following frame shows how the formula for emitter follower current gain (using β) is derived.

56.a. emitter follower current gain $= \frac{Ie}{Ib}$

and $\beta = \frac{Ic}{Ib}$

In the formula for emitter follower current gain, the emitter current, Ie, is actually the sum of the other currents. Substitute these currents as an expression in place of Ie and rewrite the formula.

////////////////////

$$\text{gain} = \frac{Ic + Ib}{Ib}$$

56.b. You now have: gain = $\frac{Ic + Ib}{Ib}$. This can be expressed as:

$$\text{gain} = \frac{Ic}{Ib} + \frac{Ib}{Ib}$$

The second fraction shows Ib divided by Ib. Anything divided by itself is equal to 1. Rewrite the formula with this substitution.

////////////////////

$$\text{gain} = \frac{Ic}{Ib} + 1$$

56.c. You now have: gain = $\frac{Ic}{Ib}$ + 1. If you look at the beginning of this frame, you will see that the expression $\frac{Ic}{Ib}$ equals (   ).

////////////////////

β

56.d. Rewrite the formula using beta.

////////////////////

emitter follower current gain = $\beta + 1$

57.a. You can work out a simple problem to show that $\beta + 1$ is the current gain of the emitter follower circuit. Assume you have a circuit with an emitter current of 6 MA, and a base current of 0.2 MA. Find the gain directly by dividing Ie by Ib. What is it?

////////////////////

$$\text{current gain} = \frac{Ie}{Ib} = \frac{6 \text{ MA}}{0.2 \text{ MA}} = 30$$

57.b. Now find the current gain by finding β and then adding 1. What is it?

////////////////////

$$\beta = \frac{Ic}{Ib}$$

$$Ic = Ie - Ib$$

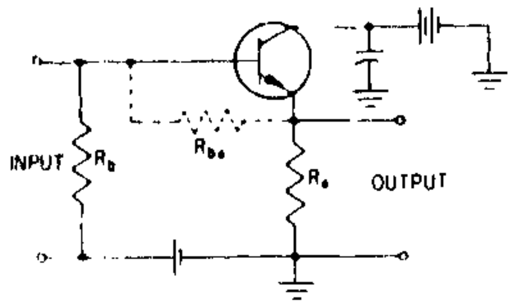
$$Ic = 6 \text{ MA} - 0.2 \text{ MA} = 5.8 \text{ MA}$$

$$\beta = \frac{5.8 \text{ MA}}{0.2 \text{ MA}} = 29$$

current gain = 29 + 1 = 30

181

58. The internal resistance of the transistor between the base and emitter is labeled (   ).



////////////////////

Rbe

59.a. Rbe is in series with the load resistor (   ).

////////////////////

Re

59.b. The input signal is effectively put across the series resistances Rbe and Re. Therefore. the voltage drop across Re is (   ) than the input voltage.

////////////////////

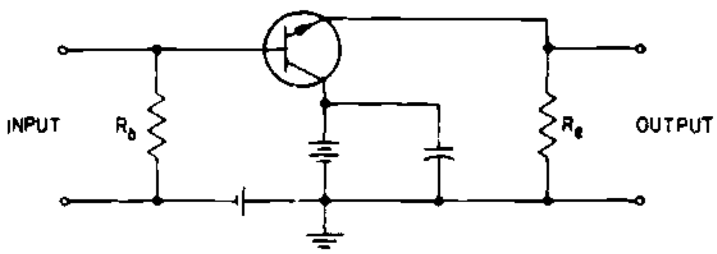
less

59.c. Because of this, the emitter follower has a voltage gain of (   ).

////////////////////

less than 1

60.a.



With the emitter follower circuit redrawn, you will be able to see that the voltage gain of the circuit is less than 1 because the resistance gain is much less than 1.

182

The emitter follower circuit is a common collector circuit. The base and collector form the ( ) circuit.

////////////////////

input

60.b. The base and collector are ( ) biased.

////////////////////

reverse

60.c. The input circuit has a ( ) resistance.

////////////////////

high

60.d. The emitter and collector form the ( ) circuit.

////////////////////

output

60.e. Current flows easily from emitter to collector. Therefore, the output circuit has ( ) resistance.

////////////////////

low

60.f. Resistance gain $= \frac{\text{output resistance}}{\text{input resistance}} = \frac{\text{low resistance}}{\text{high resistance}}$.

The emitter er has a resistance gain of ( ).

////////////////////

less than 1

---

61. The output resistance is typically between 100 and 500 ohms. Therefore, the input resistance must be more than ( ) ohms.

////////////////////

500

---

62. A typical input resistance is 500,000 ohms. In comparison with the input resistance of the other circuits, this is very (high/low).

////////////////////

high

63. In the common base circuit, the input signal is applied to the (   ).

////////////////////

emitter

64. In the common emitter circuit, the input signal is applied to the (   ).

////////////////////

base

65. The common collector circuit is known as an (   ).

////////////////////

emitter follower

66.a. In the common base circuit, the output signal is taken off the (   ).

////////////////////

collector

66.b. In the common emitter circuit, the output signal is taken off the (   ).

////////////////////

collector

66.c. In the common collector circuit, the output signal is taken off the (   ).

////////////////////

emitter

67.a. What is the formula for current gain in the common base circuit? Use symbols.

////////////////////

$$\alpha = \frac{Ic}{Ie}$$

67.b. What is the formula for current gain in the common emitter circuit? Use symbols.

////////////////////

$$\beta = \frac{Ic}{Ib}$$

67.c. What is the formula for current gain in the emitter follower circuit? Use symbols.

////////////////////

current gain $= \beta + 1 = \frac{Ie}{Ib}$

RELATIONSHIP OF ALPHA AND BETA

Although the common emitter circuit is the one that is most often used, the common base circuit is still used to a large extent, particularly in sine wave oscillator circuits. Since manufacturers usually only give β in their transistor characteristics, it is still often necessary to know α. However, this is not really a problem because there is a definite mathematical relationship between α and β. If you know one, you can easily find the other using the proper equation. The following frames show you how these equations are derived.

---

68. $\beta = \frac{Ic}{Ib}$. To set up the relationship between α and β, you must express Ic and Ib in terms of α. α = ?

////////////////////

$$\frac{Ic}{Ie}$$

---

69. $\alpha = \frac{Ic}{Ie}$

Rearrange the formula to solve for Ic.

////////////////////

$Ic = \alpha\, Ie$

---

70. Therefore, since $Ic = \alpha\, Ie$, insert it in the formula for β.

////////////////////

$$\beta = \frac{Ic}{Ib} = \frac{\alpha\, Ie}{Ib}$$

71.a. $\beta = \frac{\alpha \, Ie}{Ib}$.

Now you must express Ib in terms of α.

Ic = α Ie. In this rearranged formula for α, Ic can be expressed in terms of Ib and Ie. How are Ib and Ie related to Ic?

////////////////////

Ie - Ib = Ic

71.b. Substitute Ie - Ib in the formula Ic = α Ie.

////////////////////

Ie - Ib = α Ie

71.c. Ie - Ib = α Ie. Transpose α Ie and - Ib.

////////////////////

Ie - α Ie = Ib

71.d. Ie - α Ie = Ib can also be expressed as Ib = Ie - α Ie. Simplify the right side of the formula.

////////////////////

Ib = Ie(1- α)

71.e. Substitute Ie(1-α) for Ib in the formula for β.

////////////////////

$$\beta = \frac{\alpha \, Ie}{Ie(1-\alpha)}$$

---

72. $\beta = \frac{\alpha \, Ie}{Ie(1-\alpha)}$

F. tor out Ie.

////////////////////

$$\beta = \frac{\alpha}{1-\alpha}$$

---

73. What is the relationship between alpha and beta?

////////////////////

$$\beta = \frac{\alpha}{1-\alpha}$$

74.a. The equation $\beta = \frac{\alpha}{1-\alpha}$ will allow you to find β when α is known. Now you must derive the equation that will let you find α when β is known. The above equation can be rearranged to produce a formula in terms of α.

$\beta = \frac{\alpha}{1-\alpha}$. Cross multiply the terms in this equation.

////////////////////

$$\alpha = \beta - \beta\alpha$$

74.b. $\alpha = \beta - \beta\alpha$. Transpose $-\beta\alpha$ from the right to the left side of the equation.

////////////////////

$$\alpha + \beta\alpha = \beta$$

74.c. $\alpha + \beta\alpha = \beta$. Simplify the left side of the equation.

////////////////////

$$\alpha(1+\beta) = \beta$$

74.d. $\alpha(1+\beta) = \beta$. Divide both sides of the equation by $1+\beta$.

////////////////////

$$\alpha = \frac{\beta}{1+\beta}$$

---

75. Write the two equations that show the relationship between α and β.

////////////////////

$$\alpha = \frac{\beta}{1+\beta} \qquad \beta = \frac{\alpha}{1-\alpha}$$

---

76. Alpha is used for current gain in a common (   ) circuit.

////////////////////

base

---

77. Beta is used for gain in a common (   ) circuit.

////////////////////

emitter

---

78. If a transistor in a common base circuit has a current gain of 0.96, find the current gain if the same transistor were used in a common emitter circuit.

////////////////////

$\alpha = 0.96$

$$\beta = \frac{\alpha}{1-\alpha}$$

$$\beta = \frac{.96}{1-.96}$$

$$\beta = \frac{.96}{.04}$$

$\beta = 24$

79. If a transistor in a common emitter circuit has a current gain of 75, find the current gain if the transistor were used in a common base circuit.

////////////////////

$\beta = 75$

$$\alpha = \frac{\beta}{1+\beta}$$

$$\alpha = \frac{75}{1+75}$$

$$\alpha = \frac{75}{76}$$

$\alpha = .987$ (approx.)

SUMMARY

1. The collector of a transistor gathers the current which comes from the emitter. The current from emitter to collector passes through the base. The bias voltage between the base and emitter of a transistor controls collector current.

2. In the common base amplifier, the input signal is applied to the emitter, and the output signal appears across the load resistor in the collector circuit. In an NPN common base amplifier, a positive going input signal decreases collector current, making the collector voltage go more positive. In a PNP common base amplifier, a positive going input signal increases collector current, and because of the direction of current flow, makes the collector go in the positive direction. In both NPN and PNP common base amplifiers, there is no phase reversal between the input and output signals.

3. Current gain in the common base amplifier, is called alpha (α), and equals collector current divided by emitter current. Alpha is always less than 1.

4. The common base amplifier provides resistance, voltage, and power gains.

5. The input resistance of the common base amplifier is usually between 30 and 100 ohms. The output resistance is generally about 1 or 2 megohms.

6. In the common emitter amplifier, the input signal is applied to the base and the output signal appears across the load resistor in the collector circuit. In the NPN common emitter amplifier, a positive going input signal increases the collector current through the load causing the collector voltage to go in the negative direction. In a PNP common emitter amplifier, a positive going input signal decreases collector current through the load and, because of the direction of current flow, makes the collector more negative. In both NPN and PNP common emitter transistors, the input and output signals are phase-shifted 180°.

7. Current gain in the common emitter amplifier, called beta (β), equals collector current divided by base current, and is usually much greater than 1. The circuit also provides resistance, voltage, and power gains.

8. The input resistance of a common emitter circuit is typically 800 to 2,000 ohms. A typical output resistance is about 500,000 ohms.

9. In the emitter follower, the input signal is applied to the base and the output signal appears across the load resistor in the emitter circuit. In an NPN emitter follower, a positive going input signal increases the current through the load resistor, making the output voltage go more positive. In a PNP emitter follower, a positive going input signal decreases the current through the load resistor and, because of the direction of current flow, causes the output voltage to go in the positive direction. In both NPN and PNP emitter follower amplifiers, the input and output signals are in phase.

10. Current gain of an emitter follower is $\beta + 1$; it equals emitter current divided by base current. The circuit also provides a power gain, but the voltage gain is always less than 1.

11. The output resistance of an emitter follower is typically between 100 and 500 ohms. A typical input resistance is 500,000 ohms.

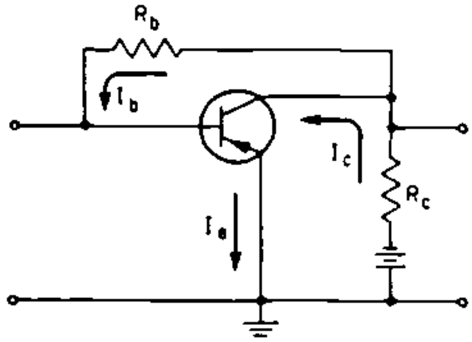
12. $\beta = \frac{\alpha}{1-\alpha}$ $\qquad$ $\alpha = \frac{\beta}{1+\beta}$

VII. TRANSISTOR BIASING AND STABILIZATION

The preceding section dealt with the basic common base, common emitter, and common collector amplifiers in their simplest forms. However, these circuits as they were shown are rarely used because they are affected too much by the inherent sensitivity of transistors to temperature changes. This section shows how practical transistor circuits use bias and stabilization methods to compensate for temperature effects. The common emitter circuit is used in the examples since it is the most commonly used circuit.

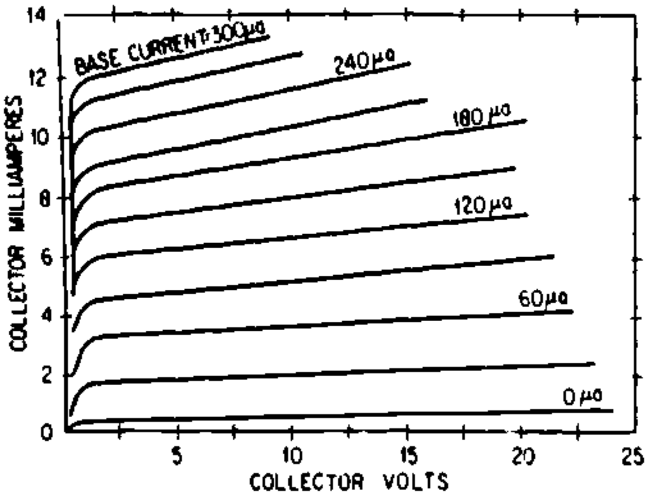
BIASING METHODS

The behavior of a transistor under various bias conditions can be represented by a group of curves called "characteristic curves." These curves are provided by the manufacturer and are usually given for the common emitter configuration. Sometimes they are given for the common base configuration and, occasionally, for both the common base configurations. Because the common emitter configuration is used so frequently in the Polaris system, it will be the one discussed here.



The values of Rb, Rc, Eb, and Ec in this common emitter amplifier determine the bias currents and, therefore, the "operating point" of the transistor. The operating point, is the bias level that establishes a STEADY LEVEL OF COLLECTOR CURRENT FOR ZERO INPUT SIGNAL VOLTAGE. This will be discussed shortly.

1.a. This is a group of characteristic curves for a typical transistor connected in the common emitter configuration.



The curves show how collector current varies for different values of collector voltage and (   ).

////////////////////

base current

You will recall that the amount of collector current depends upon the level of the base-collector bias voltage and the emitter-base bias voltage. Yet here, emitter-base CURRENT is plotted rather than emitter-base VOLTAGE. This is done because emitter-base bias voltage is VERY SMALL and difficult to measure. A specific amount of base current will flow for a specific emitter-base bias voltage. And, since base current is relatively easy to measure, it is standard practice to plot base current rather than base voltage. Keep in mind, however, that the amount of base current is dependent upon the emitter-base BIAS VOLTAGE.

1.b. From the characteristic curves, you can see that the amount of collector current that flows depends upon . . . .

////////////////////

collector voltage and base current (emitter-base voltage).

1.c. Therefore, the operating point of a transistor, which is the bias levels that establishes the level of collector current for zero input signal voltage, is determined by . . . .

////////////////////

collector voltage and base current

1.d. Assume a transistor with a collector voltage of 7.5 volts and a base current of 60 microamperes. From the characteristic curves, how much collector current will flow in this circuit?

////////////////////

about 3.3 milliamperes

1.e. Now assume that the base resistor is changed so that 120 microamperes base current flows. Collector voltage is not changed and remains 7.5 volts. How much collector current will flow?

////////////////////

about 6 milliamperes

1.f. Now let's go back and connect the original base resistor into the circuit so that base current again becomes 60 microamperes. If the collector voltage is increased to 15 volts, how much collector current will flow?

////////////////////

about 3.6 milliamperes

1.g. Summarizing:

COLLECTOR VOLTAGE	BASE CURRENT	COLLECTOR CURRENT
7.5V	60 MA	3.3 MA
7.5V	120 MA	6.0 MA
15V	60 MA	3.6 MA

What conclusion can you draw from these figures?

////////////////////

A small change in base current results in a relatively large change in collector current. The amount of collector current depends MOSTLY on the amount of base current (and, therefore on the emitter-base BIAS VOLTAGE).

1.h. Define operating point. Which two transistor parameters determine the operating point of a transistor? Which one of these two parameters has the most affect on the operating point?

////////////////////

The operating point is the bias levels that establish that amount of collector current that flows for zero input signal voltage.

collector voltage and base current (emitter-base bias voltage)

base current

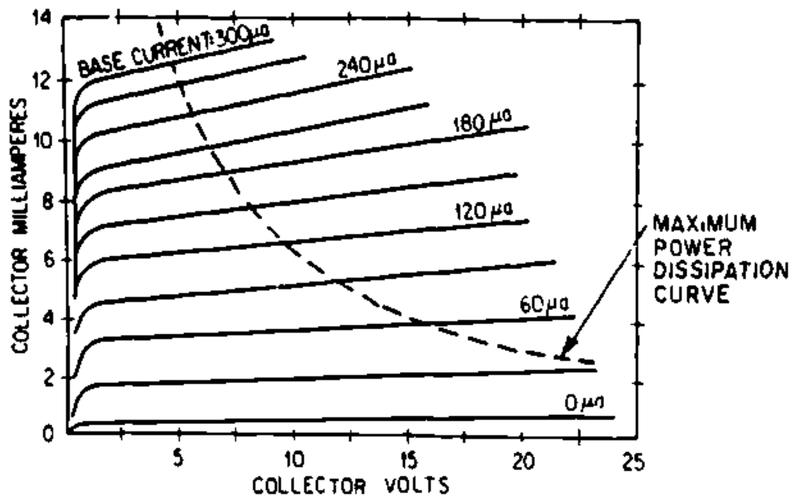
2.a. Along with the operating curves, the transistor manufacturer usually lists maximum safe operation values such as the maximum voltages that can be applied to the collector and emitter, the maximum permissable collector current, and the maximum collector power dissipation.

As long as the applied voltages and currents are kept below these maximum values, the transistor will not be (   ).

////////////////////

damaged

2.b. Sometimes, a maximum power dissipation curve, represented by a dotted line, is given with the operating curves, as shown on the diagram below. If the operating point is to the left of this curve, the transistor will operate safely. To the right of the curve, the transistor may be (   ).



////////////////////

damaged

To obtain a good understanding of biasing, it will be worthwhile to go through a typical problem to show how the values of circuit components are determined to set a desired operating point.

The exact manner in which you go about determining the operating point depends upon what you start with. For example, in some cases, you may have a particular power source or particular transistor available that you must use; in other cases you will be able to select a power source or a transistor. Sometimes you must use a specific load while other times you will have some leeway in selecting the value of the load. In some cases you will be "stuck" with a certain level input signal and in other cases you may have control over what the input signal level will be. Many times you can use the "typical values" provided by the transistor manufacturer and, at other times, these values may not be suitable for your particular application. All of these things affect the way in which you go about selecting the operating point.

(Continued on next page)

In the following example, assume:

1. You must use a 1200-ohm load
2. You have a couple of 12-volt batteries (power sources available).
3. You have a transistor with enough gain to amplify the input signal to the desired level.

The following frames show how to use this information to set the operating point.

3.a. The first thing you must do is construct a "load line." A load line is a line that is drawn on the transistor characteristic curves to show what happens when a load is connected into the collector circuit and the input current varies. The load line will show the behavior of the collector circuit between the points of maximum collector voltage (minimum collector current) and minimum collector voltage (maximum collector current). To construct a load line, you must locate these points.

First, what is the maximum collector voltage that is possible in the circuit you are designing?

////////////////////

12 volts (the battery voltage)

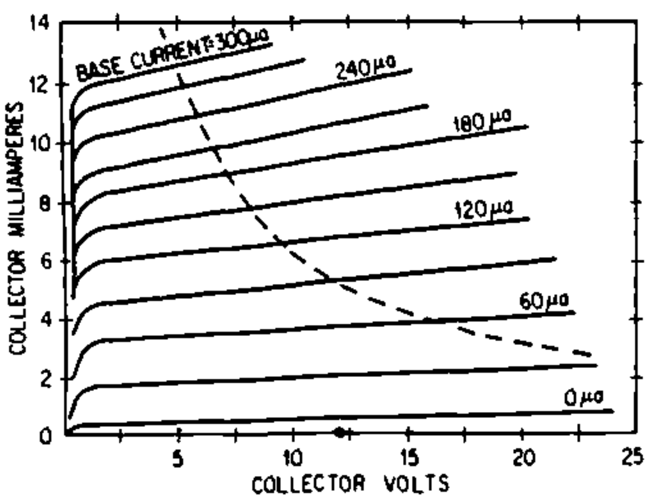
3.b. What would be the level of collector current if the collector voltage is at 12 volts?

////////////////////

0 (essentially)

3.c. Plot this point (collector voltage—12 volts, collector current—0 MA) on your answer sheet.

////////////////////



3.d. Now compute the maximum collector current that can flow. You know that you must use a 1200-ohm load and a 12-volt battery. Therefore, you can use ohms law to compute maximum collector current.

////////////////////

$$Ic\ (max.) = \frac{Ec\ (max.)}{Rc} = \frac{12}{1200} = 0.1A, \text{ or } 10\ MA$$

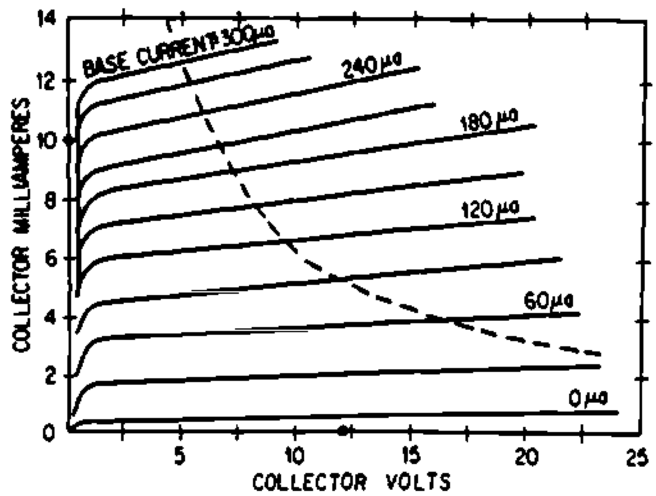
3.e. If maximum current (10 MA) is flowing in the collector circuit, what will be the value of collector voltage?

////////////////////

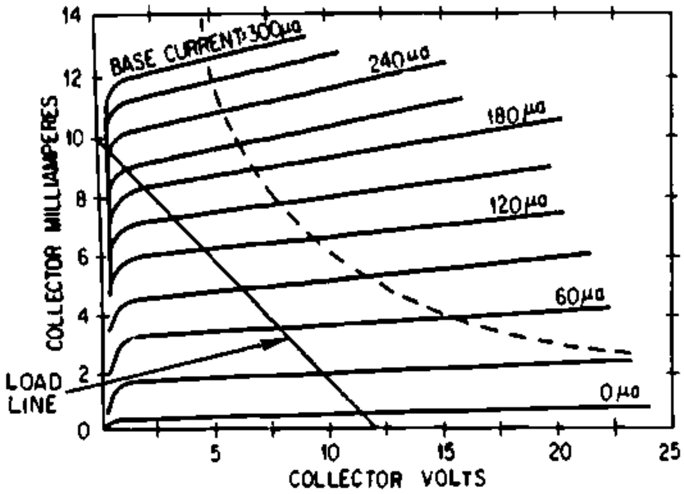
0 (essentially)

3.f. Plot this point (collector current—10 MA, collector voltage—0 volt) on your answer sheet. (Use the curves given with answer 3.c.)

////////////////////



3.g. Now that the maximum collector voltage and the maximum collector current are known, an operating LOAD LINE can be drawn between these two points, as shown below. The line is drawn between (   ) MA collector CURRENT and (   ) volts collector VOLTAGE.



////////////////////

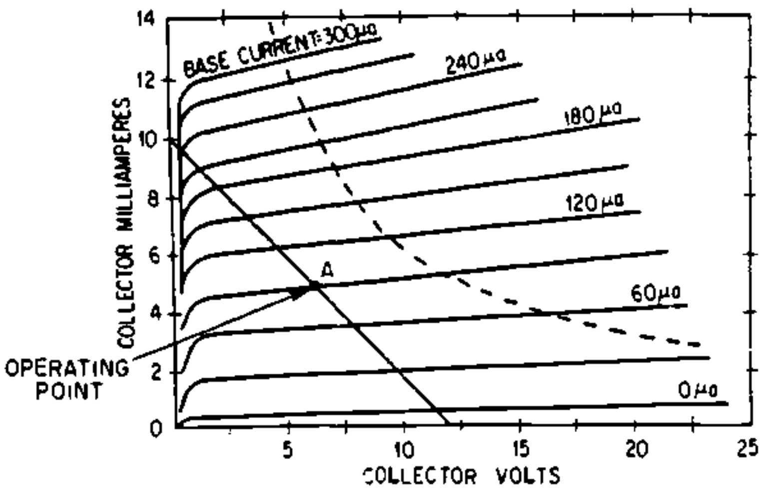
10   12

4. Now that the load line has been drawn, the next step is to select the operating point ALONG THE LOAD LINE. You can see that the load line cuts through many possible operating curves. Each curve represents a specific value of (   ).

////////////////////

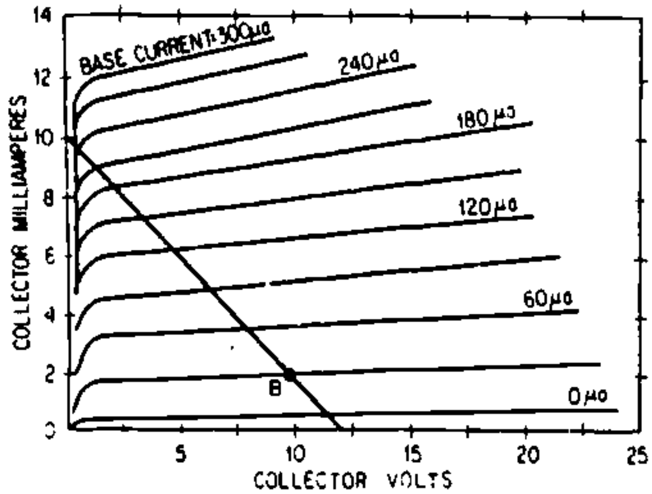
base current

The position of the operating point on the load line is usually chosen to permit the desired amount of signal swing. For example, suppose you needed an a-c output signal with an amplitude of 10 volts peak-to-peak.



If you select point A as the operating point, the collector voltage would vary between about 1 volt and 11 volts (5 volts above and 5 volts below the operating point). No amplitude distortion would be introduced; that is; the a-c signal would not be CLIPPED at either peak.

Now suppose the operating point was set at point B.



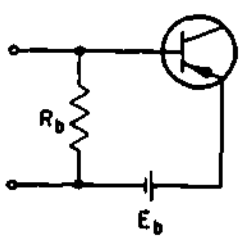
Notice that, with no input signal, the collector voltage would be about 9 volts. Now the desired 10 volt peak-to-peak a-c output signal could not swing 5 volts above the operating point; it would be clipped at about 3 volts above the operating point and distortion would be present in the output.

5.a. So, you decide to set the operating point at A. This requires that the circuit have a base current of (   ).

////////////////////

90 microamperes

5.b. Once the desired base current has been chosen, a proper value bias battery and base resistor can be used to produce the desired current. Since emitter-base junction is biased in the forward direction, its resistance is (   ) compared to the base resistor. The other 12-volt battery will be used to obtain a base current of 90 uA (microamperes). Using ohm's law, what should the base resistor value be?

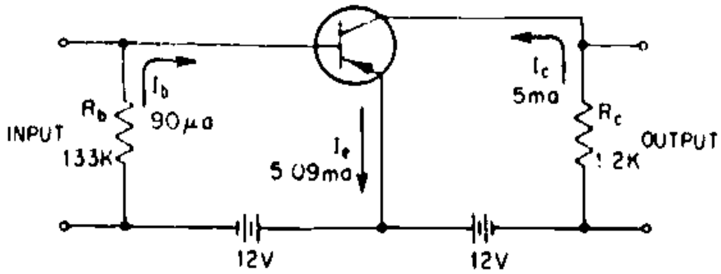


////////////////////

negligible. low

$$Rb = \frac{Ebe}{Ib} = \frac{12}{90\mu A} = 133{,}000$$

6.a.



This circuit shows all the values determined in the previous frames. It operates at Point A. Point A was picked along the load line that was drawn between chosen values of maximum collector voltage and (   ). What are those values?

////////////////////

current   12 V and 10 MA

6.b. The maximum collector voltage was arbitrarily set with a 12-volt battery. What determines the maximum collector current that could flow?

////////////////////

The specified value of Rc. $Ic = \frac{Ec}{Rc} = \frac{12}{1.2K} = 10$ MA

6.c. If a different value of Rc is used, the maximum collector (   ) will change. This would produce a new load line.

////////////////////

current

6.d. When Point A was chosen, it indicated the value of (   ) bias current that was needed.

////////////////////

base

6.e. The required value of base current was obtained with an arbitrarily chosen 12-volt bias battery and a base resistor, Rb. How was the value of Rb found?

////////////////////

$Rb = \frac{Eb}{Ib} = \frac{12\ V}{90\mu A} = 133{,}000$ ohms

---

6.f. The specific location of Point A was chosen to produce a desired collector current and linear signal swings. With the transistor operating at Point A, what would be the static voltage between the collector and emitter and what would be the operating d-collector current?

////////////////////

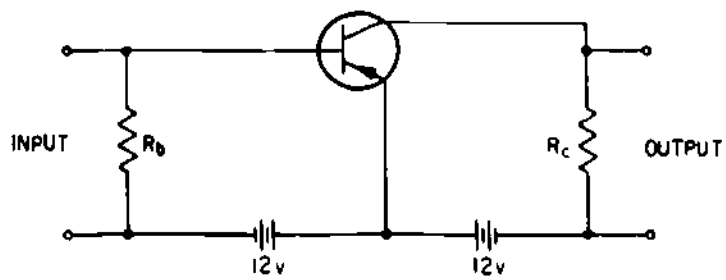
6 V   5 MA

6.g. The emitter current is Ie = Ic + Ib. What is the value of Ie?

////////////////////

Ie = Ic + Ib = 5 MA + 90µA = 5 MA + 0.09 MA = 5.09 MA

7.a.



In this circuit, the base and collector bias battery values were chosen arbitrarily. Larger or smaller batteries could be used for a given operating point; but then, different values of (   ) and (   ) would be needed.

////////////////////

Rb   Rc

7.b. Although the base bias battery that was chosen is the same value as the collector battery, the base battery could be larger or smaller. In either event, the value of (   ) would have to be chosen to produce the proper (   ) current.

////////////////////

Rb   base

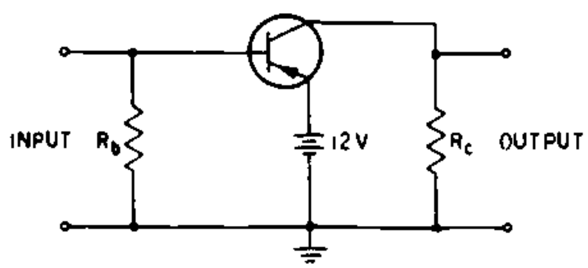
7.c. In the circuit shown, two batteries are used to make both the base and collector (   ) in respect to the emitter.

////////////////////

negative

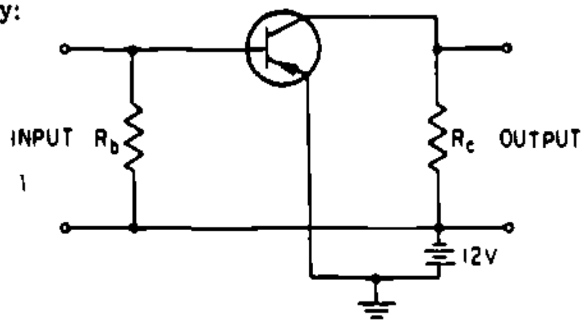
7.d. Actually, since the emitter has the same polarity in respect to the other two elements, only one battery is really needed. Try and redraw the circuit with only one battery.

////////////////////

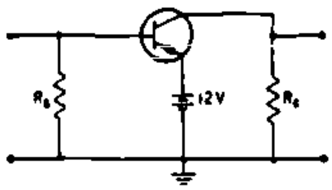


(Continued on next page)

Quite often, this circuit is drawn this way:



8.a. Since the d-c bias currents that flow in this circuit are produced by a fixed battery value together with fixed resistors, the method is known as ( ) bias.



////////////////////

fixed

8.b. The fixed bias circuit has some drawbacks because it does not compensate for variations in the bias currents that are caused by changing transistor characteristics. For example, the internal resistance of transistors tends to vary inversely with temperature. If the temperature of a transistor goes up, its internal resistance will go ( ); this will cause the d-c bias currents to go ( ).

////////////////////

down up

8.c. When the bias currents change, the transistor will DRIFT to a different ( ) point.

////////////////////

operating

8.d. All of the circuit's characteristics, such as gain, output current, and power dissipation, will also ( ).

////////////////////

drift, change, be different

---

9. The ability of a circuit to compensate for temperature changes is called thermal stability. Fixed bias does not provide ( ).

////////////////////

thermal stability

200

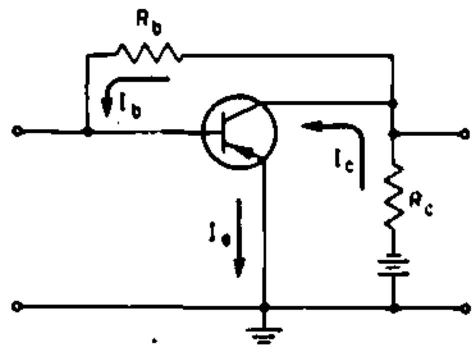
10. To provide for thermal stability, the changes in bias current that result from varying transistor characteristics should be fed back into the transistor to counteract the changes. This is known as (   ) feedback.

////////////////////

negative, degenerative

11.a. This circuit shows a biasing method known as self-bias. It is so called because the operation of the transistor itself has a controlling effect on the bias currents that flow.

The amount of d-c collector current that flows is determined the same as with fixed bias. The bias current supplied by the battery to the collector is limited by resistor (   ).



////////////////////

Rc

11.b. The voltage drop across Rc subtracts from the battery potential, and a reduced voltage is applied at the (   ).

////////////////////

collector

11.c. The collector voltage is the potential that is used to provide the base bias current. Resistor R^b provides a path for the current, and the amount of current that flows through the base is determined by the (   ) of Rb.

////////////////////

resistance, value

11.d. Besides the resistance of Rb, the amount of base current that flows also depends on the voltage at the (   ).

////////////////////

collector

11.e. If any temperature change varies the internal impedance of the transistor, the bias ( ) through the transistor will also tend to change.

////////////////////

currents

11.f. However, if the d-c collector current increases or decreases, the voltage drop across ( ) will change accordingly. This will raise or lower the voltage at the ( ).

////////////////////

resistor Rc collector

11.g. If the collector current goes up, the collector voltage will go ( ).

////////////////////

down

11.h. This, in turn, will lower the bias voltage applied to the ( ) circuit.

////////////////////

base

11.i. Base-to-emitter current will then go ( ).

////////////////////

down

11.j. This will reduce ( ) current, returning it to normal.

////////////////////

collector

11.k. The tendency of collector current to change is counteracted by ( ) feedback through the base bias circuit.

////////////////////

negative, degenerative

11.l. This circuit has thermal ( ).

////////////////////

stability

202

11.m. Any change in collector current will cause a corresponding change in base current to return the (   ) to its normal d-c level.

////////////////////

collector current

11.n. This method of biasing is called (   ).

////////////////////

self-bias

11.o. Why is it called self-bias?

////////////////////

Because the operation of the transistor itself has a controlling effect on the bias currents that flow.

12.a. Name the two methods of bias you have learned about.

////////////////////

fixed-bias and self-bias.

12.b. What is the disadvantage of fixed bias?

////////////////////

It has no thermal stability.

13. Since the self-bias circuit you have just learned about used negative feedback for thermal stability, it also has a disadvantage. The a-c signals in the collector circuit will also be fed back to the base circuit. This negative feedback reduces the (   ) of the stage.

////////////////////

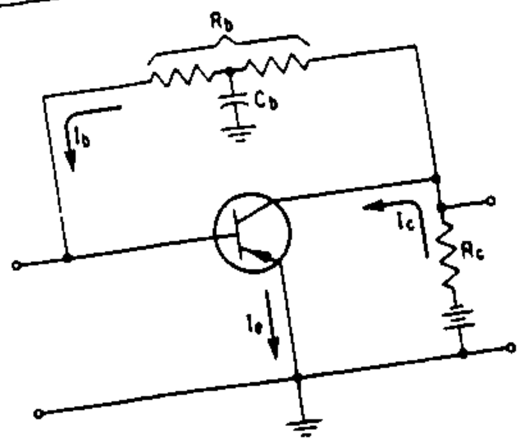
gain

14.a. However, the self-bias circuit can be modified so that there will be no negative feedback for the (   ) signals.

////////////////////

a-c

14.b. The following circuit shows how self-bias can be obtained without loss of gain. How does this circuit differ from the other one?



////////////////////

RB is comprised of two resistors, and their junction is bypassed by a capacitor.

15.a. The capacitor ( ) the a-c signals.

////////////////////

bypasses

15.b. The a-c signals are not fed back to the ( ).

////////////////////

base

15.c. There is no negative feedback for a-c signals, so that the gain of this self-bias circuit is not ( ).

////////////////////

reduced, lowered

15.d. The sum total of the two resistors is chosen for the needed value of ( ) current.

////////////////////

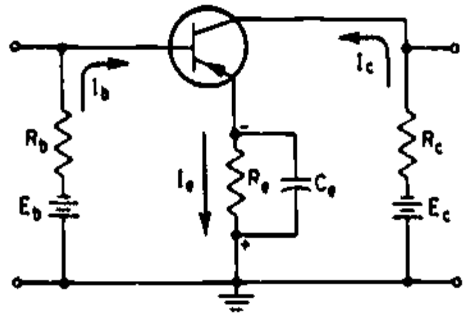
base

213

204

16.a. Another method of obtaining thermal stability, is with a circuit that provides emitter bias.

Since the transistor here is a PNP type, the base must be ( ) in respect to the emitter to forward bias the input circuit.



////////////////////

negative

16.b. Relative to the base, then, the emitter should be ( ).

////////////////////

positive

16.c. Battery Eb applies a negative voltage to the ( ).

////////////////////

base

16.d. Resistor Re is in the emitter circuit and produces a voltage drop that corresponds to the value of emitter current. This voltage drop applies a ( ) voltage to the emitter.

////////////////////

negative

16.e. Since the emitter should be positive in respect to the base, the voltage drop produced by Re (aids/opposes) the forward bias.

////////////////////

opposes

16.f. The actual base bias current that flows depends on the difference between the voltages produced by ( ) and ( ).

////////////////////

Eb Re

16.g. If the temperature of the transistor goes up, the currents through the transistor will go ( ).

////////////////////

up

16.h. An increased emitter current will produce a ( ) voltage drop across Re.

////////////////////

greater, larger

16.i. Since this voltage drop opposes the voltage supplied by Eb, the forward bias of the base-emitter circuit goes ( ).

////////////////////

down

16.j. This reduces base current, which ( ) the collector and emitter current to normal.

////////////////////

lowers

16.k. This circuit has thermal ( ).

////////////////////

stability

16.l. What kind of bias does this circuit use to get this stability?

////////////////////

emitter bias

16.m. The emitter resistor, Re, provides ( ) feedback.

////////////////////

negative, degenerative

16.n. Capacitor Ce bypasses Re so that there is no negative feedback for ( ) signals.

////////////////////

a-c

16.o. If you look at the diagram at the beginning of this frame, you will see that the basic bias currents for the circuit are provided by the batteries and the series limiting resistors. This is actually (   ) bias.

////////////////////

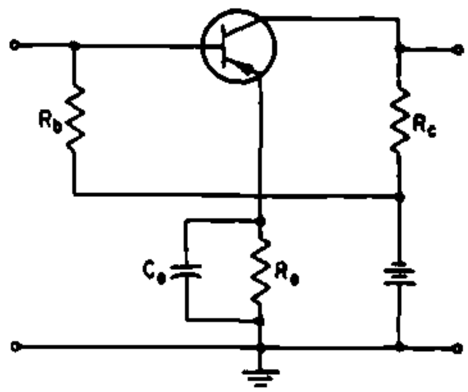
fixed

16.p. The emitter bias is really needed only to provide (   ) stability.

////////////////////

the:mal

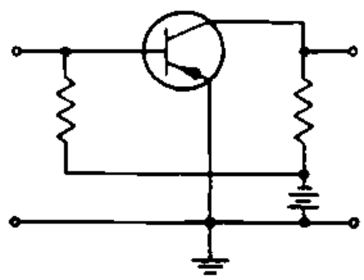
17. This circuit shows how emitter bias stability is obtained with a circuit that has only one battery to provide bias currents. Resistors Rb and (   ) limit base-emitter current flow.



////////////////////

Re

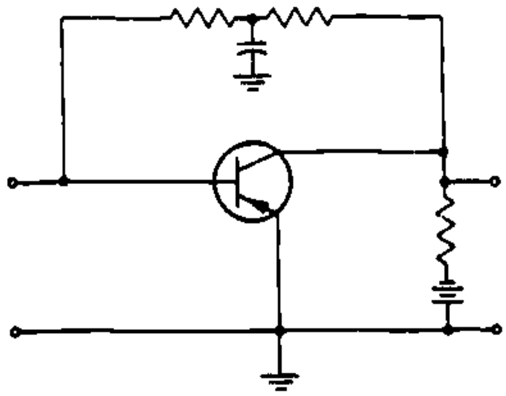
18.a. What type of bias is this?



////////////////////

fixed bias

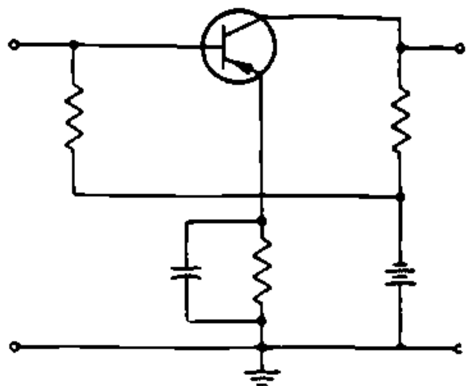
18.b. What type is this?



////////////////////

self-bias

18.c. What types are shown here?



////////////////////

fixed bias and emitter bias

18.d. What is the disadvantage of the circuit shown in frame 18.a.?

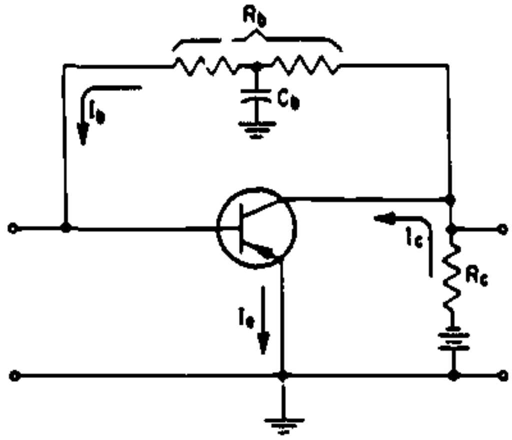
////////////////////

no thermal stability

19.a. Often, the different forms of bias stabilization circuits can be combined to get greater thermal stability.

Draw a circuit using self-bias.

////////////////////



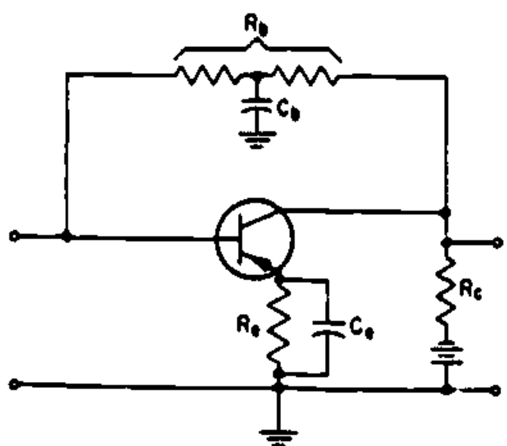
19.b. This circuit couples the changes in d-c collector current back to the ( ) to stabilize the circuit.

////////////////////

base

19.c. Now add emitter bias to the self-bias circuit.

////////////////////



19.d. This circuit also has the changes in d-c emitter current coupled back to the (   ) to stabilize the circuit.

////////////////////

base

19.e. By using both methods of bias together, much greater (   ) is obtained.

////////////////////

thermal stability

STABILIZING CIRCUITS

20.a. The bias stabilizing circuits that were taught in the previous frames first allowed the transistor current to change with temperature, and then had this current change produce a corresponding voltage change. The voltage change, then, was fed back degeneratively to return the transistor current to normal.

The self-bias circuit fed back changes in (   ) voltage.

////////////////////

collector

20.b. The emitter-bias circuit fed back changes in (   ) voltage.

////////////////////

emitter

21. For stabilizing circuits to be most effective, they should prevent the transistor current from changing in the first place. One way to do this is to have the circuit automatically produce an effect on the transistor that is (   ) to the normal effect of temperature.

////////////////////

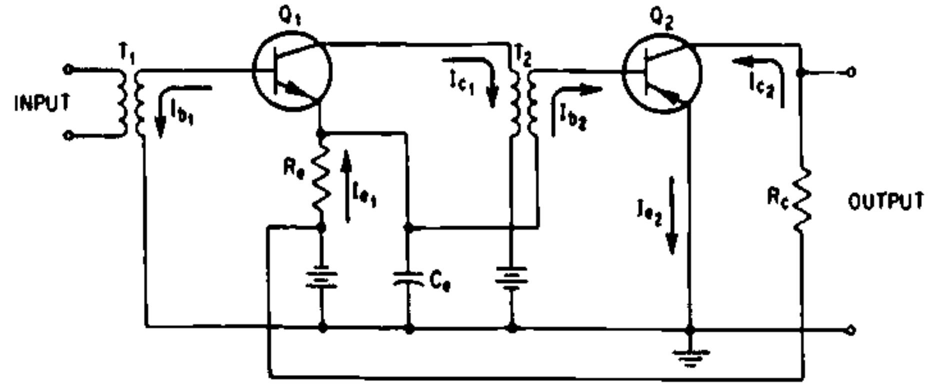
opposite

Temperature compensation can be accomplished by:

a. having one transistor stabilize another.
b. using a thermistor to control emitter-base current.
c. using a semiconductor diode to control emitter-base current.
d. using a semiconductor diode to control collector-base current.
e. using combinations of the above.

These are covered in the following frames.

22.a.



This diagram shows a circuit in which one transistor is used to stablize another. Transistor Q1 uses emitter bias to stablize itself; and the bias of Q1 is applied to transistor Q2 to stablize that stage. The base of transistor Q2 is returned to the ( ) of transistor Q1.

////////////////////

emitter

22.b. The emitter of transistor Q2 is returned to the ( ) of transistor Q1 through ground.

////////////////////

base

22.c. Because of these connections, the polarity of the bias voltage of transistor Q1 is ( ) when it is applied to Q2.

////////////////////

reversed

22.d. Since Q1 is an NPN transistor and Q2 is a PNP transistor, they are both ( ) biased.

////////////////////

forward

22.e. Resistor Re stabilizes transistor Q1 by providing ( ) bias.

////////////////////

emitter

22.f. If the temperature increased, the emitter bias (increases/decreases) the forward bias of Q1.

////////////////////

decreases

22.g. Since the emitter-base voltage of Q1 is applied to the emitter-base section of Q2, any increase in temperature also causes the forward bias of Q2 to (increase/decrease).

////////////////////

decrease

22.h. Thus, Q2 is stabilized by the emitter-base bias voltage of (   ).

////////////////////

Q1

23.a. If both transistors in the previous circuit were the same type, and the emitter-base voltage of transistor Q1 is to be applied to the emitter-base section of transistor Q2, the base of transistor Q2 would be returned to the (   ) of transistor Q1.

////////////////////

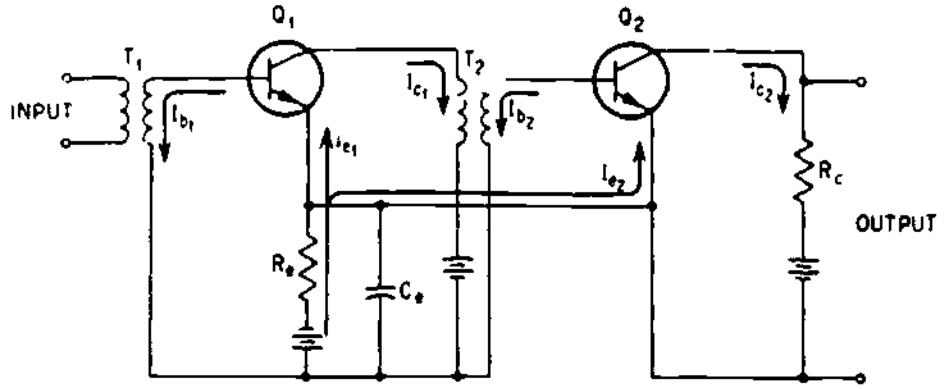
base

23.b. The emitter of transistor Q2 would be returned to the (   ) of transistor Q1.

////////////////////

emitter

23.c.



Current flow through the emitter resistor of Q1 consists of (   ) and (   ).

////////////////////

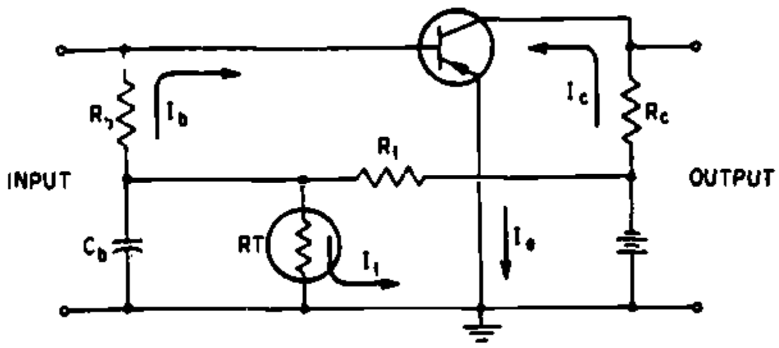
I_{e_1} I_{e_2}

23.d. Thus, a change in the emitter current of either transistor affects (one transistor/ both transistors).

////////////////////

both transistors

24.a.



This diagram shows a circuit using a thermistor to stabilize emitter-base current. The thermistor, labeled RT, has a negative temperature coefficient; as the temperature increases, the resistance of the thermistor (   ).

////////////////////

decreases

24.b. The thermistor, RT, and resistor R1 form a voltage dividing network which provides forward bias voltage for the (   ) section of the transistor.

////////////////////

base-emitter

24.c. If the temperature of the transistor increases, emitter current tends to (   ).

////////////////////

increase

24.d. However, the resistance of the thermistor also decreases when the temperature rises. This causes the voltage drop across it to (   ).

////////////////////

decrease

24.e. A reduced voltage drop across the thermistor reduces the (   ) applied to the base emitter.

////////////////////

forward bias

24.f. This tends to (   ) emitter current.

////////////////////

reduce

24.g. The tendency of the emitter current to go up with temperature is thereby (   ) by the thermistor action.

////////////////////

canceled

24.h. For best stabilization results, the negative temperature coefficient of the transistor should be approximated by that of the (   ).

////////////////////

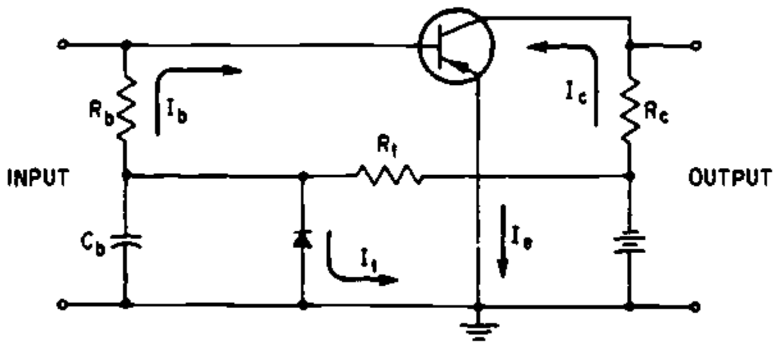
thermistor

24.i. Capacitor Cb prevents the thermistor from being affected by any (   ) voltages.

////////////////////

a-c, signal

25.a.



The circuit in the schematic is similar to the circuit using thermistor stabilization, except that a semiconductor diode is used instead of a thermistor. It, too, stablizes the circuit by keeping emitter-base current steady.

In this circuit, the temperature coefficient of the transistor should be matched by that of the (   ).

////////////////////

diode

25.b. The diode is biased so that it will be affected by temperature in the same way that the transistor is. The diode is (   ) biased.

////////////////////

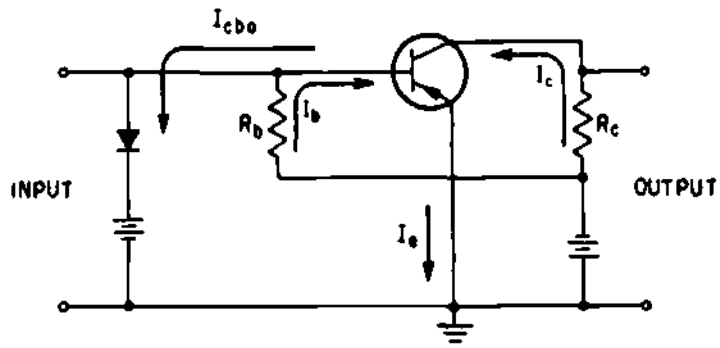
forward

25.c. The resistance-versus-temperature characteristic of a thermistor cannot match that of a transistor as closely as a diode can. Better stabilization is provided by the (thermistor/semiconductor diode).

////////////////////

semiconductor diode

26.a.



This circuit uses a semiconductor diode to stablize collector-base current. To follow the resistance changes of the collector-base section, the diode should be biased the same as the collector-base junction. The diode is (   ) biased.

////////////////////

reverse

26.b. Collector-base current is with (   ) carriers.

////////////////////

minority

26.c. When the temperature of the transistor goes up, the flow of collector minority carriers tends to (   ).

////////////////////

increase

26.d. An increased number of minority carriers in the base would also cause an increase in (-) current flow.

////////////////////

base-emitter

26.e. However, the increase in temperature also lowers the diode ( ).

////////////////////

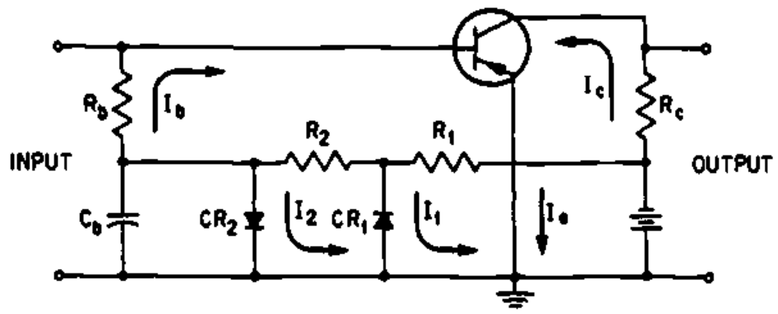
resistance

26.f. The lower diode resistance allows the excess collector minority carriers (Icbo) to flow out of the base to the battery. Base-emitter current will then be ( ).

////////////////////

stabilized

27.a.



This diagram shows a circuit using double diode stabilization. It is actually a combination of the two previous diode stabilization circuits.

Diode CR1 is ( ) biased.

////////////////////

forward

27.b. When the temperature rises, CR1 ( ) the base-emitter bias voltage.

////////////////////

lowers

27.c. This prevents the base-emitter current from ( ).

////////////////////

increasing

27.d. **Diode CR2 is reverse biased. It stabilizes base-( ) current.**

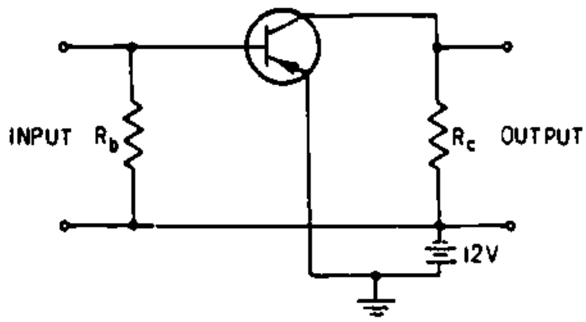
////////////////////

collector

REVIEW

28.a. **Draw a fixed-bias circuit using one battery.**

////////////////////



28.b. **What is the disadvantage of this circuit?**

////////////////////

No thermal stability.

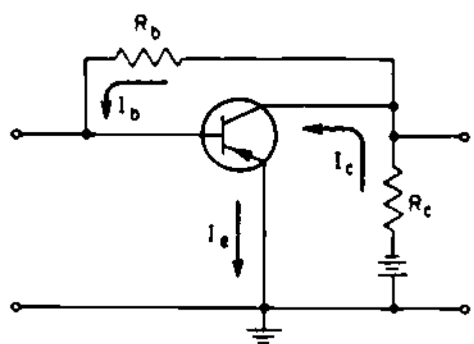
29. **What two methods of biasing provide thermal stability?**

////////////////////

Self bias and emitter bias.

30.a. **Draw a self-bias circuit.**

////////////////////



30.b. Generally, how does the circuit work, and how does it stabilize the circuit?

////////////////////

Under static conditions, the amount of emitter and collector current that flows produces a certain level of collector voltage. This voltage is applied through Rb to the base. Rb limits the base current to the proper value. If any temperature variations cause the transistor d-c bias currents to change, the collector voltage will also change. This will vary the base bias, causing the transistor currents to return to normal.

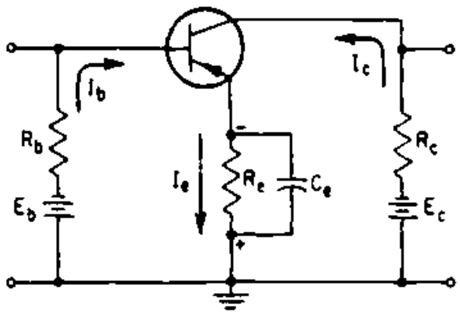
30.c. What is the purpose of capacitor Cb?

////////////////////

Cb prevents degenerative feedback of the a-c signal.

31.a. Draw an emitter-bias circuit that has two batteries.

////////////////////



31.b. Generally, how does the circuit work, and how does it provide thermal stability?

////////////////////

Battery Eb provides the basic bias voltage for the base-emitter section. Emitter current flow through resistor Re, though, produces a voltage drop that counteracts the Eb voltage. When emitter current changes with temperature, the drop across Re varies. This causes the emitter-base bias voltage and current to change to return the emitter current to normal.

31.c. What is the purpose of Ce?

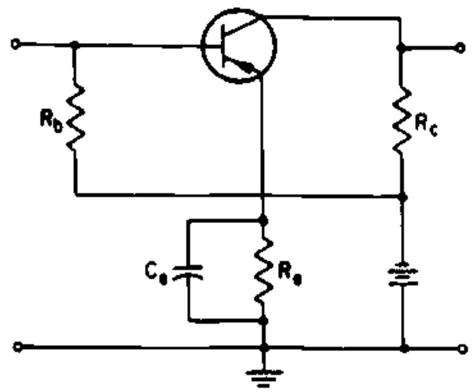
////////////////////

Ce prevents degenerative feedback of the a-c signal.

214

31.d. Draw an emitter-bias circuit that has only one battery.

////////////////////



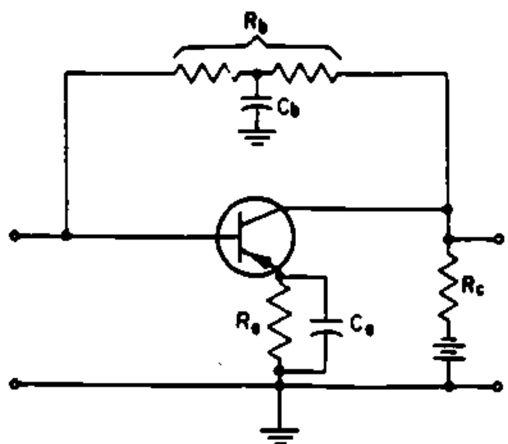
32. What kind of feedback does the self-bias and emitter-bias circuits use to obtain thermal stability?

////////////////////

negative, degenerative

33.a. Draw a circuit using both self and emitter bias.

////////////////////



33.b. What is the advantage of this circuit?

////////////////////

Its thermal stability is greater than if only one type of bias were used.

34. The self-bias and emitter-bias circuits must first allow some current instability to occur before they can work. A good stabilizing circuit should prevent the change from occurring. It can do this by producing an (   ) change.

////////////////////

opposite

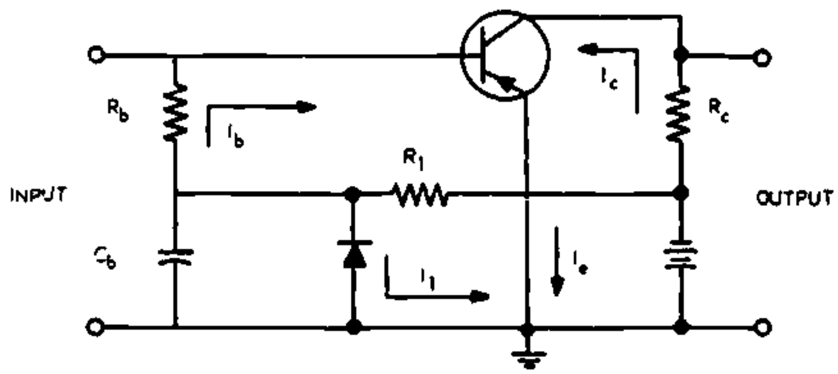
35. Such circuits use extra parts that are affected by temperature in a manner similar to that of the transistor. Name two such parts.

////////////////////

Semiconductor diodes and thermistors.

36.a. Draw a circuit that uses a semiconductor diode to stabilize base-emitter current.

////////////////////



36.b. What kind of bias does the diode have?

////////////////////

forward

36.c. Generally, how does the circuit work?

////////////////////

Any temperature variations that tend to affect the transistor d-c currents also affect the diode. The diode changes its resistance with temperature, causing the base-emitter voltage and current to change in a direction that is opposite to how the transistor is affected. This prevents any change from occurring.

36.d. Does the circuit differ when a thermistor is used?

////////////////////

It doesn't. The thermistor is merely used in place of the diode.

36.e. If the terminals of the diode were reversed, so that it was reverse biased, what current in the transistor would be stabilized?

////////////////////

base-collector current

36.f. Can two diodes be used in the same circuit, one forward biased and one reverse biased?

////////////////////

Yes.

37.a. Describe how one transistor can be used to stabilize another.

////////////////////

A transistor that has emitter bias to stabilize itself can apply its emitter-base voltage to another transistor.

37.b. Generally, if the transistor that does the stablizing is an NPN type, the other transistor is a (   ) type.

////////////////////

PNP

37.c. Because of this, the em'ᵗter of the PNP transistor is returned to the (   ) of the NPN transistor.

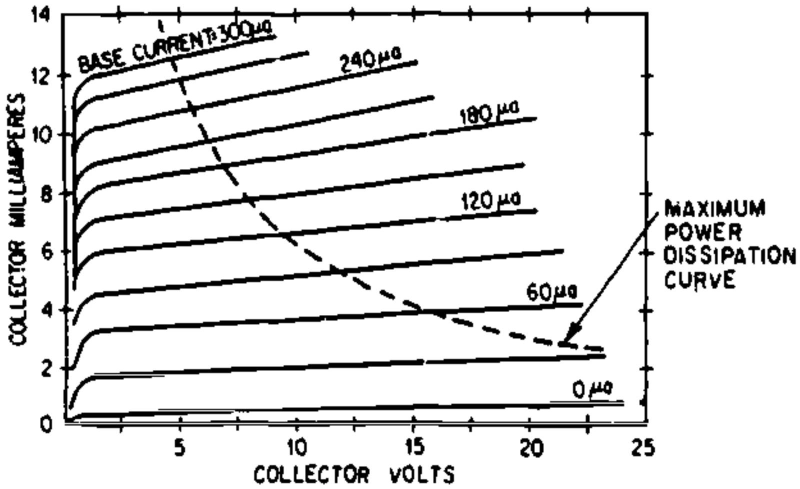
////////////////////

base

SUMMARY

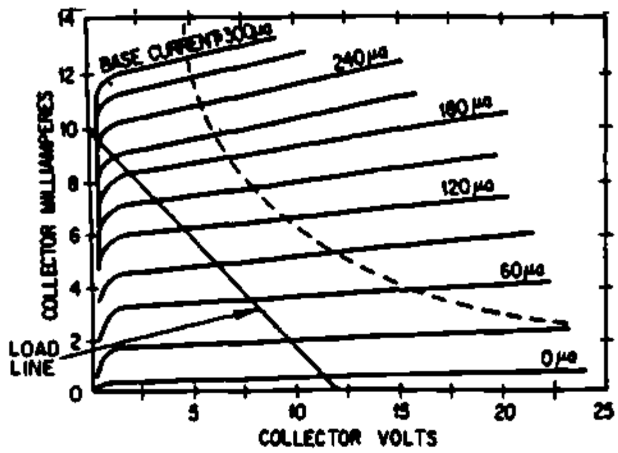
1. The values of the base resistor, base battery, collector resistor, and collector battery determine the bias currents and, therefore, the operating point of a transistor. The operating point is important because it determines how well the transistor performs its particular function.

2.



In picking an operating point, care must be taken to stay within maximum safe values given by the manufacturer. These include maximum collector voltage, emitter voltage, collector current, and power dissipation. Sometimes, the maximum power dissipation curve is shown with a dotted line.

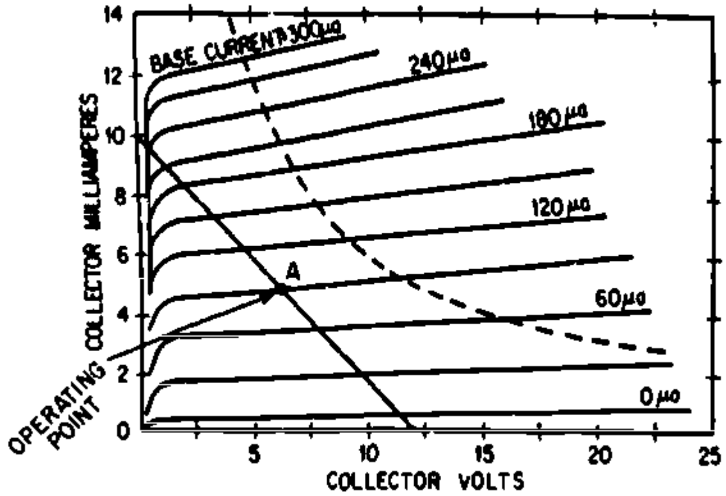
3.



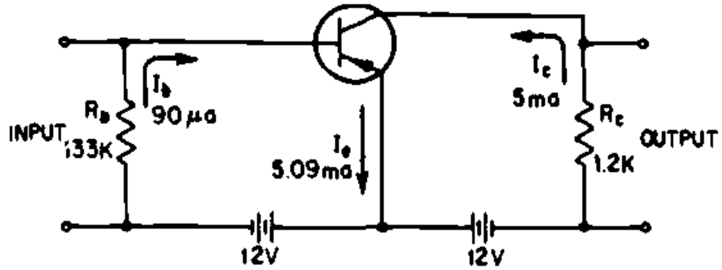
The first step in picking an operating point is to draw the load line. The load line in the illustration represents a 1200-ohm collector resistor and a 12-volt collector battery. Maximum collector current is found by the formula $Ic = \frac{Ec}{Rc} = \frac{12}{1200} = 10$ MA.

4. Once the load line is drawn, an operating point is picked to produce the desired currents and to allow a fairly linear signal swing above and below the operating point along the load line.

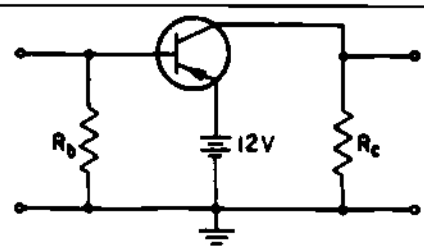
5. The operating point in the illustration falls on the 90 μa base current curve. The base resistor is computed by the formula $Rb = \frac{Eb}{Ib}$. Assuming the same 12-volt battery is used, then $Rb = \frac{12}{90 \mu A} = 133{,}000$ ohms. The operating point also shows that the collector current is 5 MA. The emitter current is the sum of the base and collector currents, or 5.09 MA.



6. This circuit shows all the values determined in the previous steps.

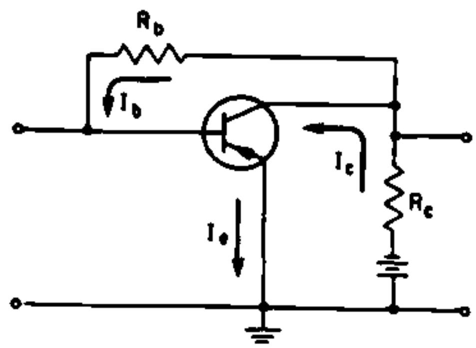


7. The circuit can be redrawn so that only one battery is used. Since the bias currents are produced by a fixed battery value and fixed resistors, the circuit uses FIXED bias.

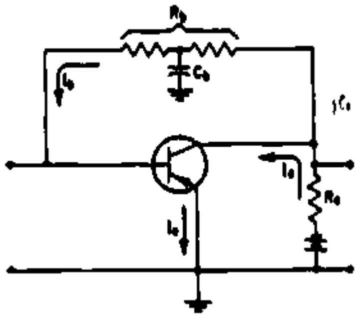


8. A change in temperature causes the operating point to shift in a transistor circuit using fixed bias. Thus, fixed bias does not provide thermal stability.

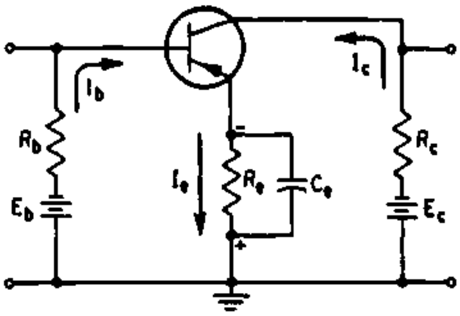
9. Since the collector-to-emitter voltage in this circuit is used to bias the base-to-emitter junction, the circuit uses SELF bias. An increase in temperature decreases the internal impedance of the transistor, causing an increase in current. This increases the voltage drop across Rc, lowering the collector-to-emitter voltage. This, in turn, reduces the voltage applied to the base-emitter section, so that the increase in current tends to be minimized. Thus, the circuit uses negative feedback to provide thermal stability.



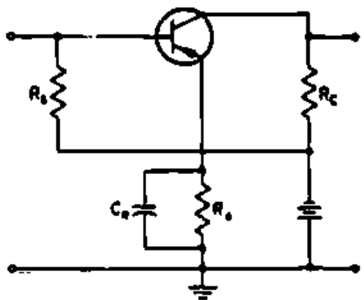
10. Since negative feedback causes a loss of amplification, the circuit must be modified so that the a-c signal at the output is not fed back to the base. By making the base resistor two separate resistors and bypassing their junction through a capacitor to ground, the a-c signal is decoupled from the feedback. This prevents a-c degeneration.



11. This circuit provides thermal stability by developing a compensating voltage, called EMITTER bias, across emitter resistor Re. The polarity of this voltage is such that it opposes the emitter-base forward bias voltage. An increase in current, caused by an increase in temperature, increases the voltage drop across Re. This reduces the forward bias, thereby minimizing the increase in current. Capacitor Ce prevents a-c degeneration.

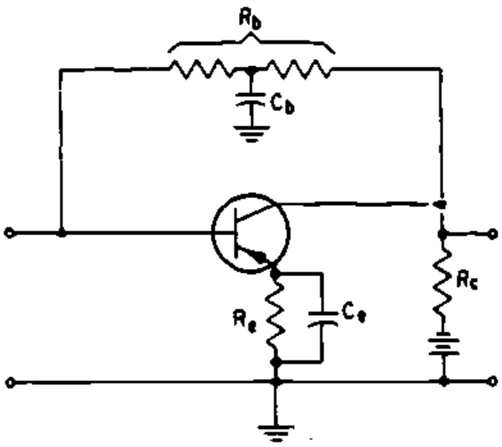


12. The circuit using emitter bias can be modified so that only one battery is used.



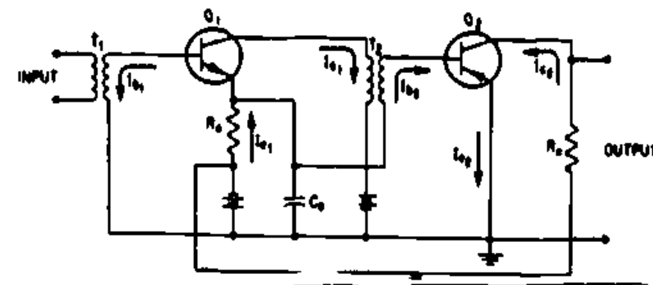
13. By combining different bias stabilization circuits, greater thermal stability can be obtained than that provided by any one circuit.

14. This circuit shows a combination of self bias and emitter bias.

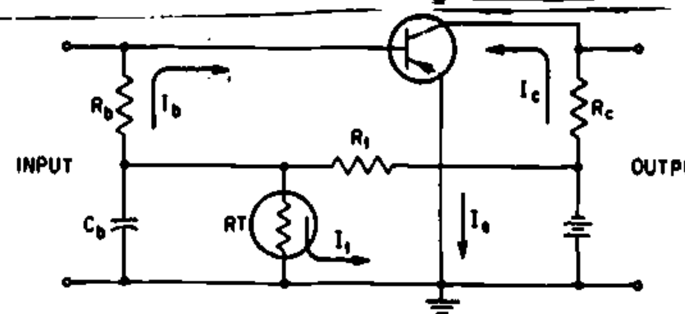


229

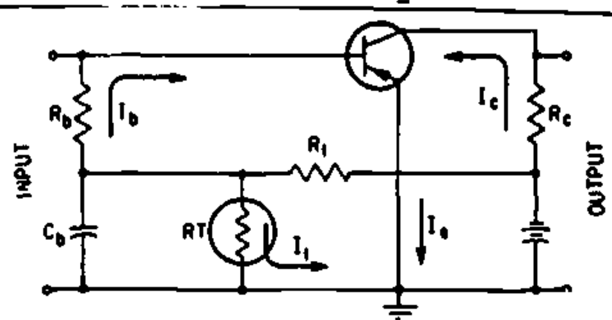
15. Transistor Q1 uses emitter bias. If the temperature increases, the emitter-base forward bias of Q1 decreases. Since this voltage is applied to the emitter-base diode of Q2, it is also stabilized.



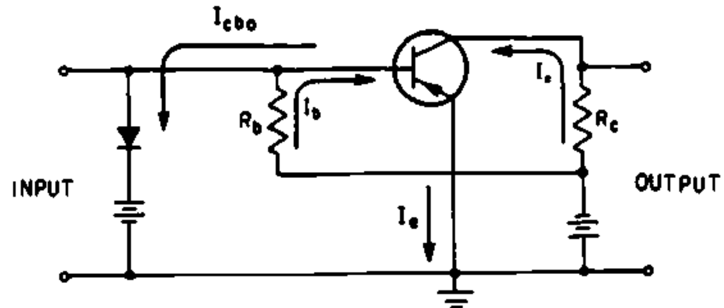
16. If the temperature increases, the resistance of the thermistor decreases, causing the voltage drop across R1 to increase. This reduces the emitter-base forward bias. The capacitor bypasses the a-c signal.



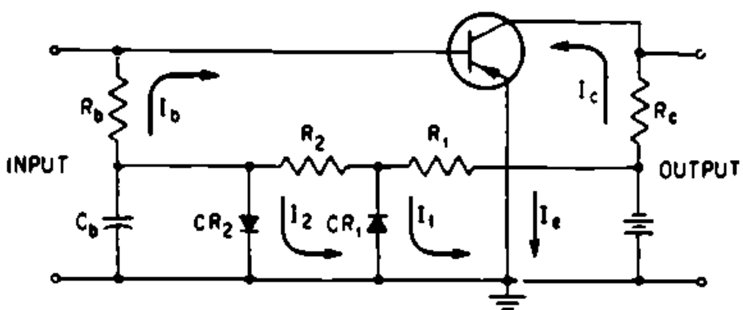
17. The circuit operates in the same manner as thermistor stabilization. However, the diode characteristics more closely approximate those of the transistor, thereby providing better stability.



16. If the temperature increases, base-collector minority carriers increases. If base-collector minority carriers are allowed to accumulate, emitter current will rise. However, the resistance of the diode decreases with an increase in temperature, allowing the minority carriers to flow through the diode.



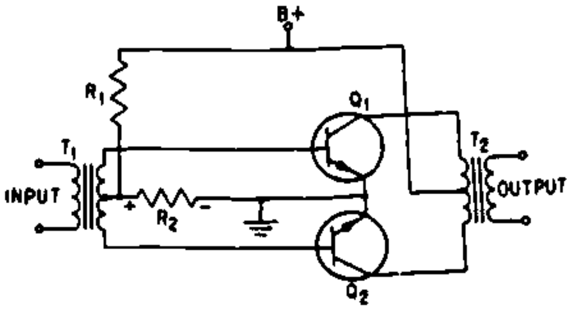
19. Diode CR1 is forward biased and compensates for changes in the emitter-base junction resistance. CR2 is reverse biased and compensates for changes in the base-collector minority carriers. If the temperature increases, the voltage drop across CR2 decreases, this reducing the voltage applied to the base-emitter diode.



225

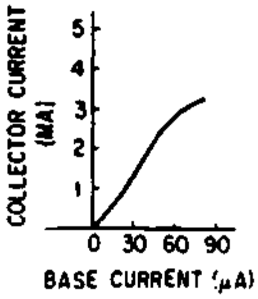
The following lessons apply the knowledge you have obtained so far about transistor fundamentals to many basic transistor circuits. You will be able to understand the operation of these circuits only if you have a thorough grasp of the fundamental principles covered in the previous sections.

1. PUSH-PULL POWER AMPLIFIER:

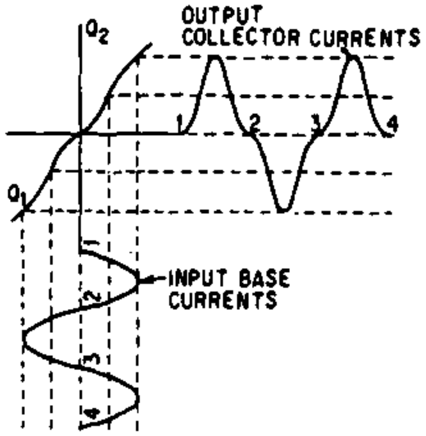


The schematic shows a class B push-pull power amplifier. The circuit uses two NPN transistors biased near cutoff. Because transformer T1 applies signals that are 180 degrees out of phase to each transistor, one conducts while the other is cut off. The transistors conduct only during the half cycle that forward biases the circuit. As a result, each transistor only amplifies and reproduces half a sine wave. But, since both transistors feed the same output transformer, the two half cycles are combined to produce a complete signal. Actually, a small forward bias is applied to the base-emitter junctions of both transistors. This bias is supplied by the voltage divider formed by R1 and R2. The purpose of the bias is to eliminate crossover distortion.

2. Distortion exists with zero bias because collector current becomes very nonlinear as cutoff is approached, as shown in the diagram.

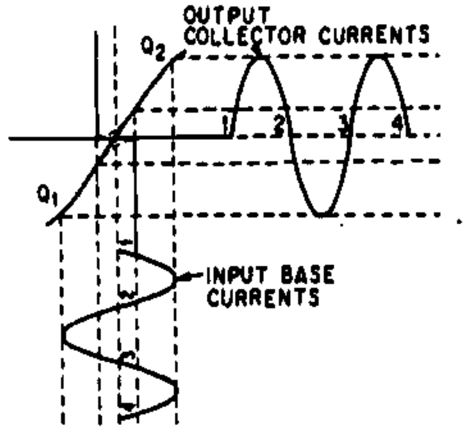


3. The diagram shows the characteristic curves of both transistors back to back for push-pull operation. A sine wave input will produce a distorted output because of the nonlinearity of the curves near cutoff.

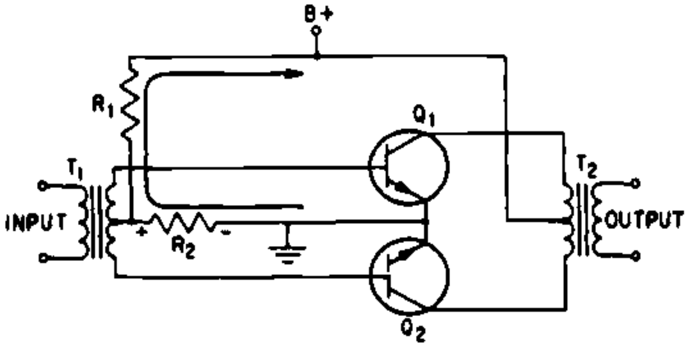


224

4. By putting a small forward bias on the transistors, each will conduct before the other gets to cutoff. This causes the curves to overlap, so that in the cutoff region the net result is a straight line continuation of the two curves. This allows a linear reproduction of the signal.



5.a.



In the above circuit, are the transistors NPN or PNP?

////////////////////

NPN

5.b. Since it is a push-pull circuit, both transistors are operated near (   ).

////////////////////

cutoff

5.c. The signals applied to each transistor by T1 are out of (   ).

////////////////////

phase

5.d. While one transistor is cut off, the other (   ).

////////////////////

conducts

5.e. Each transistor conducts on a ( ) cycle of a sine wave.

////////////////////

half

5.f. The two half cycles from both transistors are combined in ( ) to form a complete signal.

////////////////////

transformer T2

5.g. The voltage drop across R2 ( ) biases the transistors.

////////////////////

forward

5.h. Since R2 has a much lower value than R1, the forward bias is very (high/low).

////////////////////

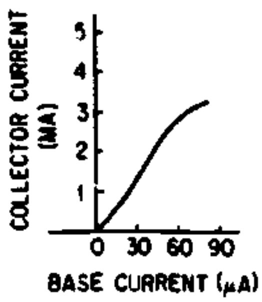
low

5.i. The small forward bias prevents the output signal from being ( ).

////////////////////

distorted

6.a. Distortion is due to the (linearity/nonlinearity) of a characteristic curve.



////////////////////

nonlinearity

6.b. The curve in the diagram becomes nonlinear near (   ).

////////////////////

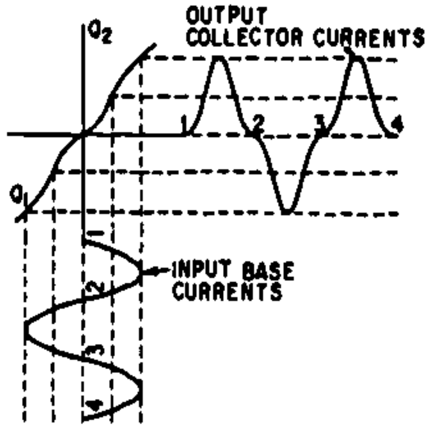
cutoff

6.c. Therefore, an amplifier will distort more if the forward bias is (low/zero).

////////////////////

zero

7.a. The diagram shows two characteristic curves back to back for push-pull operation with (   ) forward bias.



////////////////////

zero

7.b. With zero forward bias, each transistor reaches cutoff (before/after) the other conducts.

////////////////////

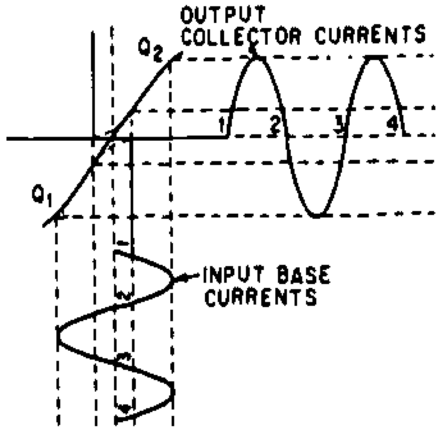
before

7.c. Because of this, the output signal is (   ).

////////////////////

distorted

8.a. Distortion can be prevented by putting a small (   ) bias on the transistor.



////////////////////

forward

8.b. With forward bias, each transistor reaches cutoff (before/after) the other conducts.

////////////////////

after

8.c. Since BOTH transistors conduct in the nonlinear region, the result is a more (   ) curve in this region.

////////////////////

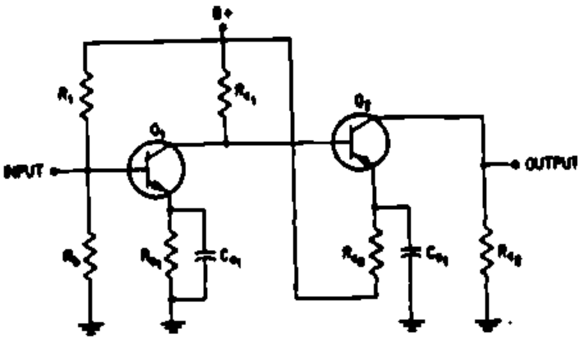
linear

8.d. This allows an output signal to be produced without (   ).

////////////////////

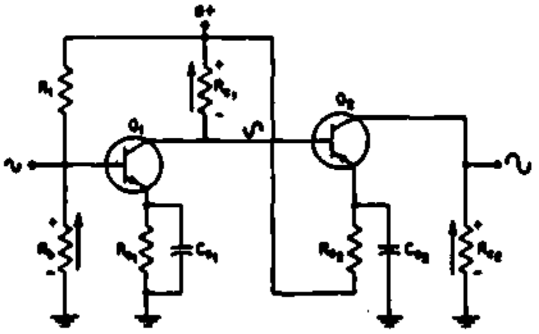
distortion

9. DIRECT-COUPLED AMPLIFIER:



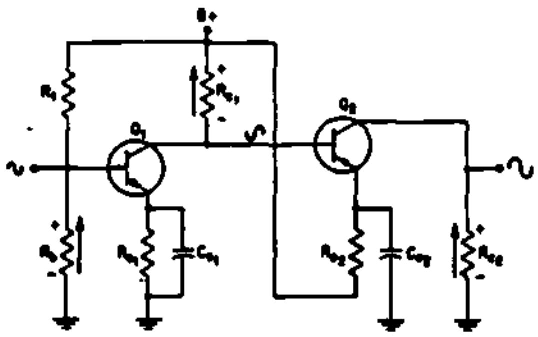
A direct-coupled amplifier has the input circuit of one stage directly connected to the output of another stage. There is no blocking of d-c voltages. The direct-coupled amplifier can be used when very low frequency response is required. Since no coupling capacitor is used, the circuit will amplify the lower frequencies without appreciable falloff in response. By using NPN and PNP transistors, fewer parts are required because the collector circuit of one can be used to bias the base circuit of the other.

10.



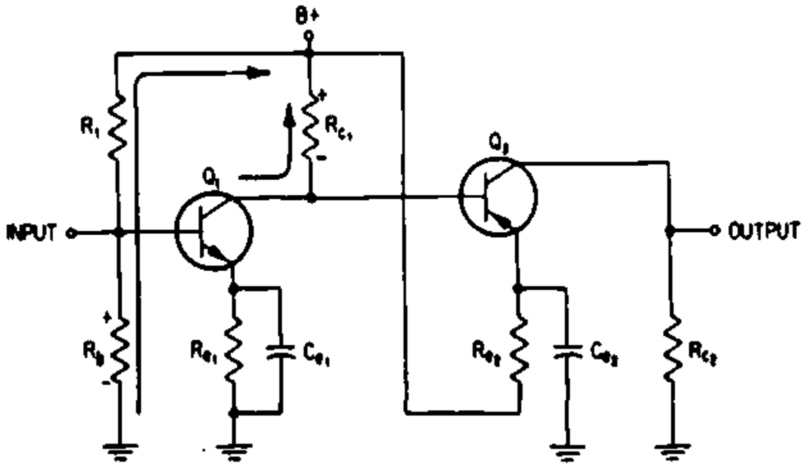
R1 and Rb form a voltage divider. The voltage across Rb forward biases the emitter-base junction of Q1. This allows collector current to flow, producing a voltage drop across Rc1. The collector of Q1 is directly connected to the base of Q2, and the emitter of Q2 is returned to B+. Since Q2 is a PNP type, the voltage across Rc1 makes the emitter more positive than the base and forward biases Q2. The collector of Q2 is returned to ground, and so is more negative than the base; the collector circuit, then, is reverse biased.

11.



A positive going input signal aids the forward bias of Q1. Collector current goes up, increasing the voltage drop across Rc1. This increases the forward bias of Q2, causing its collector current to go up. As a result, the voltage drop across Rc2 increases, making the collector of Q2 more positive. When the signal goes negative, the action is reversed.

12.a.



A direct-coupled amplifier gives good ( ) frequency response.

////////////////////

low

12.b. Between the two stages, there is no blocking of ( ) voltages.

////////////////////

d-c

12.c. The voltage drop across Rb ( ) biases the base-emitter junction of Q1.

////////////////////

forward

12.d. This allows ( ) current to flow through Rc1.

////////////////////

collector

12.e. Rc1 is connected across the ( ) junction of Q2.

////////////////////

base-emitter

12.f. Current through Rc1 produces a voltage drop that ( ) biases the base-emitter junction of Q2.

////////////////////

forward

12.g. Q2 is a (   ) type of transistor.

////////////////////

PNP

12.h. The collector of Q2 is more (   ) than the BASE of Q2.

////////////////////

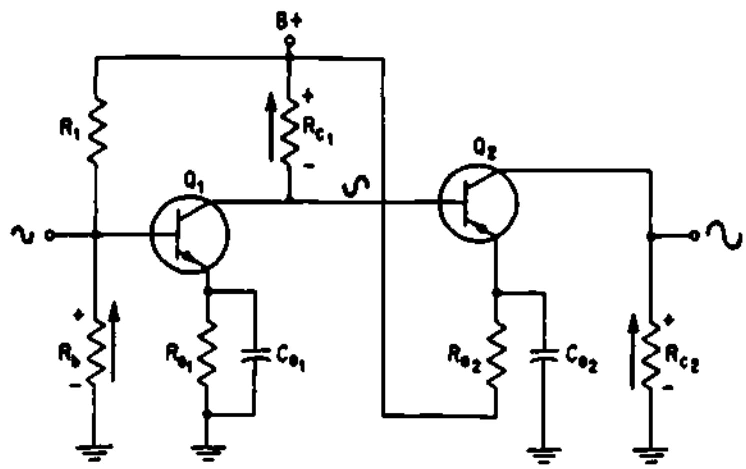
negative

12.i. The collector of Q2 is (   ) biased.

////////////////////

reverse

13.a.



A positive going input signal (aids/opposes) the forward bias of Q1.

////////////////////

aids

13.b. This causes collector current to (   ).

////////////////////

increase

13.c. An increase in collector current (   ) the voltage drop across Rc1.

////////////////////

increases

13.d. This increases the (   ) bias of Q2.

////////////////////

forward

13.e. As a result, the collector current of Q2 (   ).

////////////////////

increases

13.f. Increasing the collector current of Q2 (   ) the voltage drop across Rc2.

////////////////////

increases

13.g. This makes the collector of Q2 more (   ).

////////////////////

positive

13.h. When the input signal goes negative, the output signal goes (   ).

////////////////////

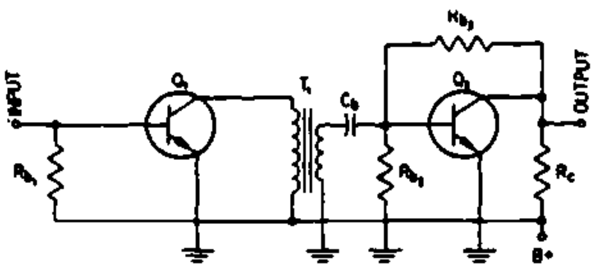
negative

13.i. Emitter resistors Re1 and Re2 provide (   ) stabilization to both stages.

////////////////////

emitter

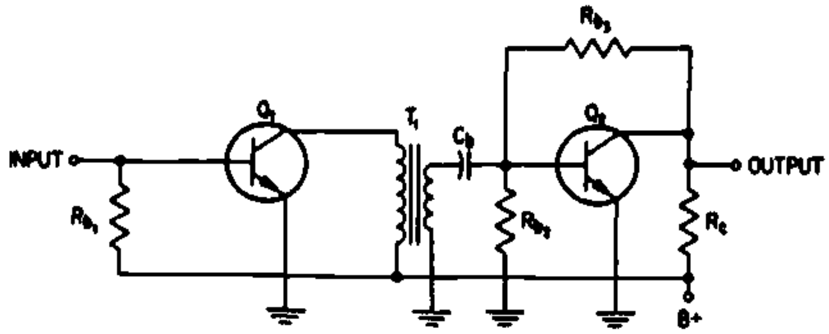
14. TRANSFORMER-COUPLED AMPLIFIER:



Transformer coupling is often used to match the output of one stage to the input of the next. A common emitter circuit, for example, has an input impedance of about 1,000 ohms and an output impedance of about 10,000 ohms. If other than transformer coupling is used, the mismatch between stages results in a considerable signal loss. Thus, transformer coupling keeps the efficiency high, so that fewer stages are required to obtain the desired output amplitude. Although the transformer steps down the voltage, it steps up the current, and so provides a current gain. Since transistors are current-sensitive devices, the gain of the stage is greater.

Transformer T1 is a step-down type, so that the high output impedance of Q1 is matched to the low input impedance of Q2. Capacitor Cb prevents the positive d-c voltage on the base of Q2 from being shorted to ground through the low d-c resistance of the secondary winding T1.

15.a.



Q1 and Q2 are connected as common ( ) amplifiers.

////////////////////

emitter

15.b. In a common emitter amplifier, the output impedance is (higher/lower) than the input impedance.

////////////////////

higher

15.c. The purpose of transformer T1 is to . . . .

////////////////////

couple the signal from Q1 to Q2 and to match the output impedance of Q1 to the input impedance of Q2.

15.d. T1 is a step- (up/down) transformer.

////////////////////

down

15.e. By matching impedances, the ( ) of the amplifier is kept high.

////////////////////

efficiency

15.f. What kind of bias does Rb3 provide to the base emitter circuit of Q2?

////////////////////

self bias

15.g. Does self bias provide stabilization?

////////////////////

Yes.

15.h. Transistors are (   ) sensitive.

////////////////////

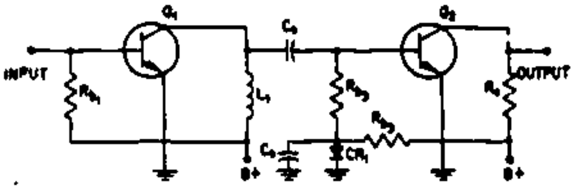
current

15.i. Transformer T1 provides a (   ) gain.

////////////////////

current

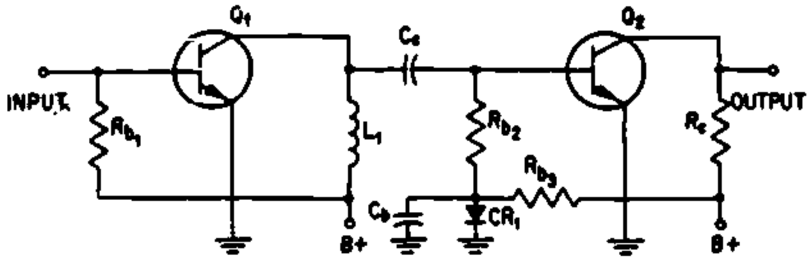
16. IMPEDANCE-COUPLED AMPLIFIER:



Impedance-coupled amplifiers are a compromise between RC-coupled and transformer-coupled amplifiers. The efficiency of an impedance-coupled amplifier is better than that of an RC-coupled amplifier, but not as good as that of a transformer-coupled amplifier. It is easier to match impedances with a transformer, and the transformer provides current gain.

The impedance-coupled amplifier uses and inductor, such as L1, as the load in the collector circuit. The d-c power loss is less than if a resistive load were used because of the low d-c resistance of the inductor. The output signal is developed by the high inductive reactance of the coil. In the above diagram, capacitor Cc couples the signal from across L1 to the base of Q2.

17.a.



The load in the collector circuit of Q1 is formed by (   ).

////////////////////

L1

17.b. The d-c resistance of L1 is very (high/low).

////////////////////

low

17.c. The d-c power loss in the collector circuit of Q1 is very (high/low).

////////////////////

low

17.d. The purpose of Cc is to . . . .

////////////////////

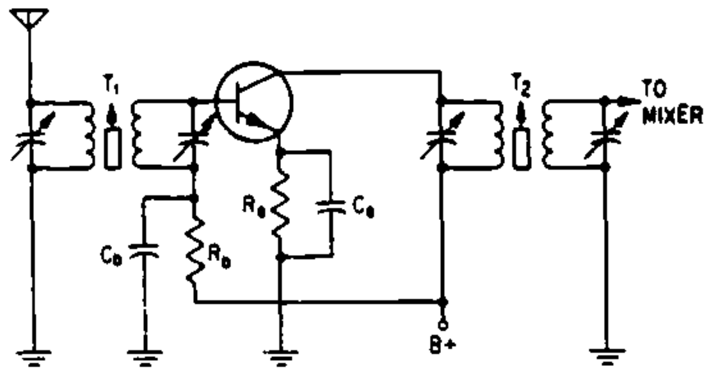
couple the signal from the collector of Q1 to the base of Q2.

17.e. What is the purpose of CR1 in the above diagram?

////////////////////

It provides thermal stability.

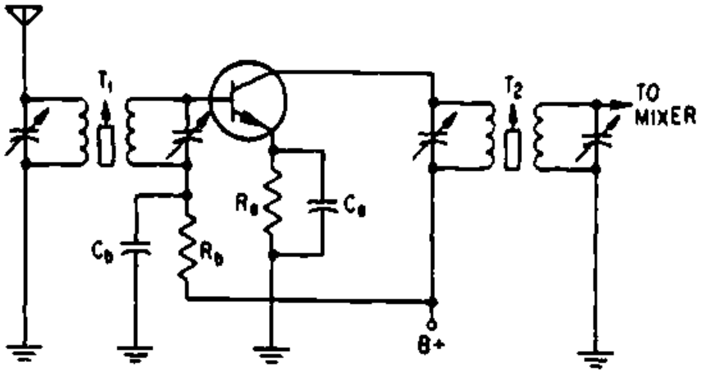
18. RF AMPLIFIER:



RF amplifiers are used immediately after the antenna so that a fairly strong signal can be fed to the mixer; this decreases the amount of gain required of the mixer and improves the signal to noise ratio, since the mixer produces more noise than any other stage. In additioo, the sensitivity of the overall receiver is increased. An RF amplifier also isolates the oscillator from the antenna, keeping the local oscillator signal from being transmitted.

The usual RF amplifier is transformer coupled, but it can also be impedance coupled. Transformer T1 couples the signal from the antenna to the RF amplifier. The resonant frequency of the antenna tank circuit is varied by capacitive and inductive tuning. Resistor Rb limits base current to the proper value, and capacitor Cb bypasses the RF signal so that the entire signal is developed across the secondary winding of T1. Resistor Re develops emitter bias and capacitor Ce prevents degenerative feedback. Transformer T2 couples the amplified signal from the RF amplifier to the mixer. The resonant frequency of the output tank circuit is also varied by capacitive and inductive tuning; the slugs of T1 and T2 are ganged, and the tripper capacitors are used for alignment.

19.a.



What two characteristics of a receiver are improved when an RF amplifier is used?

////////////////////

sensitivity and signal-to-noise ratio

19.b. An RF amplifier also prevents the local oscillator signal from reaching the ( ).

////////////////////

antenna

19.c. The resonant frequency of the antenna and amplifier output tank circuits are varied (separately/together).

////////////////////

together

19.d. Rb sets the proper value of ( ).

////////////////////

base current

19.e. What type of bias does Rb provide?

////////////////////

fixed

19.f. RF signals are prevented from being developed across Rb by ( ).

////////////////////

Cb

19.g. Re develops ( ).

////////////////////

emitter bias

19.h. Emitter bias provides ( ) stability.

////////////////////

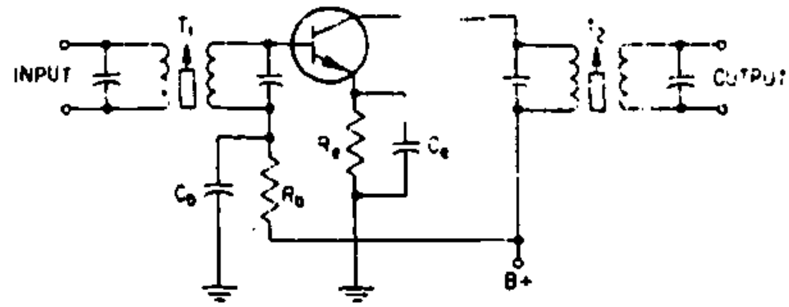
thermal

19.i. Ce prevents ( ) feedback.

////////////////////

degenerative

20. IF AMPLIFIER:



Basically, an IF amplifier is similar to an RF amplifier. Although IF transformers are tunable, they are made to operate over a small range of frequencies. The input of an IF amplifier can come from the mixer or another IF amplifier; the output can go to the second detector or another IF amplifier. The tuning slugs in the transformers are not ganged, and are preset during alignment. Inductive coupling could be used in place of transformers.

21.a. IF amplifiers are designed to operate over a (wide/narrow) band of frequencies.

////////////////////

narrow

21.b. The stage preceding an IF amplifier can be another IF amplifier or the ( ).

////////////////////

mixer

21.c. The stage following an IF amplifier can be another IF amplifier or the ( ).

////////////////////

second detector

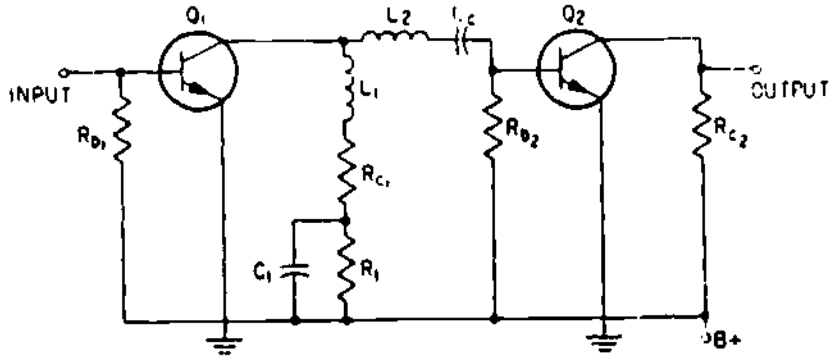
231

21.d. The tuning slugs are preset during (   ).

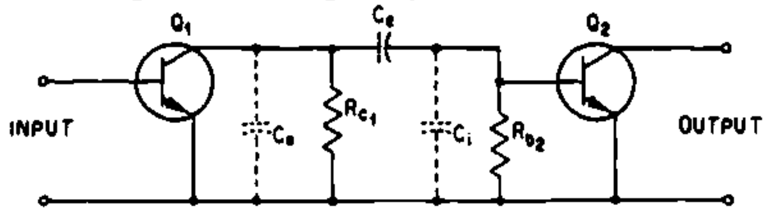
////////////////////

alignment

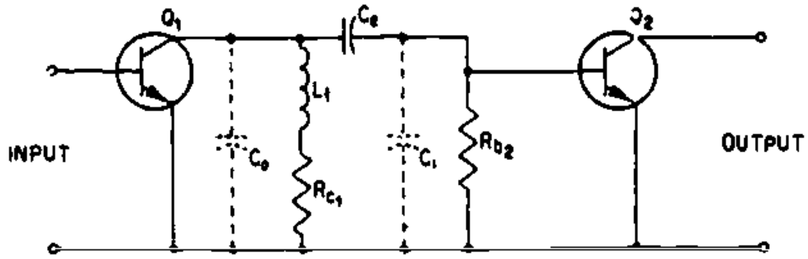
22. VIDEO AMPLIFIER: A video amplifier is used when a bandwidth from about 30 cycles to 4 megacycles is needed. To obtain this wide bandwidth, low- and high-frequency compensation circuits must be used. C1 and R1 in the circuit provide low-frequency compensation; L1 and L2 provide high-frequency compensation by resonating with the shunt capacities of the circuit.



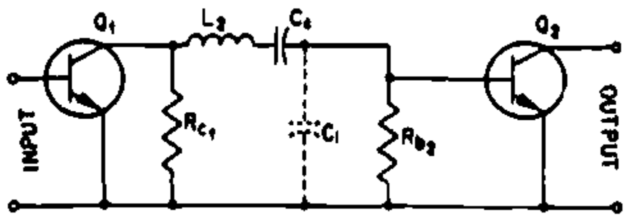
23. Co and Ci Cause High Frequency Loss—This simplified schematic shows one cause of high frequency loss. Co represents the output capacitance of Q1 and Ci represents the input capacitance of Q2, both of which are essentially in parallel with the output load of Q1. As the frequency goes up, the reactances of Co and Ci go down, bypassing the load Rc. This lowers the gain of Q1 at high frequencies.



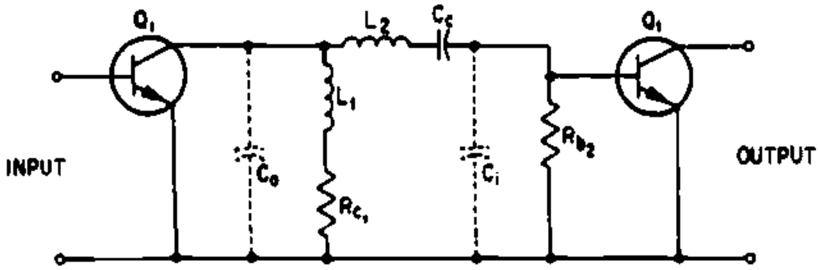
24. L1 Forms Parallel Resonant Circuit with Co and Ci—This simplified schematic shows L1 in series with Rc1. L1 forms a parallel resonant circuit with Co. As the frequency goes up, and approaches the parallel resonant frequency, the impedance of the parallel resonant circuit also goes up, maintaining the gain of the amplifier. This extends the high frequency range of the amplifier.



25. L2 Forms Series Resonant circuit with Ci—This simplified schematic shows L2 in series with Cc. Since Cc is practically a short at high frequencies, L2 can be considered to form a series resonant circuit with Ci. As the frequency goes up and approaches the series resonant frequency, the voltage across each of the series elements also goes up. Since the voltage across Ci goes up, the gain of the amplifier is maintained. This extends the high frequency range of the amplifier.

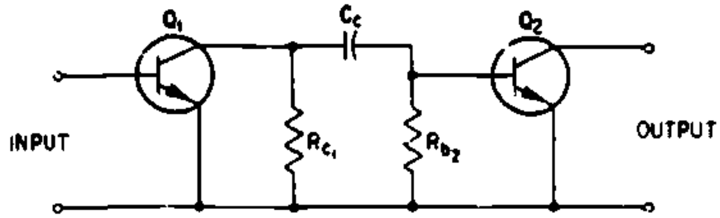


26.

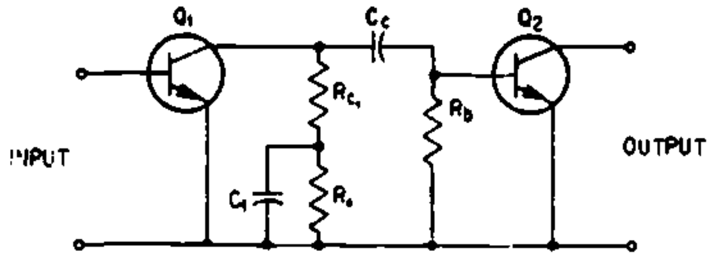


The high frequency response is improved by combining the compensating effects of L1 and L2 in the same circuit.

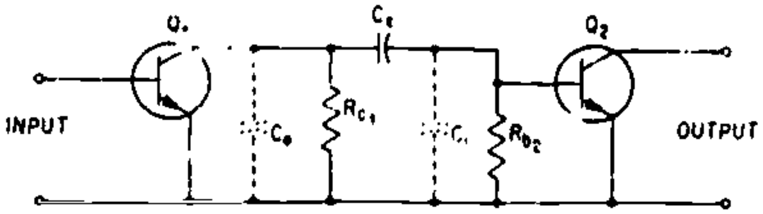
27. Cc Reduces Low Frequency Response—At low frequencies, L1 and L2 have very low reactances, and can be considered out of the circuit. This puts Cc in series with Rb2. As the frequency goes down, the reactance of Cc goes up, forming a voltage divider with Rb2. This reduces the low frequency gain, since only the voltage across Rb2 is applied to Q2.



28. C1 and R1 increase Low Frequency Response—This simplified schematic shows the parallel circuit of C1 and R1 in series with Rc1. As the frequency goes down, the reactance of C1 goes up. At very low frequencies, C1 is practically an open circuit, and so R1 becomes part of the load. This increases the output impedance of Q1 to maintain the gain of the amplifier at the low frequencies.



29.a.



Co represents the ( ) capacitance of Q1.

////////////////////

output

29.b. Ci represents the ( ) capacitance of Q2.

////////////////////

input

29.c. At high frequencies, Cc is essentially (a short/an open) circuit.

////////////////////

a short

29.d. Therefore, Co and Ci are in ( ) with the output of Q1.

////////////////////

parallel

29.e. As the frequency increases, the reactances of Co and Ci ( ).

////////////////////

decrease

29.f. This causes the output impedance of Q1 to ( ).

////////////////////

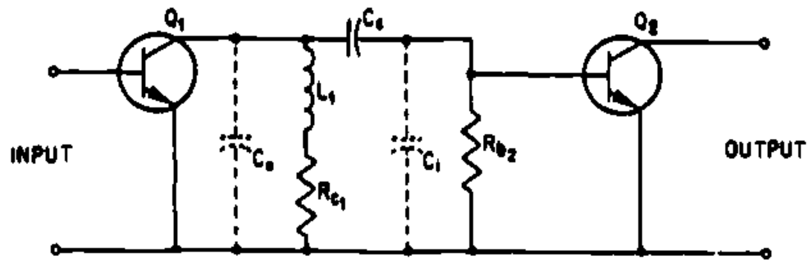
decrease

29.g. As a result, the gain of Q1 decreases at (high/low) frequencies.

////////////////////

high

30.a.



L1 and Co form a ( ) resonant circuit.

////////////////////

parallel

30.b. As the signal frequency approaches the resonant frequency, the impedance of the parallel resonant circuit ( ).

////////////////////

increases

30.c. This causes the output impedance of Q1 to ( ).

////////////////////

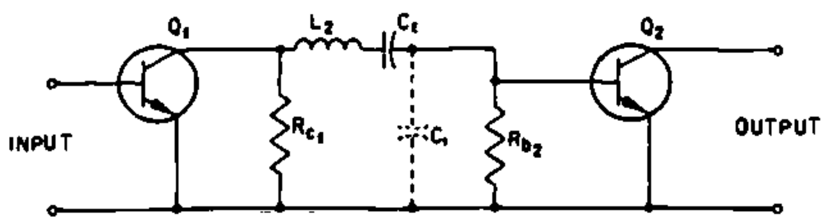
increase

30.d. As a result, the range of the ( ) frequency response is increased.

////////////////////

high

31.a.



At high frequencies, Cc is still essentially (a short/an open) circuit.

////////////////////

a short

31.b. Therefore, L2 and Ci form a (   ) resonant circuit.

////////////////////

series

31.c. As the signal frequency approaches the L2-Ci resonant frequency, the voltage across each of the series elements (   ).

////////////////////

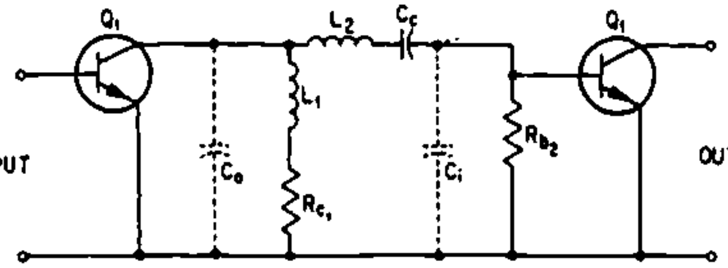
increases

31.d. Since the voltage across Ci increases at high frequencies, the range of the high frequency response (   ).

////////////////////

increases

32.

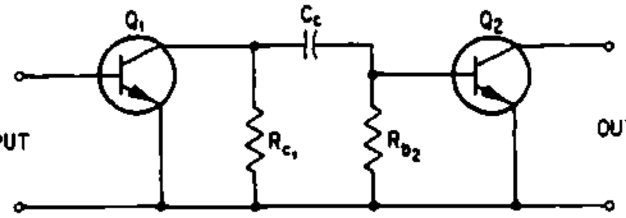


The compensating effects of L1 and L2 in the schematic (aid/oppose) each other.

////////////////////

aid

33.a.



At low frequencies, L1 and L2 can be considered (open/short) circuits.

////////////////////

short

33.b. Therefore, L1 and L2 have (an/no) effect on low frequency operation.

////////////////////

no

33.c. As the signal frequency decreases, the reactance of Cc ( ).

////////////////////

increases

33.d. This causes Cc to form a voltage divider with ( ).

////////////////////

Rb2

33.e. The voltage across Rb2 is applied to ( ).

////////////////////

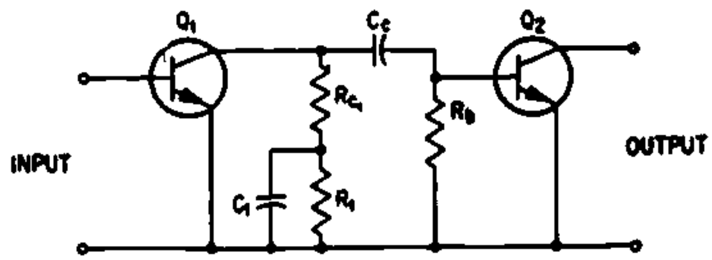
Q2

33.f. Therefore, as the frequency decreases, the low frequency gain ( ).

////////////////////

decreases

34.a.



At high frequencies, C1 is essentially (an open/a short) circuit.

////////////////////

a short

34.b. Therefore, at high frequencies, the load of Q1 is ( ).

////////////////////

Rc1

34.c. As the signal frequency decreases, the reactance of C1 (   ).

////////////////////

increases

34.d. As the reactance of C1 increases, the load also includes (   ).

////////////////////

R1

34.e. At very low frequencies, C1 is essentially (an open/a short) circuit.

////////////////////

an open

34.f. Therefore, at very low frequencies, the load of Q1 is (+   ).

////////////////////

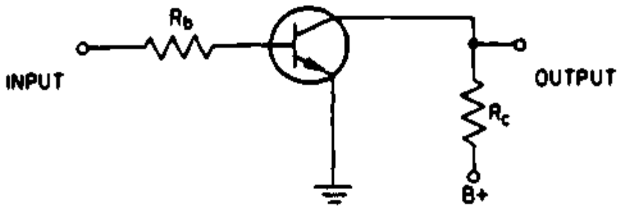
Rc1   R1

34.g. This increase in output load increases the (   ) frequency gain.

////////////////////

low

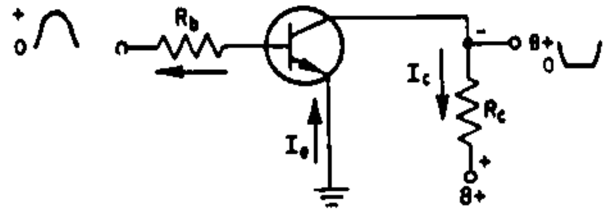
35. LIMITER:



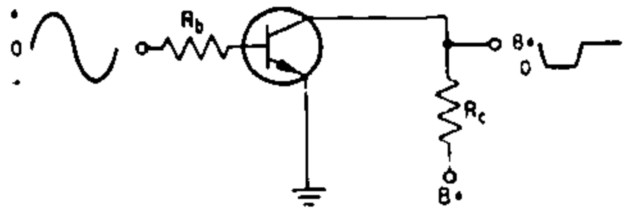
Limiters are used to prevent the amplitude of a signal from going above a certain value. It does this by clamping the peaks of a signal. Often, a sine wave is clamped in a limiter to produce a rectangular wave at the output. This clamping action can be produced by causing the transistor to saturate during one half of the cycle, and become cut off during the other half. The transistor can be easily cut off if zero bias is used at the base-emitter junction.

With zero bias at the base, the transistor will not work during one half cycle. With the circuit shown above, the transistor will conduct only on the positive cycles, because that polarity forward biases a PNP transistor. The base resistor (Rb) is usually small, so that the base current is high when a positive signal is applied. A large collector resistor (Rc) and low value of B+ voltage are used, so that the maximum collector current is kept small. As a result, a relatively small input signal is able to drive the transistor to saturation.

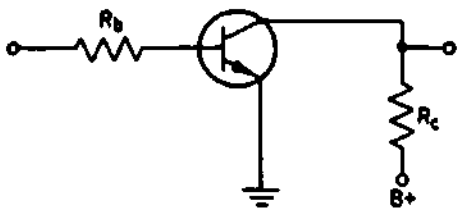
36. **Signal Clamped by Saturation**—A positive going input signal forward biases the base-emitter junction and allows base current to flow. When the collector current reaches saturation, the remainder of the signal is clamped. This produces a rectangular type of pulse at the output.



37. **Negative-Going Input Cuts Off Transistor**—When the input signal starts to go negative, the base-emitter junction becomes reverse biased. This cuts off the transistor, so that no output is produced.



38.a. A small base resistor is used in this circuit so that the base current will be (high/low).



////////////////////

high

38.b. Collector current is kept low by using a (large/small) collector resistor.

////////////////////

large

38.c. In addition, collector current is kept low by using a (high/low) B+ supply voltage.

////////////////////

low

38.d. The transistor will be driven into saturation by a relatively (large/small) input signal.

////////////////////

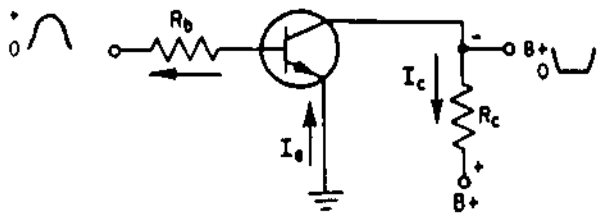
small

38.e. The input signal is also rectified because the circuit uses (   ) base-emitter bias.

////////////////////

zero

39.a.



A ( ) going input signal forward biases the base-emitter junction.

////////////////////

positive

39.b. As a result, base current (flows/is cut off).

////////////////////

flows

39.c. When base current flows, ( ) current also flows.

////////////////////

collector

39.d. Before the input signal reaches its positive peak, the transistor conducts in ( ).

////////////////////

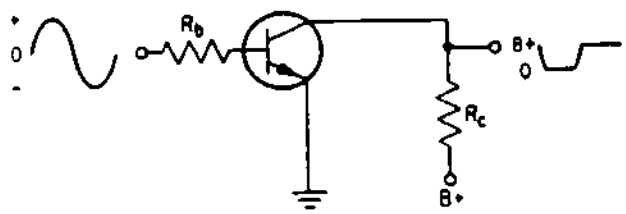
saturation

39.e. This causes the positive signal to be (reproduced/clamped) at the output.

////////////////////

clamped

40.a.



A negative going input signal ( ) biases the emitter-base junction.

////////////////////

reverse

40.b. As a result, the transistor (conducts/is cut off).

////////////////////

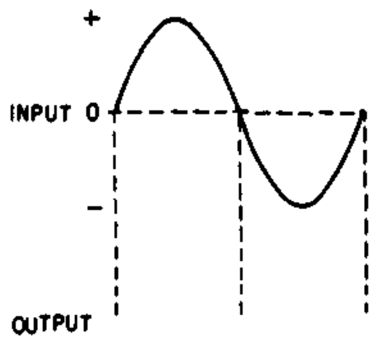
is cut off

40.c. This causes the negative portion of the input signal to be (reproduced/eliminated) at the output.

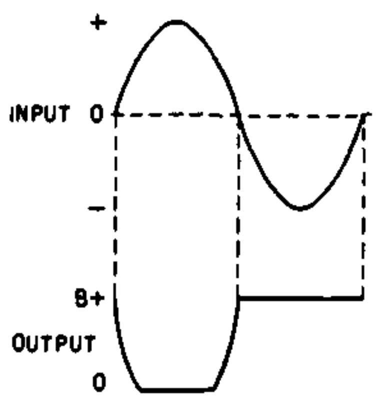
////////////////////

eliminated

40.d. Draw the output waveshape in the proper time relationship to the input signal. Show polarity.



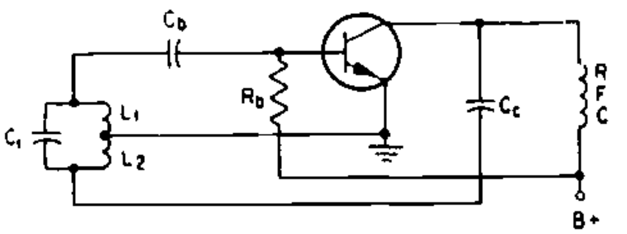
////////////////////



349

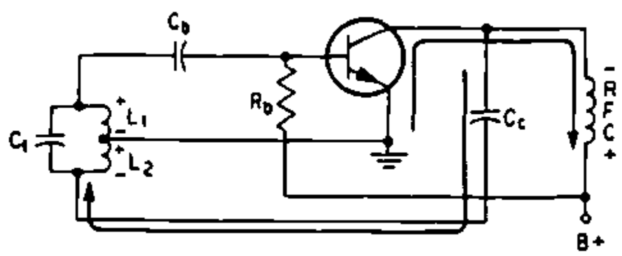
IX. SINE WAVE OSCILLATORS

1. HARTLEY OSCILLATOR:



The Hartley oscillator uses regenerative feedback from a tapped coil in a resonant LC circuit. Signals developed in the collector circuit are capacitively coupled to the tank circuit, where they are autotransformer-coupled to the base.

2.

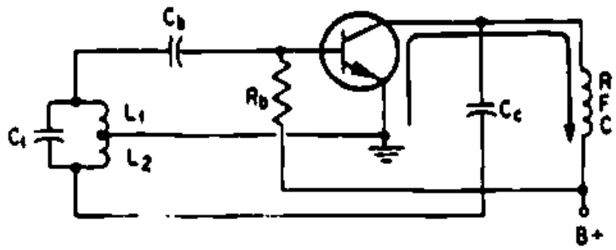


When the transistor starts to conduct, collector current flows through the RF choke, causing the collector voltage to drop. This drop in collector voltage is coupled by capacitor Cc across inductor L2 to ground with the polarity shown. Since L1 and L2 form an autotransformer, the fed back voltage is stepped up in inductor L1, and a positive swinging signal is coupled to the base by capacitor Cb. This positive signal applied to the base increases the forward bias, causing more collector current to flow. The collector voltage is dropped still further, and capacitor Cc couples the voltage drop across inductor L2. The voltage across L1 then drives the base more positive to continue the process.

The base continues to be driven more positive and the collector current continues to increase until saturation is reached. Then the collector voltage stops dropping and no voltage is coupled by capacitor Cc across L2. As the current through L2 falls off, its magnetic field reverses, inducing an opposite polarity across L2. This voltage is stepped up in L1 and a negative signal is coupled by capacitor Cb to the base. This reduces the forward bias, causing the collector current to go down. The reduced collector current causes less of a drop across the RF choke, and the collector voltage rises. The rise in voltage is coupled by capacitor Cc across L2, causing L1 to drive the base further in the negative direction to reduce collector current.

The cycle continues until the negative voltage applied to the base cancels the forward bias to drive the transistor into cutoff. The collector voltage then stays at maximum, and no voltage change is coupled by capacitor Cc across L2. As the current in L2 falls off, its field collapses and induces a voltage with an opposite polarity. This causes the other half cycle to start as explained above. The resonant frequency of C1 and L1-L2 controls the feedback to determine the oscillating frequency of the circuit.

3.a.



When the transistor conducts, the collector voltage goes ( ).

////////////////////

down

3.b. The drop in collector voltage is coupled by capacitor Cc across ( ).

////////////////////

L2

3.c. L1 and L2 form ( ).

////////////////////

an autotransformer

3.d. The voltage applied across L2 causes L1 to drive the base in the ( ) direction.

////////////////////

positive

3.e. This (increases/decreases) the forward bias.

////////////////////

increases

3.f. Collector current goes ( ).

////////////////////

up

3.g. Collector voltage continues to go ( ).

////////////////////

down

3.h. This voltage drop is coupled to the tank circuit by Cc, and L1 drives the base more ( ).

////////////////////

positive

3.i. Collector current continues to ( ).

////////////////////

rise

3.j. This regenerative action continues until ( ) is reached.

////////////////////

saturation

3.k. At saturation, the collector voltage remains ( ).

////////////////////

steady

3.l. Does Cc couple any voltage to L2?

////////////////////

No.

3.m. The magnetic field across L2 collapses, and the polarity of the voltage across L2 ( ).

////////////////////

reverses

3.n. This causes L1 to apply a ( )-going voltage to the base.

////////////////////

negative

3.o. The forward bias on the base is then ( ).

////////////////////

reduced

3.p. Collector current goes down and collector voltage goes (   ).

////////////////////

up

3.q. Capacitor Cc couples this rising voltage to L2, causing L1 to drive the base further in the (   ) direction.

////////////////////

negative

3.r. This continues to reduce collector current. The cycle goes on until the transistor is driven into (   ).

////////////////////

cutoff

3.s. At cutoff, there is no collector current, and the collector voltage is at maximum. Since there is no change in collector voltage, Cc does not couple any signal to L2, and the polarity across L2 (   ).

////////////////////

reverses

3.t. This causes L1 to drive the base in the positive direction to start the cycle over again. The frequency of oscillation is determined by . . . .

////////////////////

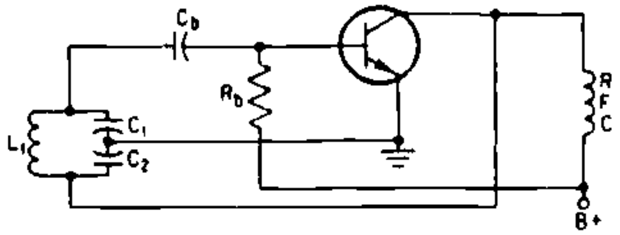
the resonant frequency of C1 and L1-L2.

3.u. The circuit shown uses fixed bias. The amount of bias current is determined by the value of (   ).

////////////////////

Rb

4.a. COLPITTS OSCILLATOR:



The Colpitts oscillator works similarly to the Hartley oscillator. The Colpitts, though, uses a (   ) divider for the feedback instead of a tapped inductor.

////////////////////

capacitive

4.b. Collector voltage changes are applied across C2 to maintain oscillation of the tank circuit; and the voltage across (   ) is applied regeneratively to the base of the transistor.

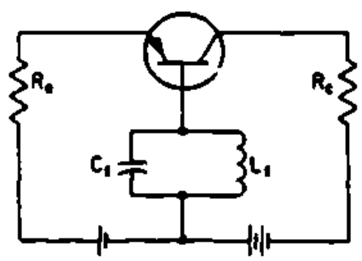
////////////////////

C1

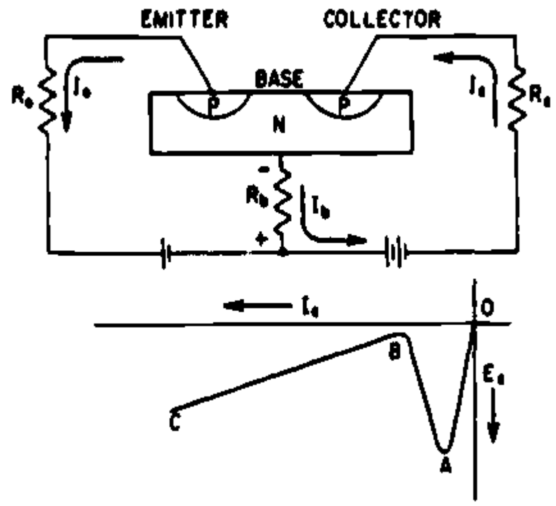
---

5. NEGATIVE RESISTANCE OSCILLATOR:

A negative resistance oscillator develops regenerative feedback because of the internal characteristics of the transistor. Junction transistors do not have a negative resistance region; point contact transistors must be used. A point contact transistor is made with two "cat's-whisker" wires fused very close together into a semiconductor base. Emitter and collector semiconductor regions are formed around the wire points.



6. To bias a point contact transistor in the negative resistance region, the bias voltages and currents are set up so that the collector current actually exceeds the emitter current. As a result, the direction of the base current through Rb produces a voltage drop that aids the forward bias on the emitter. The collector circuit operates in the negative resistance region shown between points A and B on the Ic-Ec curve. In this region, when collector voltage (Ec) goes down, the collector current (Ic) goes up. The area shown between B and C is the positive resistance region, where collector current follows collector voltage.



When the circuit is first turned on, emitter and collector current starts to flow. As the collector current flows, it produces a voltage drop across Rc that lowers the collector voltage. Because of the negative resistance, this drop in collector voltage causes an increase in collector current. At the same time, the increase in collector current raises the voltage drop across Rb, which increases emitter forward bias, and also emitter current; this, in turn, also raises the collector current, which continues the regenerative cycle. The collector current continues to rise until point B is reached. At his point, the emitter current has risen to a value that exceeds the collector current, essentially taking the circuit out of the negative resistance region. The polarity of the voltage drop across Rb is then reversed, so that it opposes the forward bias. This reduces emitter current, and collector current as well, and the circuit goes back into the negative resistance region. As the collector current goes down, the drop across Rc is reduced, and the collector voltage goes up. The increased collector voltage further reduces the collector current. Since the drop across Rb is again aiding the emitter forward bias, the emitter voltage and current are also reduced to further diminish the collector current. This regenerative action continues until the collector current drops to point A, which is close to cutoff. At point A, the circuit is back in a positive resistance region. Therefore, as the collector voltage rises due to the last drop in current, it raises the collector current and the regeneration starts in the other half cycle. The circuit oscillates with the collector current rising and falling between points A and B. The resonant tank in the base circuit stablizes the frequency of oscillations.

7.a. In a negative resistance oscillator, as collector voltage goes up, collector current goes (   ).

//////////////////

down

7.b. Because of the drop across the load resistor, a reduced collector current increases (   ).

////////////////////

collector voltage

7.c. The regenerative action continues until the circuit reaches a point that is in the ( ) resistance region.

////////////////////

positive

7.d. Then th~ action reverses and regeneration causes collector voltage to go ( ), and collector current to go ( ).

////////////////////

down up

7.e. Because of the action of the base resistance, collector current also changes ( ) bias.

////////////////////

emitter

7.f. The changing emitter bias also provides ( ) feedback.

////////////////////

regenerative, positive

7.g. A negative resistance oscillator must use a ( ) transistor.

////////////////////

point contact

7.h. The negative resistance oscillator uses a common ( ) circuit.

////////////////////

base

7.i. You remember that α equals $\frac{Ic}{Ie}$. When a junction transistor is used in a common base circuit, collector current is always slightly less than emitter current; and α is always ( ) than 1.

////////////////////

less

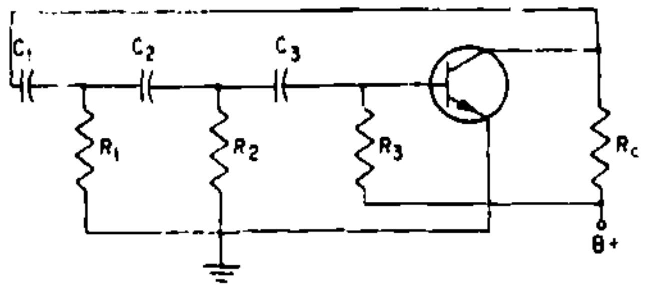
7.j. In a negative resistance oscillator, Ic is greater than Ie. Therefore, α can be greater than 1 with a common base circuit when a ( ) transistor is used.

////////////////////

point contact

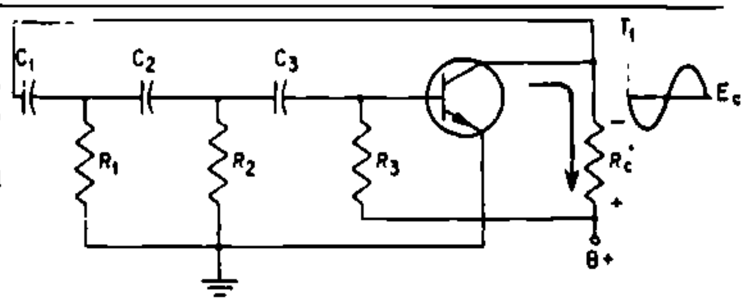
256

8. PHASE-SHIFT OSCILLATOR:

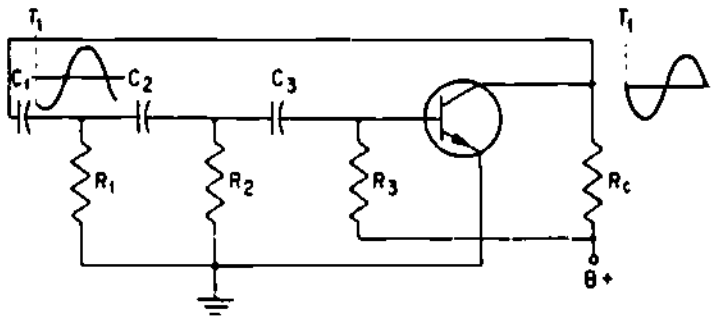


A phase-shift oscillator produces sine waves at a frequency determined by an RC coupling network. In a common emitter amplifier, the input and output signals are 180° out of phase; the RC network must provide an additional 180° phase shift for oscillation to occur.

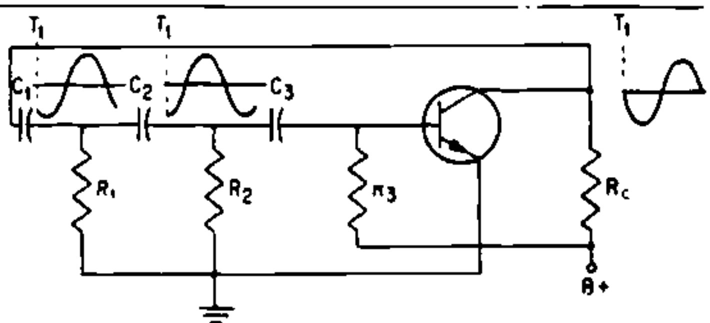
9. Collector Starts To Go Negative—When the circuit is first energized, the transistor starts to conduct, making the collector go negative (T1). The negative voltage is fed back across C1 and R1.



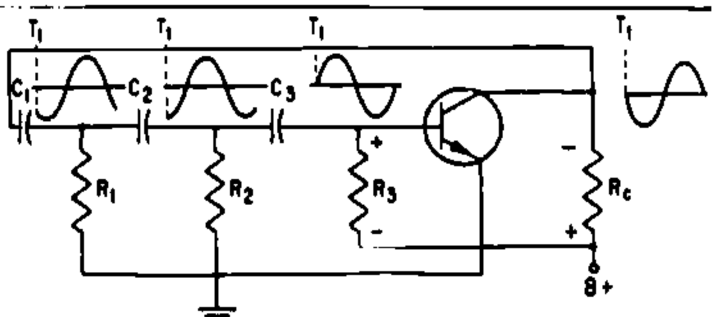
10. R1 Voltage Leads Collector Voltage By 60°—The voltage across C1 and R1 causes a current to flow that produces a voltage across R1. The values of C1 and R1 are such that the current will lead the applied voltage by 60°. As a result, the voltage drop across R1 leads the collector voltage by 60°. The voltage developed by R1 is then applied across C2 and R2.



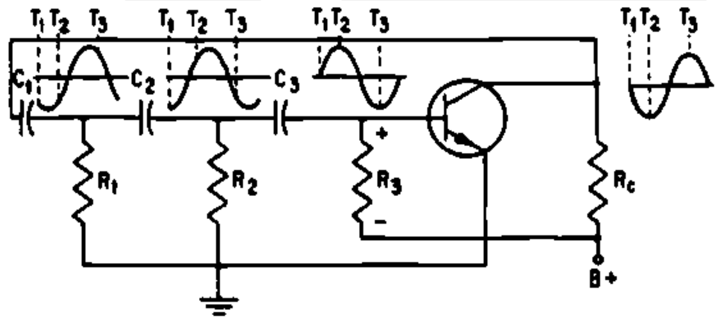
11. R2 Voltage Leads Collector Voltage By 120°—The voltage across C2 and R2 causes a current to flow that produces a voltage across R2. The values of C2 and R2 are also chosen so that the current will lead the applied voltage by 60°. As a result, the voltage drop across R2 leads the collector voltage by 120°. This means that the voltage drop across R2 is actually going less negative. This voltage is applied across C3 and R3.



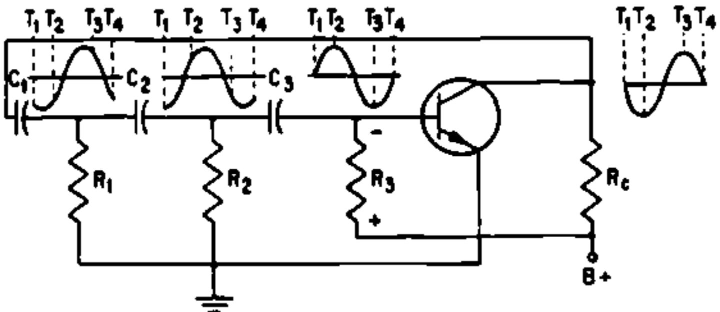
257



12. R3 Voltage Leads Collector Voltage By 180°—The voltage across C3 and R3 causes a current to flow that produces a voltage across R3. Again, the values of C3 and R3 are chosen so that the current will lead the applied voltage by 60°. As a result, the voltage drop across R3 leads the collector voltage by 180°. Although the collector voltage is going in a negative direction, the voltage drop across R3 actually goes positive, increasing the forward bias. This increases collector current, which reduces collector voltage even further. The RC network phase shifts this voltage change and drives the base more positive. The process continues until the transistor conducts in saturation.

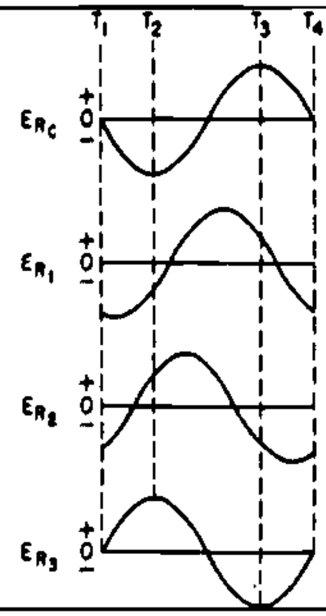


13. Voltage Across R3 Starts To Go Negative—When the transistor reaches saturation, the voltage across Rc is at maximum negative (T2). The voltage across R3 is at maximum positive. The charging current to C3 starts diminishing, and the drop across R3 is reduced. This reduces the forward bias, which decreases collector current. As the collector current goes down, the collector voltage rises. The RC network phase shifts the voltage change to apply a negative voltage to the base. This lowers the collector voltage still more, causing the collector voltage to go more positive, which in turn drives the base more in a negative direction. This regenerative action continues collector current is at minimum (T3).

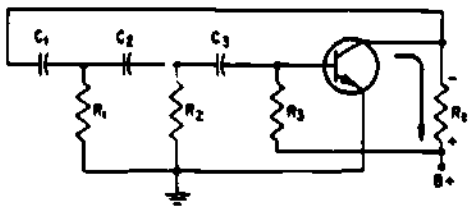


14. Voltage Across R3 Starts To Go Positive — When conduction reaches its minimum value, the collector voltage is maximum positive (T3). The voltage across R3 is at maximum negative. This cuts off the transistor, and the collector voltage stays steady. The discharge current of C3 diminishes and there is less of a drop across R3. This increases the forward bias, which increases collector current to start the next half cycle.

15. The diagram shows the voltages in their proper time relationships for one complete cycle. At any instant of time, the voltage across R3 leads the collector voltage by 180°.



16.a.



When the transistor conducts, the collector voltage goes (   ).

////////////////////

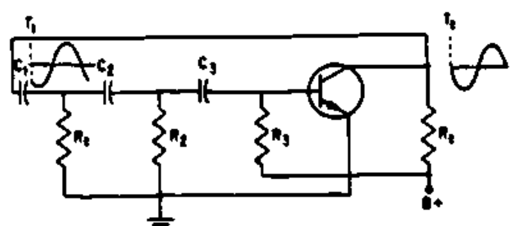
down, in a negative direction

16.b. The collector voltage is effectively first applied across (   ) and (   ).

////////////////////

C1   R1

17.a.



The values of C1 and R1 are such that the current through R1 (   ) the applied voltage by 60°.

////////////////////

leads

17.b. This causes the voltage drop across R1 to lead the collector voltage by (   ).

////////////////////

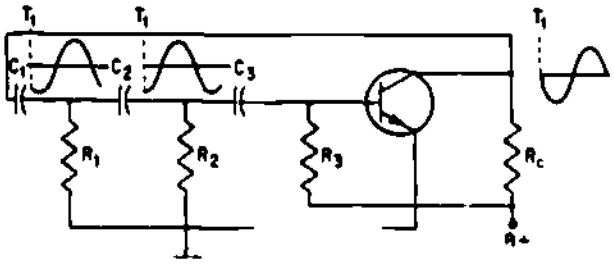
60°

17.c. The voltage developed by R1 is applied across (   ) and (   ).

////////////////////

C2   R2

18.a.



The values of C2 and R2 are chosen so that the current through R2 leads the applied voltage by (   ).

////////////////////

60°

18.b. This causes the voltage drop across R2 to lead the collector voltage by (   ).

////////////////////

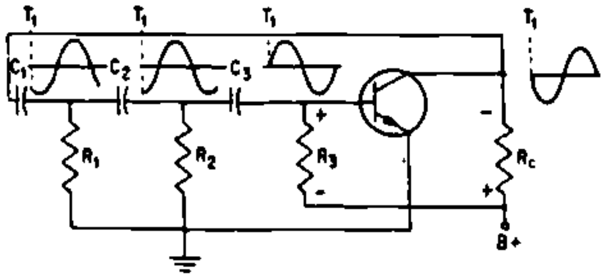
120°

18.c. The voltage developed by R2 is applied across (   ) and (   ).

////////////////////

C3   R3

19.a.



The values of C3 and R3 are such that the current through them leads the voltage across (   ) by 60°.

////////////////////

R2

19.b. This causes the voltage developed by R3 to lead the collector voltage by ( ).

////////////////////

180°

19.c. As a result, when the collector voltage goes negative, the base voltage goes ( ).

////////////////////

positive

19.d. This ( ) the forward bias.

////////////////////

increases

19.e. This increases collector ( ) and reduces collector ( ).

////////////////////

current voltage

19.f. This additional voltage change drives the base more ( ).

////////////////////

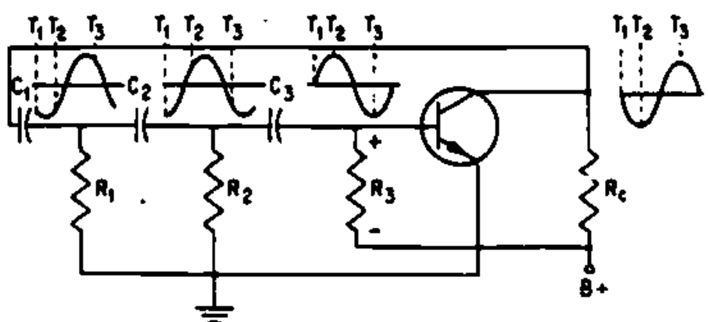
positive

19.g. The process continues until the collector current is driven into ( ).

////////////////////

saturation

20.a.



When the collector current is maximum, the collector voltage is at maximum (negative/positive).

////////////////////

negative

20.b. The voltage across R3, which is at maximum positive, starts to go in the ( ) direction.

////////////////////

negative

20.c. This ( ) the forward bias.

////////////////////

decreases

20.d. As a result, collector current ( ).

////////////////////

decreases

20.e. Collector voltage, then, starts to ( ).

////////////////////

increase

20.f. The positive change in the collector voltage is coupled by the RC network to drive the base in a more ( ) direction.

////////////////////

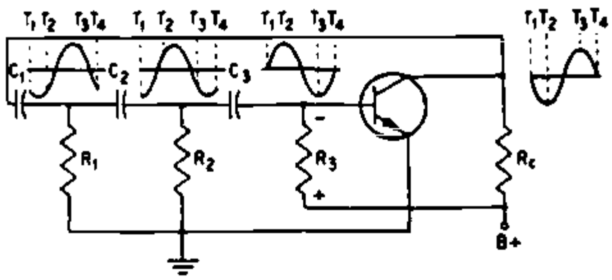
negative

20.g. This reduces collector current even more to raise collector voltage. This process continues until collector current reaches ( ).

////////////////////

cutoff, minimum

21.a.



When the collector current is at minimum, the collector voltage is at maximum (negative/positive).

////////////////////

positive

21.b. The voltage across Rc, which is at maximum negative, starts to go (   ).

////////////////////

positive

21.c. This (   ) the forward bias.

////////////////////

increases

21.d. As a result, collector current (   ).

////////////////////

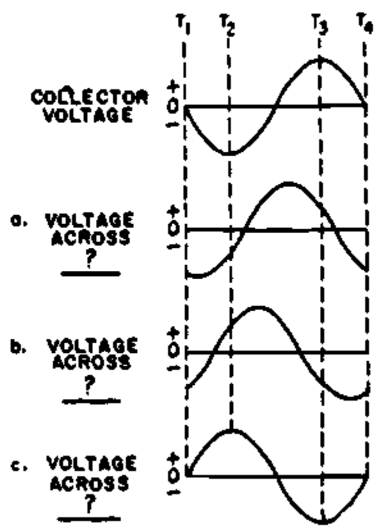
increases

21.e. The cycle is repeated as the collector voltage starts to go in a (   ) direction.

////////////////////

negative

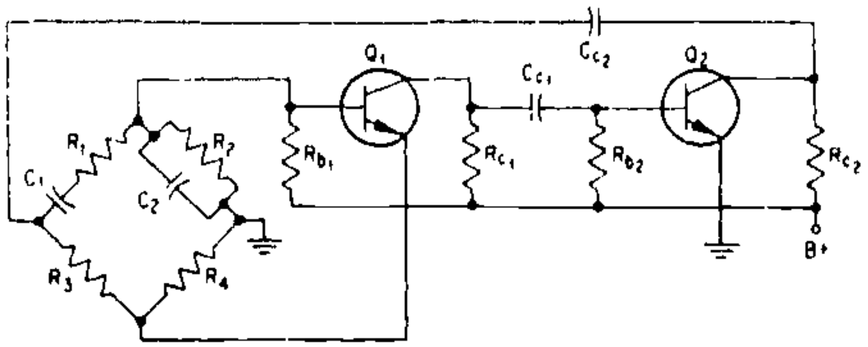
22. Label the a., b., and c. waveshapes so that they coincide with the collector waveshape in their proper time relationships.



////////////////////

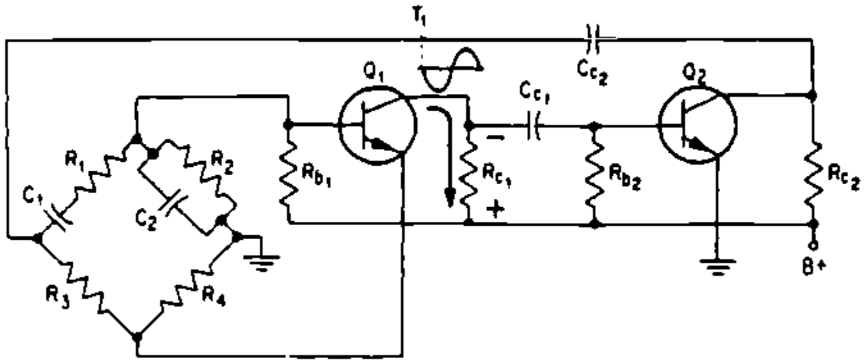
a. R1   b. R2   c. R3

23. WIEN-BRIDGE OSCILLATOR:

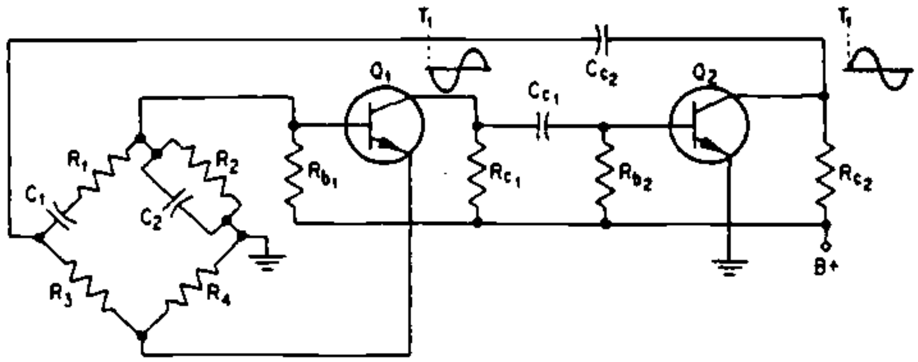


A Wien-bridge oscillator also produces sine waves at a frequency determined by an RC network. In this case, the RC network is in the form of a bridge. The 180° phase shift necessary for regenerative feedback is provided by a second transistor.

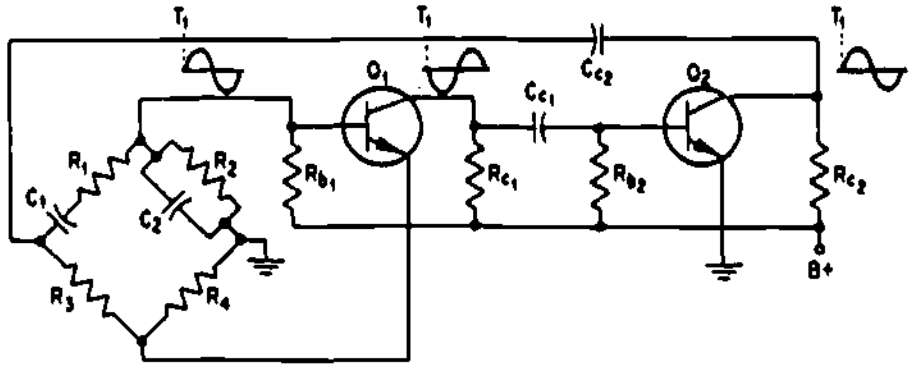
24. Collector of Q1 Goes Negative—When the circuit is first energized, the transistors start to conduct. Collector current through Rc1 causes the collector voltage of Q1 to go negative (T1). This negative voltage is coupled by Cc1 to the base of Q2, decreasing the forward bias of Q2.



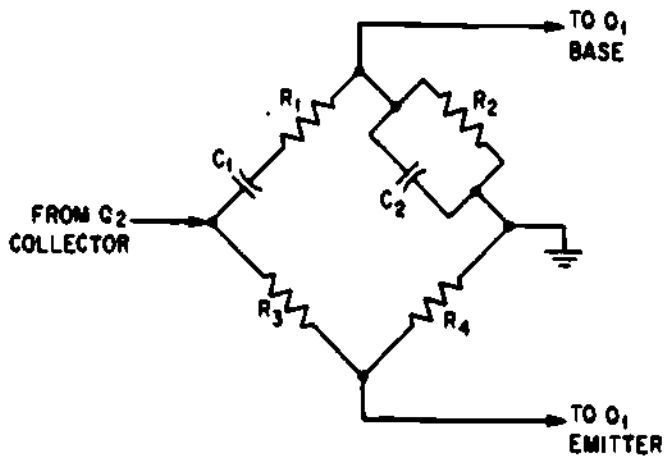
25. Collector of Q2 Goes Positive—The reduced forward bias of Q2 decreases its collector current, causing the collector voltage to go in a positive direction. This positive signal voltage is coupled by Cc2 to the bridge circuit.



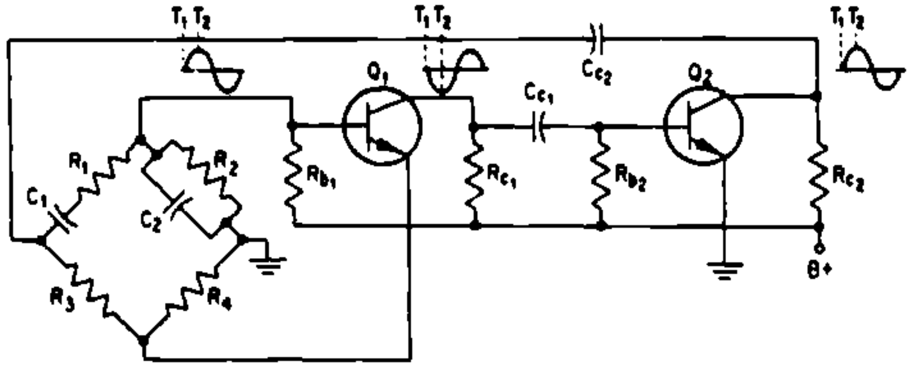
26. Positive Signal Applied To Base of Q1—The bridge circuit provides voltage divider action, with the voltage across R2 applied to the base of Q1.



27. Bridge Stabilizes Frequency—The bridge acts to stabilize the frequency of operation. The voltage divider, consisting of C1, R1, C2, and R2, supplies regenerative feedback to the base, while the voltage divider consisting of R3 and R4 supplies degenerative feedback to the emitter. If the frequency tends to increase, the reactances of C1 and C2 decrease. Since C2 is across R2, the impedance of the parallel circuit decreases, thereby reducing the regenerative feedback to the base. If the frequency tries to decrease, the reactances of C1 and C2 increase. Since C1 is in series with R1, current flow through the circuit decreases, again reducing the regenerative feedback to the base. In both cases, the regenerative feedback to the base becomes less than the degenerative feedback to the emitter, so that only one frequency provides enough regeneration to sustain oscillations.



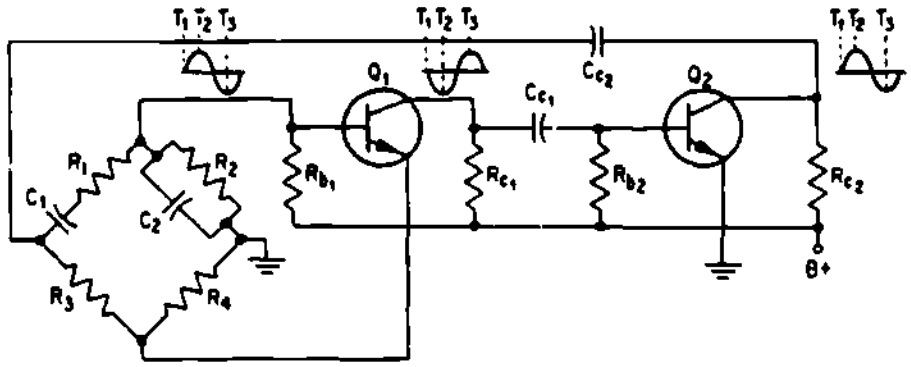
28. Collector of Q2 At Maximum Positive—The positive signal applied to the base of Q1 increases its conduction, making the Q1 collector more negative (T1 to T2). This voltage is coupled to the base of Q2, decreasing its forward bias. As a result, the conduction of Q2 decreases, making its collector more positive. The process continues until the collector voltage of Q2 is at maximum positive (T2).



29. Voltage Across R2 Starts to Decrease—When the collector voltage of Q2 is at maximum positive, the voltage across R2 begins to decrease (T2 to T3). This decreases the forward bias of Q1.

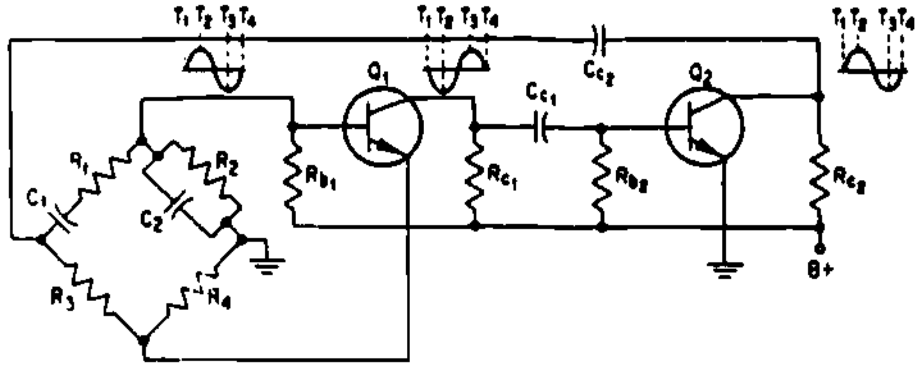
Decreasing the forward bias of Q1 decreases its conduction, causing the collector voltage to rise. This positive going signal is coupled to the base of Q2, increasing its forward bias.

Increasing the forward bias of Q2 increases its conduction, causing the collector voltage to fall. This negative going voltage is coupled back to the bridge.

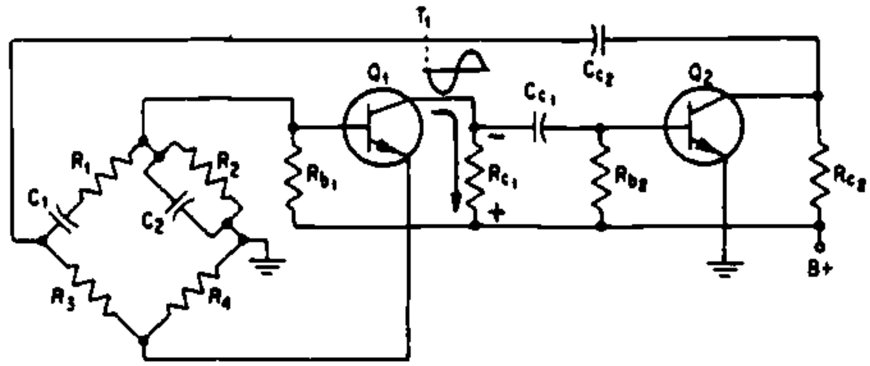


266

30. Cycle is Repeated—The negative going voltage applied to the bridge causes the voltage across R2 to go more negative. The process continues until the collector voltage of Q2 reaches maximum negative (T3). When this occurs, the voltage drop across R2 begins to decrease, causing it to go in the positive direction (T3 to T4). The cycle is then repeated.



31.a.



When collector current starts to flow through Rc1, the collector voltage of Q1 goes in the ( ) direction.

////////////////////

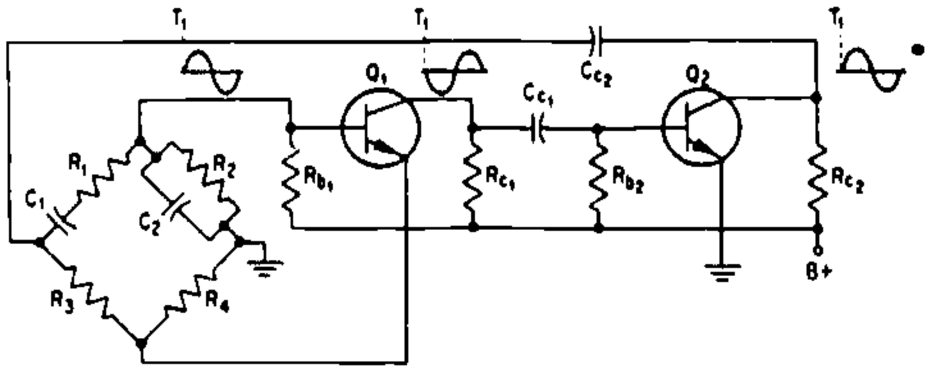
negative

31.b. This voltage, coupled to the base of Q2, ( ) the forward bias of Q2.

////////////////////

decreases

32.a



The decreasing of the forward bias of Q2 causes the collector current to (   ).

////////////////////

decrease

32.b. When the collector current decreases, the collector voltage goes in the (   ) direction.

////////////////////

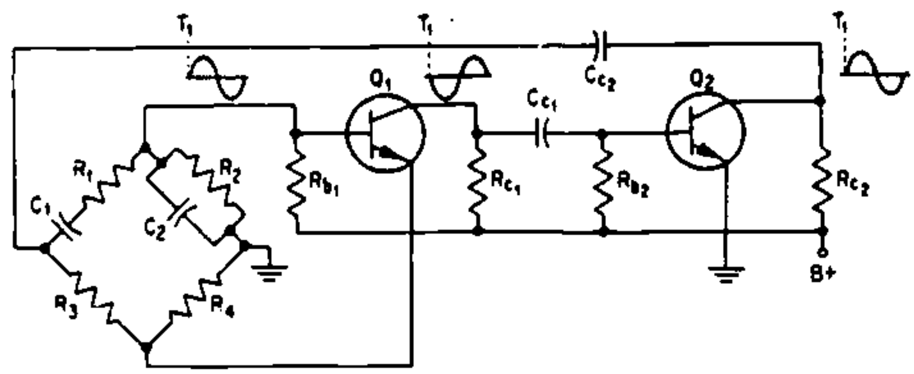
positive

32.c. This positive signal is coupled to (   ).

////////////////////

the bridge circuit

33.a.



Part of the positive signal across the bridge is applied to the base of Q1 by (   ).

////////////////////

R2

33.b. This provides the base with ( ) feedback.

////////////////////

regenerative

33.c. Part of the positive signal across the bridge is also applied to the emitter of Q1 by ( ).

////////////////////

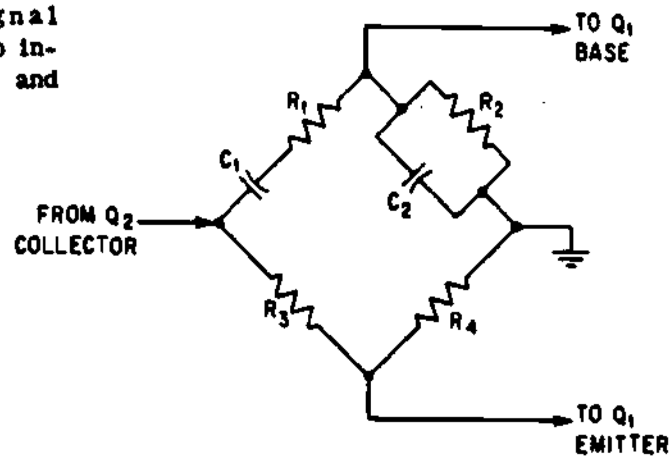
R4

33.d. This provides the emitter with ( ) feedback.

////////////////////

degenerative

34.a. If the frequency of the signal coupled to the bridge tries to increase, the reactances of C1 and C2 ( ).



////////////////////

decrease

34.b. This causes the impedance of the parallel circuit formed by R2 and C2 to ( ).

////////////////////

decrease

34.c. As a result, less ( ) feedback is applied to the base.

////////////////////

regenerative

34.d. If the frequency tries to decrease, the reactances of C1 and C2 (   ).

////////////////////

increase

34.e. This causes the current flow through R1 and R2 to (   ).

////////////////////

decrease

34.f. As a result, the regenerative feedback applied to the base (   ).

////////////////////

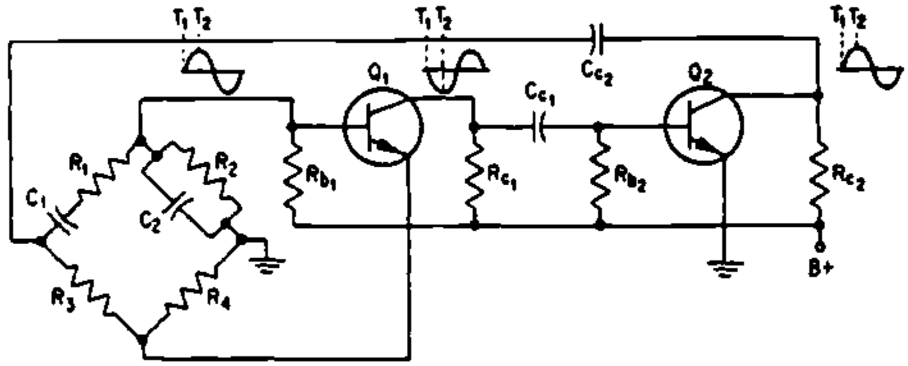
decreases

34.g. The circuit is designed so that the regenerative feedback to the base exceeds the degenerative feedback to the emitter at (one frequency/many frequencies).

////////////////////

one frequency

35.a.



The positive signal applied to the base of Q1 (   ) the forward bias.

////////////////////

increases

35.b. This causes the collector current to (   ).

////////////////////

increase

35.c. As a result, the collector voltage goes more (   ).

////////////////////

negative

35.d. This voltage, coupled to the base of Q2, (   ) the forward bias of Q2.

////////////////////

decreases

35.e. Decreasing the forward bias (   ) collector current.

////////////////////

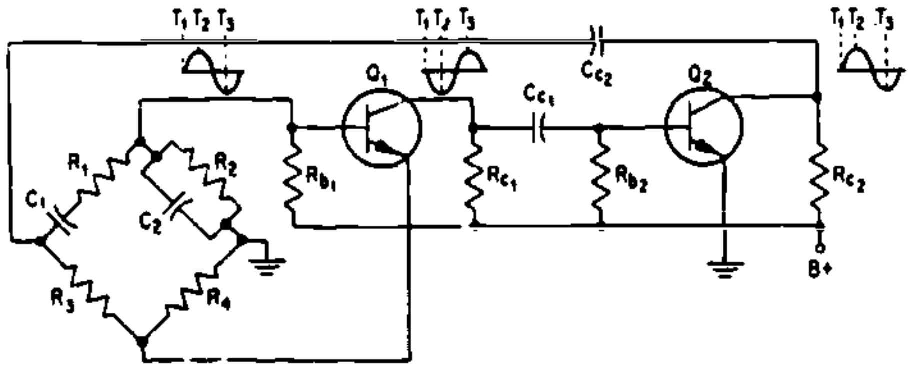
decreases

35.f. As a result, the collector voltage goes more (   ).

////////////////////

positive

36a.



After the collector voltage of Q2 reaches maximum positive, the voltage drop across R2 (   ).

////////////////////

decreases

36.b. This causes the forward bias of Q1 to (   ).

////////////////////

decrease

36.c. Decreasing the forward bias of Q1 (   ) the collector current.

////////////////////

decreases

36.d. This causes the collector voltage to go in the (   ) direction.

////////////////////

positive

36.e. This signal, coupled to the base of Q2, (   ) the forward bias of Q2.

////////////////////

increases

36.f. Increasing the forward bias of Q2 (   ) the collector current.

////////////////////

increases

36.g. This causes the collector voltage to go in the (   ) direction.

////////////////////

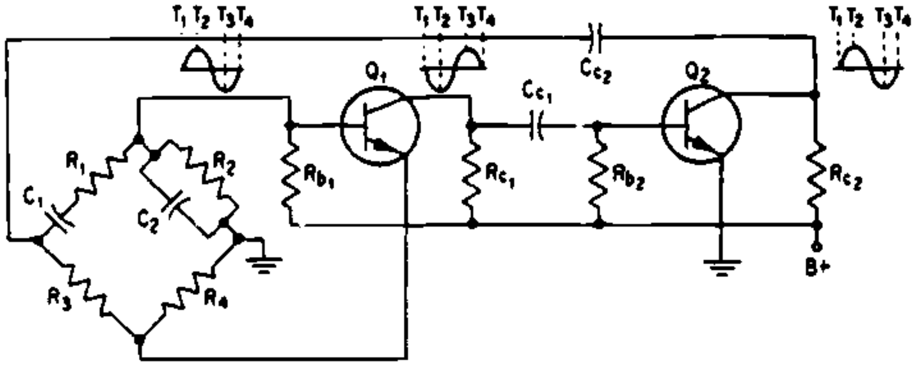
negative

36.h. This voltage is coupled to the (   ).

////////////////////

bridge

37.a.



The negative signal coupled to the bridge causes the voltage across R2 to go more (   ).

////////////////////

negative

37.b. The process continues until the collector current of Q2 reaches (   ).

////////////////////

saturation

37.c. When the collector current of Q2 reaches saturation, the cycle is repeated as the voltage across R2 starts to go in the (   ) direction.

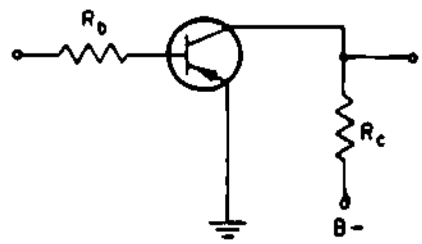
////////////////////

positive

X. SWITCHING, GATING, AND PULSE CIRCUITS

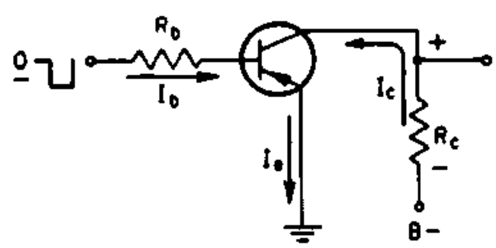
SWITCHING AND GATING CIRCUITS

1. SWITCHING CIRCUIT:



Switching circuits are used to turn circuits on and off; they perform the function of a switch by having transitors either conduct or not conduct to produce the "on" and "off" conditions. Many circuits, such as those used in computers, require fast switching times. Special junction transistors that have switching times in the micromicroseconds (10^{-9} sec.) range are made for such applications. The switching circuit in the above schematic is typical. It shows a circuit with no bias applied to the base-emitter diode so that the transistor is essentially cut off. A negative signal applied to the base turns the transistor on. If the signal goes positive or just to zero, the transistor is again turned off. Resistor Rb is used to limit base current flow when the signal is applied.

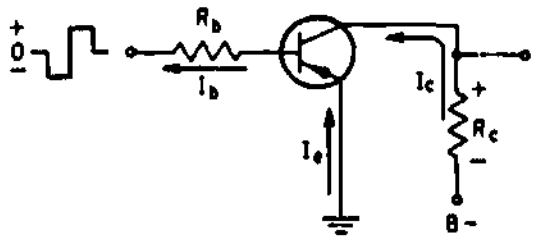
2. A negative input signal forward biases the base-emitter diode, allowing collector current to flow. As the signal amplitude increases, collector increases to saturation until almost all the battery voltage is developed across Rc.



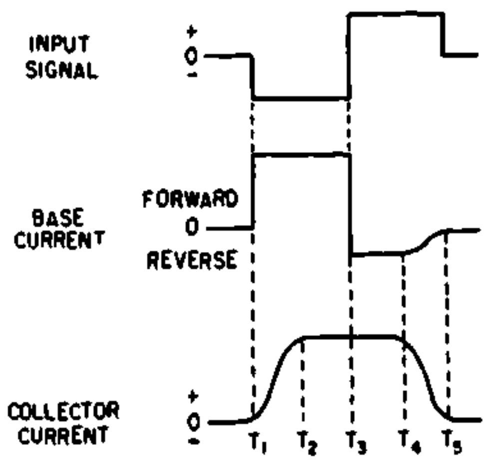
3. If the input signal is larger than the bias battery voltage, a further increase in signal amplitude has very little effect on collector current since the transistor is saturated. But base current continues to increase until the base becomes more negative than the collector. This forward biases the collector base diode, allowing holes to enter the base from the collector.

273

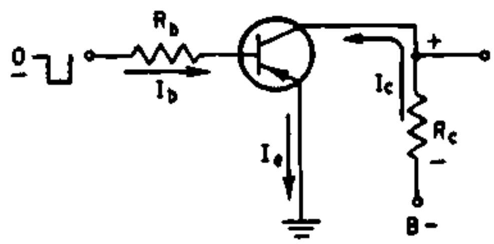
4. When the input signal goes positive, the base-emitter diode becomes reverse biased. Because a relatively large number of holes have been allowed to accumulate in the base, the collector current does not immediately decrease. Instead, it continues until the holes in the base have recombined with minority electrons from the collector. The holes also combine with minority electrons from the emitter, allowing a reverse current to flow through the base-emitter circuit.



5. The diagram shows the base and collector current waveshapes caused by a square-wave input signal. The rise of collector current is delayed from T1 to T2 because of the time it takes for emitter current to diffuse through the junction to the base. At T3 the base-emitter diode becomes reverse biased by the input signal. The collector current, however, does not begin to decrease until T4 because of the large number of holes which have accumulated in the base. This also allows a reverse current to flow in the base-emitter circuit while the signal is positive. From T4 to T5 the number of holes in the base decreases, until the base and collector current are zero. The current decrease begins even though the input signal is still positive because the holes in the base are not replaced. Thus, the width of the positive pulse will not affect the T4 to T5 time.



6.a. The negative input signal ( ) biases the base-emitter diode.



////////////////////

forward

6.b. As the signal amplitude increases, collector current ( ).

////////////////////

increases

283

6.c. When most of the battery voltage is developed across Rc the collector current is saturated; the collector voltage is essentially (   ).

////////////////////

zero

6.d. A further increase in signal amplitude will (increase/not affect) collector current.

////////////////////

not affect

6.e. A further increase in signal amplitude will (increase/not affect) base current.

////////////////////

increase

6.f. As base current increases, the base becomes more (   ) than the collector.

////////////////////

negative

6.g. This (   ) biases the collector-base diode.

////////////////////

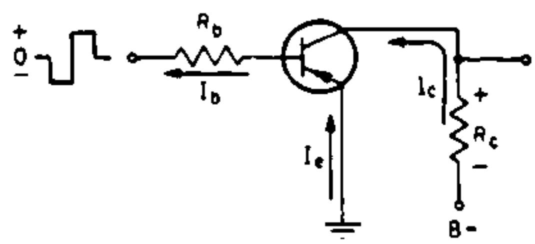
forward

6.h. Forward biasing the collector-base diode allows collector majority carriers or (   ) to accumulate in the base.

////////////////////

holes

7.a. When the input signal goes positive, the base-emitter diode becomes (   ) biased.



////////////////////

reverse

7.b. Collector current continues to flow because of the large number of holes that accumulated in the (   ).

////////////////////

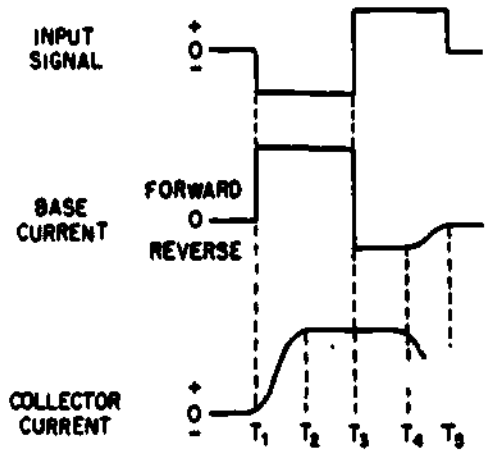
base

7.c. The holes in the base also allow a reverse current to flow in the base-(   ) circuit.

////////////////////

emitter

8.a. Collector current rises (T1-T2) relatively slowly because the holes from the emitter have to diffuse through the junction to the (   ).



////////////////////

base

8.b. After the base-emitter diode is reverse biased (T3), collector current continues to flow (T3-T4) because of the large number of (   ) accumulated in the base.

////////////////////

holes

8.c. The holes in the base also allow a (   ) current to flow in the base-emitter circuit (T3-T4).

////////////////////

reverse

8.d. The base and collector currents decrease (T4-T5) as the number of holes in the base ( ).

////////////////////

decrease

9.a. Increasing the width of the positive portion of the signal will (increase/not affect) the decay time of the base and collector currents.

////////////////////

not affect

9.b. The switching circuit you have just studied uses a ( ) type of transistor.

////////////////////

PNP

9.c. The majority carriers in the emitter and collector are ( ).

////////////////////

holes

9.d. A switching circuit is used to turn other circuits ( ) and ( ).

////////////////////

on off

9.e. Without an input signal, the circuit is ( ).

////////////////////

cut off

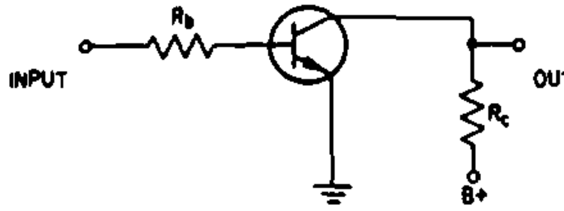
9.f. What is the purpose of Rb?

////////////////////

It limits base current when a signal is applied

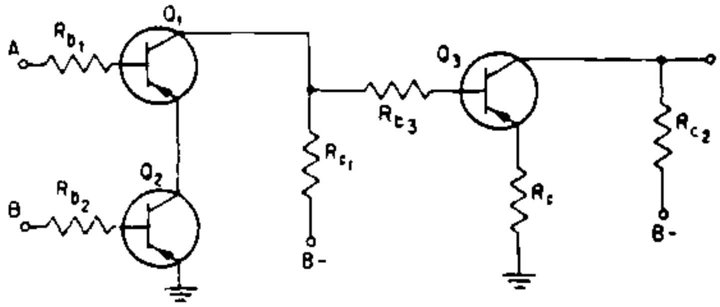
INVERTERS

You have not yet studied "symbolic logic" but, when you do, you will find that in the Polaris computers, the output signals of many circuits have to be in phase with the input signals. Many computer circuits, such as AND gates and OR gates, are BASICALLY common emitter amplifiers and, therefore, cause the output signal to be 180° out of phase with the input signal. In these cases, it is common practice to feed this signal into another circuit, called an inverter, to again shift the signal 180°. Thus, the original signal has been shifted twice, for a TOTAL 360°. The output signal of the inverter is, therefore, IN PHASE with the original input signal.



As you can see, the inverter circuit is basically a common emitter amplifier, which was covered earlier in the program. Its bias is set to accomodate the type of input signal applied to it. Actually, the inverter shown here operates very similarly to the limiter circuit just described. The following pages show how an inverter can be used with AND and OR gates.

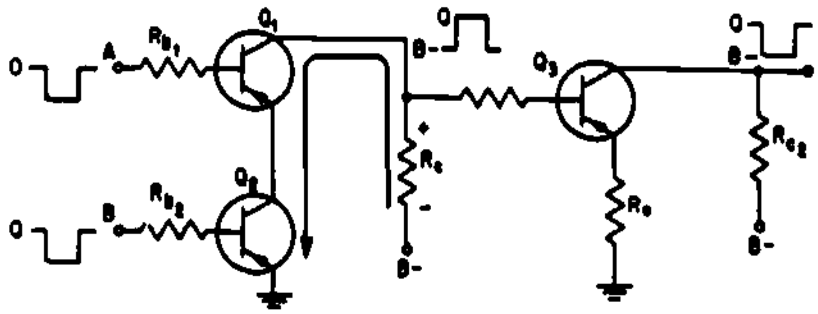
10. "AND" GATE:



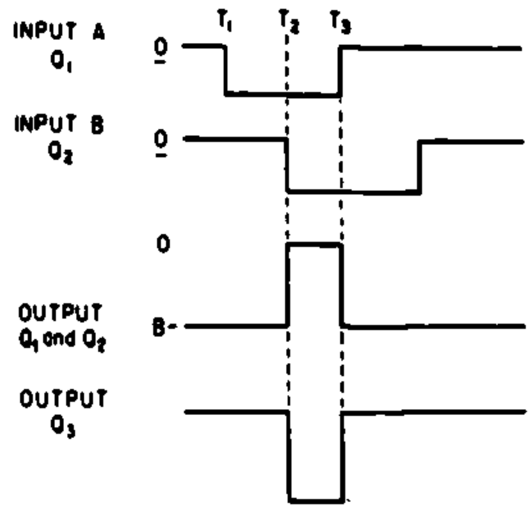
The "AND" gate (stage Q1 and Q2) is used in computers as a form of switching circuit that produces an output only when a combination of signals is applied at the input at the same time. Q3 is simply an inverter (amplifier) stage that shifts the output of Q1 and Q2 180°, so that the output signal is in phase with the original input signals. Q1 and Q2 are normally cut off because of zero bias on the base-emitter junctions of both transistors. Q3 is normally conducting. Since transistors Q1 and Q2 are in series, if EITHER one stays cut off the other cannot conduct. To produce an output from the circuit, signals must be applied to A and B. When BOTH Q1 and Q2 are forward biased at the same time, current through Q1 also flows through Q2. The output signal across Rc1 reverse biases Q3 cutting it off. The output signal that appears across Rc2 is IN PHASE with the signals applied to A and B.

Since the transistors are in series, deenergizing either one will open the circuit so that current flow is discontinued. If three or more signals are to be "ANDED," a transistor must be used for each input signal.

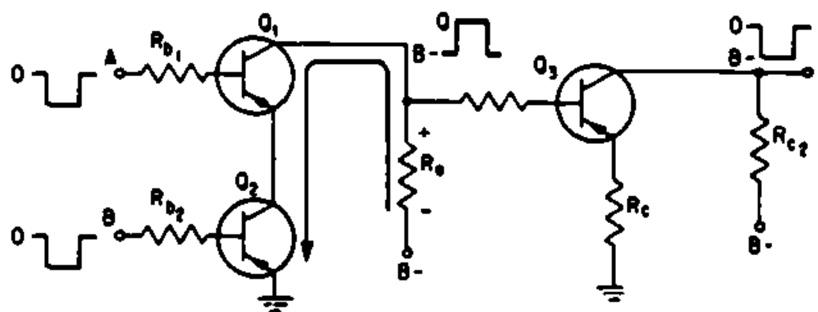
11. **Q1 and Q2 Forward Biased By Negative Input**—Negative pulses applied to A and B forward bias both transistors. Current flow develops a voltage drop across Rc. The signal across Rc1, which is 180° out of phase with the signals applied to A and B, is applied to the input of inverter Q3. This reverse biases Q3, cutting it off. The signal appearing at the output of Q3 is, therefore, a negative-going pulse that is in phase with the negative-going pulses applied to A and B. When either input signal goes to zero, current flow stops and there is no output signal.



12. The diagram shows how the time relationship of the input pulses determines the output waveshape. At T1 transistor Q1 is forward biased, but no output is produced because Q2 still has zero bias. At T2 the output is produced when Q2 becomes forward biased. The output pulse ends at T3 when Q1 is again zero biased, even though Q2 is still forward biased. In most computer applications, the A and B signals are kept in phase, so that the output signal has the same time duration at the input signals.



13.a.



With no input signals, Q1 and Q2 are normally (conducting/cut off) and Q3 is normally (conducting/cut off).

////////////////////

cut off conducting

13.b. To forward bias transistors Q1 and Q2, the input signals must be (   ).

////////////////////

negative

13.c. An output signal is produced from Q1 and Q2 when a negative signal is applied to (either transistor/both transistors).

////////////////////

both transistors

13.d. Output current stops flowing through Rc1 when the negative signal is removed from (either transistor/both transistors).

////////////////////

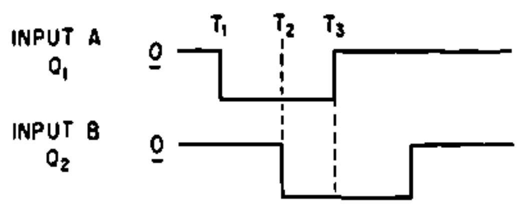
either transistor

13.e. The purpose of Q3 is . . . .

////////////////////

to shift the output signal of Q1 and Q2 180° so that it is in phase with the input signals applied to A and B.

14.a. Draw the output waveshape to correspond in the proper time relationship with the input signals.



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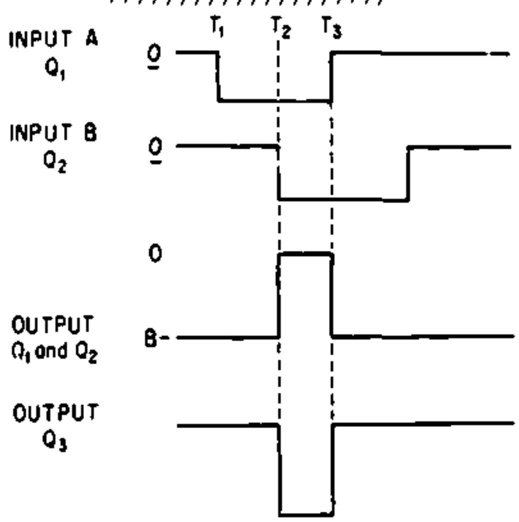
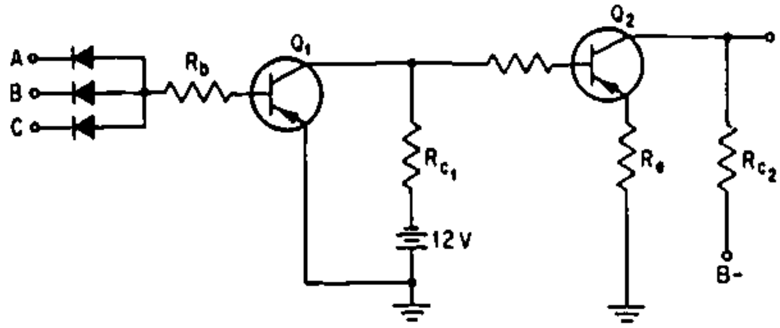


14.b. What is the purpose of Rb1 and Rb2?

////////////////////

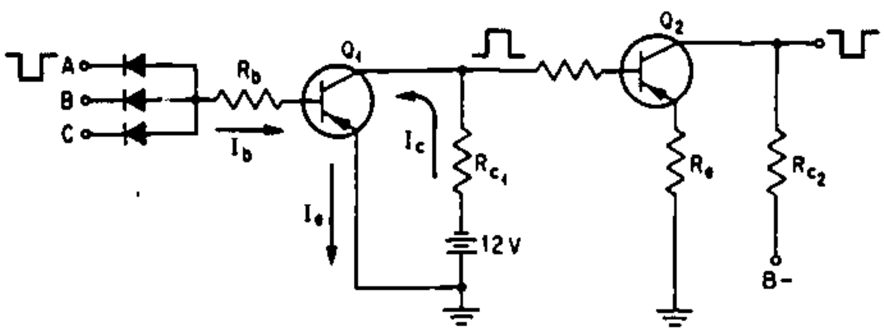
They limit base current.

15. "OR" GATE:

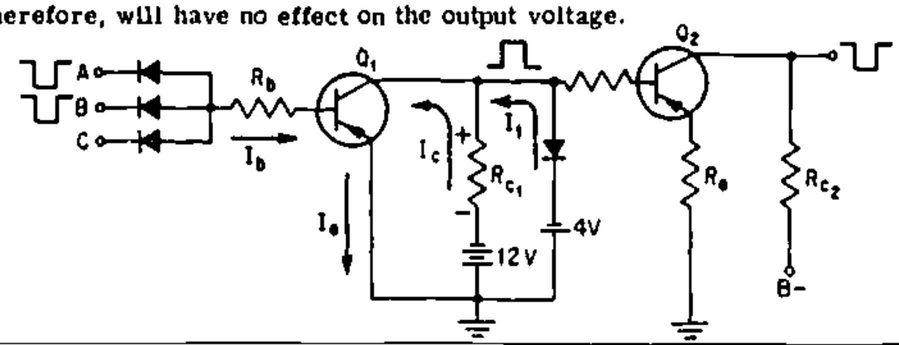


This circuit is called an "OR" circuit because an input signal applied to A or B or C or any combination of them will produce an output signal. Transistor Q1 is normally cut off because no bias voltage is applied to the base-emitter diode. Transistor Q2 is an inverter circuit that is normally conducting. The COUPLING DIODE inputs to the base isolate the stages that are not supplying a signal from those that are supply , a signal; this keeps the circuit stable. As before, inverter Q2 shifts the signal 180° so that the output signal is in phase with the input signal.

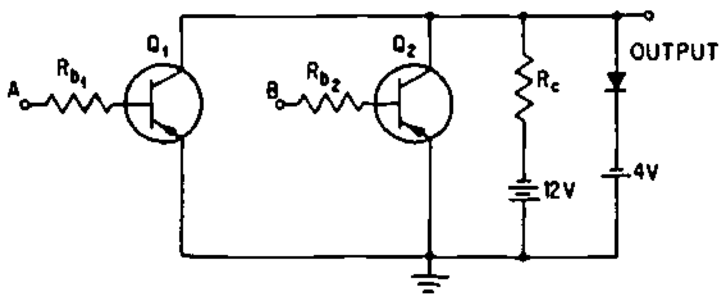
16. Signal At A or B or C Produces Output—A negative signal applied to A, B, or C forward biases the COUPLING DIODE and the base-emitter diode, allowing the transistor to conduct. The stages not sending a signal to the OR circuit are isolated from the circuit by the nonconducting diodes.



17\. Clamping Diode Holds Collector At -4V—If more than one input signal is applied at the same time, the output signal of Q1 tends to increase. A CLAMPING DIODE, however, is generally used in the collector circuit to keep the output constant. The diode battery (4V) tries to forward bias the clamping diode; but with no signal input, the collector voltage is highly negative. The clamping diode, then, does not conduct. But when there is a signal input, collector current flows and the collector voltage drops to less than 4 volts. The diode conducts and clamps the collector voltage at about -4 volts by providing a low resistance path for any increase in collector current. More than one input signal, therefore, will have no effect on the output voltage.

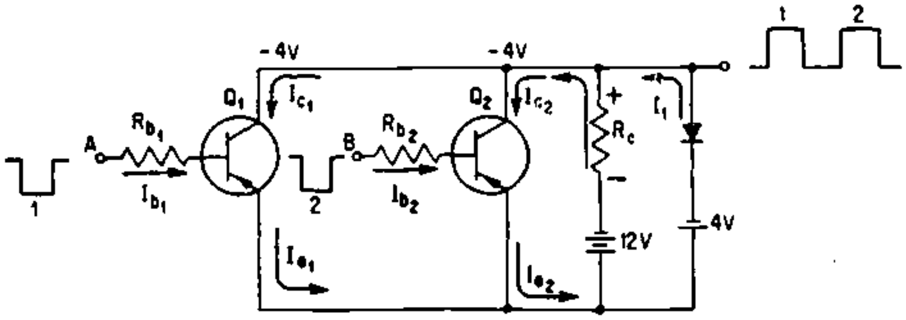


18\. ANOTHER "OR" GATE:



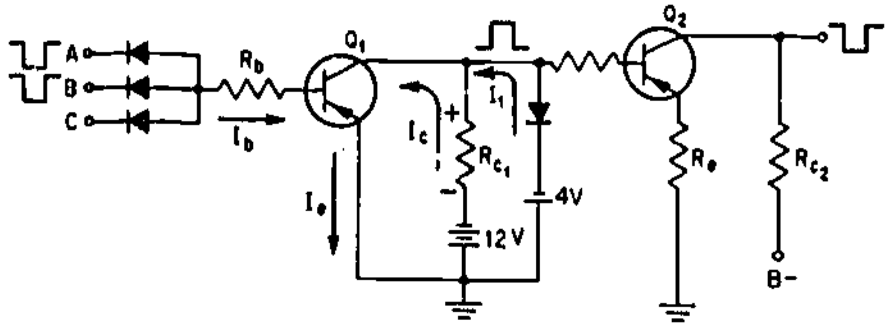
Another method of isolating the stages that provide input signals is by using more than one transistor. As before, an input signal applied to A or B will produce an output signal. The output of both transistors appears across the same collector resistor. This output signal would be fed to an inverter, which is not shown here.

19\.



Both transistors are normally cut off because there is no base-emitter bias voltage applied to them. A negative signal applied to A forward biases the base-emitter diode and allows transistor Q1 to conduct. Similarly, a negative signal at B allows Q2 to conduct. Both transistors produce output signals across the same collector resistor. If both transistors conduct at the same time, the clamping diode prevents the output signal from increasing in amplitude.

20.a.



In this circuit, isolation between the stages supplying input signals is provided by the ( ).

////////////////////

coupling diodes

20.b. With no input signal, the emitter-base diode of transistor Q1 is not biased. Therefore, the transistor is ( ). Q2 is normally ( ).

////////////////////

cut off conducting

20.c. A negative signal at A, B, or C ( ) biases the base-emitter diode.

////////////////////

forward

20.d. If more than one input signal is applied at the same time, Q1 collector current ( ).

////////////////////

increases

20.e. As collector current increases, the voltage drop across Rc1 tends to ( ).

////////////////////

increase

20.f. As a result, the collector voltage tends to ( ).

////////////////////

decrease

20.g. When the collector voltage drops, the clamping diode becomes ( ) biased.

////////////////////

forward

20.h. When the clamping diode conducts, it provides a low resistance path for any increase in ( ) current.

////////////////////

collector

20.i. This keeps the ( ) voltage fairly constant.

////////////////////

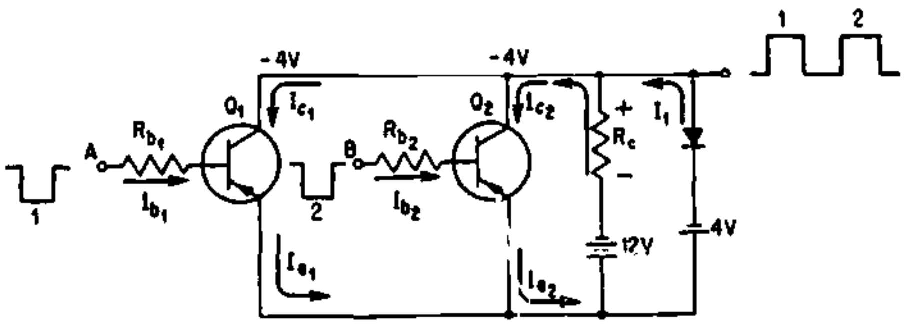
collector

20.j. The purpose of Q3 is . . . .

////////////////////

to shift the output signal of Q1 180° so that it is in phase with the input signal applied to Q1.

21.a.



This circuit isolates the input stages by using . . . .

////////////////////

using more than one transistor.

21.b. With no signal, the base-emitter voltage in either transistor is ( ). This keeps the transistors ( ).

////////////////////

zero cut off

21.c. A negative signal applied to A or B ( ) biases the base-emitter diode.

////////////////////

forward

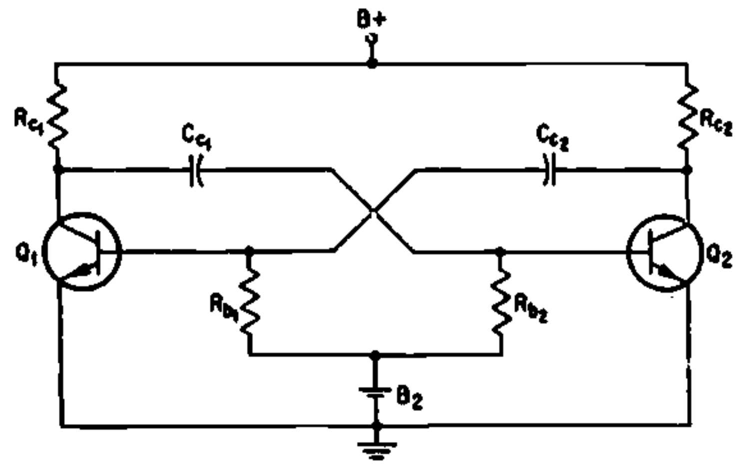
21.d. The output signal is kept fairly constant by the ( ).

////////////////////

clamping diode

PULSE CIRCUITS

1. FREE-RUNNING MULTIVIBRATOR:



A free-running multivibrator is a relaxation oscillator that produces square waves. The circuit consists of two RC coupled transistors, connected so that each one provides feedback for the other. Each transistor, therefore, is responsible for cutting off the other. The transistors alternately conduct and cut off, so that the output waveshape can be taken from either collector.

When the circuit is first energized, the transistors start to conduct and the capacitors become charged. Assuming Q2 conducts more heavily, its collector voltage will decrease more than the collector voltage of Q1. This means the voltage applied across Cc2 is reduced, causing it to discharge through Rb1. As a result, the voltage drop across Rb1 opposes the forward bias of Q1. The conduction of Q1 decreases and its collector voltage goes up. This means more voltage is applied across Cc1, causing it to charge through the emitter-base junction of Q2. As a result, the forward bias current of Q2 increases.

The conduction of Q2 becomes greater and its collector voltage decreases, further reducing the voltage applied across Cc2. The action is regenerative and continues until Q1 is cut off and Q2 conducts in saturation.

As Cc2 contines to discharge, the voltage drop across Rb1 decreases. When the base voltage of Q1 reaches zero, Q1 starts conducting, decreasing its collector voltage. This starts the second half cycle. This means less voltage is applied across Cc1, causing it to discharge through Rb2. As a result, the voltage drop across Rb2 opposes the forward bias of Q2. The conduction of Q2 decreases and its collector voltage goes

285

up. This means more voltage is applied across Cc2, causing it to charge through the emitter-base junction of Q1. As a result, the forward bias current of Q1 increases. The conduction of Q1 goes up and its collector voltage goes down, further reducing the voltage applied across Cc1. Again, the action is regenerative and continues until Q2 is cut off and Q1 conducts in saturation.

As Cc1 continues to discharge, the voltage drop across Rb2 decreases. When the base voltage of Q2 reaches zero, Q2 again starts conducting, repeating the cycle.

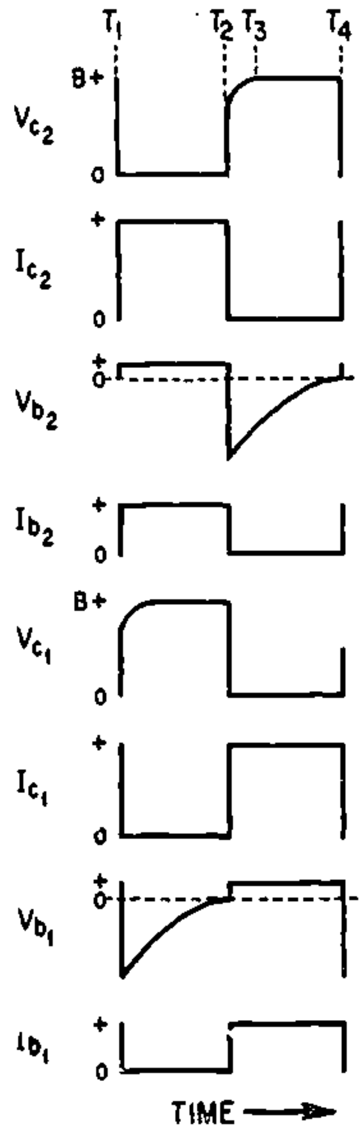
The amount of time either transistor conducts depends on how long the other transistor is cut off. This in turn, is controlled by the capacitor discharge circuits. Therefore, the conduction time of Q1 is determined by the time constant of Cc1 and Rb2; similarly, the conduction time of Q2 is determined by the time constant of Cc2 and Rb1.

---

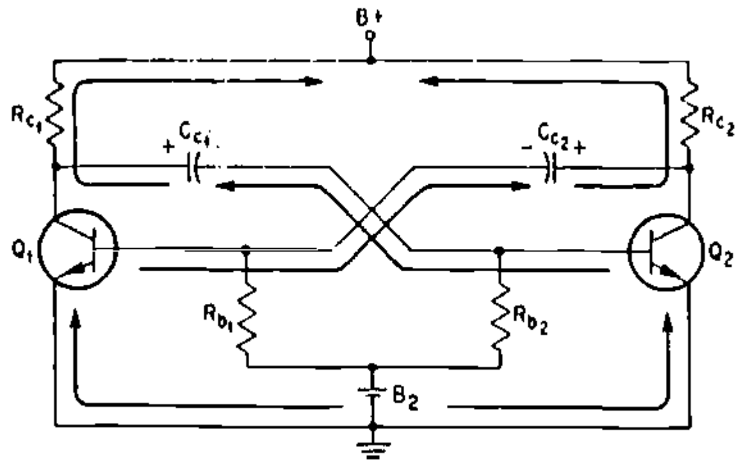
2. The results of the operation are shown in the following waveform diagram. Usually, the circuit is designed so that the transistors conduct in saturation. This brings the collector voltage of Q2 (Vc2) almost to zero in a relatively short time, so that the start of the waveshape (T1) is fairly linear. Simultaneously, the base voltage of Q2 (Vb2) goes slightly positive because of the voltage drop across the emitter-base junction. The base voltage of Q1 (Vb1) is driven negative by the discharge of Cc2. While Q1 is cut off Cc1 charges through Rc1, limiting the collector voltage (Vc1) to an expotential rise.

   Since Cc1 charges through Rc1 while Q1 is cut off, the collector voltage of Q1 (Vc1) does not reach the B+ value until Cc1 has completely charged. Therefore, the amount of time it takes the Q1 collector voltage to reach the B+ value depends on the time constant of Rc1 and Cc1: similarly, the amount of time it takes the Q2 collector voltage (Vc2) to reach the B+ value (T2 to T3) depends on the time constant of Rc2 and Cc2. Assuming the circuit is symmetrical, the base and collector waveshapes of Q1 will be similar to those of Q2, but of opposite phase.

   If the time constants of Cc1-Rb2 and Cc2-Rb1 are different, the cut off time of the transistors would be different. This would cause unsymmetrical waveshapes.



3.a.



When the circuit is first energized, the capacitors start to charge through the ( ) and the ( ) in the collector circuits.

////////////////////

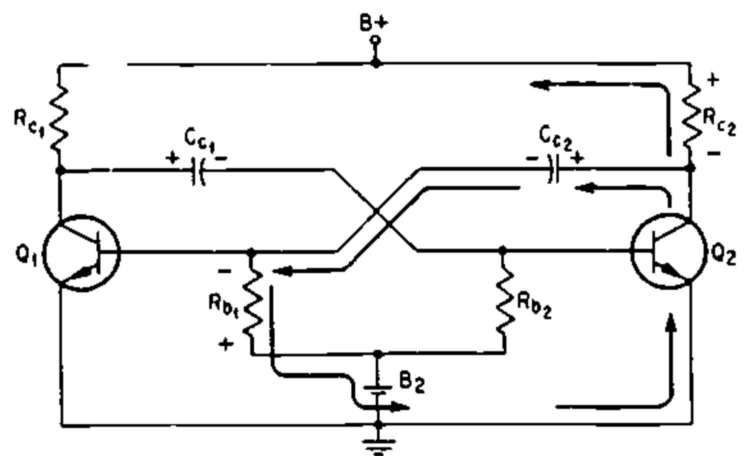
transistors resistors

3.b. Assuming Q2 conducts more heavily, its collector voltage will go (higher/lower) than that of Q1.

////////////////////

lower

4.a.



A decrease in the collector voltage of Q2 causes Cc2 to ( ) through Rb1.

////////////////////

discharge

4.b. The voltage developed across Rb1 ( ) the forward bias of Q1.

////////////////////

opposes

4.c. This causes the conduction of Q1 to ( ).

////////////////////

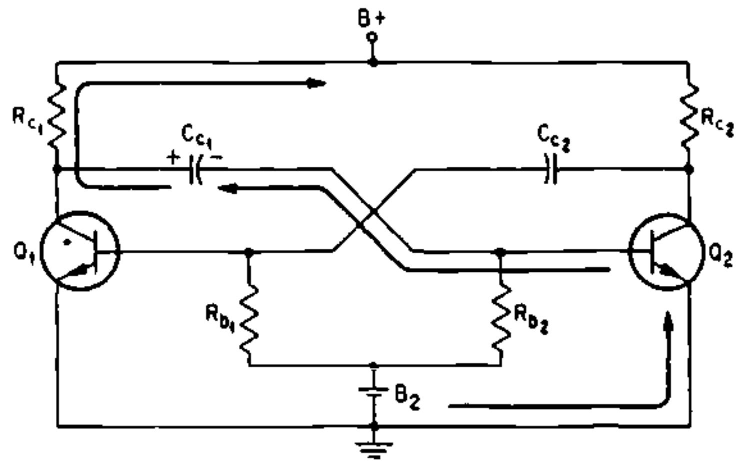
decrease

4.d. As a result, the collector voltage of Q1 ( ).

////////////////////

increases

5.a.



The increased collector voltage of Q1 causes Cc1 to ( ) through Q2.

////////////////////

charge

5.b. Charging current through Q2 ( ) its forward bias, driving it to ( ).

////////////////////

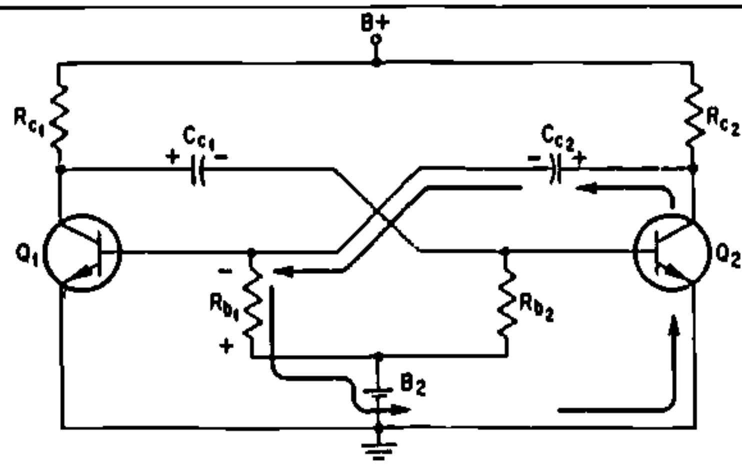
increases saturation

5.c. This further reduces the ( ) voltage of Q2.

////////////////////

collector

6.a.



The reduced collector voltage of Q2 causes the discharge of Cc2 through Rbl to ( ).

////////////////////

increase

6.b. The increased voltage developed across Rbl ( ) biases Q1.

////////////////////

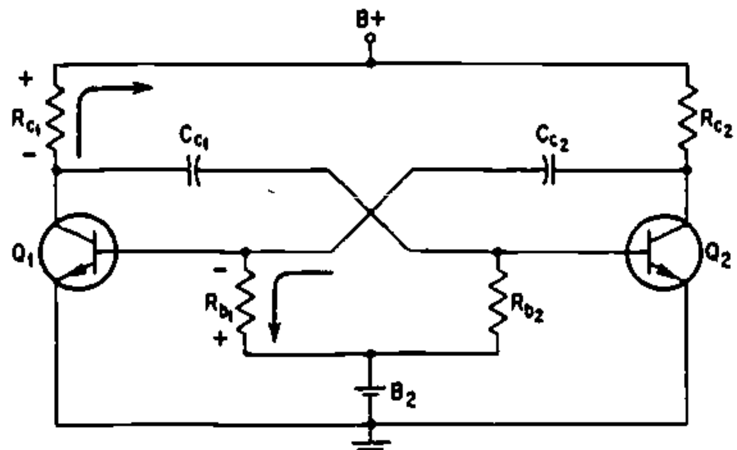
reverse

6.c. As a result, Q1 is driven to ( ).

////////////////////

cutoff

7.a.



As Cc2 continues to discharge, the reverse bias across Rbl ( ).

////////////////////

decreases

7.b. When the base voltage of Q1 reaches zero, Q1 ( ).

////////////////////

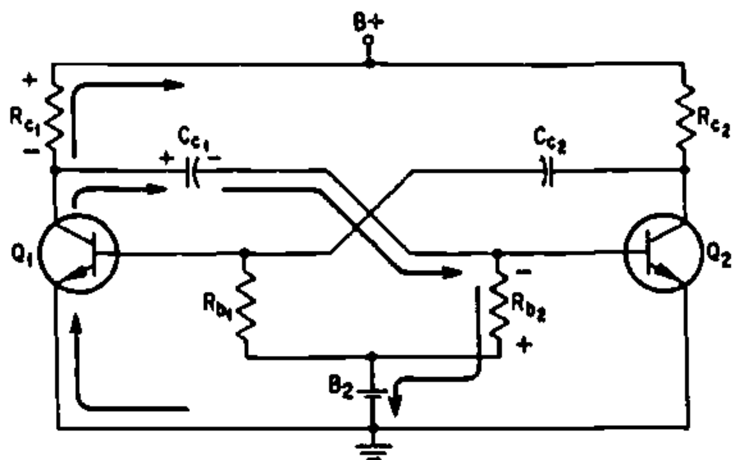
conducts

7.c. This causes the collector voltage of Q1 to ( ).

////////////////////

decrease

8.a.



The decreased collector voltage of Q1 causes Cc1 to ( ) through Rb2.

////////////////////

discharge

8.b. The voltage developed across Rb2 ( ) the forward bias of Q2.

////////////////////

opposes

8.c. This causes the conduction of Q2 to ( ).

////////////////////

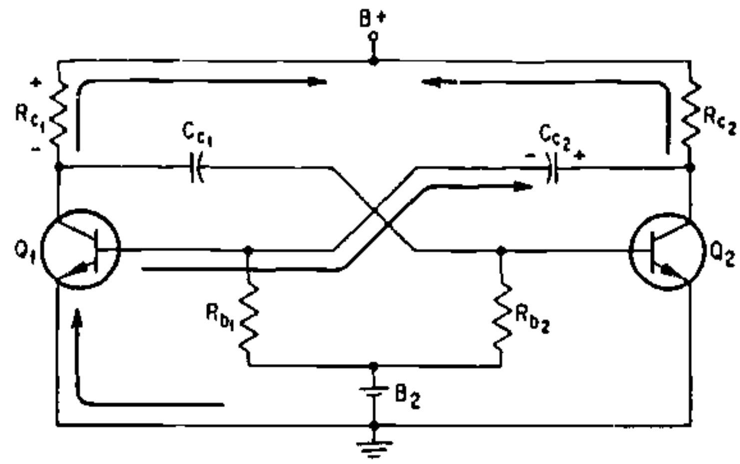
decrease

8.d. As a result, the collector voltage of Q2 ( ).

////////////////////

increases

9.a.



The increased collector voltage of Q2 causes Cc2 to ( ) through Q1.

////////////////////

charge

9.b. The charging current ( ) the forward bias of Q1.

////////////////////

increases

9.c. This drives Q1 to ( ).

////////////////////

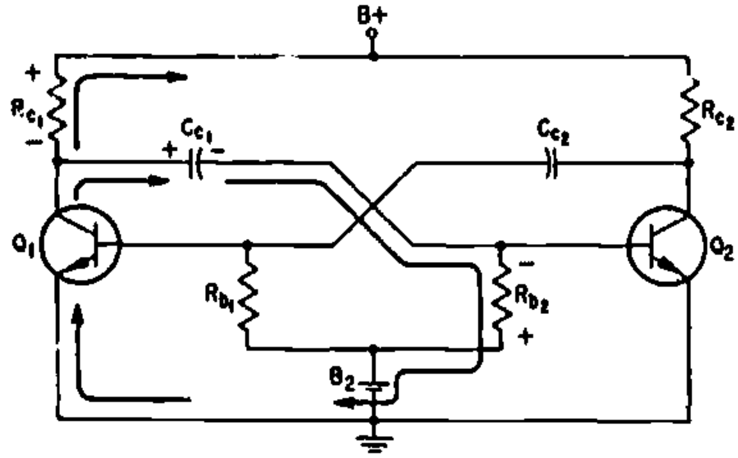
saturation

9.d. As a result, the collector voltage of Q1 is further ( ).

////////////////////

decreased

10.a



The decreased collector voltage of Q1 (   ) the discharge current of Cc1 through Rb2.

////////////////////

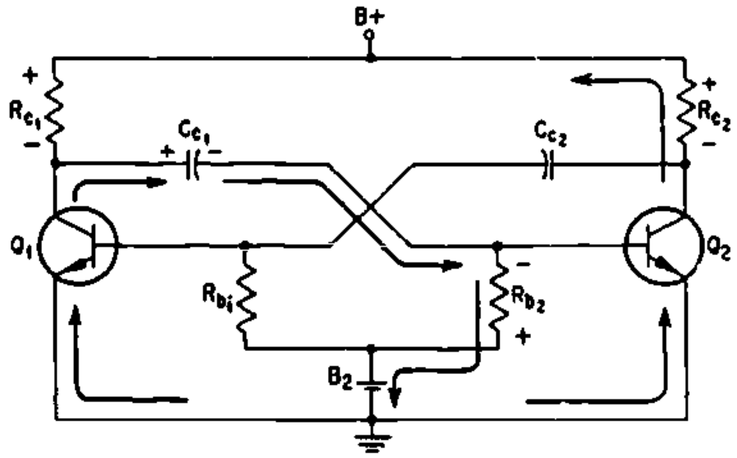
increases

10.b. The increased voltage drop across Rb2 drives Q2 to (   ).

////////////////////

cutoff

11.a.



As Cc1 continues to discharge, the voltage drop across Rb2 (   ).

////////////////////

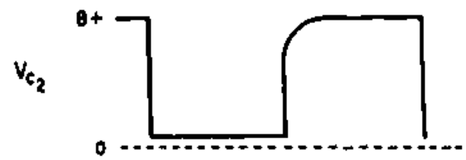
decreases

11.b. When the base voltage of Q2 reaches zero, Q2 ( ), repeating the cycle.

////////////////////

conducts

12.a. When Q2 is cut off, its collector voltage is at (zero/B+).



////////////////////

B+

12.b. The collector voltage of Q2 drops almost to zero when Q2 ( ).

////////////////////

conducts

12.c. Q2 remains in conduction while ( ) discharges through ( ).

////////////////////

Cc2 Rb1

12.d. If the value of Cc2 is increased, the conduction time of Q2 ( ).

////////////////////

increased

12.e. If the value of Rb1 is decreased, the conduction time of Q2 ( ).

////////////////////

decreased

12.f. The collector voltage of Q2 rises again to B+ while ( ) charges through ( ).

////////////////////

Cc2 Rc2

12.g. If the value of Cc2 is increased, the rise time of Vc2 ( ).

////////////////////

increases

12.h. If the value of Rc2 is decreased, the rise time of Vc2 (   ).

////////////////////

decreases

12.i. Q2 remains cut off while (   ) discharges through (   ).

////////////////////

Cc1   Rb2

12.j. If the value of Cc1 is increased, the cutoff time of Q2 (   ).

////////////////////

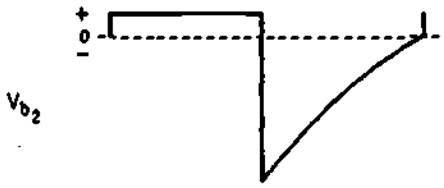
increases

12.k. If the value of Rb2 is decreased, the cutoff time of Q2 (   ).

////////////////////

decreases

13.a. When Q2 conducts, its base voltage goes slightly (   ).



////////////////////

positive

13.b. Vb2 remains positive while Q2 is (   ).

////////////////////

conducting

13.c. Vb2 goes negative when (   ) discharges through (   ).

////////////////////

Cc1   Rb2

13.d. As Cc1 discharges, Vb2 (   ) exponentially.

////////////////////

rises

13.e. Assuming the circuit is symmetrical, the collector and base waveshapes of Q1 will be the same but of opposite (   ).

////////////////////

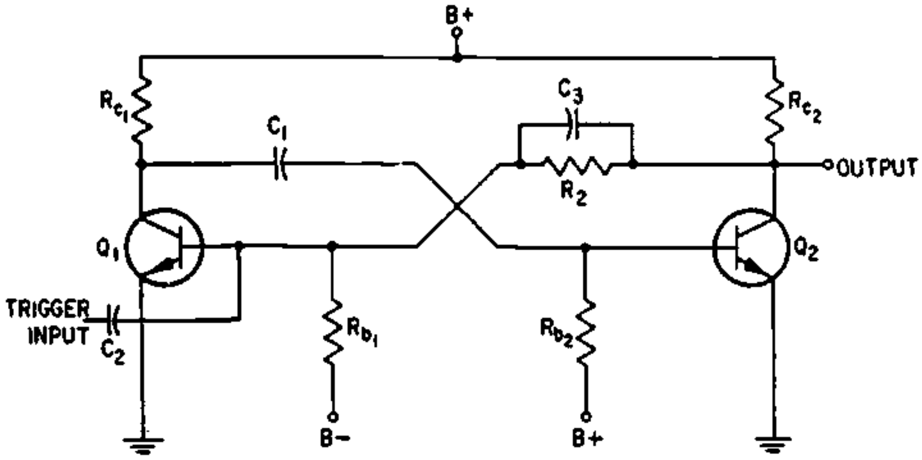
phase

13.f. How can the waveshape be made unsymmetrical?

////////////////////

By making the time constants of Cc1-Rb2 and Cc2-Rb1 different.

1. MONOSTABLE (ONE-SHOT) MULTIVIBRATOR:



A monostable multivibrator has only one stable state; one transistor is conducting and the other is cut off. When a trigger pulse is applied to the circuit, the stages switch states. After a certain time period, the stages revert back to their stable state by themselves.

When no trigger pulse is applied to the monostable multivibrator, both transistors go into their stable states because of the way that they are biased. The B- supply reverse biases the base of Q1. Rb1 and R2 form a voltage divider and, as a result, the bias voltage at the base of Q1 depends on how highly positive the collector voltage of Q2 is. If the positive collector voltage of Q2 is high, the base of Q1 will be positive and forward biased. If the collector voltage is low, the base of Q1 will be negative and reverse biased. The B+ power supply biases the base-emitter circuit of Q2 in the forward direction so that Q2 normally conducts heavily. Its collector voltage is therefore low, so that Q1 is reverse biased and cut off. The stable state of this monostable multivibrator is with Q1 cut off and Q2 conducting.

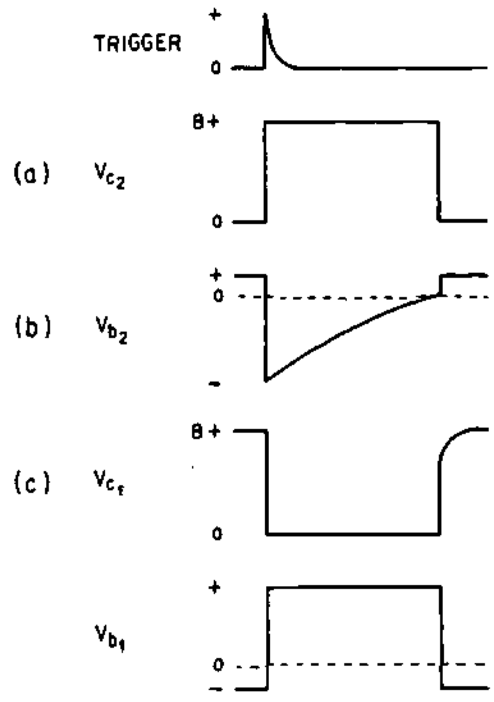
A positive trigger pulse of sufficient amplitude overcomes the reverse bias on Q1 and drives it into conduction; this lowers the Q1 collector voltage and causes C1 to discharge through Rb2, reducing the forward bias of Q2. The conduction of Q2 decreases, causing its collector voltage to rise. This increases the positive potential applied to R2 and Rb1, so that Q1 becomes forward biased and conducts heavily. The collector voltage of Q1 falls to a minimum, increasing the discharge of C1 through Rb2. This reverse biases Q2, driving it to cutoff. The collector voltage of Q2 rises again and causes Q1 to be driven into saturation. The transistors will stay in these new states as long as the discharge of C1 keeps Q2 cut off.

As C1 continues to discharge, the voltage drop across Rb2 decreases. When it decreases enough, the B+ power supply again forward biases Q2, and Q2 conducts. The collector voltage of Q2 drops, lowering the potential applied to R2 and Rb1. The lower voltage across Rb1 reduces the forward bias of Q1. As a result, the conduction of Q1 decreases and its collector voltage increases. This causes C1 to charge through Q2, increasing the forward bias of Q2 and driving it into saturation. The collector voltage of Q2 drops to a minimum, further lowering the potential applied to R2 and Rb1. As a result, the drop across Rb1 becomes less than the value of the B- supply. This reverse biases Q1 and drives it to cutoff. This puts the circuit back into its stable state. The circuit remains with Q2 conducting and Q1 cut off until the next trigger pulse is applied.

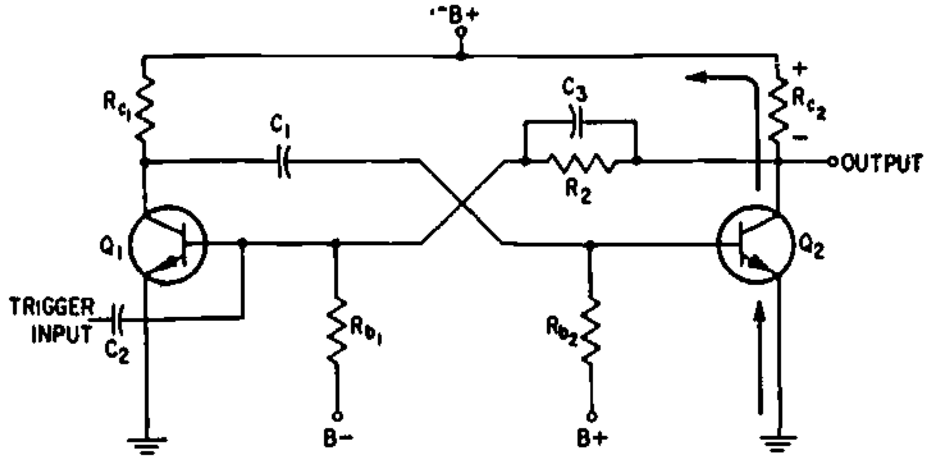
When pulses of VERY SHORT duration are used to trigger the multivibrator, the trigger pulse may pass through the circuit BEFORE the circuit has time to respond. To prevent this from occurring, a small capacitor (C3), is usually placed across coupling resistor R2 to increase the response time of the circuit, thereby insuring more positive triggering. This capacitor is called a commutating capacitor, and it is used in most "triggered" multivibrators.

---

2. The diagram shows the effect of a trigger pulse. The circuit returns to its stable state—Q2 conducting and Q1 cut off—when the Rb2 voltage drop, caused by C1 discharging, equals the voltage of the B+ power supply. Vb2 rises from a negative value to zero as C1 discharges. The curved rise of Vc1 is caused by C1 discharging through Rc1.



3.a.



The B- power supply (reverse/forward) biases Q1.

////////////////////

reverse

3.b. But the bias on Q1 also depends on the ( ) voltage of Q2.

////////////////////

collector

3.c. If the Q2 collector voltage is highly positive, Q1 will be ( ) biased.

////////////////////

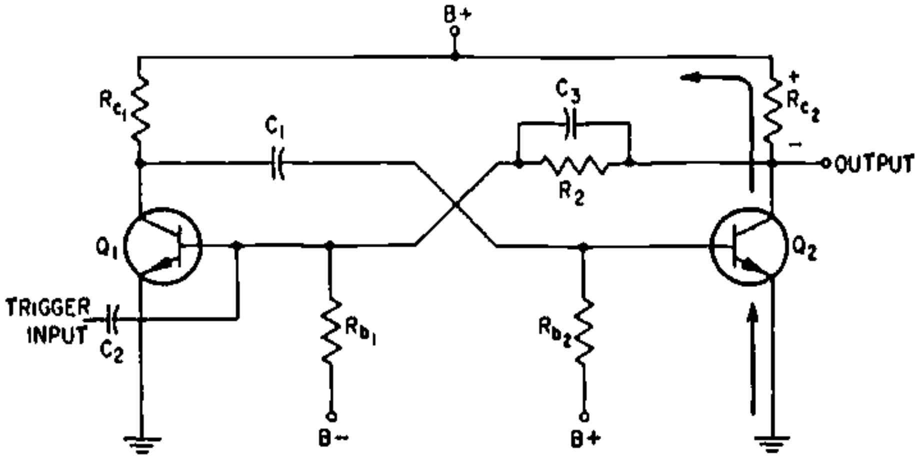
forward

3.d. If the Q2 collector voltage is low, Q1 will be ( ) biased.

////////////////////

reverse

4.a.



The B+ power supply causes Q2 to be ( ) biased.

////////////////////

forward

4.b. Q2 conducts heavily, causing its collector voltage to be ( ).

////////////////////

low, small

4.c. This causes the base-to-emitter voltage of Q1 to be (negative/positive).

////////////////////

negative

4.d. Q1, then, is reverse biased. The stage is (conducting/cut off).

////////////////////

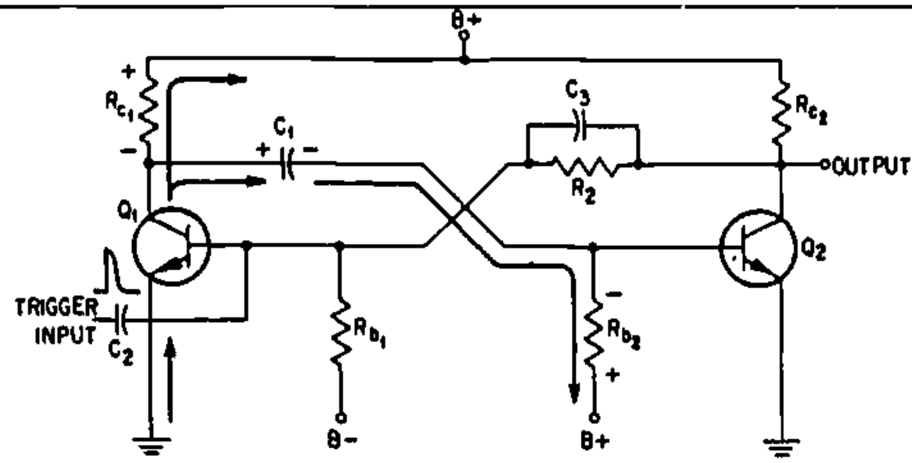
cut off

4.e. The stable state is with ( ) cut off and ( ) conducting.

////////////////////

Q1 Q2

5.a.



When a positive trigger pulse with high enough amplitude is applied at the trigger input, Q1 (   ).

////////////////////

conducts

5.b. This causes the collector voltage of Q1 to go (   ).

////////////////////

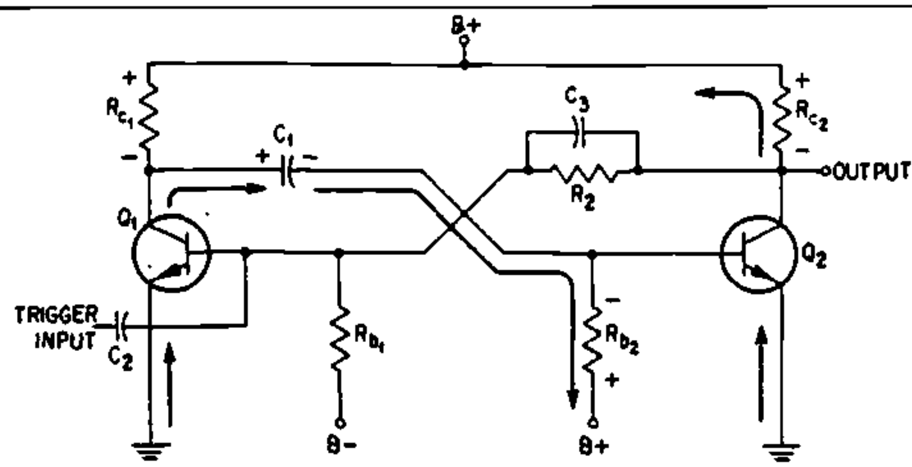
down

5.c. As a result, C1 (   ) through Rb2.

////////////////////

discharges

6.a.



The voltage developed across Rb2 (aids/opposes) the forward bias of Q2.

////////////////////

opposes

6.b. This causes the conduction of Q2 to (   ).

////////////////////

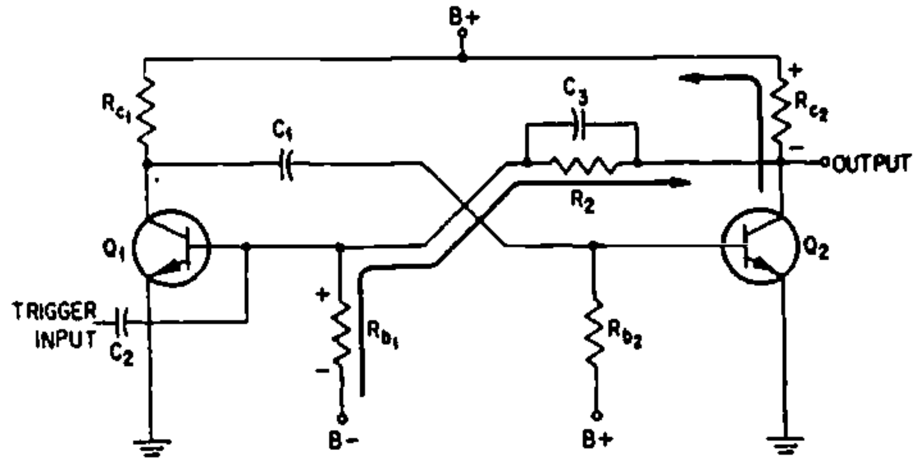
decrease

6.c. As a result, its collector voltage goes (   ).

////////////////////

up

7.

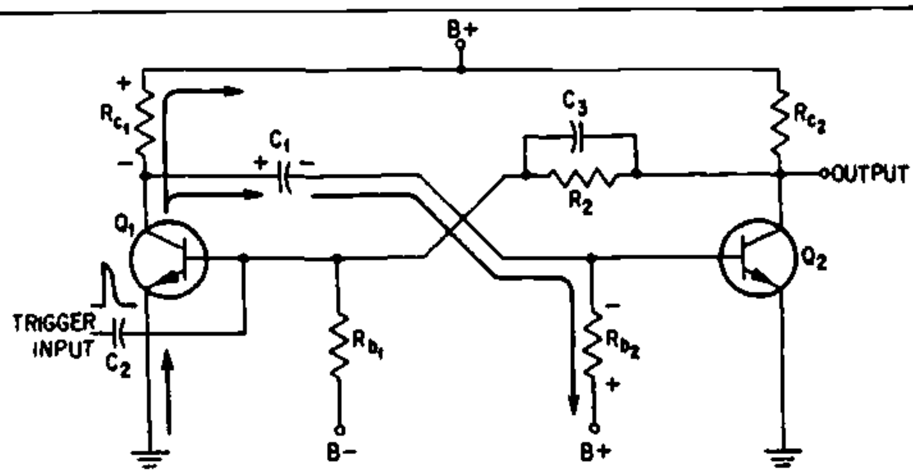


The higher collector voltage of Q2 (   ) the forward bias of Q1.

////////////////////

increases

8.a.



When the conduction of Q1 becomes maximum, its collector voltage goes to a (   ).

////////////////////

minimum

8.b. This ( ) the discharge of C1 through Rb2.

////////////////////

increases

8.c. The increased voltage across Rb2 ( ) biases Q2, driving it to ( ).

////////////////////

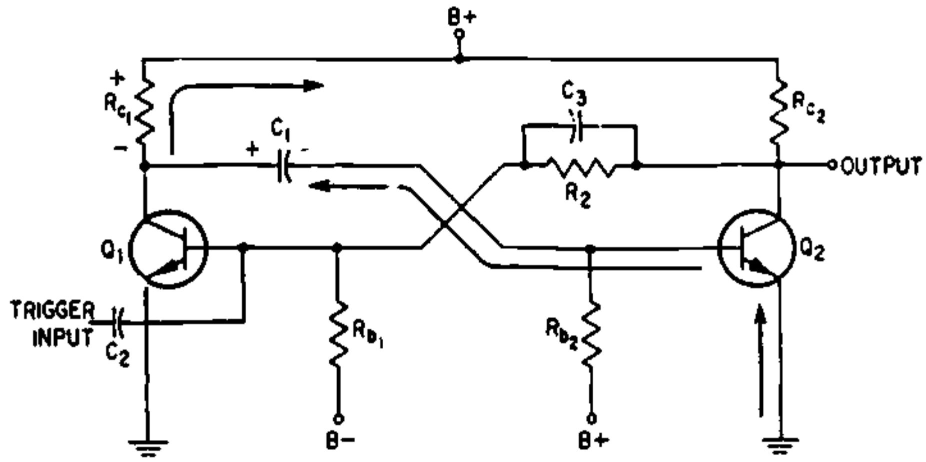
reverse cutoff

8.d. Q2 will remain cut off as long as ( ) continues to discharge through Rb2.

////////////////////

C1

9.a.



As C1 continues to discharge, the voltage drop across Rb2 ( ).

////////////////////

decreases

9.b. When the voltage drop across Rb2 goes below the value of the B+ supply, Q2 ( ).

////////////////////

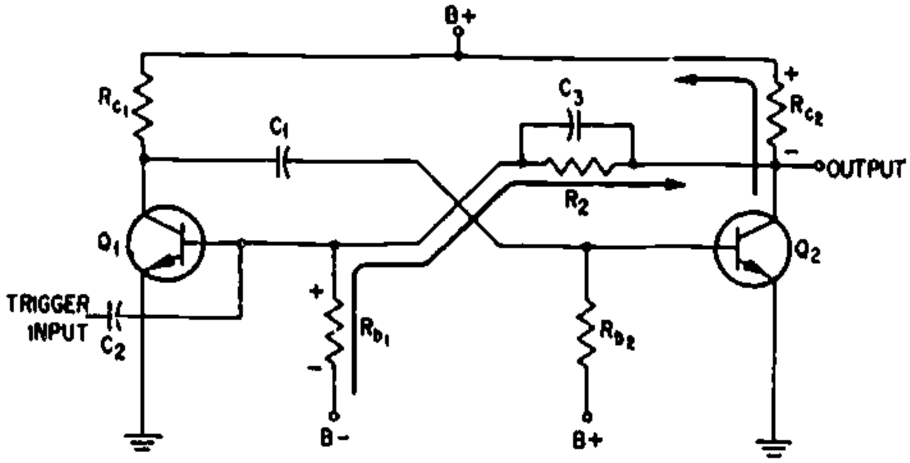
conducts

9.c. The collector voltage of Q2 then goes ( ).

////////////////////

down

10.a.



The lower collector voltage at Q2 (   ) the voltage drop across Rb1.

////////////////////

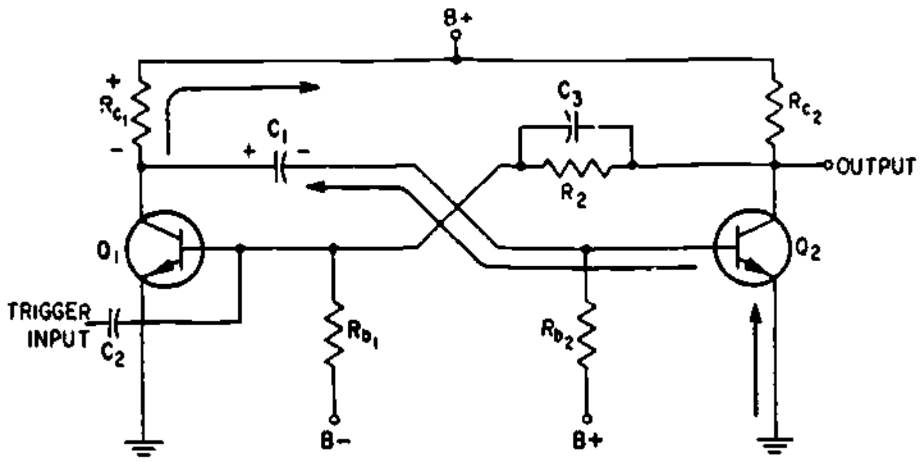
decreases

10.b. This reduces the forward bias on (   ).

////////////////////

Q1

11.a.



The reduced forward bias of Q1 causes the conduction of Q1 to go (   ).

////////////////////

down

11.b. The collector voltage of Q1 then goes ( ).

////////////////////

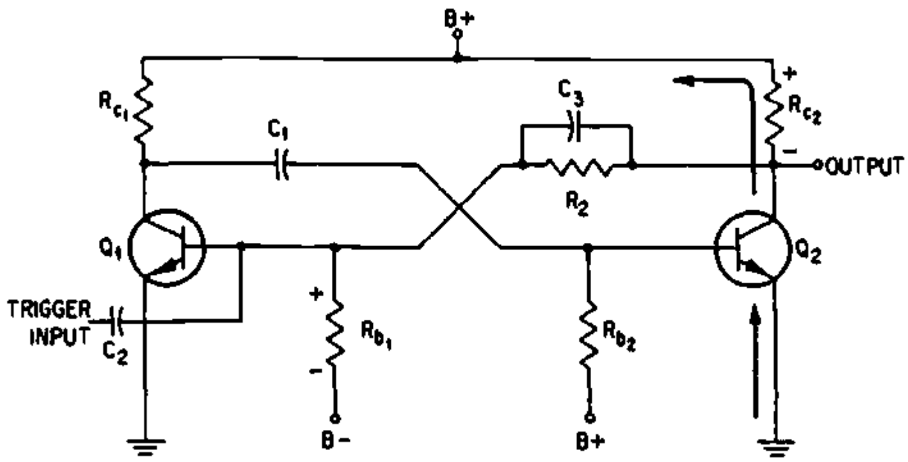
up

11.c. This causes C1 to charge through ( ).

////////////////////

Q2

12.a.



The charging current of C1 ( ) the forward bias of Q2, driving it to ( ).

////////////////////

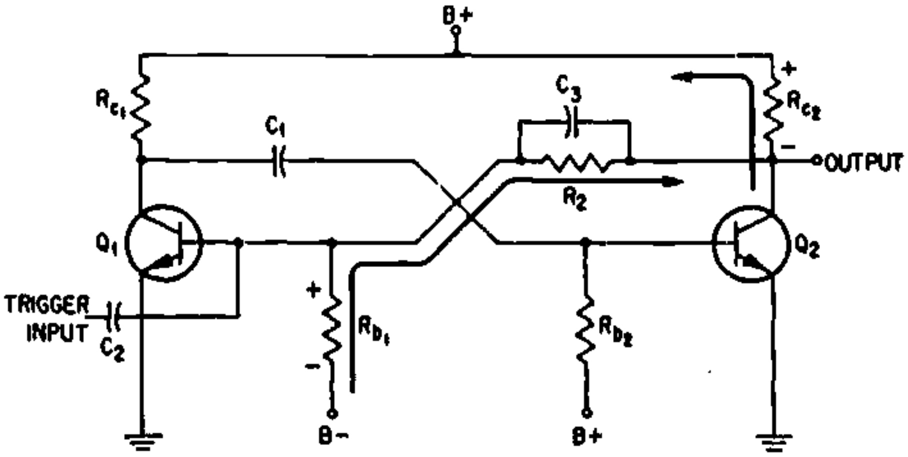
increases saturation

12.b. When the conduction of Q2 becomes maximum, its collector voltage goes to a ( ).

////////////////////

minimum

13.a.



The voltage across Rb1 falls below the value of the ( ).

////////////////////

B- power supply

13.b. As a result, Q1 is ( ) biased and is driven to ( ).

////////////////////

reverse cutoff

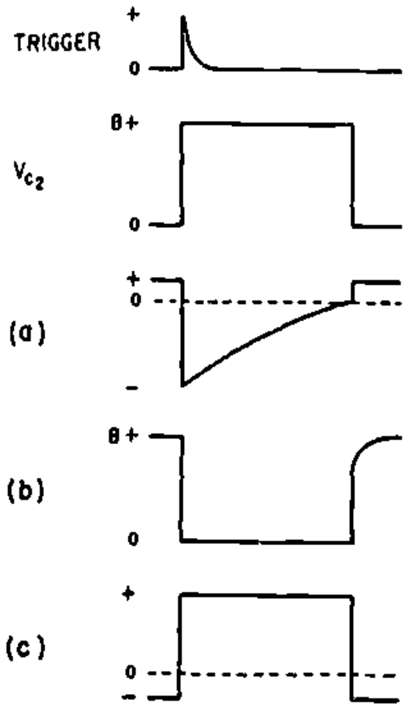
13.c. The circuit is again in its ( ) state.

////////////////////

stable

---

14. Label the a., b., and c. waveshapes in the diagram to coincide with the Q2 collector voltage in their proper time relationships.



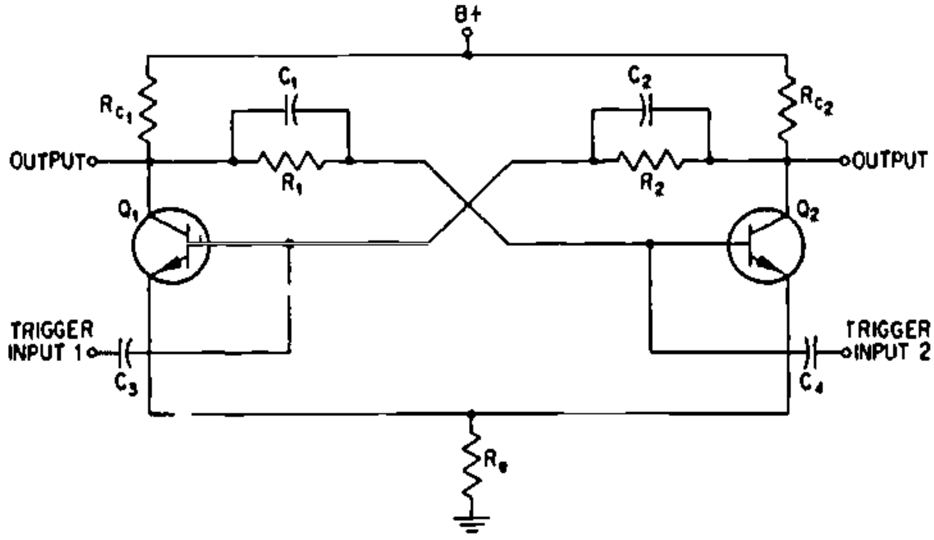
//////////////////////

a. Q2 base voltage (Vb2) b. Q1 collector voltage (Vc1) c. Q1 base voltage (Vb2)

In the monostable multivibrator just described, the circuit was made to switch states by applying a positive trigger pulse to Q1, thereby forward biasing Q1 and driving it into conduction. The circuit could also have been made to switch states by applying a NEGATIVE trigger pulse to Q2, thereby reverse biasing Q2 and causing it to cut off.

Also, the output of the monostable multivibrator just described was taken off at the collector of Q2. The output could have been taken off at the collector of Q1 instead. Of course, the voltage at each collector is 180° out of phase with the other; i.e., when a positive-going pulse is present on the collector of Q2, a negative-going pulse is present on the collector of Q2.

1. BISTABLE (FLIP-FLOP) MULTIVIBRATOR:



A bistable multivibrator is similar to the free-running multivibrator discussed earlier, except that it does not run freely. The circuit has two stable states: Q1 conducting and Q2 cut off; and Q2 conducting and Q1 cut off. A trigger pulse applied to the circuit will cause it to switch from one state to the other. Another trigger pulse is then required to cause the circuit to switch back again.

You can see from the diagram above that the trigger pulse can be applied to either stage and that the output can be taken off from either stage. Since NPN transistors are used here, a positive trigger pulse can be used to drive the nonconducting stage into conduction or a negative trigger pulse can be used to cut off the conducting stage. For this discussion, assume that the trigger pulse is applied to Q1 and the output signal is taken off at the collector of Q2.

Before going on to discuss how the bistable multivibrator works, notice that, unlike the free-running and monostable multivibrators just discussed, this bistable multivibrator does not use base resistors to develop emitter-base bias voltages. Instead it uses an emitter resistor, Re, which, along with the emitter-base resistance of each transistor and the coupling resistor (either R1 or R2), form a voltage divider network from collector to ground. The amount of current flowing through Re will remain essentially constant because Re is common to both Q1 and Q2. As the current through Q1 increases, the current through Q2 will decrease, and vice versa. The SUM of currents through Q1 and Q2 will remain the same.

Look at Q2. Base current of Q2 is from ground, through emitter resistor Re, through the emitter-base junction and then through R1 to the collector of Q1. The amount of current flowing through Re will remain essentially constant and, therefore, a constant positive voltage will be present on the emitter of Q2 (and Q1 also). However, the amount of current flowing through the emitter-base junction of Q1 and through R1 depends on the value of collector voltage or Q1. Current flow through the emitter-base junction will cause the base to be positive with respect to the emitter. The emitter base bias voltage, then, is the sum of the positive voltage at the base and the positive voltage applied to the emitter by Re. Transistor Q2, which is an NPN type, will be forward biased and will conduct so long as the voltage on the base is more positive than the voltage developed across Re. When the voltage at the base drops below the voltage across Re, transistor Q2 will become reverse biased and will cut off. The manner in which emitter-base bias is developed for Q1 is exactly the same.

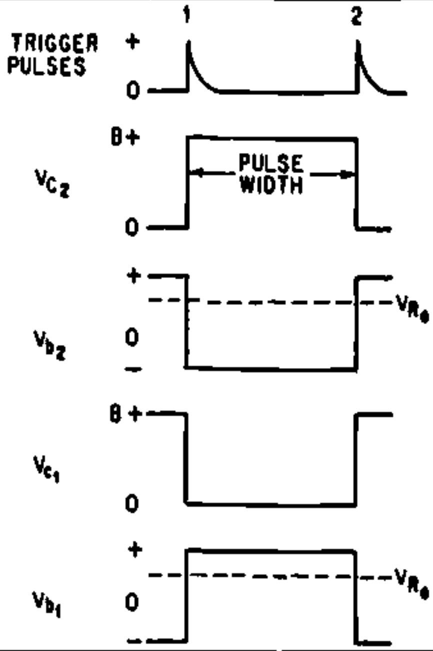
The advantage of using this method of biasing is that emitter resistor Re provides stabilization. If the current through either, or both, transistors, tends to vary because of ambient temperature changes, the voltage drop across Re will also vary to return the current to its original value.

Now go on to see how a bistable multivibrator operates.

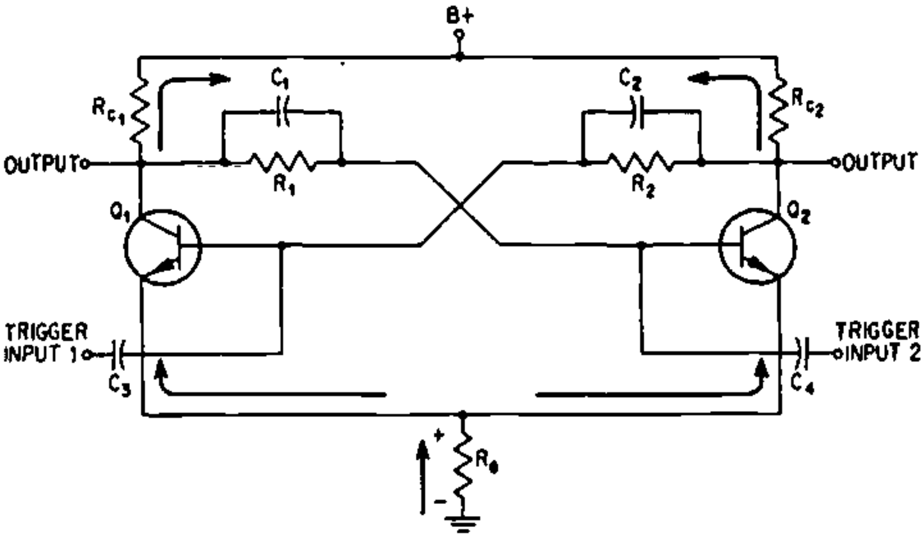
As with the free-running multivibrator, both transistors start to conduct when the circuit is first energized. Assuming Q2 conducts more heavily, its collector voltage will decrease more than the collector voltage of Q1. This lowers the potential applied across the series circuit of R2 and the emitter-base resistance of Q1; therefore, the positive voltage drop across each resistor is reduced. The lower voltage drop across the emitter-base resistance decreases the forward bias of Q1. The conduction of Q1 goes down and its collector voltage rises. This increases the potential applied across the series circuit of R1 and Q2 emitter-base resistance. As a result, the positive voltages across these two resistors increase. The bigger voltage drop across the emitter-base resistance increases the forward bias of Q2, driving it to saturation, further reducing its collector voltage. This again lowers the potential applied across R2 and Q1 emitter-base resistance so that the voltage developed across the emitter-base resistance falls below that across Re. This results in a negative bias being applied to the base. As a result of this reverse bias, Q1 is cut off. The circuit stabilizes with Q2 conducting and Q1 cut off. The circuit stays in this stable state until Q1 is made to conduct. This is done when a trigger pulse is applied to either base.

A positive trigger pulse applied to the base of Q1 will cause the circuit to switch stable states. The trigger pulse overcomes the reverse bias and drives Q1 into conduction. This causes the collector voltage of Q1 to drop, lowering the voltage applied across R1 and Q2 emitter-base resistance. The reduced voltage drop across Q2 emitter-base resistance lowers the forward bias of Q2, which, in turn, decreases the conduction of Q2. This causes the collector voltage of Q2 to rise, thereby increasing the voltage applied across R2 and Q1 emitter-base resistance. The greater voltage drop across the emitter-base resistance further increases the forward bias of Q1, driving it to saturation and lowering its collector voltage still more. This further reduces the voltage applied across R1 and Q2 emitter-base resistance. The drop across Q2 emitter-base resistance becomes less than the voltage drop across Re, so that Q2 is reverse biased and driven to cutoff. The circuit remains in this stable state with Q1 conducting and Q2 cut off until another trigger pulse is applied.

2. The diagram shows the effect of two trigger pulses. Assume that Q2 is conducting and Q1 is cut off. The first trigger pulse raises the base voltage of Q1 above the voltage across Re and brings Q1 into conduction, lowering its collector voltage (Vc1). The base voltage of Q2 goes more negative than the voltage across Re and cuts off Q2, raising its collector voltage (Vc2). The second trigger pulse has the opposite effect. The pulse width depends on the frequency of the trigger pulses.



3.a.



When the circuit is energized, the conduction of each transistor is (the same/different).

////////////////////

different

3.b. Since Re is common to Q1 and Q2, current through Re will (decrease/increase/remain constant).

////////////////////

remain constant

3.c. Assuming Q2 conducts more heavily, its collector voltage will (   ) more than that of Q1.

////////////////////

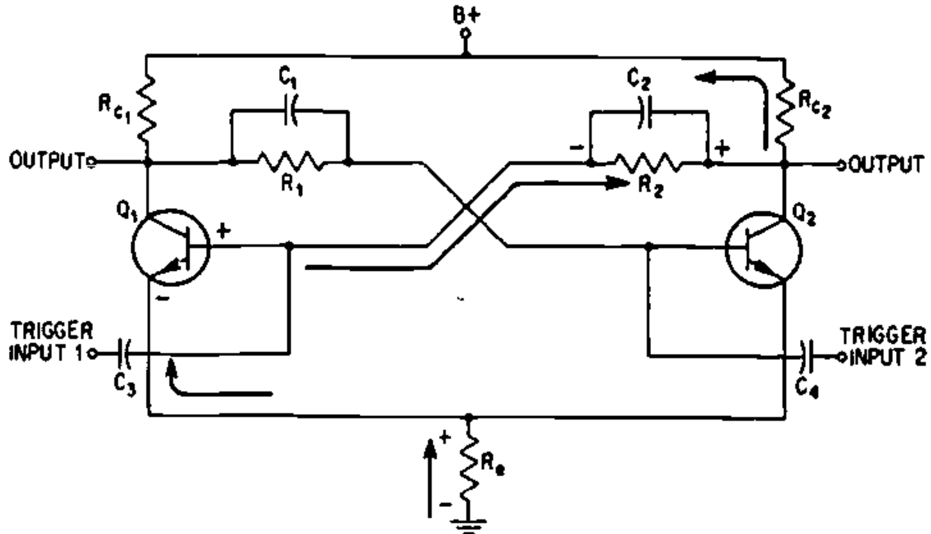
decrease

3.d. This decreases the voltage applied across the series circuit consisting of (   ) and (   ).

////////////////////

R2   Q1 emitter-base resistance

4.a.



The decreased collector voltage of Q2 causes the positive voltage dropped across Q1 emitter-base resistance to (   ).

////////////////////

decrease

4.b. The reduced drop across Q1 emitter-base resistance (   ) the forward bias of Q1.

////////////////////

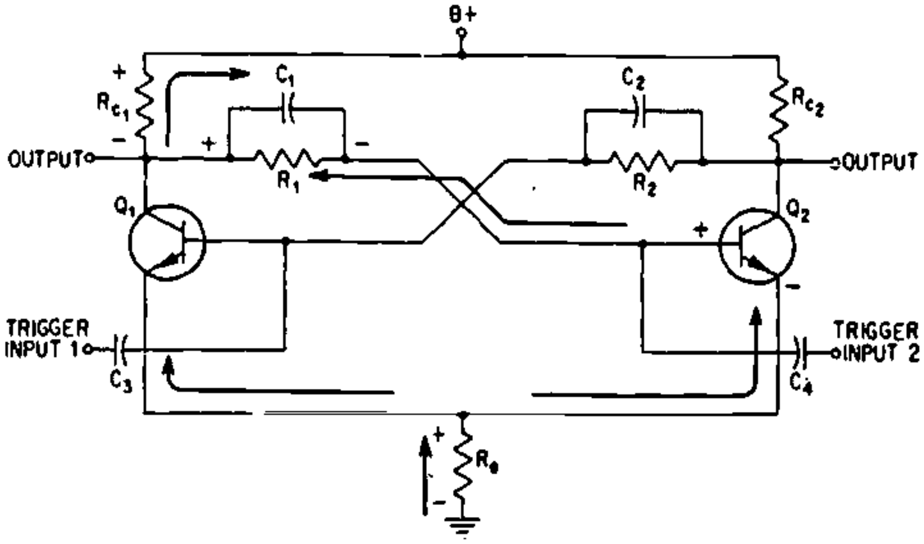
decreases

4.c. As a result, the conduction of Q1 (   ).

////////////////////

decreases

5.a.



When the conduction of Q1 goes down, its collector voltage goes (   ).

////////////////////

up

5.b. This causes the voltage applied across R1 and Q2 emitter-base resistance to (   ).

////////////////////

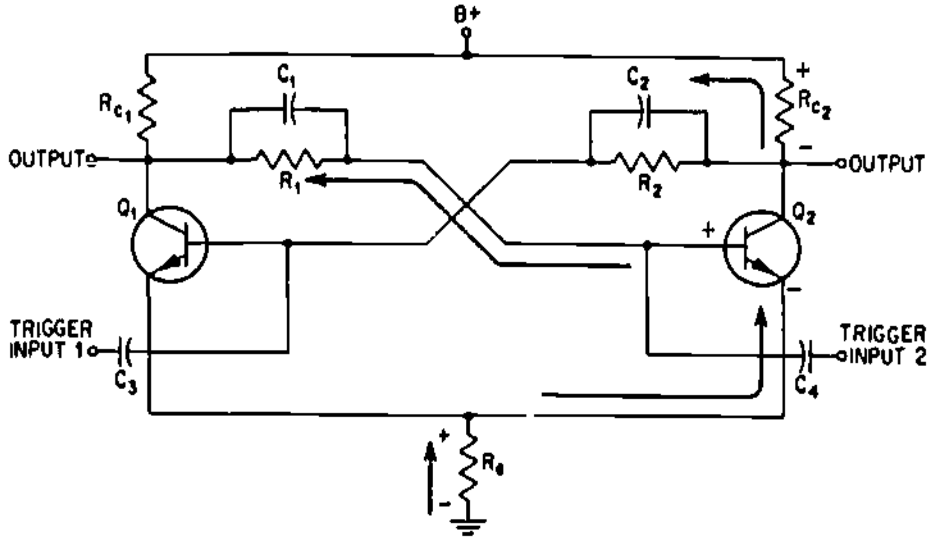
increase

5.c. As a result, the positive voltage dropped across Q2 emitter-base resistance (   ).

////////////////////

increases

6.a.



The increased voltage drop across Q2 emitter-base resistance raises the (   ) bias of Q2, driving Q2 to (   ).

////////////////////

forward   saturation

6.b. This causes the collector voltage of Q2 to go to its (minimum/maximum) value.

////////////////////

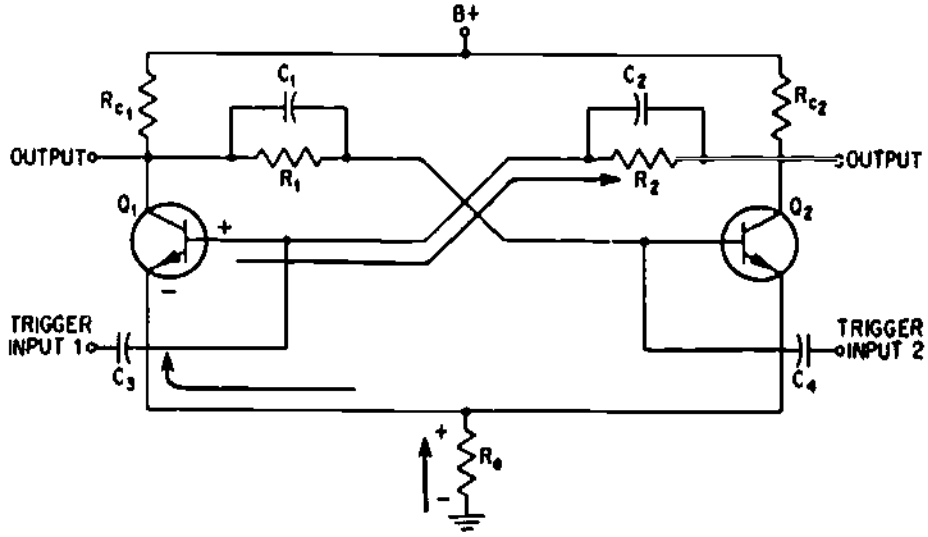
minimum

6.c. As a result, the voltage applied across R2 and Q2 emitter-base resistance is further (   ).

////////////////////

decreased

7.a.



The reduced voltage further ( ) the voltage developed across Q1 emitter-base resistance.

////////////////////

decreases

7.b. The voltage drop across Q1 emitter-base resistance becomes (smaller/greater) than the voltage across Re.

////////////////////

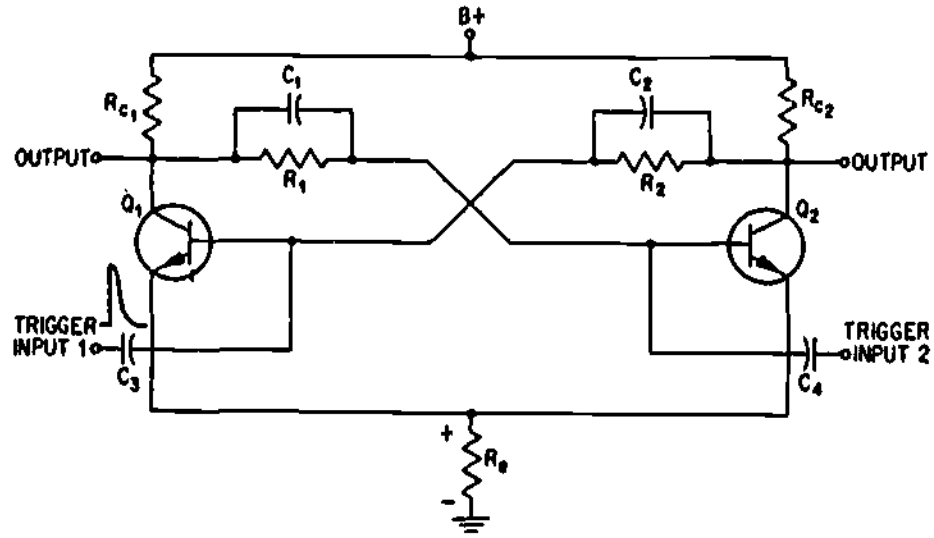
smaller

7.c. As a result, Q1 is ( ) biased and is driven to ( ).

////////////////////

reverse cutoff

8.a.



Q2 will conduct and Q1 will remain cut off until a ( ) trigger pulse is applied to the base of Q1.

////////////////////

positive (A negative pulse could be applied to the base of Q2.)

8.b. The positive trigger pulse will counteract the ( ) bias on Q1.

////////////////////

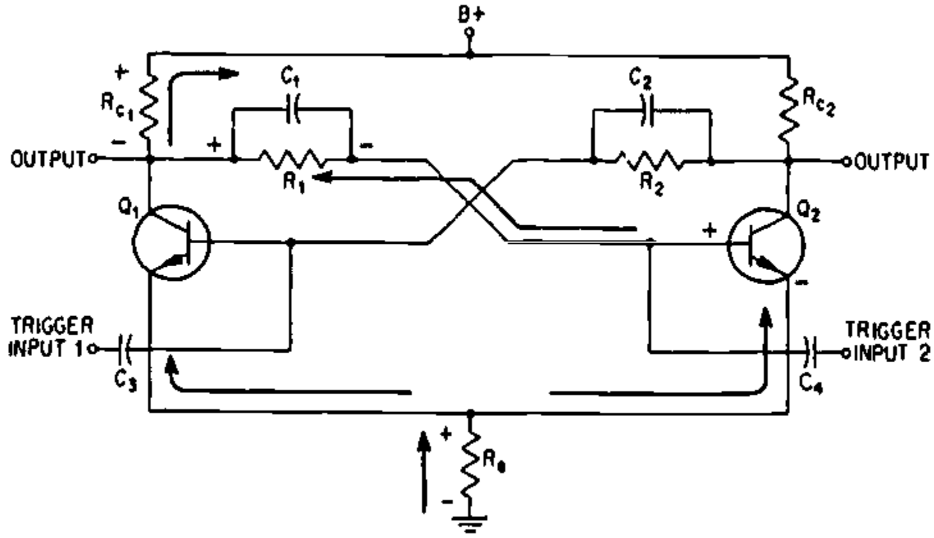
reverse

8.c. This causes Q1 to ( ).

////////////////////

conduct

9.a.



When Q1 conducts, its collector voltage (   ).

////////////////////

decreases

---

9 b. This applies (more/less) positive voltage to R1 and Q2 emitter-base resistance.

////////////////////

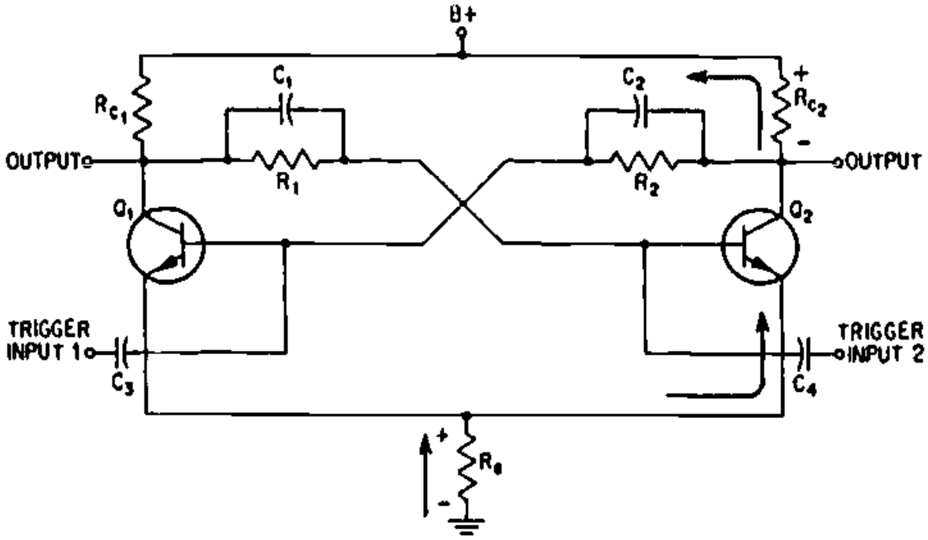
less

9.c. As a result, the voltage dropped across Q2 emitter-base resistance becomes (smaller/greater).

////////////////////

smaller

10.a.



The smaller voltage drop across Q2 emitter-base resistance (   ) the forward bias of Q2.

/////////////////////

decreases

10.b. This causes the conduction of Q2 to go (   ).

/////////////////////

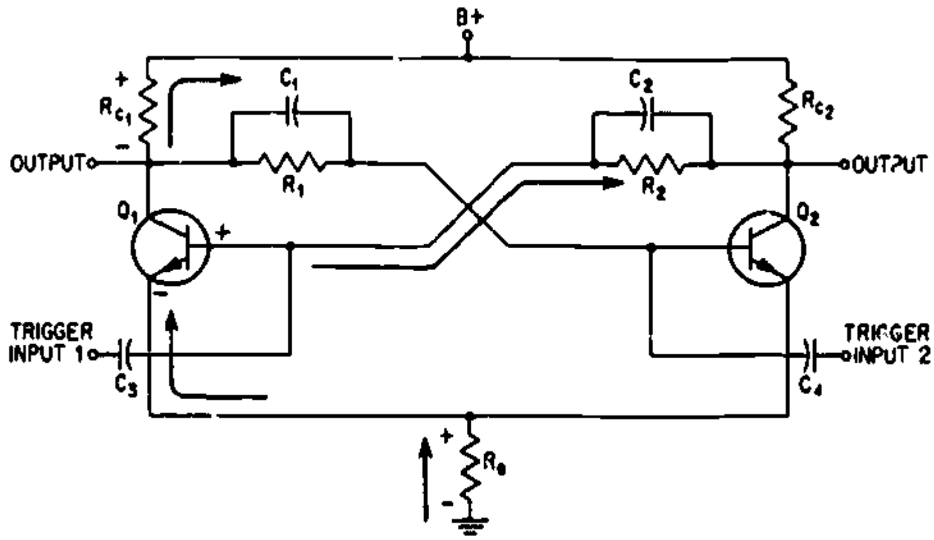
down

10.c. As a result, the collector voltage of Q2 (   ).

/////////////////////

increases

11.a.



The higher collector voltage of Q2 ( ) the voltage applied to R2 and Q1 emitter-base resistance.

////////////////////

increases

11.b. This causes the voltage developed across Q1 emitter-base resistance to become (greater/smaller).

////////////////////

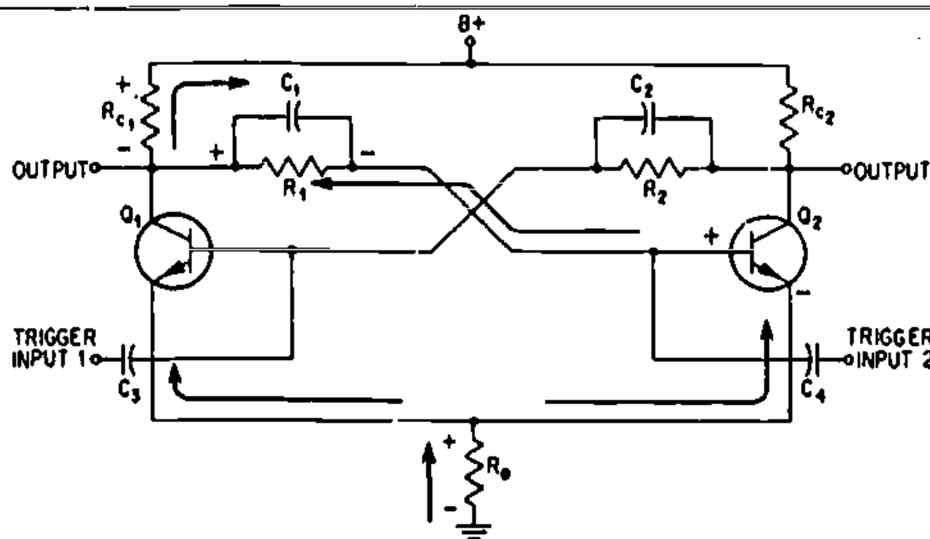
greater

11.c. The greater voltage drop developed across Q1 emitter-base resistance ( ) the forward bias of Q1, driving it to ( ).

////////////////////

increases saturation

12.a.



When the conduction of Q1 is maximum, its collector voltage is (maximum/minimum).

////////////////////

minimum

12.b. This further ( ) the voltage applied across Q2 emitter-base resistance.

////////////////////

decreases

12.c. The further reduction in voltage across Q2 emitter-base resistance causes Q2 to become ( ) biased, driving Q2 to ( ).

////////////////////

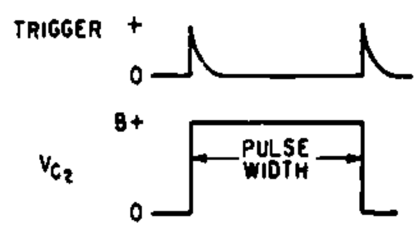
reverse cutoff

12.d. With Q1 now conducting and Q2 cut off, the circuit will again flip (of its own accord/only when triggered).

////////////////////

only when triggered

13.a. The pulse width of the output of a bistable multivibrator depends on . . . .



////////////////////

the frequency of the trigger pulses.

13.b. How many stable states does a bistable multivibrator have?

////////////////////

two

13.c. A positive pulse is applied to the transistor that is cut off to cause the circuit to flip into the other stable state. What kind of a pulse can be applied to the transistor that is conducting to also cause the circuit to change states?

////////////////////

negative

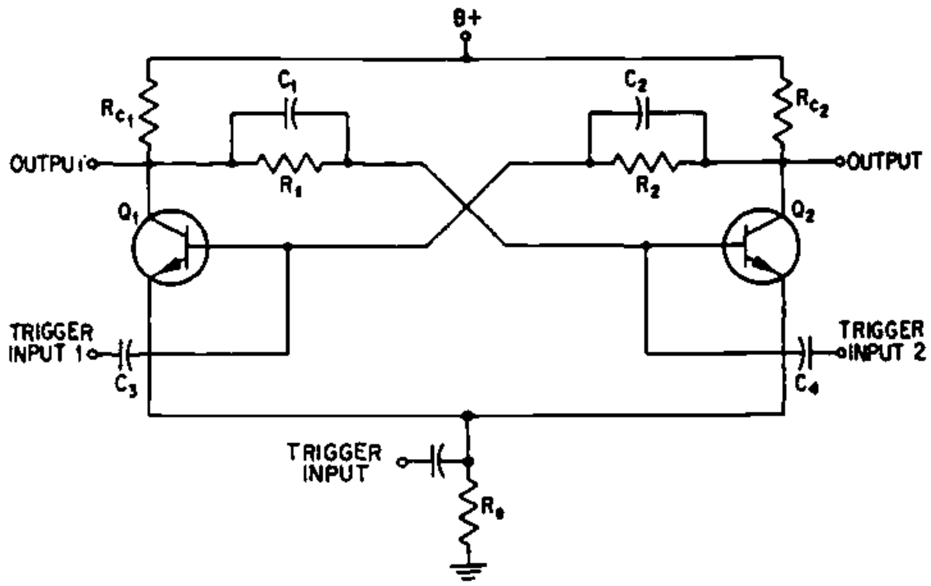
13.d. From what points can the output of this bistable multivibrator be taken? What will be the difference in the outputs of these two points?

////////////////////

From the collector of Q1 or collector of Q2.

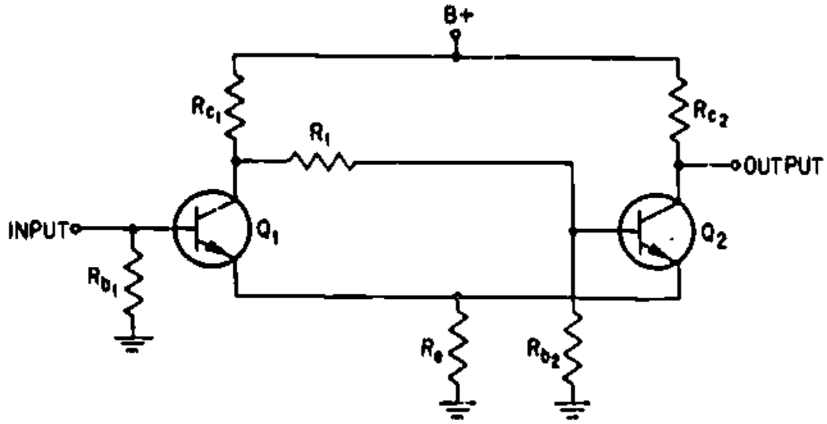
The outputs at the collectors of Q1 and Q2 will be 180° out of phase with each other; that is, when one collector is going positive, the other will be going negative.

Another method of triggering a bistable multivibrator is shown below.



Instead of applying a positive trigger pulse to the nonconducting stage or a negative trigger pulse to the conducting stage, this method applies a negative trigger pulse across Re. In affect, then, the pulse is applied to both Q1 AND Q2. No matter which stage is conducting and which one is cut off, the circuit will reverse states. The negative pulse will have no affect on the stage that is cut off, but it will overcome the forward bias of the conducting stage to start the multivibrator "action" previously described. This type of triggering is often called toggle switching or emitter triggering.

1. SCHMITT TRIGGER:



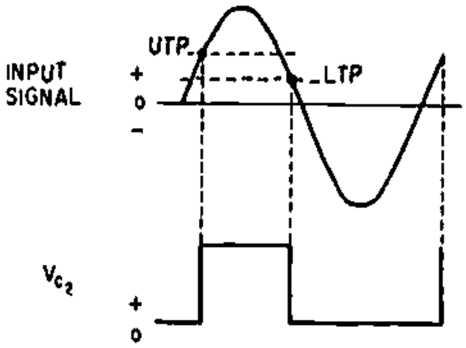
A Schmitt trigger is similar to a monostable multivibrator, except that the width of the output pulse is determined by the frequency of the triggering signal, which is usually a sine wave. The stable state of the circuit is with Q1 off and Q2 on. When the input signal goes positive, Q1 conducte and Q2 cuts off. When the input signal decreases, the circuit returns to its stable state.

When the circuit is first energized, current flows through the series circuit of Rb2 and R1. The voltage drop across Rb2 forward biases the base-emitter junction of Q2. This causes Q2 to conduct heavily through Re. Since Re is common to both transistors, the voltage drop across it reverse biases the emitter-base junction of Q1. This holds Q1 cut off, so that its collector voltage stays high. As a result, the large voltage drop across Rb2 KEEPS Q2 forward biased and in conduction. The circuit remains in this state until a signal is applied to Q1. The input trigger signal is usually a sine wave.

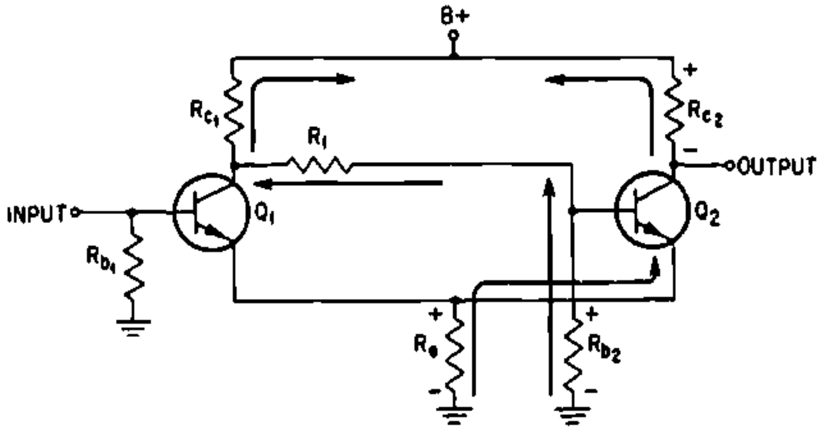
When the signal reaches a positive value high enough to overcome the reverse bias across Re, Q1 conducts. This value is called the upper triggering point (UTP). When Q1 conducts, the collector voltage of Q1 decreases, lowering the forward bias of Q2. The conduction of Q2 goes down, lowering the voltage drop across Re. This causes the conduction of Q1 to increase even more. Even though the conduction of Q1 increases, the voltage drop across Re still decreases because Q1 conducts less than Q2. This is accomplished by using a larger value resistor for Rc1 than for Rc2. When the conduction of Q1 increases, its collector voltage decreases again. This further lowers the potential applied to R1 and R2. As a result, Q2 is reverse biased and driven to cutoff. The drop across Re goes down again, and the conduction of Q1 goes up again. As long as the input signal is still applied to Q1 to keep it conducting, the circuit remains in this state.

Q1 never reaches saturation. Therefore, the voltage drop across Re when Q1 conducts is less than when Q2 conducts. As a result, the input trigger signal must go to a lower value than the UTP to cut off Q1. This new value is called the lower triggering point (LTP). When the input trigger signal swings down close to the LTP, the conduction of Q1 decreases, causing its collector voltage to rise. This increases the drop across Rb2, forward biasing Q2 and driving it into conduction. The conduction of Q2 increases the voltage drop across Re to reverse bias Q1 and drive it to cutoff. The collector voltage of Q1 rises further, increasing the forward bias of Q2 to drive it to saturation. The circuit remains in this stable state until the input signal reaches the UTP to start the cycle again.

2. The output is usually taken from the collector of Q2, since the upper part of the sine wave appears in the Q1 waveshape. This occurs because Q1 does not conduct in saturation. When the input signal reaches the UTP, Q1 conducts and cuts off Q2. This causes the collector voltage of Q2 (Vc2) to go highly positive. Q1 conducts until the LTP is reached. Then, Q1 is cut off, causing Q2 to conduct. This drives Vc2 to a low value.



3.a.



Current through Rb2 causes a voltage drop that ( ) biases Q2.

////////////////////

forward

3.b. This drives Q2 to ( ).

////////////////////

saturation

3.c. Q2 emitter current produces a voltage drop across Re that ( ) biases Q1.

////////////////////

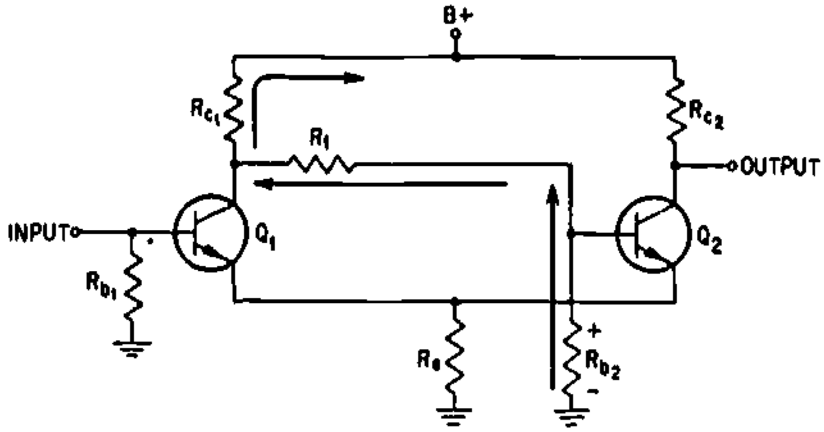
reverse

3.d. This keeps Q1 ( ).

////////////////////

cut off

4.a.



While Q1 is cut off, its collector voltage is (high/low).

////////////////////

high

4.b. This applies a (large/small) potential to R1 and Rb2.

////////////////////

large

4.c. As a result, the voltage drop across Rb2 keeps Q2 ( ) biased.

////////////////////

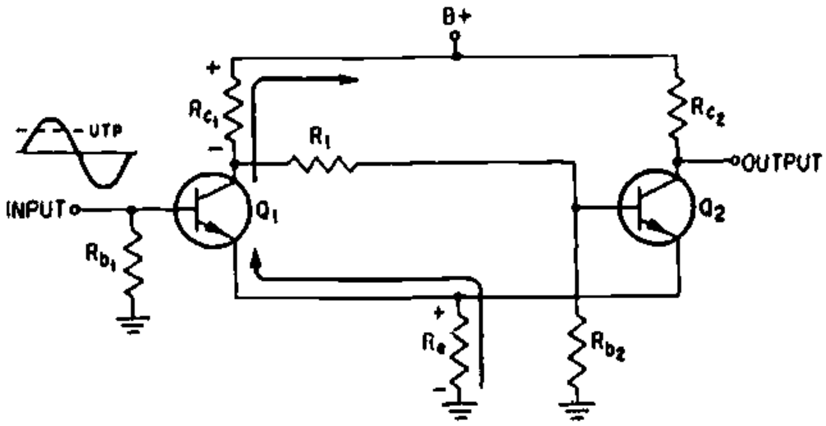
forward

4.d. The circuit remains in this stable state until an input signal overcomes the ( ) bias on Q1.

////////////////////

reverse

5.a.



The UTP is a point at which the input signal overcomes the voltage across (   ).

/////////////////////

Re

5.b. When the input signal reaches the UTP, (   ) conducts.

/////////////////////

Q1

5.c. When Q1 conducts, its collector voltage (   ).

/////////////////////

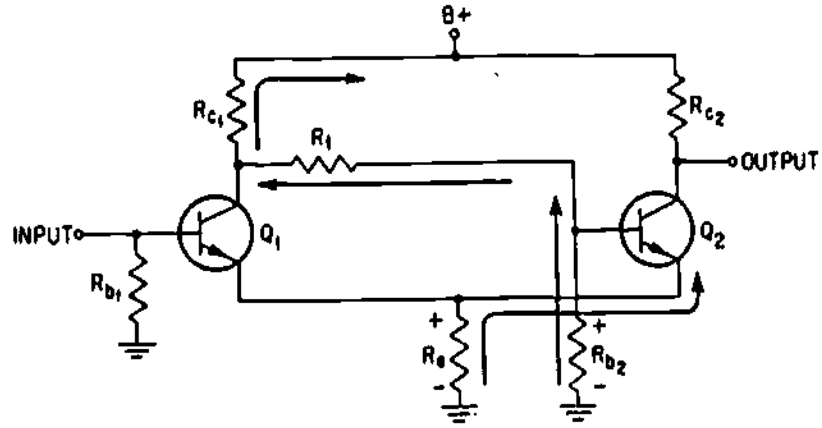
decreases

5.d. This causes the potential applied to R1 and Rb2 to go (   ).

/////////////////////

down

6.a.



The smaller drop across Rb2 ( ) the forward bias of Q2.

////////////////////

decreases

6.b. As a result, the conduction of Q2 goes ( ).

////////////////////

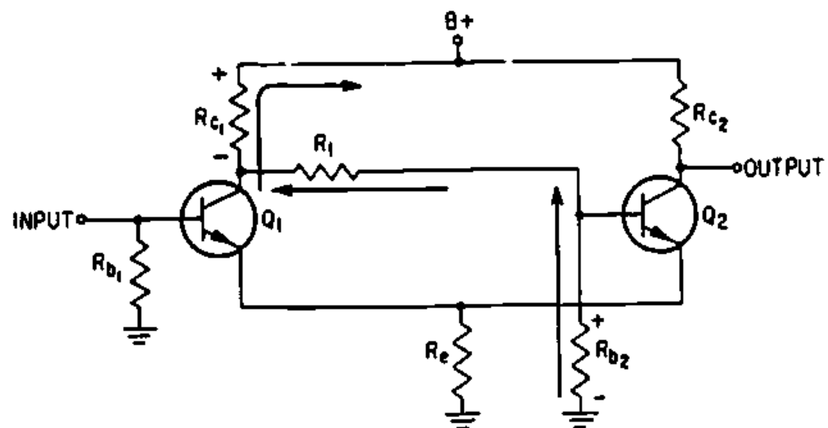
down

6.c. Therefore, the voltage drop across Re becomes (larger/smaller).

////////////////////

smaller

7.a.



The smaller drop across Re causes Q1 to conduct (more/less).

////////////////////

more

7.b. When the conduction of Q1 goes up, its collector voltage goes ( ).

////////////////////

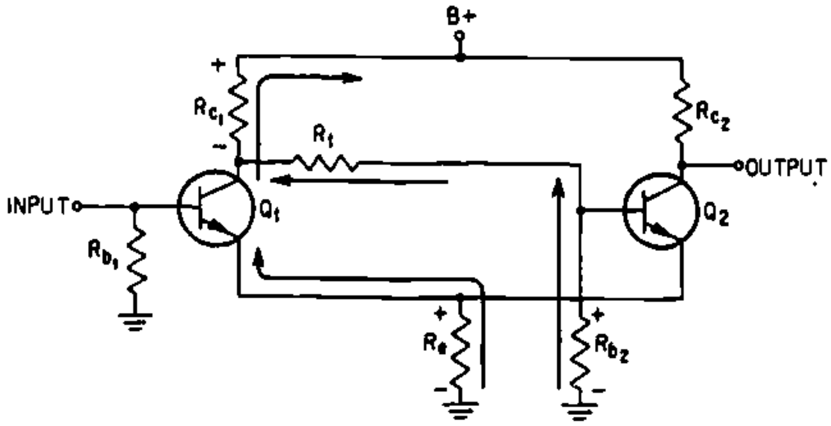
down

7.c. This causes the potential applied to R1 and Rb2 to ( ).

////////////////////

decrease

8.a.



The drop across Rb2 becomes smaller than the drop across ( ).

////////////////////

Re

8.b. This ( ) biases Q2, driving it to ( ).

////////////////////

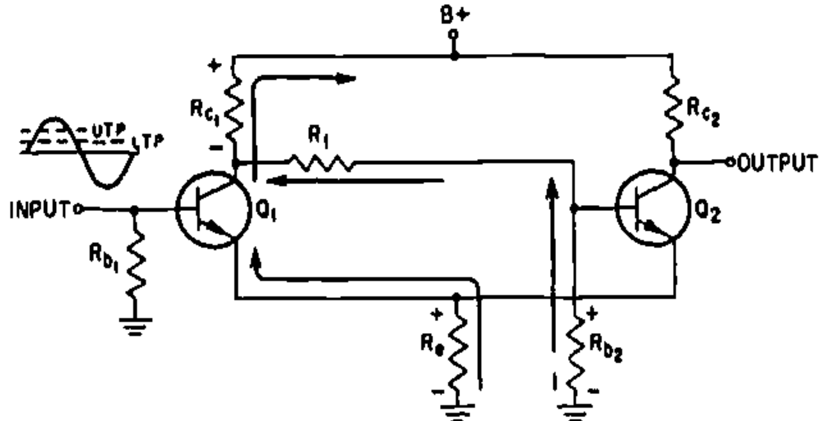
reverse cutoff

8.c. The circuit remains in this state as long as the input signal is sufficiently positive. When the signal drops enough, ( ) will be cut off.

////////////////////

Q1

9.a.



When the input signal reaches the LTP, the conduction of Q1 ( ).

////////////////////

decreases

9.b. This causes the collector voltage of Q1 to ( ).

////////////////////

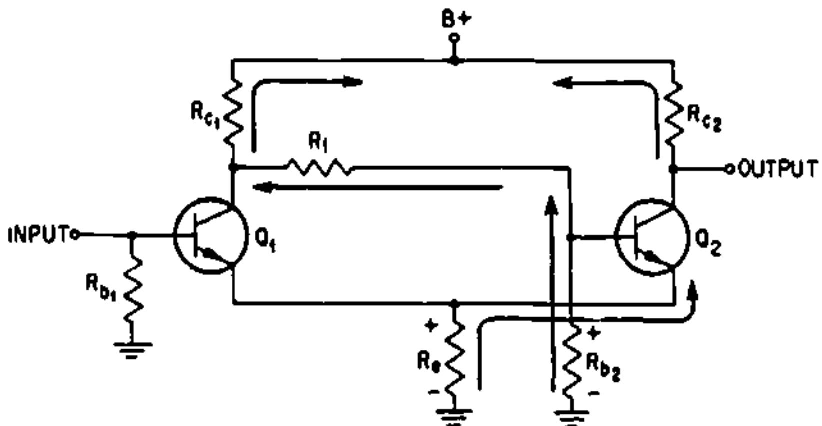
increase

9.c. As a result, the potential applied to R1 and Rb2 goes ( ).

////////////////////

up

10.a.



The increased voltage drop across Rb2 applies ( ) bias to Q2.

////////////////////

forward

10.b. This causes Q2 to (   ).

////////////////////

conduct

10.c. As a result, the voltage drop across Re (   ).

////////////////////

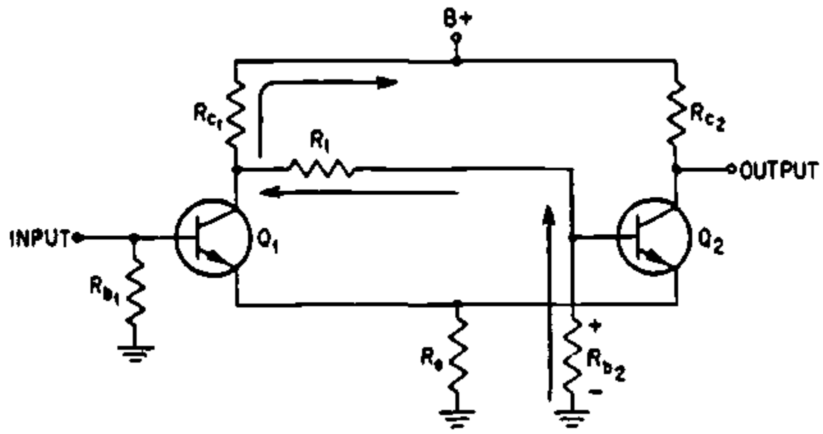
increases

10.d. The increased voltage drop across Re (   ) biases Q1, driving it to (   ).

////////////////////

reverse   cutoff

11.a.



When Q1 cuts off, its collector voltage (   ).

////////////////////

increases

11.b. This causes the potential applied to R1 and Rb2 to go (   ).

////////////////////

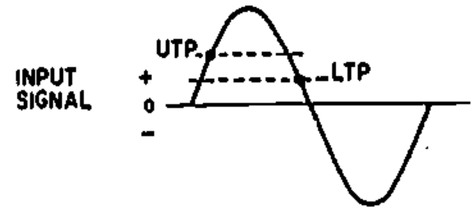
up

11.c. The larger drop across Rb2 (   ) the forward bias of Q2, driving it to (   ).

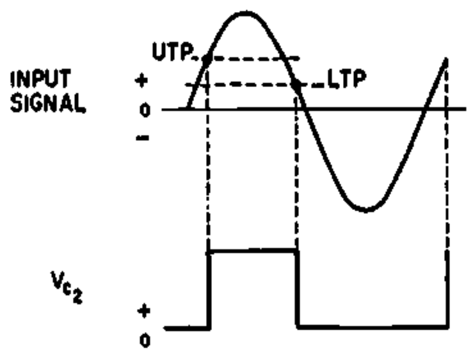
////////////////////

increases   saturation

12.a. Draw the Q2 COLLECTOR WAVESHAPE to coincide with the Q1 base input signal in the proper time relationship.



////////////////////



12.b. What do UTP and LTP mean?

////////////////////

upper trigger point and lower trigger point

12.c. Why is the LTP lower than the UTP?

////////////////////

Since Q1 does not conduct in saturation, the voltage drop across Re during that time is less, and so a lower voltage is needed to allow the drop across Re to cut off Q1.

12.d. How does the waveform at the collector of Q1 differ from that of Q2?

////////////////////

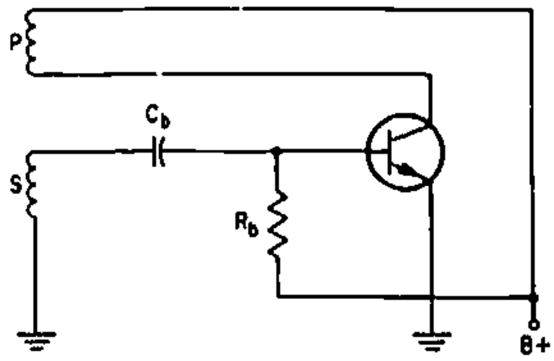
Since Q1 does not conduct in saturation, part of the trigger waveshape is reproduced at its collector. The waveform at the collector of Q2 is a square wave.

12.e. The time between the UTP and the LTP on the trigger signal determines the width of of the output square wave. What two characteristics of the sine wave trigger control this time?

////////////////////

Frequency and amplitude, in that order.

1. BLOCKING OSCILLATOR:

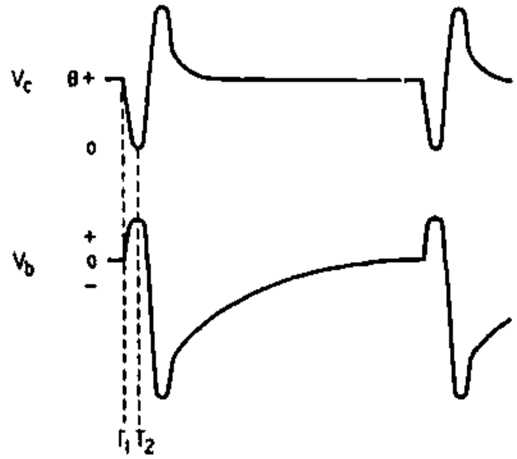


A blocking oscillator is a regenerative circuit that cuts itself off after each conduction cycle. While the transistor conducts, transformer coupling from the collector to the base provides positive feedback until saturation occurs. Then an RC network produces a reverse bias that cuts the transistor off. Current through the transistor remains blocked until the reverse bias produced by the RC network drops to a low value. Then the transistor conducts again to start a new cycle. The oscillating frequency depends on the time constant of the RC network.

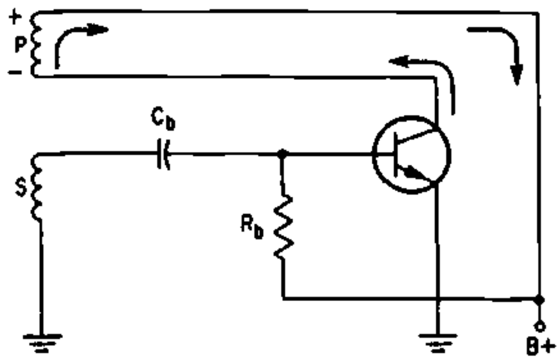
When the circuit is first energized, the transistor starts to conduct. Collector current through the primary develops a magnetic field that induces a voltage in the secondary. The connections are such that the secondary winding supplies a positive voltage, which increases the forward bias on the base-emitter junction; this increases the collector current. The increase in collector current raises the voltage induced in the secondary, which further increases the forward bias. The action is regenerative and continues until the transformer approaches saturation. During the time that the transistor conducts, the secondary winding causes a base current to charge Cb. The path of the charging current is through the emitter-base junction of the transistor. Since this junction is forward biased, it provides a low resistance path so Cb becomes fully charged.

As the collector current continues to increase, the transformer approaches saturation. This causes the voltage induced in the secondary to decrease. When this happens, Cb starts to discharge through Rb. The voltage drop across Rb opposes the forward bias, decreasing collector current. As a result, the transformer field begins to collapse, inducing a voltage of the opposite polarity in the secondary. The voltage now across the secondary is negative and adds to the voltage across Cb. The total negative potential is applied to the base. The transistor becomes reverse biased, and collector current is cut off. The transistor will remain cut off as long as the discharge voltage dropped across Rb overcomes the battery (B+) voltage. As Cb continues to discharge, the negative voltage drop across Rb decreases. The voltage continues to drop until the transistor is again forward biased. Then the transistor conducts, and the cycle is repeated.

2. The diagram shows the collector and base waveshapes. At T1 the transistor conducts, inducing a negative-going voltage across the primary and a positive going voltage across the secondary. At T2 the transformer approaches saturation. This causes the induced voltage to decrease, so that Cb begins to discharge. Collecto: current goes down, inducing a positive going voltage across the primary and a negative going voltage across the secondary. Then as Cb continues to discharge through Rb, the base voltage climbs back to a value that allows the transistor to conduct ag^in.



3.a.



When the circuit is first energized, ( ) current through the transformer induces a voltage in the secondary.

////////////////////

collector

3.b. The voltage induced in the secondary winding applies a ( ) potential to the base.

////////////////////

positive

3.c. This (aids/opposes) the forward bias.

////////////////////

aids

3.d. The higher forward bias ( ) the collector current.

////////////////////

increases

3.e. As a result, the voltage induced in the secondary winding (   ).

////////////////////

increases

3.f. This further increases the (   ) bias.

////////////////////

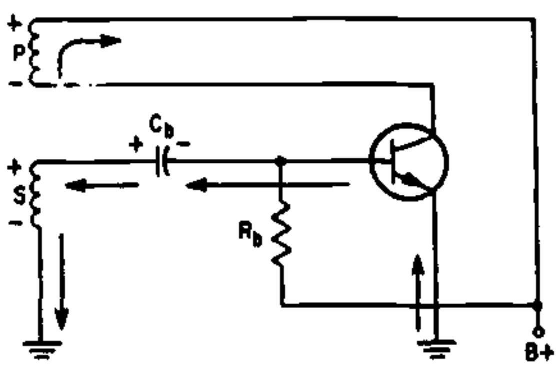
forward

3.g. The regenerative action continues until the transformer approaches (   ).

////////////////////

saturation

4.a.



While the transistor conducts, the positive secondary voltage causes Cb to (   ).

////////////////////

charge

4.b. The charging current flows through the (   ) of the transistor.

////////////////////

emitter-base junction

4.c. The emitter-base junction is (   ) biased.

////////////////////

forward

4.d. This provides a (high/low) resistance path for the charging current.

////////////////////

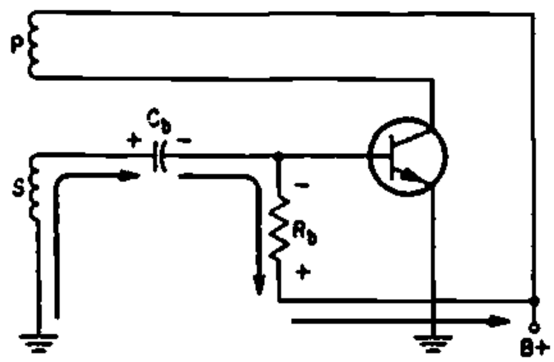
low

4.e. As a result, Cb becomes (partially/fully) charged.

////////////////////

fully

5.a.



As the transformer approaches saturation, the voltage induced in the secondary (   ).

////////////////////

decreases

5.b. This causes Cb to (   ) through Rb.

////////////////////

discharge

5.c. The voltage drop produced across Rb (aids/opposes) the forward bias.

////////////////////

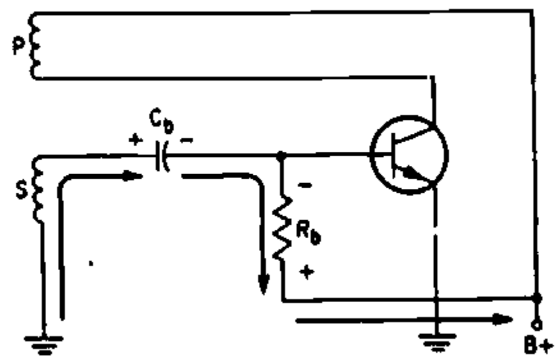
opposes

5.d. As a result, collector current ( ).

////////////////////

decreases

6.a.



The decrease in collector current causes the transformer field to start (expanding/ collapsing).

////////////////////

collapsing

6.b. This induces a ( )-going voltage in the secondary.

////////////////////

negative

6.c. The voltage across the secondary and the voltage across Cb (aid/oppose) each other.

////////////////////

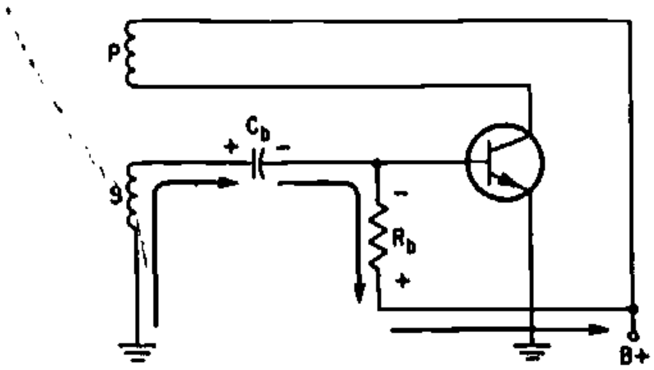
aid

6.d. As a result, the transistor becomes ( ) biased and is driven to ( ).

////////////////////

reverse cutoff

7.a.



As Cb discharges, the voltage drop across Rb (   ).

////////////////////

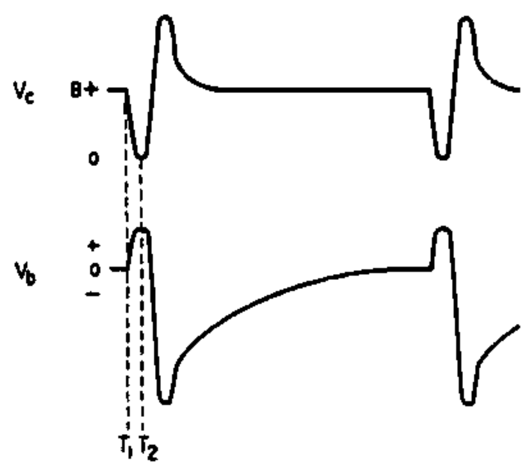
decreases

7.b. The transistor will again conduct when the voltage across Rb is less than the (   ) voltage.

////////////////////

B+

8.a. At T1, the transistor (   ).



////////////////////

conducts

8.b. At T2, the transformer approaches (   ).

//////////////////////

saturation

8.c. This causes the induced voltage to (   ).

//////////////////////

decrease

8.d. As a result, Cb begins to (   ).

//////////////////////

discharge

8.e. Collector current then (   ).

//////////////////////

increases

8.f. This induces a (   ) voltage in the primary and a (   ) voltage in the secondary.

//////////////////////

positive   negative

8.g. As Cb discharges, the base voltage goes toward (   ).

//////////////////////

zero

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VOLUME IV

SEMICONDUCTOR PRINCIPLES

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CONTENTS

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Chapter 1

PRINCIPLES OF P-N JUNCTIONS

1-1. Most of the people employed in the field of electronics are aware of the growing popularity and importance of transistors. Yet, few people, not directly involved, really understand what a transistor is or its basic operation. The transistor is only one subject in the field of electronics that falls under the heading of Solid State or Semiconductor Electronics.

1-2. The purpose of this chapter is to introduce solid state principles as a basis for the study of solid state devices. A knowledge of the atomic structure of matter is a prerequisite for understanding semiconductor theory.

1-3. Atomic Structure

1-4. The structure of an atom is best explained by analyzing the simplest of all atoms, hydrogen. The hydrogen atom has one proton in its nucleus and one electron held in orbit by two counteracting forces. One of these forces is called CENTRIFUGAL force. This force tends to cause the electron to fly outward as it travels around its orbit. This is the same force which causes a car to roll off a highway when rounding a curve at too high a speed. The other force acting on the electron is CENTRIPETAL force. This force tends to pull the electron in toward the nucleus. Centripetal force exists due to the mutual attraction between the positive nucleus and the negative electron. At some radius the two forces exactly balance each other. This balanced condition provides a stable path or ORBIT for the electron.

1-5. The electron in the hydrogen atom has two types of energy: KINETIC (by virtue of its motion) and POTENTIAL (due to its position). The total energy contained by the electron (kinetic plus potential) will determine the radius of the electron orbit. As the radius of the orbit increases, the energy contained by the electron increases.

1-6. Orbits or SHELLS are designated by either a number or a letter, as shown in Figure 1-1. The K, or first shell, is the one closest to the nucleus, and it represents the lowest amount of energy. Going outward from the nucleus, the M shell represents more energy than the L shell; the P shell represents more energy than the O shell, etc.

1-7. These shells are also called PERMISSIBLE ENERGY LEVELS. As the name implies, these are energy levels where electrons may establish orbits. The permissible energy levels are separated by areas called FORBIDDEN ENERGY LEVELS. Quantum physics theory states that an electron cannot remain in the space between permissible energy levels. Therefore, every electron orbiting a nucleus must orbit in a permissible energy level. The shells or permissible energy levels of an atom exist whether they are occupied by an electron or not. Even though hydrogen has only one electron in the K shell, the other shells still exist. The application of external energy (in the form of

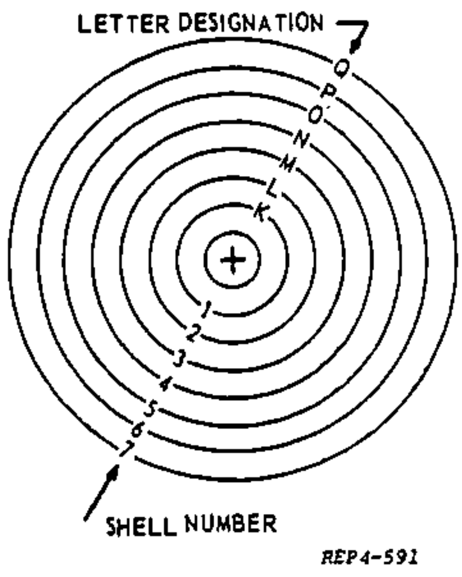

Figure 1-1. Shell Designation

heat, light, etc.) to a hydrogen atom will cause the electron to jump to one of the high permissible energy levels. When the external energy is removed, the electron will return to the K shell. Electrons try to return to the lowest energy level possible.

1-8. Figure 1-2 uses an energy level diagram to illustrate the position of the shells in relation to the nucleus. The first shell, which is closest to the nucleus, represents the next higher energy level, and so forth. An orbiting electron must exist at one of the permissible energy levels, since it cannot remain in the forbidden energy levels or bands.

1-9. The electrons in the outermost shell of an atom are the ones which enter into chemical or electrical combinations with other atoms. These electrons are called VALENCE ELECTRONS, and the outermost shell that contains electrons is called the VALENCE SHELL.

1-10. The ATOMIC NUMBER of an element represents the total number of electrons in the atom. The atomic number of hydrogen is one, indicating that hydrogen has one orbital electron. The electron of hydrogen will be in the first or K shell, and the K shell is also the outermost shell. Therefore, the K shell of hydrogen is the valence shell.

1-11. The atomic number of germanium (which is a very common element used in the manufacture of semiconductors) is 32.

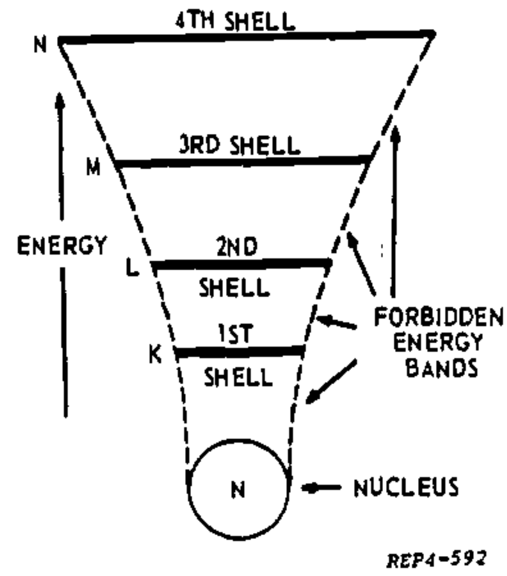

Figure 1-2. Energy Level Diagram of Shells

Silicon, another very common element used in semiconductors, has an atomic number of 14. A silicon atom is illustrated in Figure 1-3A, and a germanium atom is illustrated in Figure 1-3B. The 32 electrons in the germanium atom are distributed in the following manner:

K shell filled with 2 electrons

L shell filled with 8 electrons

M shell filled with 18 electrons

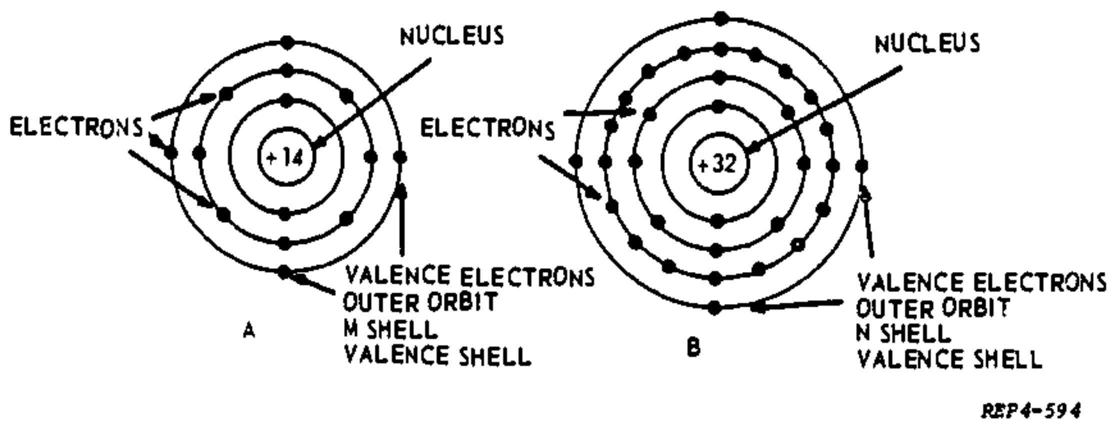

Figure 1-3. Pictorial Diagrams of Atoms

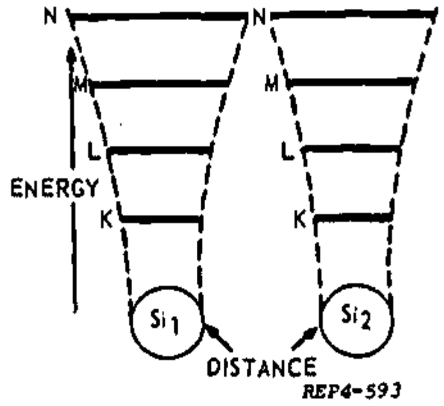

Figure 1-4. Isolated Silicon Atoms (Energy Level Diagrams)

The four remaining electrons are in the N shell, which is the outermost shell. The four electrons in the outermost shell are valence electrons. Notice there are less electrons in the silicon atom, but the manner in which they are distributed is similar.

When the outermost (valence) shell of an atom contains eight electrons, the atom is STABLE and does not attempt to gain or lose electrons. Examples of stable elements that have eight electrons in the valence shell are neon, argon, and krypton. Further, no atom will contain more than eight electrons in the outermost shell.

1-12. Energy Bands

1-13. When atoms are brought close together, there is an interaction between the individual energy levels of the atoms. Figure 1-4 illustrates the energy level of two silicon atoms (atomic number 14) that are separated by a distance large enough to prevent the shells from overlapping. Figure 1-5 illustrates the result when the atoms are moved closer together so that the valence shells overlap. Now, the valence shells of the two atoms act as a single VALENCE BAND. Only the outermost shell (M) has been affected; the inner shells (K and L) retain the individual energy levels of the separate atoms. As more and more atoms are brought together to form a piece of silicon, the

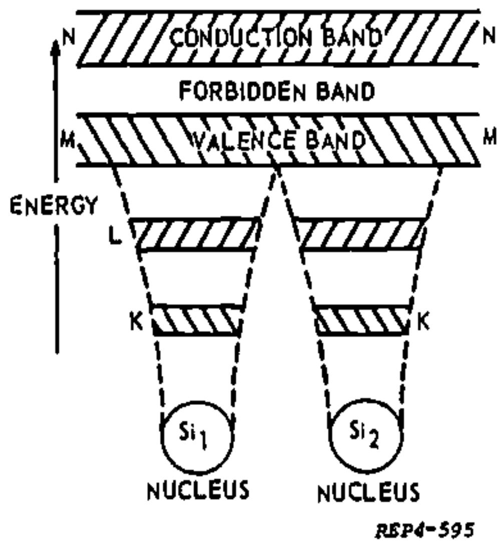

Figure 1-5. Energy Level Interaction of Silicon Atoms

valence shell energy levels continue to interact until they form a solid permissible energy level. This is called the valence band.

1-14. Recall that energy levels exist whether they are occupied by electrons or not. These unoccupied energy levels also combine when brought together with other atoms. Even though the N shells of the silicon atoms are unoccupied they will interact when brought together, forming a band of permissible energy. This is called the CONDUCTION BAND. The conduction band and the valence band are separated by the FORBIDDEN BAND. See Figure 1-5.

1-15. The electrons in the valence band are under the influence of the nucleus. Application of external energy can elevate a valence band electron to the conduction band. The applied energy must be sufficient to move the electron all the way across the forbidden band. The valence electrons will never go halfway and stop. When an electron reaches the conduction band it is considered to be free from the influence of the nucleus. It is now called a FREE ELECTRON.

1-16. Substances that have a large number of free electrons are called CONDUCTORS. Copper wire is a good conductor because it

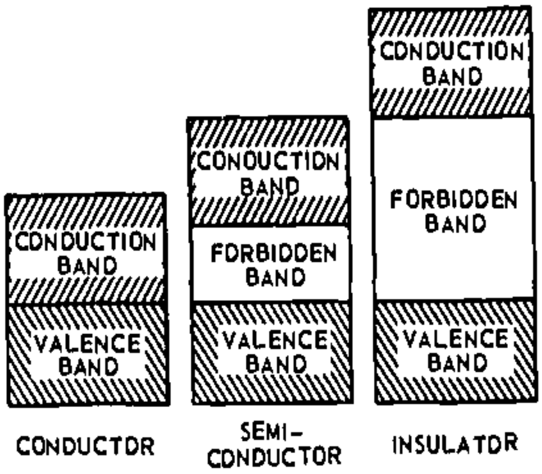

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Figure 1-6. Energy Diagrams for Conductor, Semiconductor, and Insulator

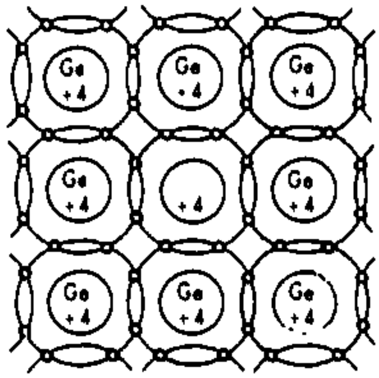

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Figure 1-7. Arrangement of Germanium Atoms in a Crystal

has many free electrons. The greater the number of free electrons, the better the conductor. In contrast to good conductors, some substances have very few free electrons, such as rubber, glass, and dry wood. Substances with few free electrons are called poor conductors or INSULATORS. Actually, there is no sharp dividing line between conductors and insulators, since free electrons exist to some extent in all matter. Substances between conductors and insulators are called SEMICONDUCTORS, and they are of prime importance in the study of solid state devices.

1-17. Energy is required to elevate a valence electron into the conduction band. The amount of energy required to elevate the electron determines whether the element is a conductor, an insulator, or a semiconductor. The energy level diagrams of a conductor, shown in Figure 1-6, show the very narrow forbidden band. Only a very small amount of energy is needed to cause the electrons to move into the conduction band. On the other hand, the distance between the conduction band and the valence band of an insulator is very wide. A wide forbidden band means that it takes a large amount of energy to free an electron. The width of the forbidden band of semiconductor material is between the extremes of the conductor and the insulator. For instance, the forbidden band of germanium is about one-tenth that of a diamond crystal insulator. Therefore, the energy required to elevate an electron to the conduction band of a semi-conductor material is less than that required for an insulator, but more than that required for a conductor.

1-18. Covalent Bonding

1-19. Germanium and silicon crystals are solid substances in which the atoms or molecules are arranged in definite repeating patterns. Figure 1-7 shows how atoms of germanium align themselves when a piece of germanium crystal is formed. A germanium atom has four valence electrons. To become stable, it must have a total of eight electrons in the valence shell. To accomplish this, each germanium atom aligns itself equally between its neighbor atoms. This arrangement allows each atom to share its valence electrons with neighboring atoms. Figure 1-7 shows the result of this alignment, which is called a LATTICE STRUCTURE. Notice that each germanium atom appears to have eight electrons in its outer shell. This sharing of the electrons is referred to as COVALENT BONDING. The covalent bonding of the germanium atoms makes the crystal stable, and is the force that holds crystal together.

1-20. Figure 1-8 illustrates covalent bonding in a pure germanium crystal. The center atom shares one electron with each of the four neighbor atoms. Thus, the center atom

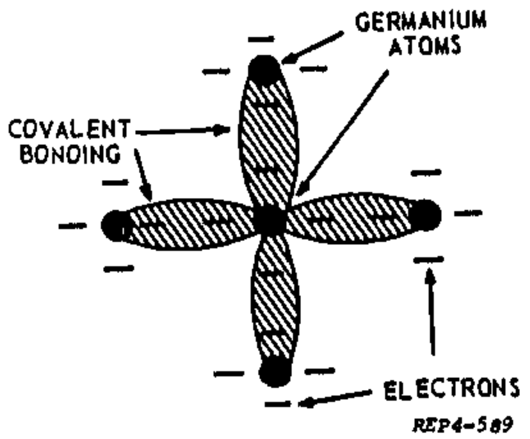


Figure 1-8. Pure Germanium Crystal

"sees" its own four electrons plus one each from the four neighbors, or a total of eight. The shaded area between atoms indicates the covalent bonding or electron pair bonding between atoms.

1-21. As mentioned before, a semiconductor has characteristics between those of a conductor and those of an insulator. The electrons in the outer shell of the atoms of a semiconductor can be set free when enough external energy is applied. When electrons are freed, the material acquires some of the properties of a conductor. The heat contained by a pure germanium or silicon crystal at room temperature is sufficient to cause a few of the valence electrons to break their covalent bonds and to be elevated to the conduction band. This is illustrated by energy level diagram in Figure 1-9. Every electron elevated to the conduction band leaves a vacancy in the valence band structure. This vacancy is termed a "HOLE" and acts like a mobile POSITIVE charge equal and opposite to the electron's negative charge. The breaking of a covalent bond that produces a free electron and a hole is called the GENERATION of an ELECTRON-HOLE PAIR.

1-22. If a pure (intrinsic) crystal of germanium or silicon, with broken covalent bonds, is subjected to a voltage, two kinds of current will flow. The free electrons move through the crystal in the conduction band from negative to positive, constituting ELECTRON CURRENT FLOW. The second current is HOLE FLOW in the valence band. Hole flow depends on the movement or shifting of valence electrons from one covalent bond to another. As a valence electron from a neighbor atom moves in to fill a hole, the hole appears in the neighbor atom. Thus, holes seem to move in a direction OPPOSITE to that of electron flow, or they flow from positive to negative. It is important to remember that holes move only in the valence band. Therefore, current flow in a semiconductor can be either by ELECTRON FLOW or HOLE FLOW.

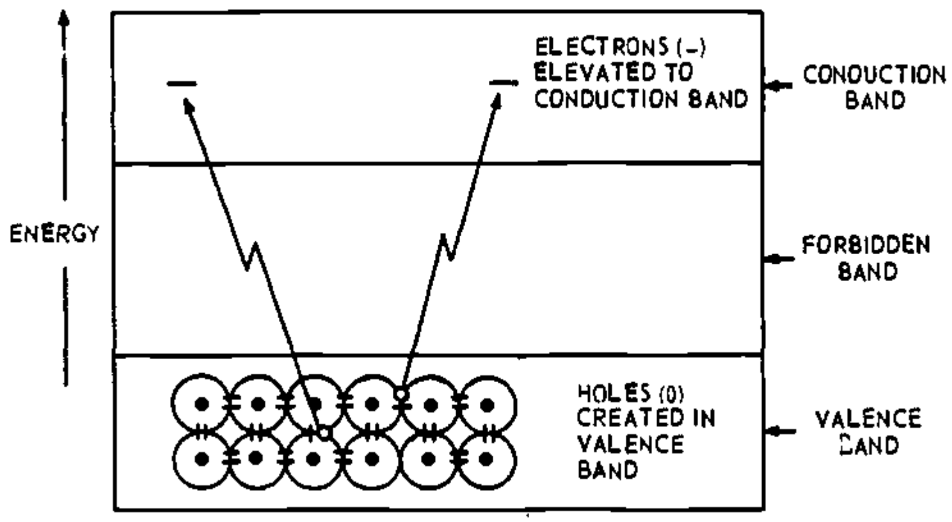


Figure 1-9. Electron-Hole Pair Generation (Energy Level Diagram)

1-23. Crystal With Impurities

1-24. Pure INTRINSIC germanium and silicon crystals are of no use as a semiconductor device because of the small number of current carriers available. However, when certain impurities are added to the crystal the number of carriers can be increased to obtain a useful current. This process of adding impurities to the crystal structure is called DOPING. The added impurities create either an excess of electrons or an excess of holes, depending on the type of impurity added. Once the impurity has been added, the crystal is called EXTRINSIC.

1-25. When arsenic is added to germanium, the arsenic atom will form covalent bonds with the germanium atoms. Figure 1-10 illustrates an arsenic atom (As) in a germanium crystal structure. The arsenic atom has five valence electrons in its outer shell, but uses only four of them to form covalent bonds in the valence band with the germanium atoms. This leaves one electron that will go into the conduction band and become a free electron. This impurity donates one electron to increase the number of free electrons without increasing the number of holes. Because the impurity donated free electrons to the semiconductor material it is often referred to as a DONOR impurity. The resulting material conducts by electron movement and is called NEGATIVE-CARRIER or N-TYPE semiconductor material. Other donor impurities are phosphorous, antimony, and bismuth. They also have five valence electrons. The amount of the impurity added is very small; it is on the order of one atom of impurity to 10 million atoms of germanium. The more impurities added, the more free electrons in the crystal.

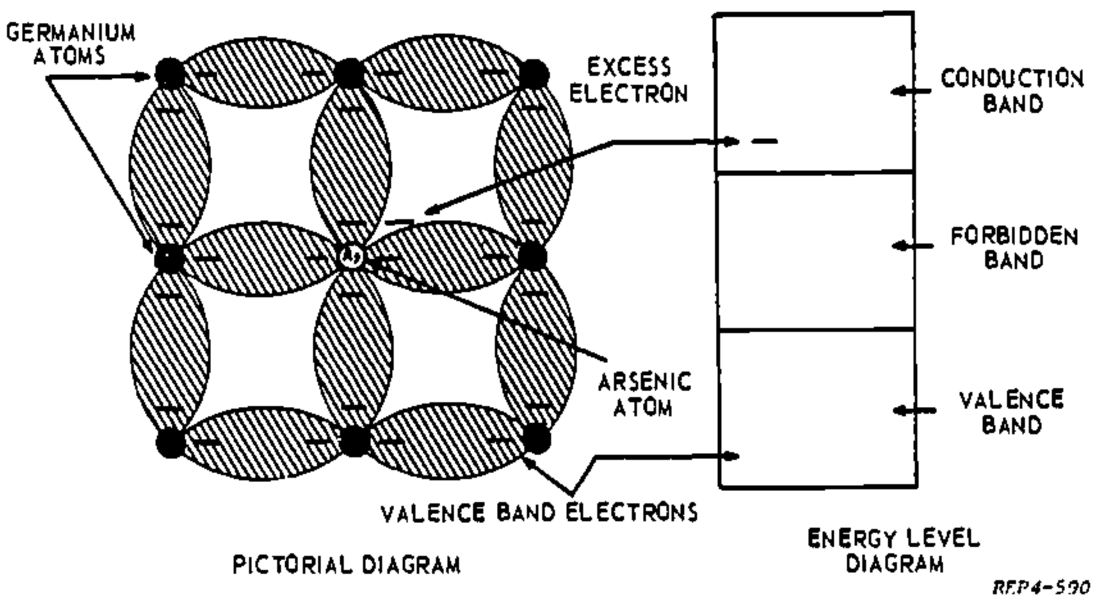


Figure 1-10. Donor Impurity

1-26. An impurity having three valence electrons can be added to pure germanium to "dope" the material. Figure 1-11 shows a germanium crystal with indium (In) added as the impurity. Indium has three valence electrons, therefore it has one electron less than it needs to form all the covalent bonds with the four neighboring atoms. Therefore, an incomplete covalent bond (hole) is created. Because this impurity created a hole which will accept one electron to complete the covalent bond, it is called an ACCEPTOR IMPURITY. Acceptor impurities are added to a crystal to increase the number of holes without increasing the number of free electrons. The resulting material conducts by hole movement and is called POSITIVE-CARRIER or P-TYPE semiconductor material. Other available acceptor (three valent electron) impurities that are used as dopants are gallium, boron, and aluminum. When external energy (heat, light, voltage) releases an electron favorably close to the impurity atom, the acceptor atom will capture or "accept" the electron. This capture occurs as a result of a natural tendency of atom to form complete covalent bonds. The acceptor atom thus "stores" an electron from the valence band structure of the crystal. The instant a valence electron leaves the bonding structure for STORAGE, a hole is CREATED in the valence band. Thus, a hole is actually a positive mobile charge and exists in the valence band, as shown in Figure 1-11.

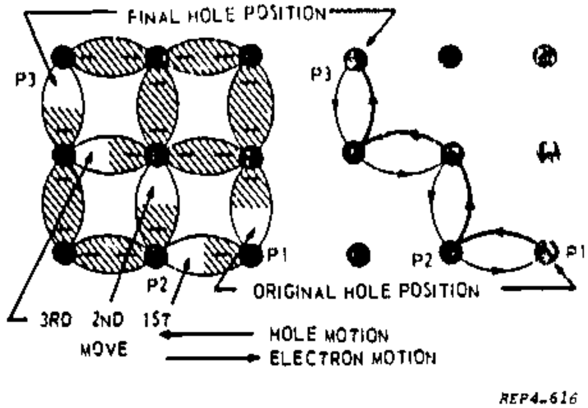


Figure 1-12. Hole Movement Through Crystal

1-27. Figure 1-12 illustrates the movement of a hole through a crystal. The original position of the hole is at P1. One of the valence electrons from P2 moves over and

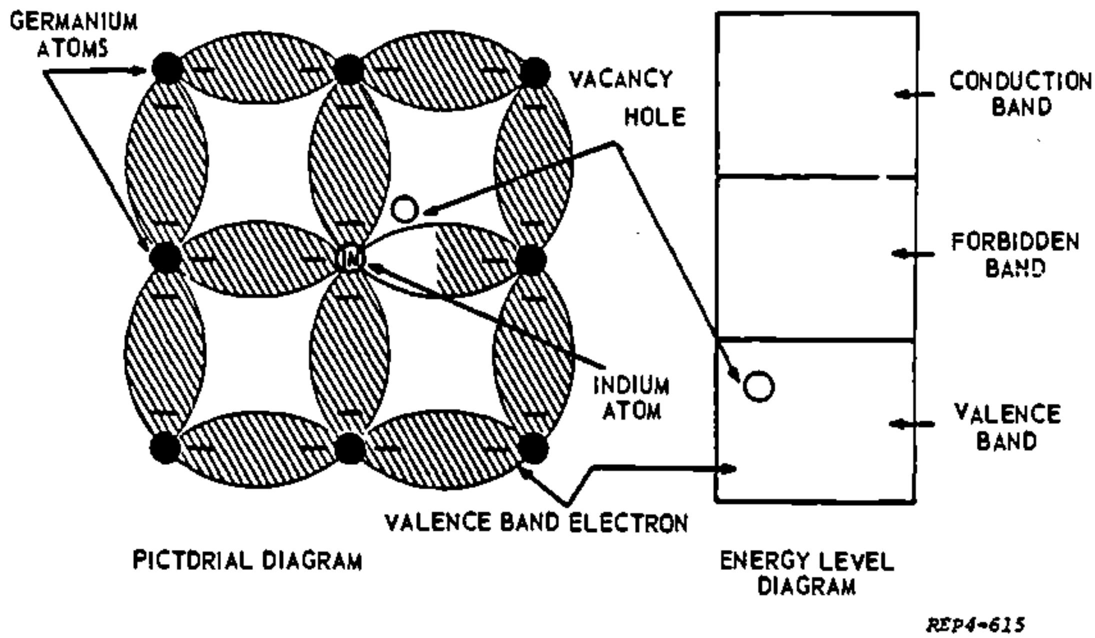


Figure 1-11. Acceptor Impurity

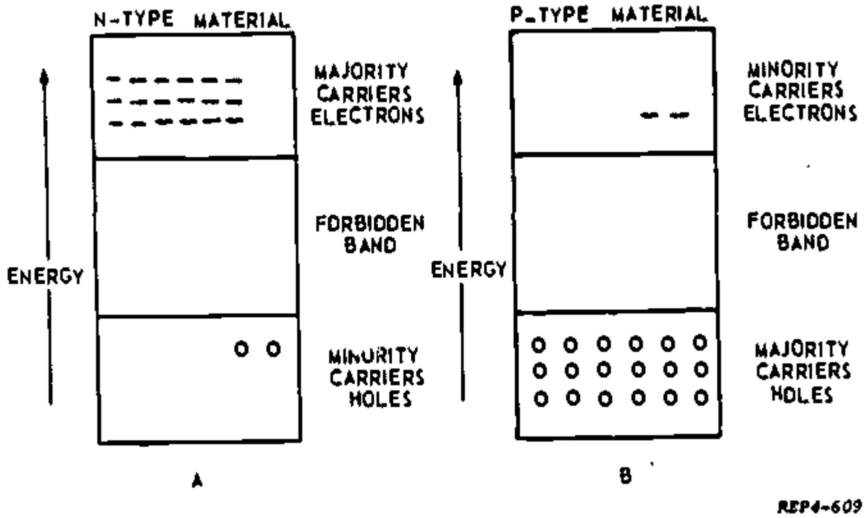


Figure 1-13. Majority Vs Minority Carrier (Energy Level Diagram)

fills the hole at P1. In moving to fill the hole, the electron leaves a hole at P2. Thus, the hole has moved from P1 to P2. The above action repeats as the hole moves through the valence structure of the crystal.

1-28. Current Carriers in N- and P-Type Materials

1-29. Both holes and electrons are current "carriers." The holes are positive carriers, and the electrons are negative carriers. The carriers produced by doping are referred to as MAJORITY CARRIERS. In the N-type material, electrons are the majority carriers and they are in the conduction band. In the P-type material, holes are the majority carriers and they are in the valence band. When energy is gained by the electrons in the crystal structure of either the N- or the P-type materials, the electron can break its bond. This electron will go into the conduction band. The electron will add to the majority carriers electrons in the conduction band. The hole created in the valence band is referred to as a MINORITY CARRIER. In the P-type material, the electron which breaks its bond and goes into the conduction band is referred to as the MINORITY CARRIER. The hole created is in the valence band and adds to the majority carriers (holes). The number of minority carriers in both the N- and P-type materials is small when compared to the number of majority current carriers. As you recall from a previous discussion, this creation of an electron and a hole (electron-hole pair generation) is due to the amount of energy applied to the crystal. Therefore, the greater the amount of energy, the greater the number of minority and majority carriers. This energy is generally in the form of heat. Figure 1-13 illustrates the majority and minority carriers of an energy level diagram of N- and P-type material.

1-30. Current Flow in N-Type Material

1-31. Current flow in N-type material is illustrated in Figure 1-14. Conduction in

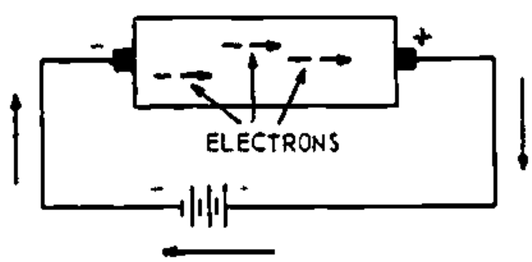


Figure 1-14. Current Flow in N-Type Material

this type of semiconductor is similar to conduction in a copper conductor. That is, the application of voltage across the material will cause the electrons to move through the crystal as shown. The positive potential will attract free electrons in the crystal. Electrons will leave the crystal and flow into the positive terminal of the battery. As an electron leaves the crystal, an electron from the negative terminal of the battery will enter the crystal, thus, completing the current path. Therefore, the majority current carriers in the N-type material (electrons) are repelled by the negative side of the battery and move through the crystal toward the positive.

1-32. Differences exist between the N-type semiconductor and a copper conductor with reference to temperature changes. For example, the semiconductor's ability to conduct increases with temperature. Increasing the temperature will generate more electron-hole pairs, which produce more carrier electrons. This causes increased conductivity, or a lower resistance. In the copper conductor, increasing temperature decreases current flow. Semiconductors have a NEGATIVE TEMPERATURE COEFFICIENT OF RESISTANCE. As temperature increases, resistance decreases.

1-33. Current Flow in P-Type Material

1-34. Current flow through P-type material is illustrated in Figure 1-15. Conduction in this material is by positive carriers (holes). The hole moves from the positive terminal to the negative terminal of the P-type material. Electrons from the external circuit enter the negative terminal and fill holes in the vicinity of the terminal. At the positive terminal, electrons are removed from the covalent bonds, thus creating new holes. This process continues as the steady stream of holes (hole current) moves toward the negative terminal.

1-35. In both N-type and P-type materials, current flow in the external circuit consists of electrons moving out of the negative terminal of the battery and into the positive terminal of the battery. Also, both N-type and P-type materials have a negative temperature coefficient of resistance.

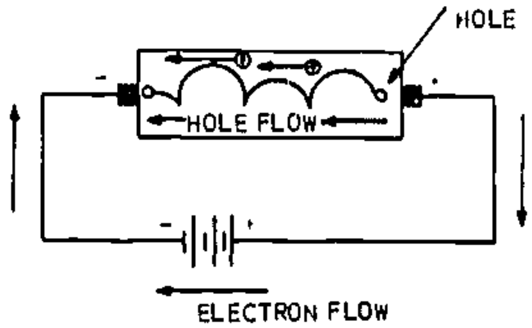


Figure 1-15. Current Flow in P-Type Material

1-36. P-N Junction

1-37. A P-N JUNCTION is manufactured by a chemical process where donor impurities are added to one region of a crystal and acceptor impurities are added to the other region of the crystal. This gives a single crystal with an N region and a P region. The area where the N and P regions meet is called a JUNCTION. Metallic contacts are bonded to the two ends of the crystal. The result is a P-N JUNCTION DIODE (diode refers to two sections or elements). One portion of the crystal is P-type material containing the acceptor impurity. The other portion is N-type material containing the donor impurity. The end contacts are large surfaces that make a good connection with the crystal. Figure 1-16 is a pictorial representation of a P-N junction diode.

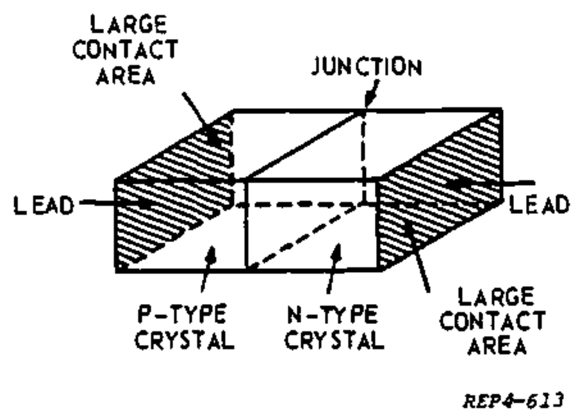


Figure 1-16. P-N Junction Pictorial Diagram

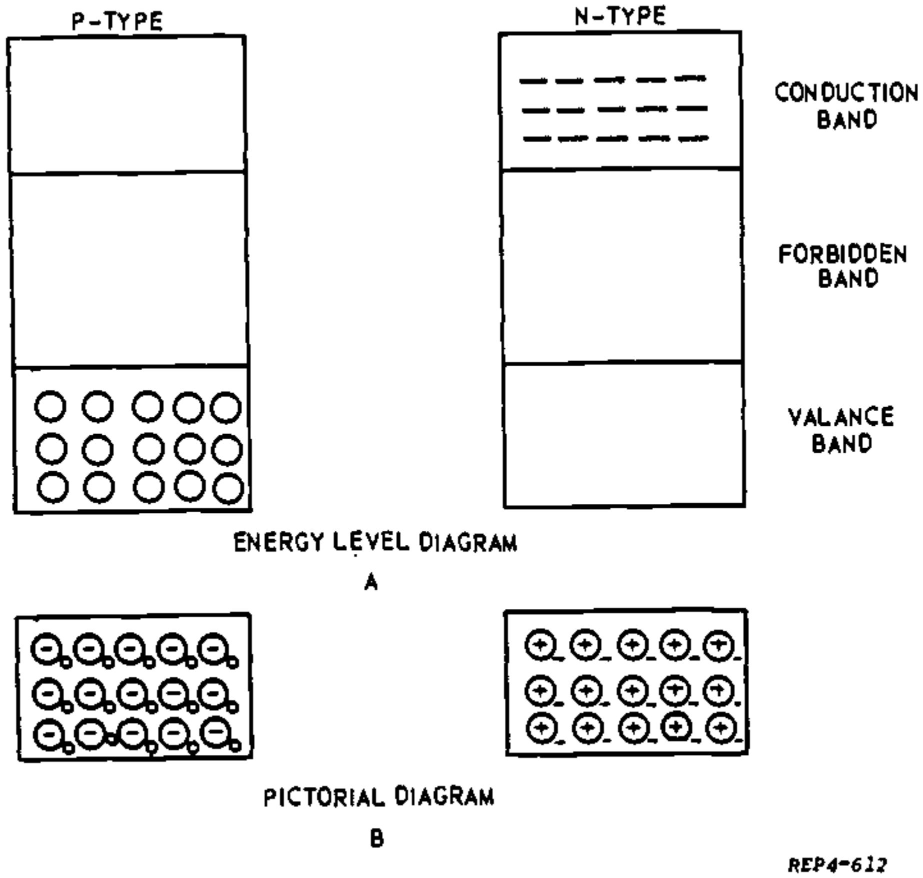


Figure 1-17. Isolated P- and N- Type Materials

1-38. An isolated piece of N-type material is electrically NEUTRAL; that is, for every free electron in the conduction band there is a positively-ionized donor atom in the crystal structure. Thus, while there is an abundance of free negative charges, each one is balanced by a fixed positive charge, and the overall charge of the N-type crystal is zero. Figure 1-17 shows an electrical representation of isolated N- and P-type materials with balanced charges. Figure 1-17A uses energy levels to show the charge carriers while Figure 1-17B is a pictorial diagram showing the charge carriers and the ions. Figure 1-17B represents the even distribution of carriers and ions throughout the crystals. The carriers are placed beside each ion to indicate the balancing of positive and negative charges. During the manufacturing process, when the P-type and N-type materials meet, a very interesting action takes place.

1-39. The electrons in the conduction band of the N-type material "see" the relatively empty conduction band of the P-type material and begin to diffuse (move or spread out) across the junction into the P material. These free electrons lose energy, fall into the valence band and fill some of the holes. At the same time the holes in the valence band of the P material "see" the relatively empty valence band of the N-type material and begin to diffuse across the junction into the N material. The free electrons in the conduction band of the N material will see the free holes as vacancies in the valence band and drop across the forbidden band to fill them. This process is called JUNCTION

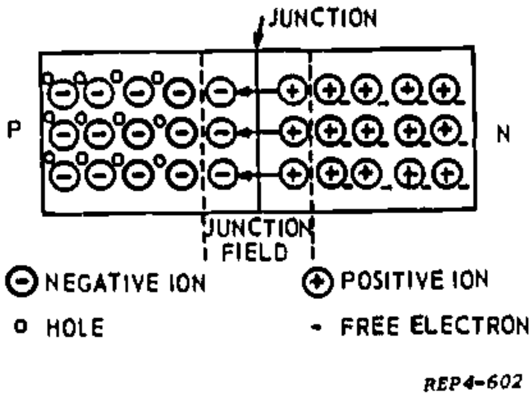


Figure 1-18. P-N Junction Field

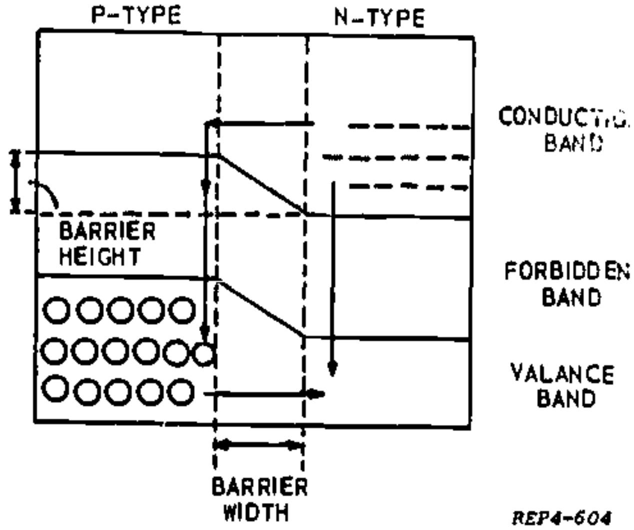


Figure 1-19. Junction Barrier Formation Energy Level Diagram

RECOMBINATION and reduces the number of free electrons and holes in the vicinity of the junction. The loss of an electron from the N-type material will create a positive ion in the N material while the loss of a hole from the P material will create a negative ion in that material.

1-40. These ions are fixed in place in the crystal lattice structure and cannot move. Thus, they make up a layer of fixed charges on the two sides of the junction. On the N side of the junction there is a layer of positively-charged ions; on the P side of the junction there is a layer of negatively-charged ions. An ELECTROSTATIC FIELD is established across the junction between the oppositely-charged ions. Figure 1-18 illustrates the electrostatic field of the junction, called the JUNCTION FIELD. The junction field is shown greatly exaggerated for purposes of explanation. The diffusion of electrons across the junction will continue until the magnitude of the electrostatic field is increased to the point where the electrons no longer have enough energy to overcome it. At this point equilibrium is established and, for all practical purposes, the movement of carriers across the junction ceases. The action just described occurs almost instantly when the junction is formed. Only the carriers in the immediate vicinity of the junction are affected. The carriers throughout the remainder of the N and P material are relatively undisturbed and remain in a balanced condition.

1-41. Figure 1-18 also indicates that there are no mobile carriers within the junction field. Since the junction field has no mobile carriers, it is often called the DEPLETION REGION or JUNCTION BARRIER.

1-42. Another method used to show the junction barrier is illustrated in Figure 1-19. An energy level diagram shows free electrons in the conduction band of the N-type material, and holes in the valence band of the P-type material. The free electrons in the N-type material move across the junction into the conduction band of the P-type material. The holes in the P-type material move across the junction and are filled by electrons from the conduction band of the N-type material. This movement results in junction barrier formation. An energy level diagram shows the barrier to have both height and width. The PHYSICAL DISTANCE from one side of the barrier to the other is referred to as the BARRIER WIDTH. The width of the barrier, with no external potential applied, depends on the amount of doping. The greater the percentage of doping, the narrower the barrier width. The BARRIER HEIGHT is the DIFFERENCE OF POTENTIAL across the depletion region (strength of the junction field). As recombination of electrons and holes continues, the barrier becomes wider and higher.

Equilibrium occurs when the barrier is large enough to prevent further recombination of electrons and holes. In other words, the barrier, or junction field, prevents total recombination.

1-43. Biased P-N Junctions

1-44. An external potential applied to a P-N junction is called BIAS. A battery connected across the P-N junction develops a "bias" across the junction. If the battery is connected so that its voltage OPPOSES the junction field, it will reduce the height and width of the junction barrier and thereby aid current flow through the junction. The junction is then FORWARD BIASED (low resistance direction). If the battery is connected across the junction so that its voltage AIDS the junction field, it will increase the height and width of the junction barrier and thereby oppose current flow through the junction. The junction is then REVERSE BIASED (high resistance direction).

1-45. Forward Bias

1-46. The forward bias connection is illustrated in Figure 1-20. Here the POSITIVE terminal of the bias battery is connected to the P-type material and the NEGATIVE terminal of the battery is connected to the N-type material.

1-47. The positive potential connected to the P-type material repels holes toward the junction. These holes neutralize some of the negative ions at the edge of the junction barrier.

1-48. In the N-type material the negative potential repels electrons toward the junction. These electrons neutralize some of the positive ions at the edge of the junction barrier. Since ions on both sides of the barrier are being neutralized, the barrier will be decreasing in both width and height. Thus, the effect of the battery voltage in the forward bias direction is to reduce the barrier potential across the junction and to allow majority carriers to cross the junction.

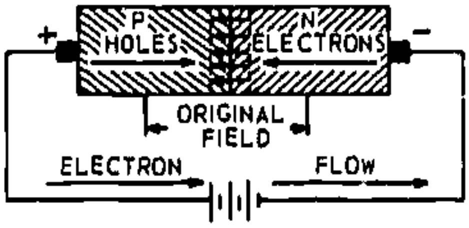


Figure 1-20. Forward Biased P-N Junction

1-49. The current flow and method of conduction in a forward biased P-N junction is as follows: An electron leaves the negative terminal of the battery and moves to the terminal of the N-type material. It enters the N material, where it is the majority carrier, and moves to the edge of the junction barrier. Due to forward bias, the barrier offers less opposition to the electron and it will pass through the depletion region into the P-type material. The electron loses energy in overcoming the opposition of the junction barrier, and upon entering the P material, combines with a hole. The hole was produced when an electron was extracted from the P material by the positive potential of the battery. The created hole moves through the P material toward the junction where it combines with an electron.

1-50. It is important to remember that in the forward biased condition, conduction is by MAJORITY current carriers (holes in the P-type material and electron in the N-type material). Increasing the battery voltage will increase the number of majority carriers arriving at the junction and the current flow increases. If the battery voltage is increased to the point where the barrier is greatly reduced, a heavy current will flow and the junction may be damaged from the resulting heat.

1-51. Figure 1-21 illustrates the effect of forward bias on the height and width of the barrier. With a forward bias voltage across the PN junction, the barrier height and width decrease. This represents a lower resistance and, therefore, more current flow.

348

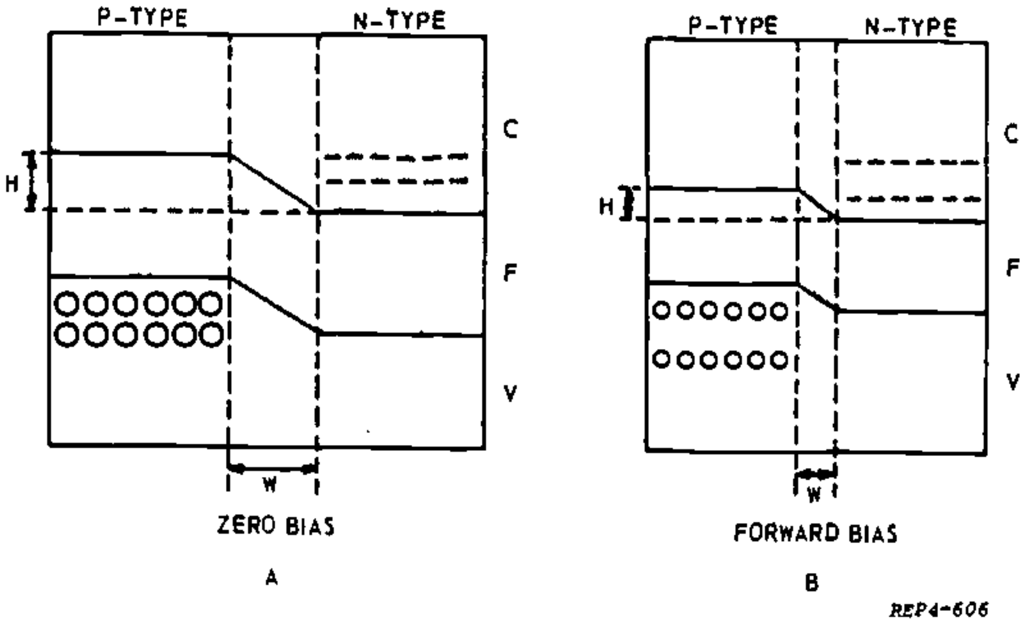


Figure 1-21. Effect of Forward Bias on Barrier Height (H) and Width (W)

1-52. Reverse Bias

1-53. To reverse bias a junction diode, connect the NEGATIVE battery terminal to the P-type material, and the POSITIVE battery terminal to the N-type material. The negative potential attracts the holes away from the edge of the junction barrier on the P side, while the positive potential attracts the electrons away from the edge of the barrier on the N side. This action increases the barrier height and width because there are more negative ions on the P side of the junction, and more positive ions on the N side of the junction. The increase in the number of ions prevents current flow across the junction by majority carriers.

1-54. Figure 1-22 illustrates a reverse-biased P-N junction. Notice that the width of the junction barrier has been increased. The concentration of the mobile carriers at the terminals has left many ions at the edge of the barrier; therefore, the barrier will extend to include these ions.

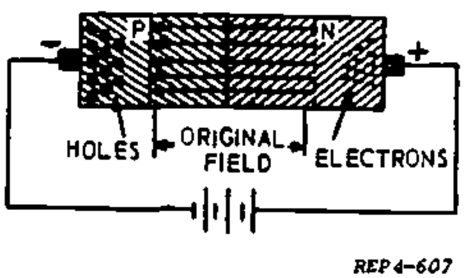


Figure 1-22. Reverse Biased P-N Junction

349

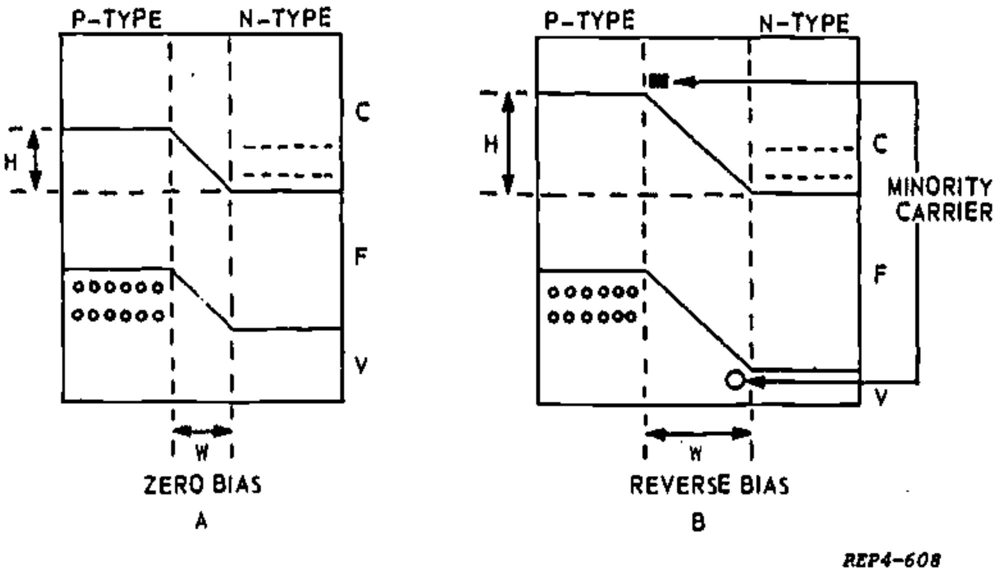


Figure 1-23. Effect of Reverse Bias on Barrier Height (H) and Width (W)

1-55. Figure 1-23 illustrates the effect of reverse bias on the height and width of the barrier. With a reverse-bias voltage across the P-N junction, the barrier height and width increases. This represents a high resistance and no majority current flow.

1-56. The current flow across the barrier is not zero, however, because of minority carriers crossing the junction. As you recall, when the crystal is subjected to an external source of energy (light, heat, etc.), electron-hole pairs are generated. These electron-hole pairs produce minority current carriers. There are minority current carriers in both regions: holes in the N material and electron in the P material. With reverse bias, the electrons in the P-type material are repelled toward the junction by the negative terminal of the battery. As the electron moves across the junction, it will neutralize a positive ion in the N-type material. Similarly, the holes in the N-type material will be repelled by the positive terminal of the battery toward the junction. As the hole crosses the junction, it will neutralize a negative ion in the P-type material. This movement of minority carriers is called MINORITY CURRENT FLOW, because the holes and electrons involved come from the generation of electron-hole pairs in the crystal lattice structure, and not from the addition of impurity atoms.

1-57. Figure 1-24A shows minority current flow on an energy level diagram. It is relatively easy for the electron in the P-type material and the hole in the N-type material to cross the junction, since this movement is aided by the junction field. Figure 1-24B illustrates holes in the N-type material and electrons in the P-type material being REPELLED (by the battery) toward the junction. In both cases these are minority carriers. The junction field aids minority carriers only. Therefore, when the minority carriers reach the junction barrier, they will move easily across the junction.

1-58. Thus, under reverse-bias conditions there will be a small current flow due to minority carriers crossing the junction. This current flow is small at normal operating temperatures. However, as temperature increases, the "minority current" increases, since more electron-hole pairs are generated.

1-59. P-N Junction Symbol and Characteristics

1-60. The schematic symbol of a P-N junction diode is shown in Figure 1-25. The bar represents the CATHODE (N-type material) and the arrow represents the ANODE (P-type material). Electron flow is against the arrow. For clarification,

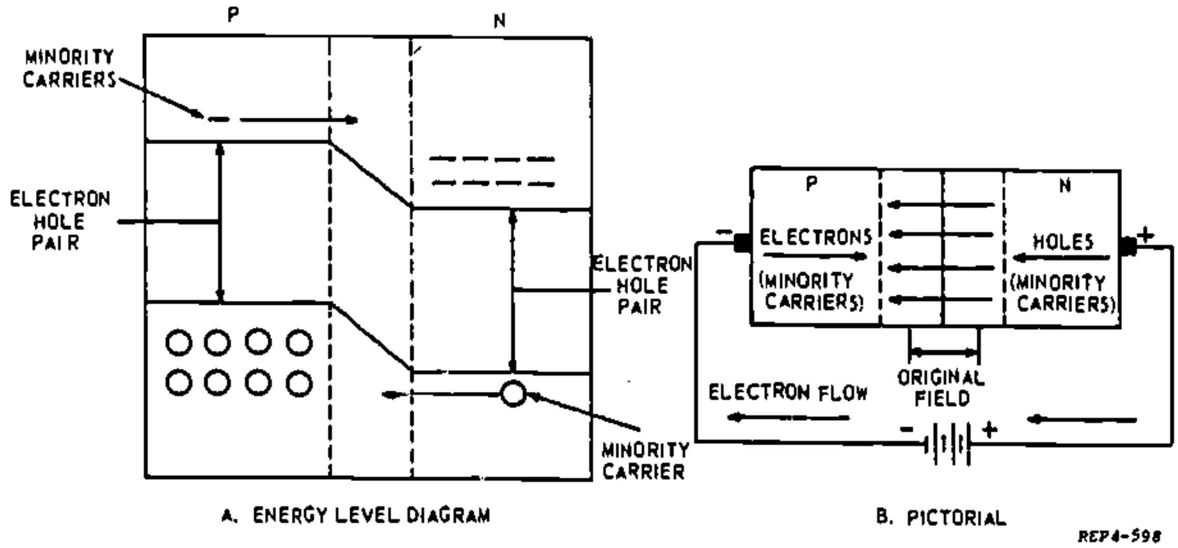


Figure 1-24. Reverse Biased P-N Junction

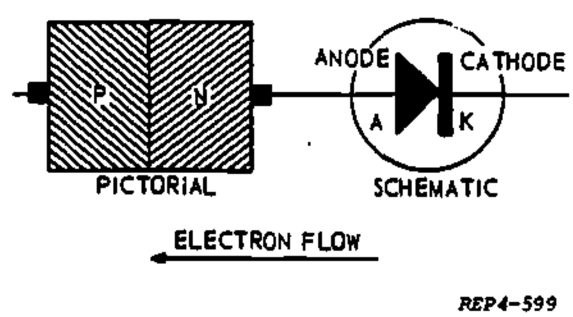


Figure 1-25. P-N Junction Symbols

351

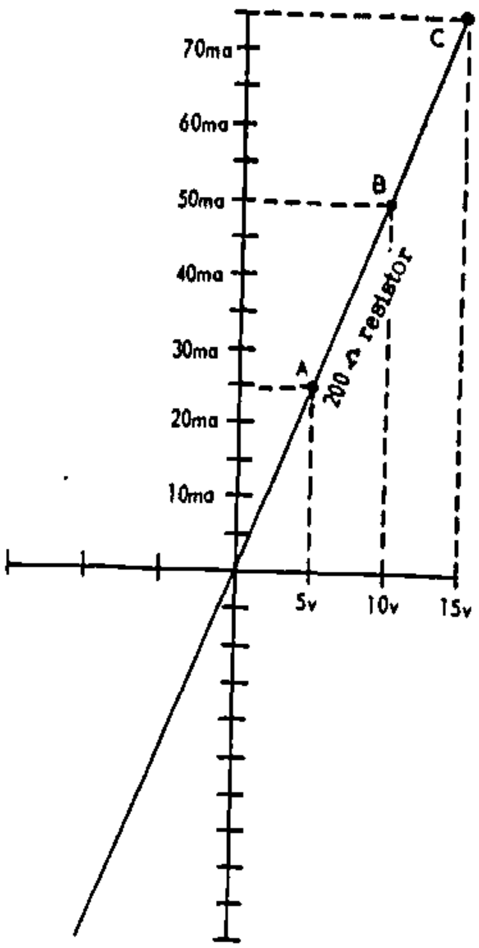


Figure 1-26. Current-Voltage Relations for a 200-Ohm Resistor.

a pictorial diagram of a PN junction is also illustrated.

1-21. A P-N junction diode is a NON-LINEAR device, whereas, a resistor is a LINEAR device. The differences can be seen by plotting the current-voltage relationships of each device and then comparing the result. The chart in Figure 1-26 shows the result of plotting voltage against current for a 200 ohm resistor. Various points can be determined by the formula E = IR or $I = \frac{E}{R}$.

1-62. At point A in Figure 1-26 the voltage applied to the 200 ohm resistor is 5 volts, resulting in 25 mA. of current. At point C, the voltage is 15 volts, and the current has increased to 75 mA. Notice the linear change in current through a resistor with a change in voltage. Tripling the voltage applied results in three times the current flow.

1-63. The voltage-current relationship (characteristic curve) of a P-N junction diode is shown in Figure 1-27. The resistance can be determined from the curve by using the formula $R = \frac{E}{I}$. At point A in Figure 1-27, the forward voltage is 1 volt and the forward current is 5 mA. This represents 200 ohms of resistance (1 volt/5mA. = 200 ohms). At point B, the voltage is 3 volts and the current is 50 mA. This gives 60 ohms of resistance for the diode. Notice that, when the forward bias voltage was tripled (1 volt to 3 volts), the current increased ten times (5 mA. to 50 mA). This illustrates the NONLINEAR relationship between voltage and current in a P-N junction. Note also that resistance decreased from 200 ohms to 60 ohms when forward bias voltage increased.

1-64. The diode conducts very little when reverse biased. At point C in Figure 1-27 the reverse bias voltage is 60 volts and the current is 100 micro amps. The diode has 600 k ohms of resistance, which is very much larger than the resistance of the junction with forward bias. This also indicates the nonlinear characteristics of a P-N diode.

1-65. Notice on the curve at point D the current increases rapidly. This rapid increase in reverse current is called AVALANCHE CURRENT. This avalanche current is caused by excessive reverse bias voltage.

1-66. Structure breakdown occurs when the applied voltage is sufficiently large to cause the covalent bond structure to be broken, causing a large number of electron-hole pairs to be generated. At this point a sharp rise in reverse current occurs. The generation of the new holes and electrons continues

352

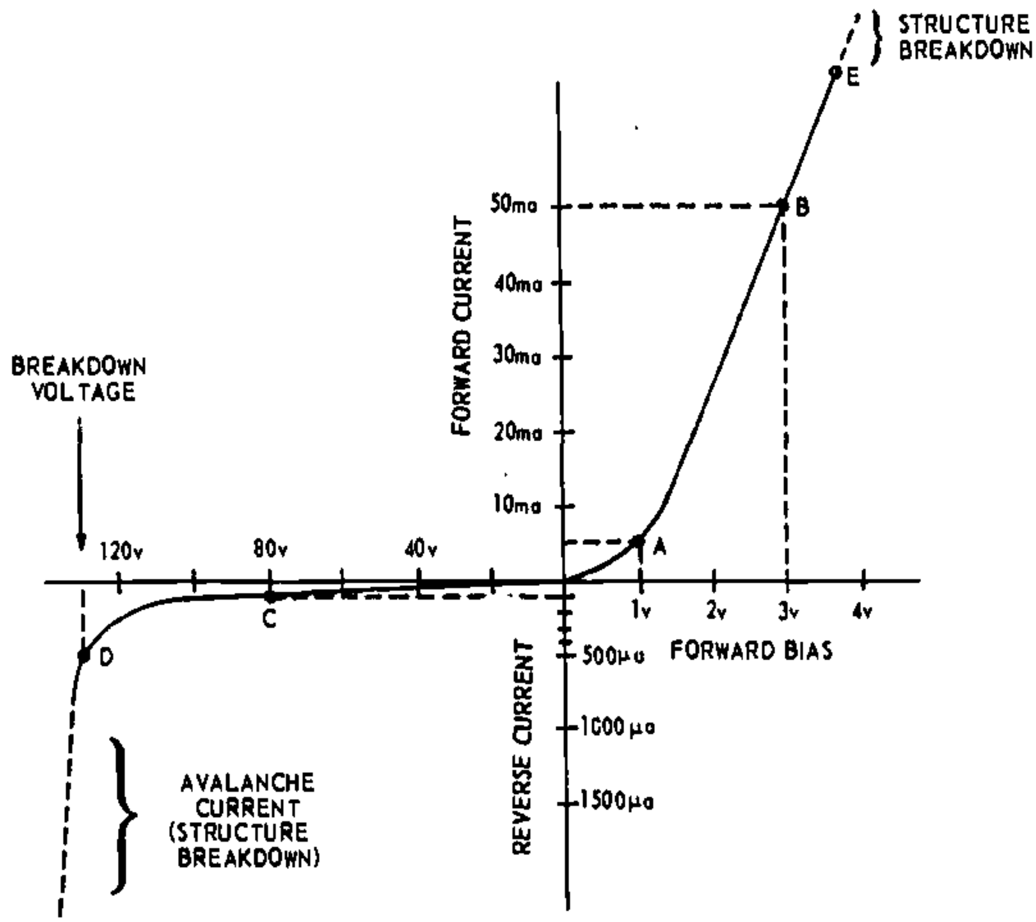


Figure 1-27. Voltage-Current Characteristics of Diodes

to such a point that they have violent collisions with the valence band electrons of the germanium crystal atoms, releasing more and more carriers. Because of the heat generated, the diode will be destroyed.

1-67. The diode can also be destroyed by applying excessive forward bias. Note in Figure 1-27, as forward bias is increased, forward current increases. If this forward current is allowed to become too large, the heat generated by this excessive current will cause structure breakdown. As you recall, any time heat is applied to a P-N junction, electron-hole pairs are generated, which increases current flow. This increase in current generatee more heat and the cycle repeats. This action is referred to as THERMAL RUNAWAY.

1-68. Normal operation of the diode is between points D and E in Figure 1-27. Operating beyond these points will cause structure breakdown and can destroy the diode.

1-69. Many types of semiconductor diodes are available. They vary in size from the size of a pinhead, used in subminiature circuitry, to large 250-ampere diodes used in high power circuits. Some of the typical

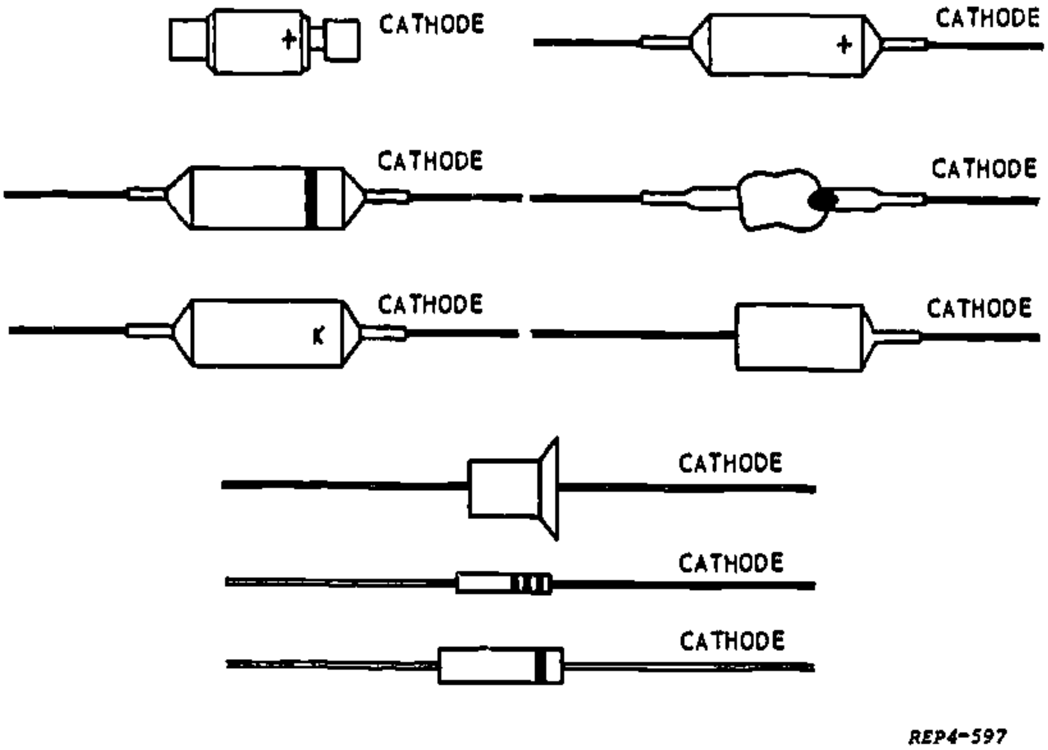


Figure 1-28. Physical Appearance of Semiconductor Diodes

diodes are shown in Figure 1-28. The cathode lead of the diode is identified by a distinctive marking (color dot or band, & sign) or by its unusual shape (raised edge or taper).

1-70. PN Junction Diode Ratings

1-71. P-N junction diodes are generally rated for:

Maximum average forward current.

Peak recurrent forward current.

Maximum surge current.

Peak reverse voltage (PRV).

1-72. Maximum average forward current is usually given at a specified temperature, (usually 25°C), and refers to the maximum amount of average current which can be permitted to flow in the forward direction. If this rating is exceeded, structure breakdown can occur, as illustrated in Figure 1-27 beyond point E.

1-73. Peak recurrent forward current is the maximum peak current which can be permitted to flow in the forward direction in the form of recurring pulses.

1-74. Maximum surge current is the maximum current permitted to flow in the forward direction in the form of non-recurring pulses. Current should not equal this value for more than a few milliseconds.

1-75. Peak reverse voltage (PRV) is one of the most important ratings. PRV indicates the maximum reverse bias voltage which may be applied to a diode without causing structure breakdown (point D in Figure 1-27). All of the above ratings are subject to change with temperature variations. If the operating temperature is above that stated for the ratings, the ratings must be decreased.

Chapter 2

TRANSISTORS

2-1. The transistor is another electronic device that makes use of the flow of current carriers through a semiconductor. We discussed two-element semiconductor diodes, which permit more current to flow in one direction than in the other. The next semiconductor that we will study has three elements and can be used as an amplifier.

2-2. Transistors are semiconductor devices that have three or more electrodes. The term transistor was derived from the words TRANSFER and RESISTOR. There are many different types of transistors with individual characteristics, but the basic theory of operation is the same for all of them.

2-3. This chapter first discusses the construction and operation of the THREE ELEMENT device. Then we show how the transistor can be connected in various circuits and we will discuss the characteristics of each. Finally, we discuss the CURRENT TRANSFER RATIO or control characteristics for each configuration.

2-4. The JUNCTION TRANSISTOR triode (TRIODE meaning three electrodes) has three elements and two P-N junctions. These three elements are: (1) the EMITTER, which gives off or "emits" current carriers (electrons or holes), (2) the BASE, which controls the flow of the current carriers and (3) the COLLECTOR, which collects the current carriers. A metal lead or contact is attached to each element or section, to allow the transistor to be connected to the external circuitry. Transistors are classed as PNP or NPN according to the arrangement of the N and P materials.

2-5. Transistors have two PN junctions. One PN junction is between the emitter and the base (called the EMITTER-BASE or EB junction); the other PN junction is between the collector and the base (called the COLLECTOR-BASE or CB junction). (If you need a review of junction characteristics, refer back to Chapter 1.) Because the junction transistor has 2 PN junctions, it is sometimes called a BIPOLAR device. One type of junction transistor is formed by introducing a thin region of P-type material between two regions of N-type material in a single crystal of germanium or silicon. The transistor so formed is called an NPN transistor. By introducing a thin region of N-type material between two regions of P-type material a PNP transistor is formed.

2-6. The electrostatic fields are established at the junction barriers in the same manner as in the basic PN junction. Figure 2-1 shows a pictorial view of an unbiased NPN transistor, with the ions, carriers (holes and electrons), and junction barrier illustrated.

2-7. In this unbiased transistor, recombination has already occurred, and the junction barriers have been established. The base in Figure 2-1 is formed of P-type material and contains holes. The emitter and collector are both N-type material and contain free electrons.

2-8. An energy level diagram, as shown in Figure 2-2, can also be used to illustrate the junction barriers in a transistor. Recombination between the base and emitter materials results in the formation of the emitter-base junction barrier. The same actions take place between the collector and base materials, forming the collector-base junction barrier.

2-9. For normal operation of a transistor, the following rules apply:

a. The EMITTER-BASE junction is normally FORWARD BIASED.

b. The COLLECTOR-BASE junction is REVERSE BIASED.

2-10. In certain applications, these rules are modified, as will be discussed in a later chapter. Forward bias at the emitter-base junction reduces the size and intensity of the

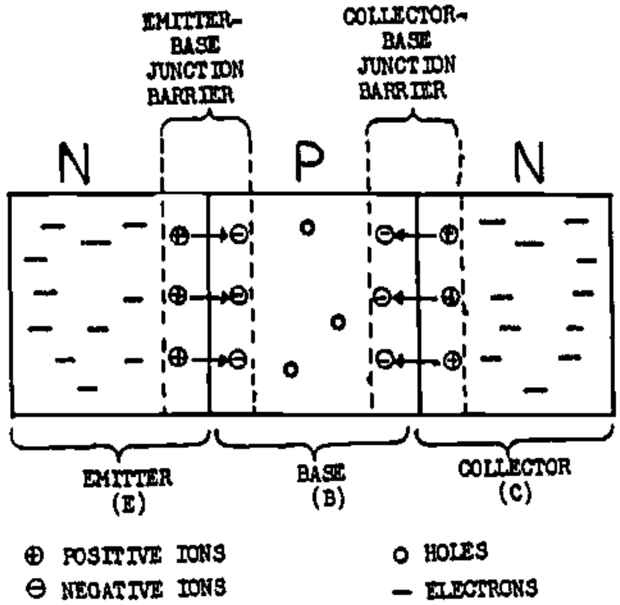


Figure 2-1. Unbiased Junction Transistor

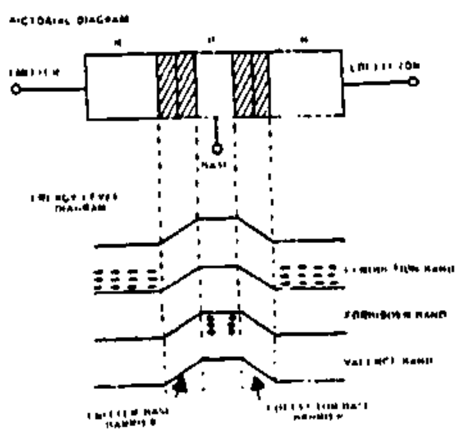
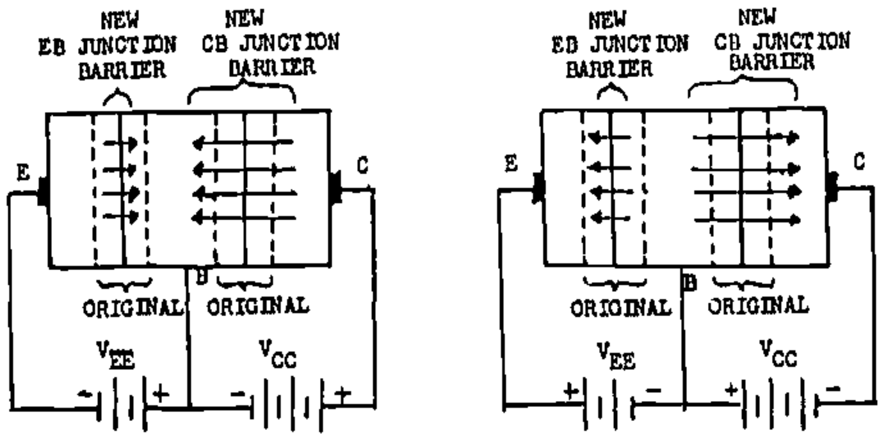


Figure 2-2. Pictorial and Energy Level Diagram, No-Bias NPN



A. NPN Transistor

B. PNP Transistor

Figure 2-3. Biased Transistors

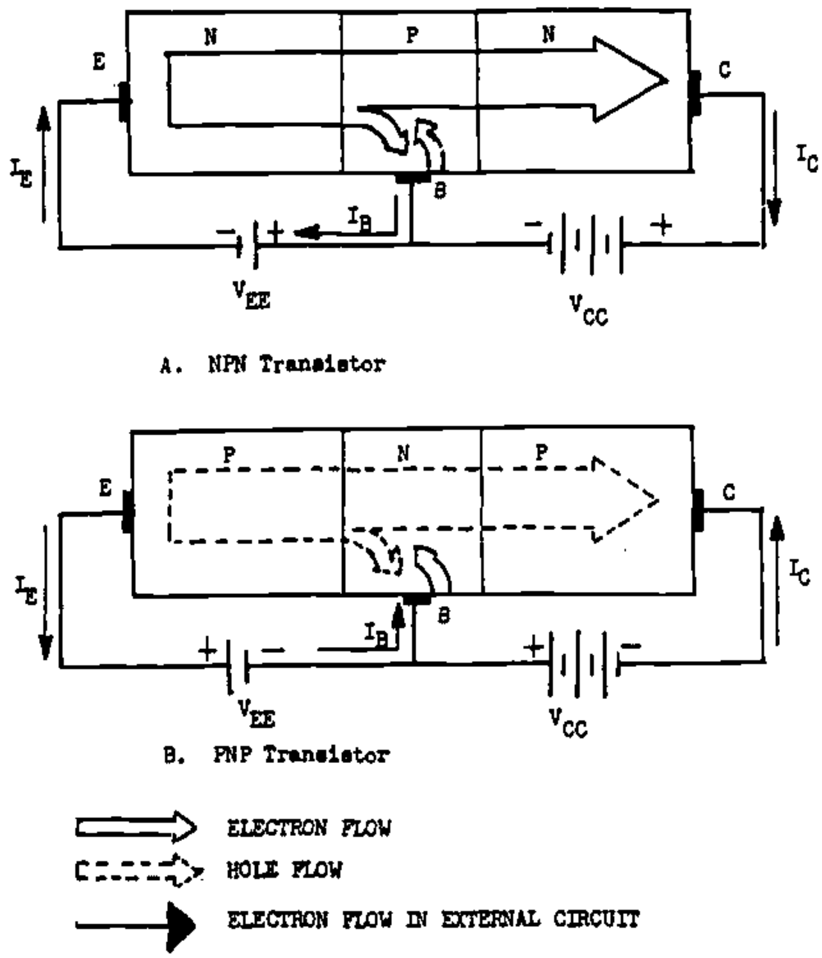


Figure 2-4. Current Paths of NPN and PNP Transistors

emitter-base junction barrier. Therefore, the emitter-base junction has a low resistance due to the forward bias. Reverse bias at the CB junction increases the size of the collector-base junction barrier. Reverse bias opposes conduction by majority carriers; thus, the CB junction has a high resistance.

2-11. Figure 2-3 is a pictorial diagram of two transistors showing the effect on the junction barrier when the bias batteries are connected. The bias batteries are labeled V_{CC} for the collector voltage supply and V_{EE} for the emitter voltage supply. Notice that V_{EE}, which supplies forward bias, reduces the junction barrier of the emitter-base junction, and that V_{CC}, which supplies reverse bias, increases the junction barrier of the CB junction in both the NPN and PNP transistor.

2-12. The basic current paths through an NPN transistor are illustrated in Figure 2-4A. The solid arrows indicate electron flow. The dotted arrows indicate hole flow. Current flow in the external circuit is always electron flow. Emitter current (I_E) is shown leaving the emitter supply battery and flowing to the N-type emitter. Since electrons are the majority carriere in N material, the electrons will move through the emitter to the emitter-base junction barrier. Having gained energy from V_{EE}, the electrons will overcome the small opposition of the forward biased junction, and cross into the base region.

2-13. The base region is P-type material and the electrons are now minority carriers. As they move into the base region, some of them will recombine with available holes. The electrons that recombine will move out through the base lead as base current (I_B), and return to the emitter supply battery V_{EE}. Most of the electrons that move into the P-type base region will come under the influence of the very intense collector-base junction field. The direction of the reverse biased collector-base field is such that movement of these electrons will be aided. Since the electrons are minority carriers at this time, they will be aided by the CB field and cross into the collector region. The collector is N-type material, and the electrons are again majority current carriers. The electrons now move through the collector material to the positive collector terminal. They will then move out of the collector and return to the positive terminal of V_{CC} as collector current (I_C). The electron, then, is the majority current carrier in the NPN transistor.

2-14. The basic current paths in a PNP transistor are as shown in Figure 2-4B. The majority current carrier in the PNP transistor is the hole. Briefly, the method of current flow through a PNP transistor is as follows: The energy supplied by the emitter supply (V_{EE}) causes an electron-hole pair to be generated at the emitter terminal. The electron travels through the wire to the positive terminal of V_{EE} as emitter current, I_E.

2-15. The hole generated in the P-type emitter is the majority carrier and will move through the emitter toward the emitter-base junction. The energy supplied by V_{EE} will enable the hole to overcome the EB junction barrier and cross into the N-type base region. Some holes will recombine with electrons in the base. This recombination causes electrons to be drawn from the negative terminal of V_{EE}, through the base lead, and into the base material. The result is a small base current flow (I_B). The holes that move into the N-type base become minority carriers, and will come under the influence of the strong CB junction field. The movement of the holes will be aided by the CB junction field, and they will cross into the collector region. The holes again become majority carriers and will move through the collector toward the negative terminal of V_{CC}, where they will recombine with electrons from the collector supply, resulting in the flow of collector current (I_C).

2-16. While electron flow in the external circuit of the PNP transistor is opposite to that of the NPN, notice that, regardless of the type of transistor, the majority carrier always moves through the transistor from the emitter to collector.

354

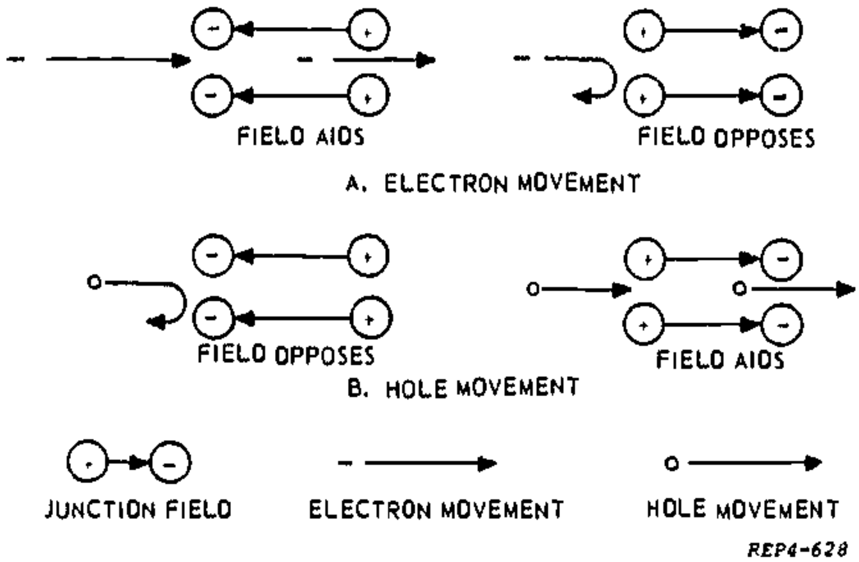


Figure 2-5. Effect of Junction Field on Carrier Movement

2-17. Figure 2-5 illustrates the movement of current carriers under the influence of a junction field. In Figure 2-5A, notice that electrons move against the field and holes move with the field.

2-18. Carriers that enter the base region and recombine become base current and are lost as far as collector current is concerned. Thus, for a transistor to be efficient, as many of the emitter carriers as possible must reach the collector region. A very thin base region will give little chance for recombination to take place. Also, if the base region is lightly doped, there will be few majority carriers in the base available for recombination. Therefore, the base region is very THIN and LIGHTLY DOPED. This reduces the opportunity for a carrier to recombine and be lost.

2-19. Normally, the collector is physically larger than the base or emitter regions. There are two reasons for this: First, to increase the chance of collecting carriers that cross the base region; and second, to give the collector the ability to dissipate more heat.

2-20. Transistor Currents

2-21. Understanding transistor currents leads to an understanding of transistor operation. We will now discuss the relative magnitude of currents and bias voltages using energy level diagrams.

2-22. Figure 2-6 shows an NPN transistor that has 0.1 volt forward bias across the base-emitter junction (V_{EE}) and 10 volts of reverse bias across the collector-base junction (V_{CC}). The 0.1 volt reduces the width and height of the emitter-base junction barrier. The 10 volts V_{CC} increases the width and height of the collector-base junction barrier. For majority carriers, the emitter-base junction appears as a low resistance, and the collector-base junction appears as a high resistance.

2-23. The N-type emitter has many free electrons in the conduction band. The P-type base has few holes because it is lightly doped. The holes exist in the valence band. The N-type collector has many free electrons that are in the conduction band. The forward bias voltage (V_{EE}) will allow some of the free electrons in the emitter to overcome the base-emitter barrier and enter the base, still as free electrons in the conduction band. These electrons have been injected from the emitter into the base.

2-24. Once the electrons are in the base region, they are minority carriers. They now

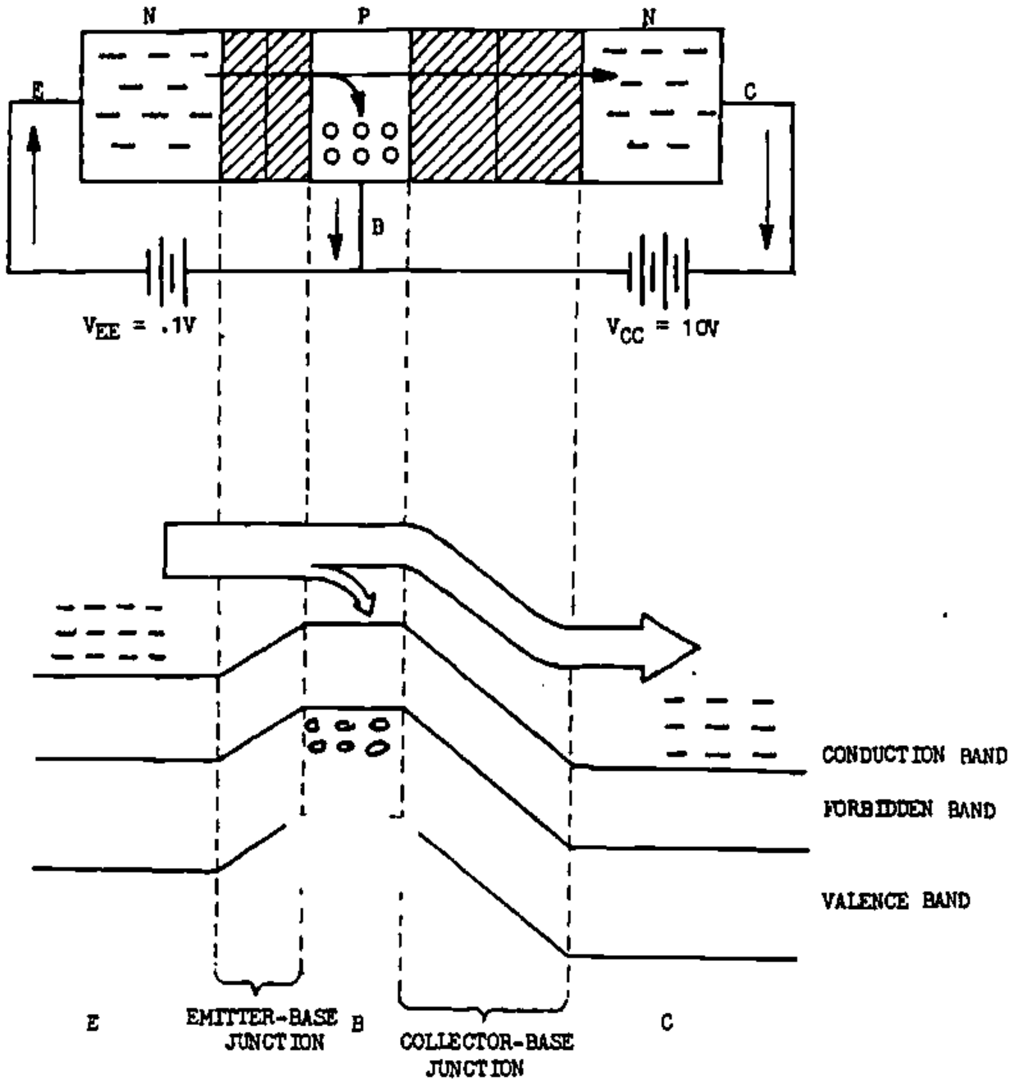


Figure 2-6. Pictorial and Energy Level Diagram of a Biased NPN Transistor

have two choices; to go on to the collector or stay in the base. To stay in the base, the electron must lose energy, fall from the conduction band into the valence band, and recombine with a hole. The recombination of an electron and a hole results in base current (I_B). Remember, however, that the base has few holes available for recombination with electrons from the emitter.

2-25. Most of the injected carriers will go on toward the collector junction, attracted by the large positive collector potential. The collector-base junction is forward biased for minority carriers (electrons in the base). The injected carriers see a forward biased jun~tion and readily move into the collector material; they have been injected from the base into the collector. Once they arrive in the collector, the electrons are majority carriers (in the conduction band of the energy level diagram) and flow through the collector region and out the collector lead.

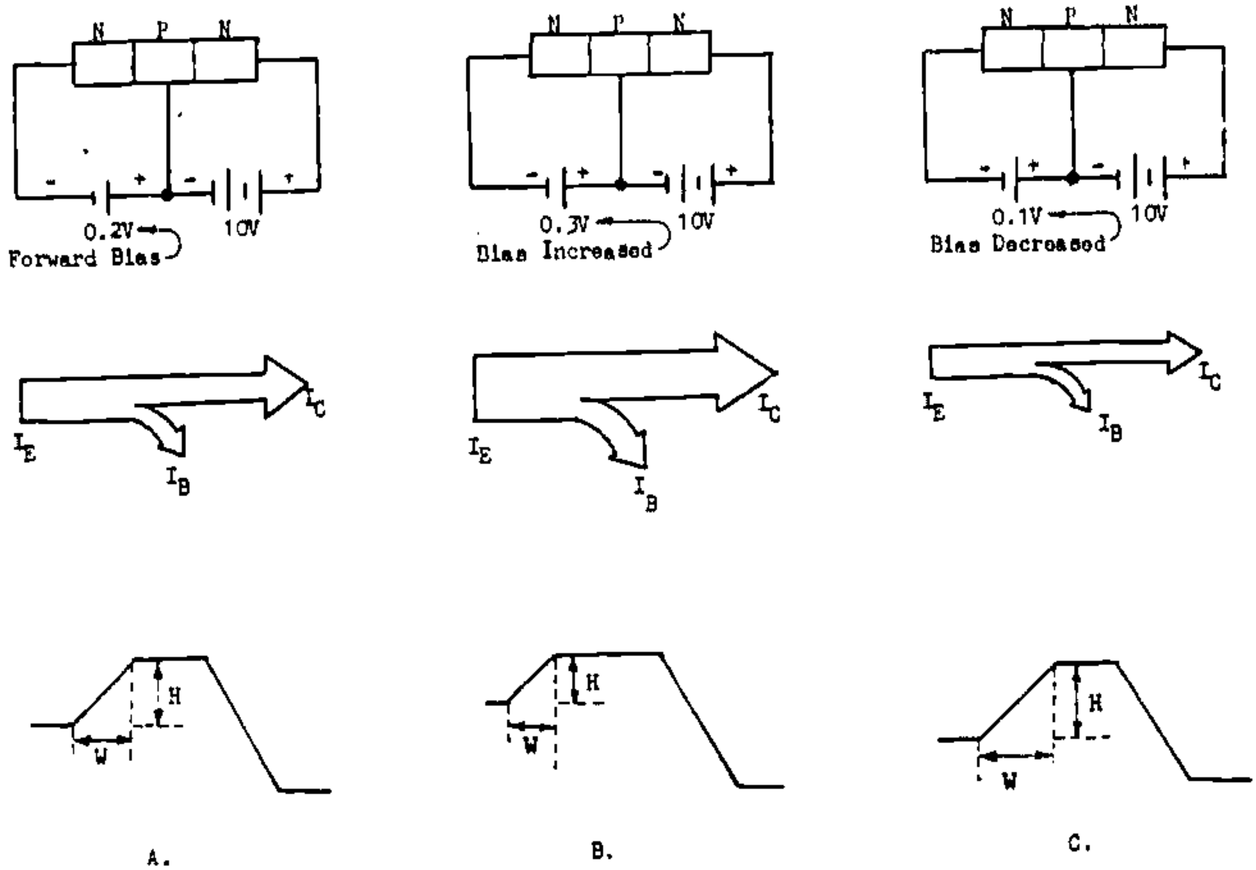


Figure 2-7. Controlling Effect of Forward Bias (NPN) Showing the Amount of Bias (top), the Resulting Electron Flow (center), and Energy Level Diagram (bottom)

2-26. The relative magnitude of the currents in the leads of a transistor can be discussed in terms of percentage. Total transistor current flows in the emitter lead, so I_E is 100 percent. Part of the current that enters the emitter goes to the collector and part of it goes to the base. Emitter current is the sum of collector current (I_C) and base current (I_B). Likewise, I_C is equal to I_E minus I_B, or I_B is equal to I_E minus I_C.

2-27. In general, transistor base current (I_B) is from two to eight percent of the emitter current (I_E); the average is about five percent. Consider a transistor that has 100%, 2%, and 98% current distribution in the emitter, base, and collector respectively, with an emitter current of 10 mA. Collector current would be 9.8 mA, and base current would be 0.2 mA or 200 microamps.

2-28. The fact that the emitter-base voltage is relatively small (with a correspondingly small base current) does not mean that it is unimportant. The emitter-base voltage and its effect on base current can be considered the CONTROLLING FACTOR for the transistor. To illustrate the controlling effect the emitter-base voltage has on the transistor currents, refer to Figure 2-7. Figure 2-7A shows an NPN transistor with 0.2 volts of forward bias and 10 volts of reverse bias. The simplified energy level diagram shows the height (H) and width (W) of the base-emitter junction barrier. Under these conditions current will flow from emitter-to-base and emitter-to-collector. The width of the arrows indicate the relative magnitudes of I_E, I_B, and I_C. Figure 2-7B has the forward bias voltage increased to 0.3 volts. The increase in forward bias reduces the base-

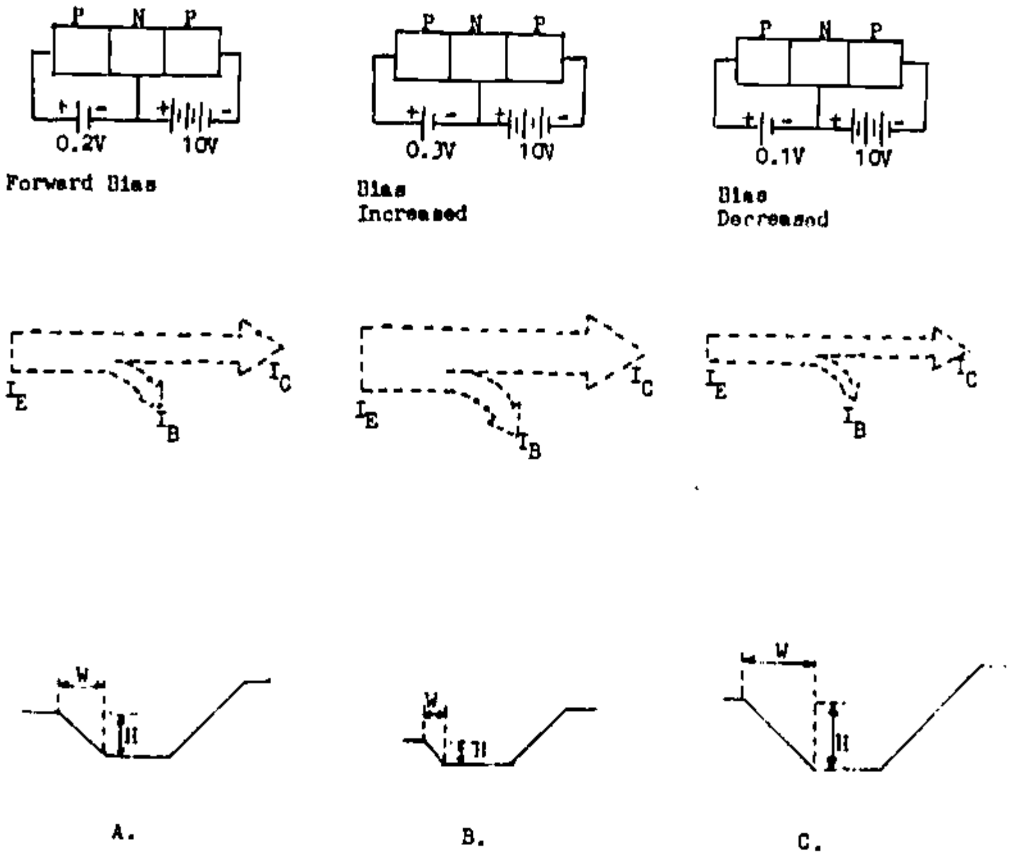


Figure 2-8. Controlling Effect of Forward Bias (PNP) Showing the Amount of Bias (Top), the Resulting Hole Flow (Center), and Energy Level Diagram (Bottom)

emitter junction barrier and allows more electrons to reach the base and collector, causing an increase in base current, emitter current, and collector current. Figure 2-7C shows what happens when the forward bias voltage is reduced to 0.1 volts. The emitter-base junction barrier increases in height and width, and reduces I_B, I_E, and I_C. The conclusion that can be made is this: The effect of the relatively small emitter-to-base voltage on BASE CURRENT controls the relatively large COLLECTOR CURRENT.

2-29. The emitter-base voltage of a PNP transistor has the same controlling effect as that of the NPN. Figure 2-8A illustrates a PNP transistor with 0.2 volts of forward bias between the base and the emitter and 10 volts of reverse bias between the collector and base.

2-30. Because holes are the majority carriers in a PNP transistor the energy level diagram is now inverted. That is, holes try to move upward in energy (electrons try to move downward in energy). For the holes in the emitter to be injected into the base material, they must cross the emitter-base junction barrier. The height and width of the barrier represents an opposition to current just like the barrier in the NPN transistor. Therefore, with 0.2 volts of forward bias (Figure 2-8A), base emitter, and collector current will flow (represented by arrow).

2-31. When the forward bias of the emitter-base junction is increased (Figure 2-8B), the base emitter, and collector currents will increase. This forward bias has reduced the height and width of the junction barrier,

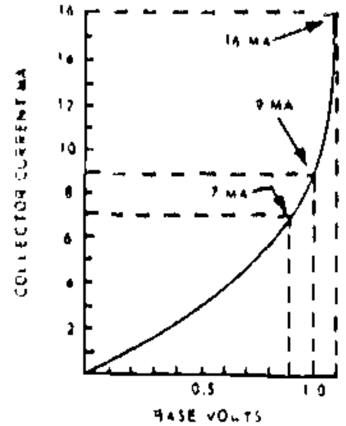


Figure 2-9. Nonlinear Characteristics of Emitter-Base Voltage Versus Collector Current

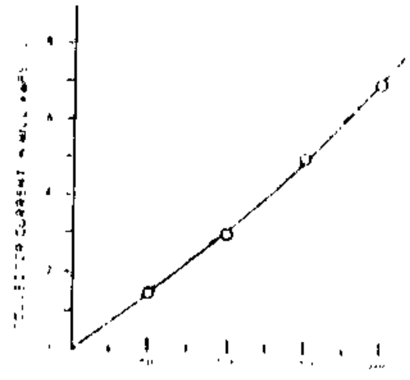


Figure 2-10. Linear Characteristics of Base Current Vs Collector Current

making it easier for holes to flow from the emitter into the base region.

2-32. When forward bias is decreased (Figure 2-8C) to 0.1 volts, the height and width of the emitter-base barrier increases and I_B, I_E, and I_C decrease. Again, the effect of the relatively small emitter-to-base voltage on base current has a very large controlling effect on the collector current.

2-33. Although the current through a transistor can be controlled by the base-emitter voltage, this control is nonlinear and does not give a clear picture of the actual transistor conditions. Figure 2-9 is a curve showing the nonlinear relationship between the base-emitter voltage and collector current. Taking 1 volt as a reference, a 0.1 volt increase causes collector current to change 7 mA (from 9 mA to 16 mA). A 0.1 volt decrease produces a collector current change of 2 mA (from 9 mA to 7 mA).

2-34. On the other hand, a very desirable condition exists when the base current is used as the controlling factor. Figure 2-10 illustrates a curve plotting base current in microamps against collector current in milliamps. Notice that there is virtually a linear relationship between I_B and I_C. Therefore, the collector current will be directly proportional to the amount of base current. The average DC base current is called BIAS. Since bias (base current) is the controlling factor in the operation of a transistor, they are referred to as CURRENT-CONTROLLED devices.

2-35. Leakage Current

2-36. As you recall, the collector-base junction is reverse biased for normal transistor operation. If the emitter lead were open, I_E would cease, allowing us to measure the small reverse leakage current which will flow from collector to base. This current flow is referred to as LEAKAGE CURRENT or I_{CBO}. In the term I_{CBO}, the I indicates current, the subscripts C and B indicate collector and base elements, and O means open emitter lead. Thus, I_{CBO} means collector-base reverse bias current measured with the emitter lead open. Although the emitter lead is opened to conveniently measure I_{CBO}, this current will flow as long as the CB junction is reverse biased.

2-37. Figure 2-11 shows an NPN transistor with the emitter circuit open and the direction of I_{CBO} indicated. Notice that the direction of I_{CBO} is OPPOSITE to that of normal base current. However, under normal operating conditions, the amount of I_{CBO} is quite small (in the microampere range) and reduces base current by only a small amount. Since this current is due to minority carriers, the amount of leakage current increases with an increase in the junction

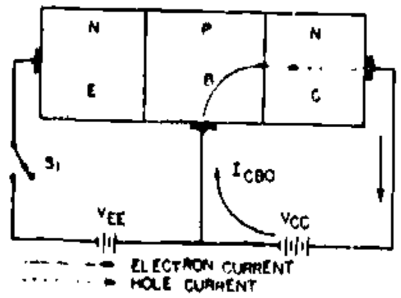


Figure 2-11. I_{CBO} in an NPN Transistor

temperature. As I_{CBO} increases, base current will be less effective in controlling transistor operation. Note also that the direction of I_{CBO} aids I_C, and as junction temperature increases, total collector current ($I_C + I_{CBO}$) increases. This increase in current generates more heat, which would greatly reduce the efficiency of the transistor and possibly destroy it (thermal runaway).

2-38. As a general rule, I_{CBO} doubles in value for each temperature rise of 8 to 10 degrees Centigrade. Since I_{CBO} is determined by heat, the junction temperature must be kept low for efficient and safe operation. The amount of leakage current is often used as a measure of transistor quality. The leakage current (I_{CBO}) in a transistor is often referred to as SATURATION CURRENT, because the amount of current is dependent primarily on junction temperature, and is relatively independent of the amount of reverse bias voltage (V_{CC}).

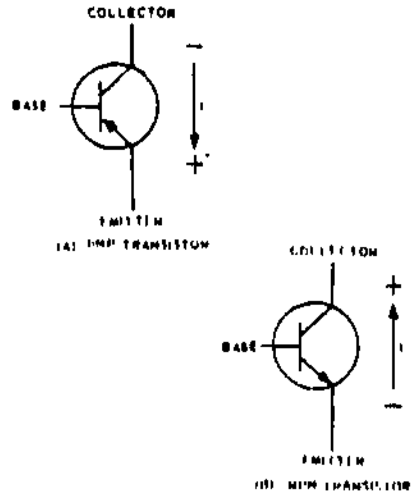
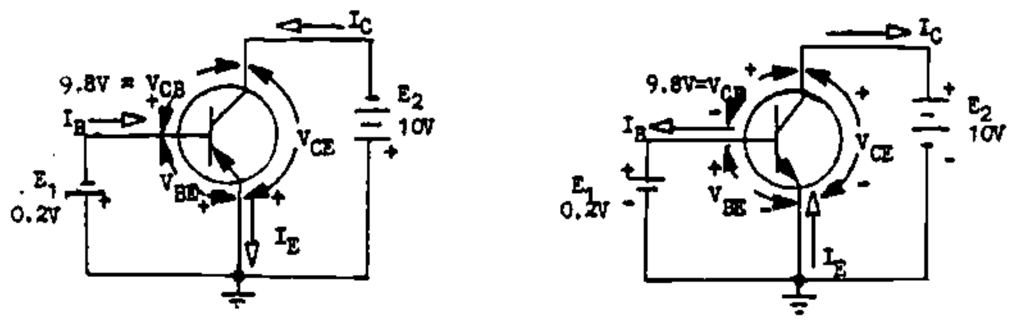


Figure 2-12. Transistor Symbols

2-39. Transistor Symbols

2-40. Figure 2-12 shows the schematic symbols for PNP and NPN transistors. The only difference between the two symbols is the direction of the arrow on the emitter lead. In the PNP, the arrow is pointing toward the base lead. In the NPN, the arrow points away from the base lead. Electrons flow AGAINST the arrow. Electron flow in a PNP transistor circuit is into the collector and base, and out of the emitter. Electron flow in an NPN transistor circuit is into the emitter and out of the base and collector. In either case, the electron flow is AGAINST the arrow on the emitter lead. Where several transistors are used in a circuit, they are generally numbered Q1, Q2, and so on, for identification.



A. PNP B. NPN

Figure 2-13. Bias Polarities and Current Directions

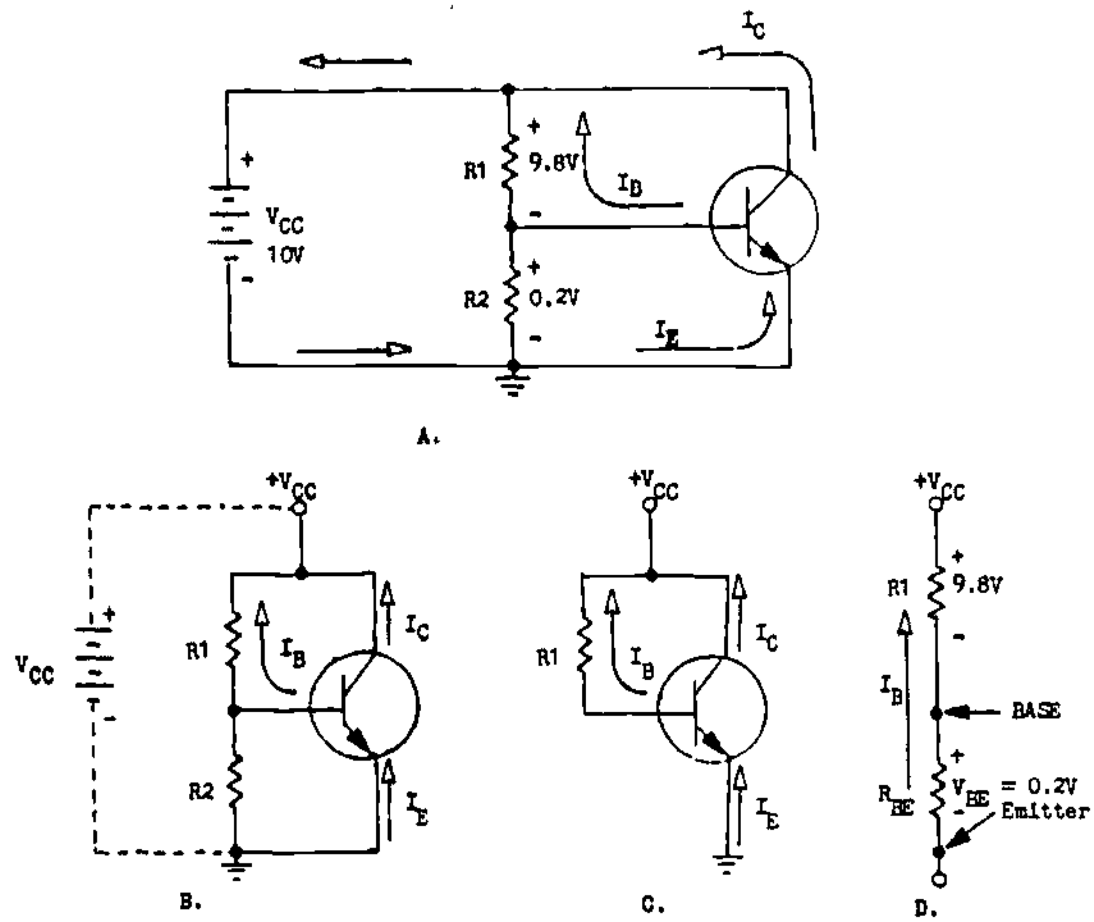


Figure 2-14. Biasing a Transistor from a Voltage Divider

2-41. Figure 2-13 uses the schematic symbols of the NPN and PNP transistors with battery symbols to show the proper bias polarities and the current directions. Figure 2-13A shows a PNP transistor biased for proper operation. The base is negative with respect to the emitter by 0.2 volts due to battery E1, which is forward bias for the emitter-base junction. Notice also that the collector is negative with respect to the emitter by 10 volts, due to battery E2. This means, the collector is more negative than the base by 9.8 volts (E2 - E1). This 9.8 volt difference in potential is felt by the collector-base junction and is the required reverse bias.

2-42. This same method can be used to properly bias an NPN transistor, as shown in Figure 2-13B. Notice that the batteries are of the opposite polarity, and electron flow in the external circuit is in the opposite direction. Battery E1 supplies the forward bias for the emitter-base junction, and E2 places the collector at $\mp$10 volts. Once again, the difference in potential between the base and collector (9.8 volts) is the reverse bias across the collector-base junction.

2-43. Biasing of transistors for proper operation has been illustrated using two batteries to supply the emitter-base forward bias and collector-base reverse bias. However, proper operation can also be achieved by using a single battery or power source and a voltage divider to obtain these voltages.

2-44. The use of a single power source to supply the necessary bias voltages is illustrated in Figure 2-14. This single power source is generally referred to as V_{CC}. R1 and R2 form a simple series voltage divider. Notice that R2 is connected across the base-emitter junction of the transistor, and the voltage drop across R2 (0.2 volts) will be felt as forward bias for the EB junction.

2-45. Resistor R1 is connected across the collector-base junction. The 9.8 volt drop across this resistor will make the collector more positive than the base, and therefore, provides the necessary reverse bias for the collector-base junction.

2-46. In most equipment, several transistors are used, all powered from a single power source. It is often convenient to indicate connections to the power source (V_{CC}) in the manner shown in Figure 2-14B. The terminal marked $+V_{CC}$ is understood to be connected to the positive (+) terminal of the power source (as indicated by the dotted line), and the other terminal is understood to be connected to ground. When $-V_{CC}$ is indicated, the negative terminal of the power source is connected to this point, and the positive terminal is understood to be connected to ground.

2-47. In some circuits, resistor R2 (see Figure 2-14A) is not used; the resulting circuit is shown in Figure 2-14C. The resistance of the emitter-base junction, R_{BE}, is used to provide proper bias in the circuit. The EQUIVALENT CIRCUIT shown in Figure 2-14D shows how this is done. Resistors R1 and RBE now form the series voltage divider to provide bias. The voltage drop across R_{BE} makes the base positive with respect to the emitter (forward bias) and R1 provides the reverse bias for the collector-base junction in the same manner as before.

2-48. Transistor Configurations

2-49. In previous lessons we have discussed the construction, biasing, and basic operation of the transistor. Now we will discuss some applications of the transistor, and its circuit characteristics. One important application of the transistor is to obtain voltage or current amplification. AMPLIFICATION is defined as the ability of a circuit to take a small change in voltage or current and produce a larger change in output voltage or current that accurately follows every detail of the input.

2-50. Examples of devices that produce these small changes in input voltage or current are microphones and magnetic tape decks. These small changes are referred to as INPUT SIGNAL voltages or currents. When these signals are applied to the input of an amplifier, much larger changes in voltage or current are produced at the output. These output changes are referred to as the OUTPUT SIGNAL.

2-51. A transistor may be connected in any one of three basic amplifier configurations. Each type has particular characteristics which make it suitable for specific applications. These circuits are the (1) common-emitter (CE), (2) the common-base (CB), and (3) the common collector (CC) configuration. They are also sometimes called the (1) grounded-emitter, (2) grounded-base, and (3) grounded-collector configurations. The COMMON or GROUNDED element of the transistor is that element which is common to both the input and output signal path. Figure 2-15 shows the three basic configurations using an NPN transistor.

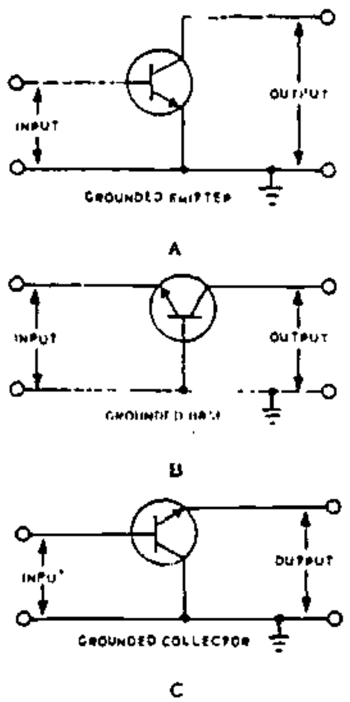


Figure 2-15. Transistor Configurations

2-52. Figure 2-15A shows the common-emitter (CE) configuration. Only the signal paths are shown; the necessary bias circuitry has been left out for simplicity. In a common emitter configuration, the input signal voltage is applied to the base of the transistor with respect to the emitter. The output is taken from the collector with respect to the emitter. Notice that the emitter is COMMON to both the input and output signal paths.

2-53. Remember that a change in voltage across the base-emitter junction (bias voltage) will cause the base current to change, producing a change in collector current. In the next chapter you will learn how this change in collector current can produce a change in collector-emitter voltage. This change in voltage will become the output signal voltage.

2-54. We can use the following steps to identify a transistor configuration:

a. Identify the element to which the input signal is applied (base); the input is always applied to the emitter or base.

b. Identify the element from which the output signal is taken (collector); there will always be a load resistance in the output. The output is never taken from the base.

c. The remaining element tells the name of the configuration (common emitter).

2-55. Let us apply these steps to identify the configuration shown in Figure 2-15B. The input signal is applied to the emitter. The output signal is taken from the collector. Since the base is the remaining element, this transistor is in the common-base (CB) configuration. Before studying the effect of the input signal on the circuits, we will first discuss the DC or STATIC operation and current paths for each configuration.

2-56. Common Emitter Configuration

2-56A. Figure 2-16 illustrates the connections for both NPN and PNP transistors in a common emitter configuration. The NPN transistor usually has a positive voltage ($+V_{CC}$), and the PNP transistor usually has a negative voltage ($-V_{CC}$) to satisfy the requirements necessary for the proper bias of the transistor. The forward bias for the EB junction and reverse bias for the CB junction are provided by V_{CC}, R1, and R2, which form a series voltage divider bias network. Resistor R_L is called a COLLECTOR LOAD RESISTOR, and its function in the circuit will be discussed in detail in the next chapter.

2-57. Figure 2-16A shows that, with proper bias applied, there will be electron flow INTO

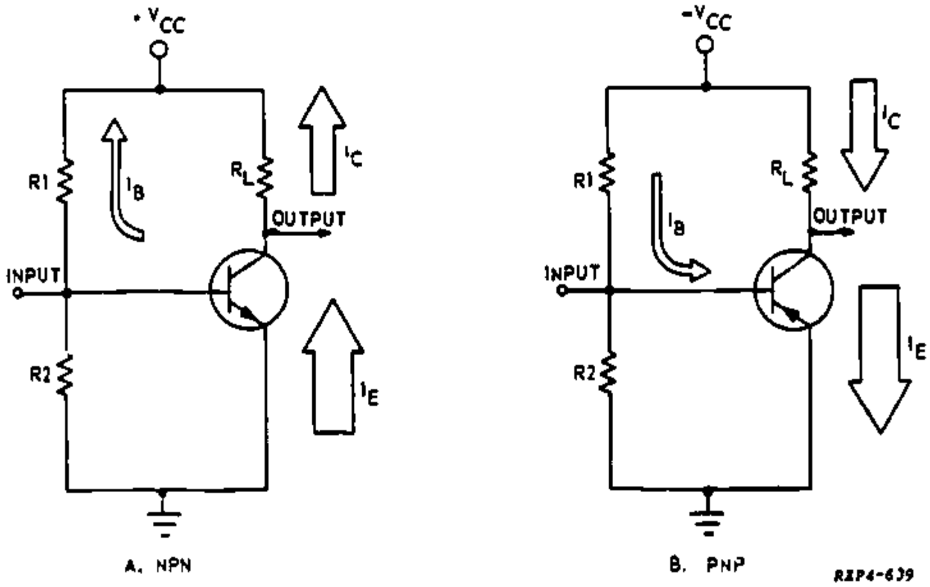
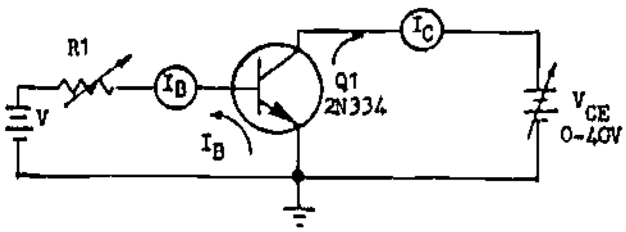
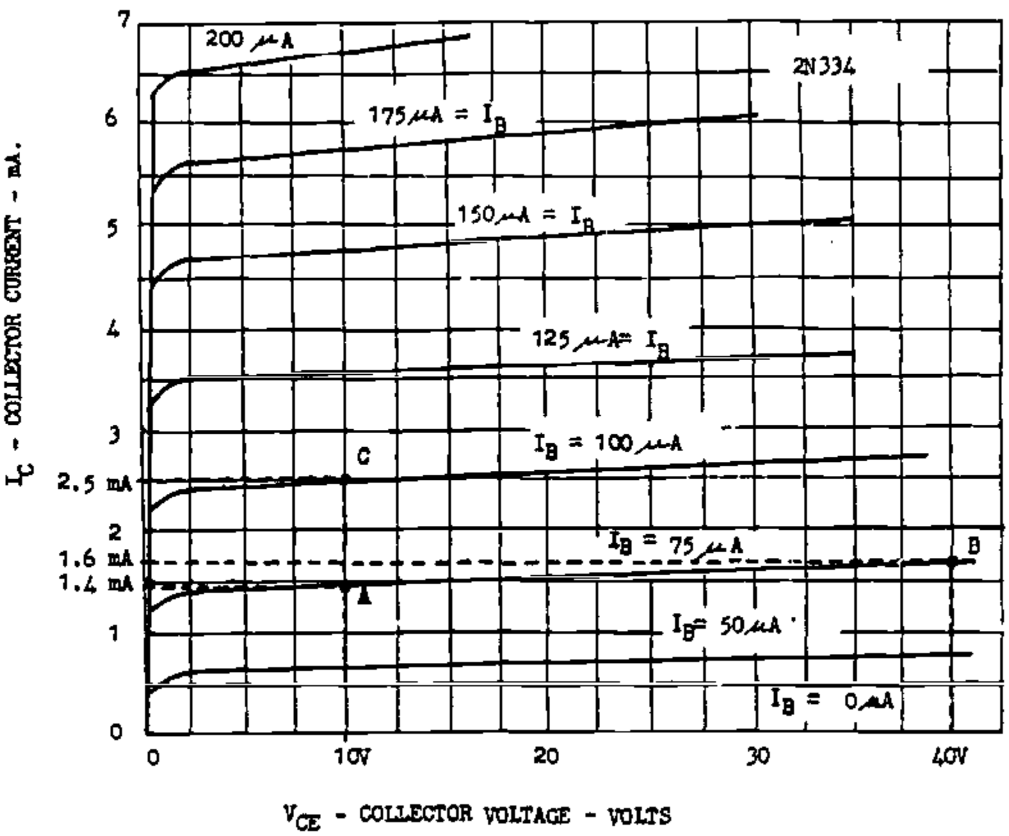


Figure 2-16. Common Emitter Configuration



A. Static Common Emitter Configuration.



B. Common Emitter Output Characteristic Curves.

Figure 2-17. Static Common Emitter Configuration and Characteristic Curves (2N334)

the emitter (I_E). A portion of this current will flow OUT of the base lead as base current (I_B). Most of the current will continue to flow through the transistor, and come OUT of the collector lead as collector current (I_C).

2-58. Figure 2-16B shows current paths for the PNP transistor. Notice that V_{CC} is now negative, and electrons flow from the power source to ground. Electrons flow INTO the the base through R1 and INTO the collector, and OUT of the emitter lead.

2-59. In our discussion of transistors we have used general terms to indicate its characteristics; that is, small voltage, small current, larger current, etc. Transistor circuit conditions and operation can be predicted much more accurately by the use of characteristic curves. A transistor CHARACTERISTIC

CURVE is a graph plotting the relationships between currents and voltages in a transistor circuit. Usually, more than one curve is plotted on the graph. The graph is then called a FAMILY of curves.

2-60. To determine the characteristic curves for a transistor, a static configuration (as shown in Figure 2-17A) is used. This static circuit allows us to measure the CONTROL ADVANTAGE the base-emitter junction will have on collector current. For example, the circuit of Figue 2-17A is a static grounded emitter configuration. R1 is used to set the level of base current at some constant value (say $I_B = 50\mu A$). Then the collector current I_C is measured for various values of collector-emitter voltage. The results are plotted, forming the $I_B = 50\mu A$ line in the family of curves (Figure 2-17B). This procedure is repeated to form the other curves in the family shown.

2-61. Figure 2-17B illustrates a family of curves for a 2N334 transistor used in a common emitter configuration. This chart can only used for the 2N334 type transistor in a CE configuration. Changing either the type of transistor or its CONFIGURATION would require a different family of curves. These curves are supplied by the manufacturer.

2-62. The HORIZONTAL AXIS of the graph plots collector-emitter voltage (V_{CE}) from 0 to 40 volts. The VERTICAL AXIS plots collector current (I_C) values from 0 to 7 mA. The curves are showing different levels of base current (I_B). For example, at any point on the curve marked $I_B = 100\mu A$, the base current will be $100\mu A$. Any point on one of the I_B curves then shows three important things - the base current, the collector to emitter voltage, and the resultant collector current. If the transistor were biased to allow $75\mu A$ base current to flow with 10 volts of collector voltage (Point A, Figure 2-17B), the curve predicts the amount of collector current that will flow (I_C = 1.4 mA).

2-63. The output characteristic curve also shows the effect that a change in collector voltage (V_C) will have on collector current (I_C). For example, with V_{CE} = 10 volts and $I_B = 75\mu A$, the collector current (I_C) is equal to 1.4 mA. If V_{CE} is increased (Point B, Figure 2-17B) notice that I_C changes from 1.4 mA at 10 volts to 1.6 mA at 40 volts. From this we can conclude that, except for very low collector voltages, large changes in V_{CE} result in only small changes in collector current.

2-64. The output characteristic curve for a transistor also shows the relationship between changes in base current (I_B) and the resulting changes in collector current. For example, with V_{CE} = 10v and $I_B = 75\mu A$, the collector current will be 1.4 mA. If the bias current (I_B) is increased from $75\mu A$ to $100\mu A$ (Point C, Figure 2-17B), collector current will increase to 2.5mA. We can readily see that a small change in I_B, from 75 μA to 100 μA (a change of 25 μA), produces a large change in collector current (2.5 1 1.4 mA = 1.1 mA).

2-65. The CONTROLLING EFFECT of base current on collector current is called BETA. Beta is the maximum theoretical current gain (amplification factor) of a common emitter configuration. BETA is therefore defined as the forward current transfer ratio of a common emitter configuration. The formula is:

$$\text{Beta } (\beta) = \frac{\Delta I_C}{\Delta I_B} \quad \text{with } V_{CE} \text{ constant}$$

(Δ is the Greek letter Delta, and is used to indicate a small change.) CE amplifier gain is somewhat less, as determined by circuit component values and will be discussed in a later chapter.

2-66. Using the curves in Figure 2-18, we can calculate beta for the 2N334 transistor in a CE configuration. As an example, let us assume a constant V_{CE} of 20 volts. If the input current (I_B) is changed from 75 μA to 100 μA, the output current (I_C) will change from 1.5 mA to 2.6 mA. Placing the values for ΔI_B (25 μA) and ΔI_C (1.1 mA) in the formula we calculate beta to be 44.

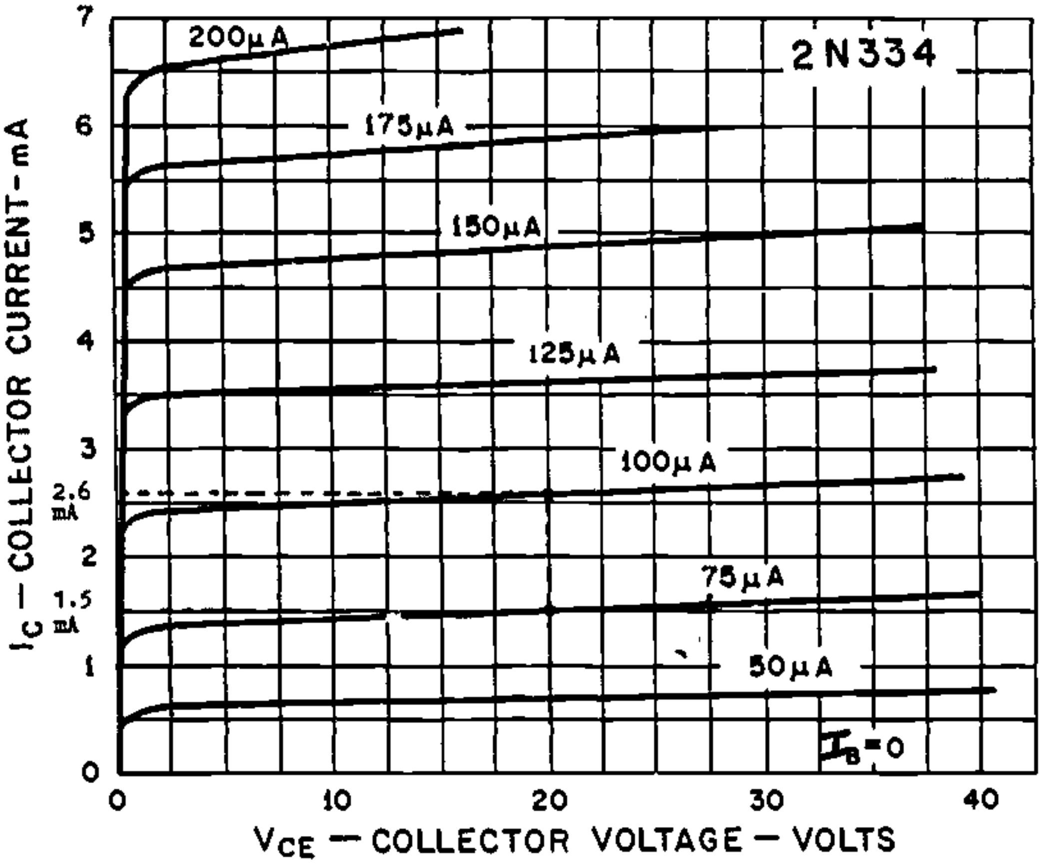


Figure 2-18. CE Characteristic Curves

$$\text{Beta } \frac{\Delta I_C}{\Delta I_B} = \frac{1.1 \times 10^{-3}}{25 \times 10^{-6}} = \frac{1100 \times 10^{-6}}{25 \times 10^{-6}} = 44$$

This simply means that a change in base current produces a change in collector current which is 44 times as large.

2-67. The characteristic curve also illustrates the DC resistance that transistors offer in a circuit, and the effects that changes in base current have on this collector to emitter resistance. Refer to Figure 2-18. If the transistor is operated with V_{CE} = 20 volts and a bias (base current) of 75 µA, there will be 1.5 mA of collector current. Using Ohm's Law, the collector to emitter resistance of the transistor can be calculated as follows:

$$\text{DC resistance} = R_{DC} = \frac{V_{CE}}{I_C} =$$

$$\frac{20 \text{ volts}}{1.5 \text{ mA}} = 13.3 \text{ k ohms}$$

Note that if the base current is increased to 125 µA, collector current will increase to 3.6 mA, and the resistance of the transistor will decrease to 5.6 k ohms.

$$R_{DC} = \frac{V_{CE}}{I_C} = \frac{20 \text{ volts}}{3.6 \text{ mA}} = 5.6 \text{ k ohms.}$$

This illustrates the fact that small changes in forward bias (base current) produce large changes in the transistors collector to emitter resistance.

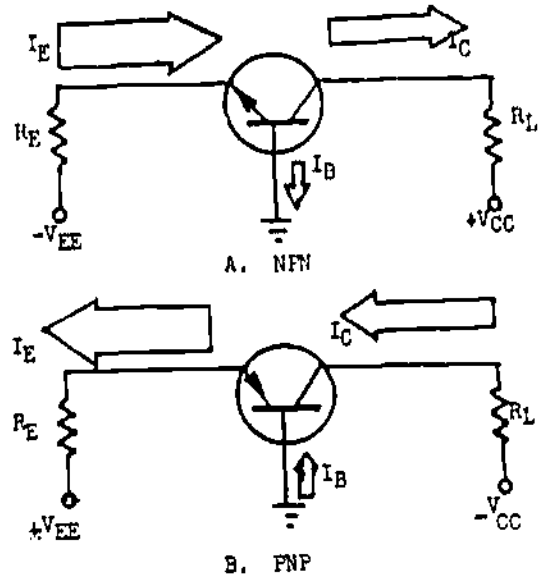


Figure 2-19. Common Base Configuration

2-68. Common Base Configuration.

2-69. Figure 2-19 illustrates PNP and NPN transistors biased for operation in common-base (CB) configuration. The NPN transistor in Figure 2-19A has a positive V_{CC} source voltage which establishes the required reverse bias between the collector and base. The forward bias for the base-emitter junction is furnished by the negative V_{EE} source voltage. R_E is used to control the amount of forward bias to the EB junction, and R_L is again the collector load resistor. For the NPN transistor, electrons will leave the $-V_{EE}$ terminal and flow INTO the emitter; part of these electrons flow OUT of the base lead as base current, I_B, and the remaining electrons flow OUT of the collector lead as collector current, I_C.

2-70. The PNP transistor (Figure 2-19B) has a negative V_{CC} to provide the reverse bias between collector and base, and a positive V_{EE} to provide the forward bias between base and emitter. Electrons flow INTO the collector and base and OUT of the emitter lead, as shown in Figure 2-19B.

2-71. Figure 2-20 shows a family of characteristic curves for the 2N334 type transistor

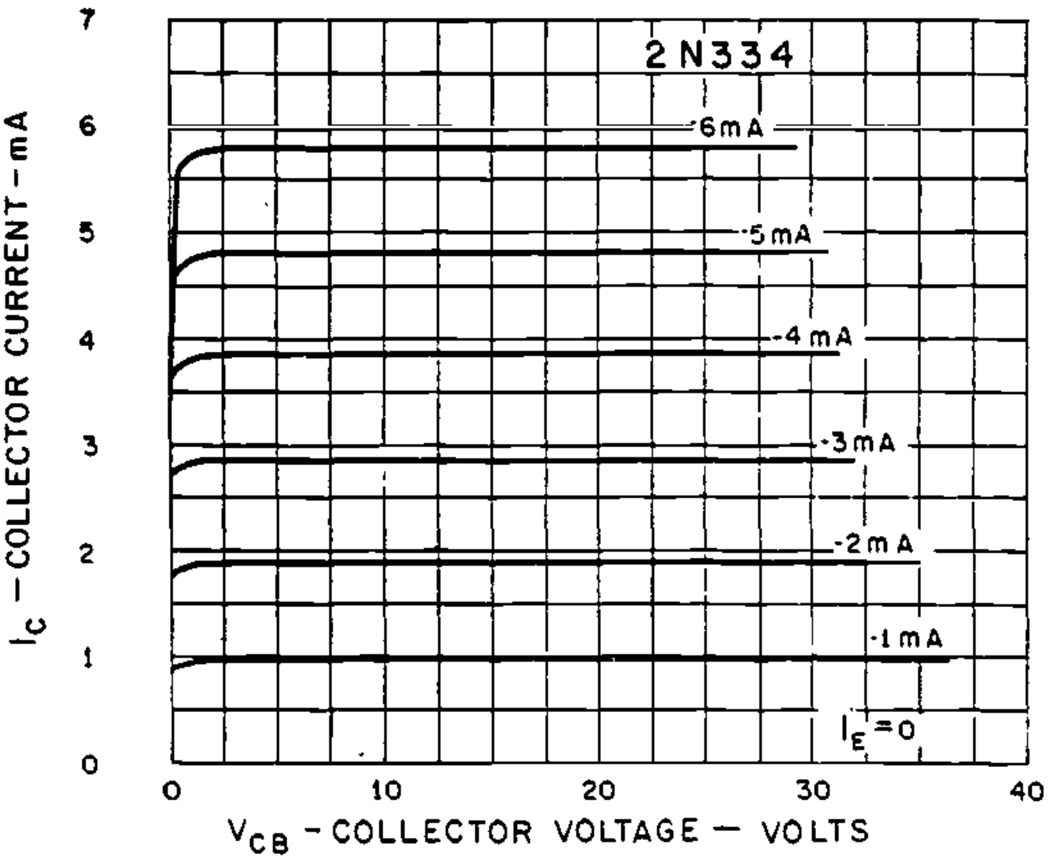


Figure 2-20. Common Base Output Characteristic Curves

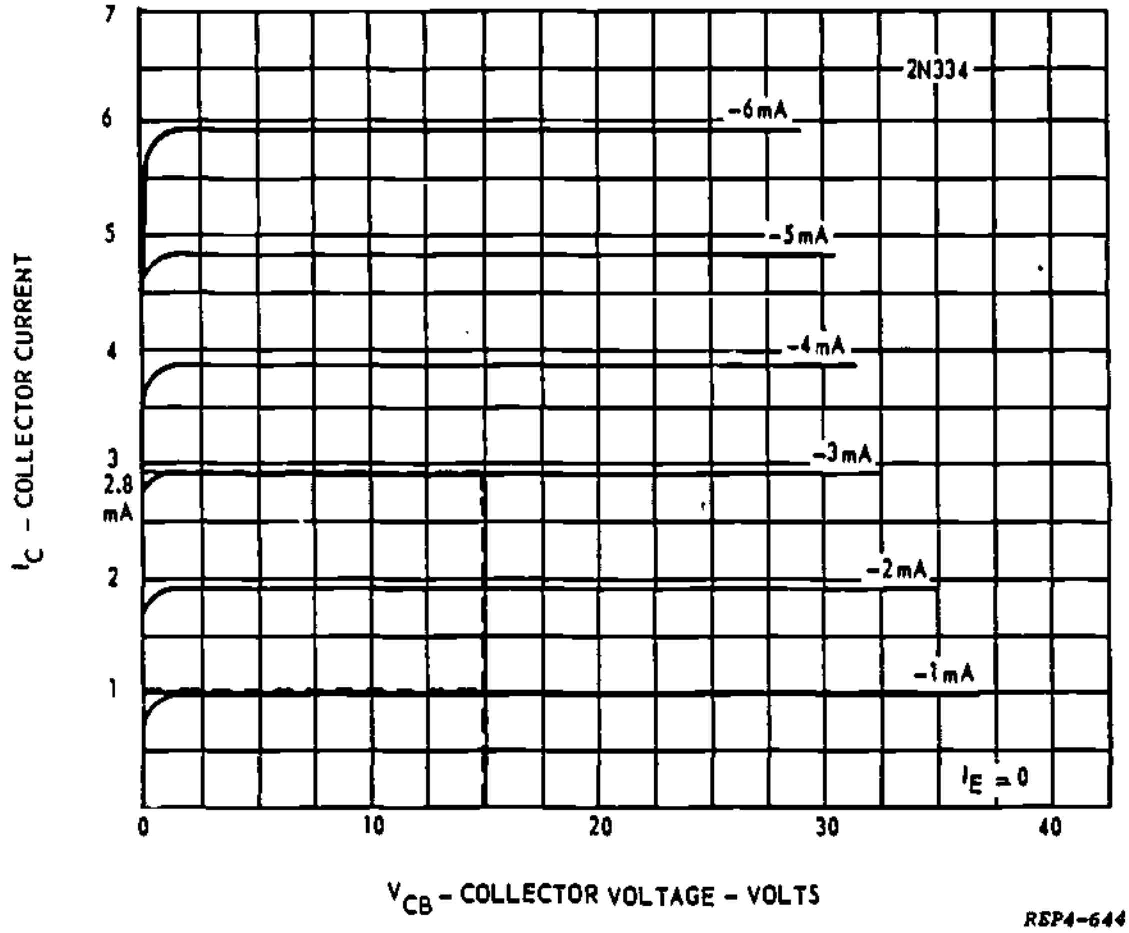


Figure 2-21. CB Characteristic Curves

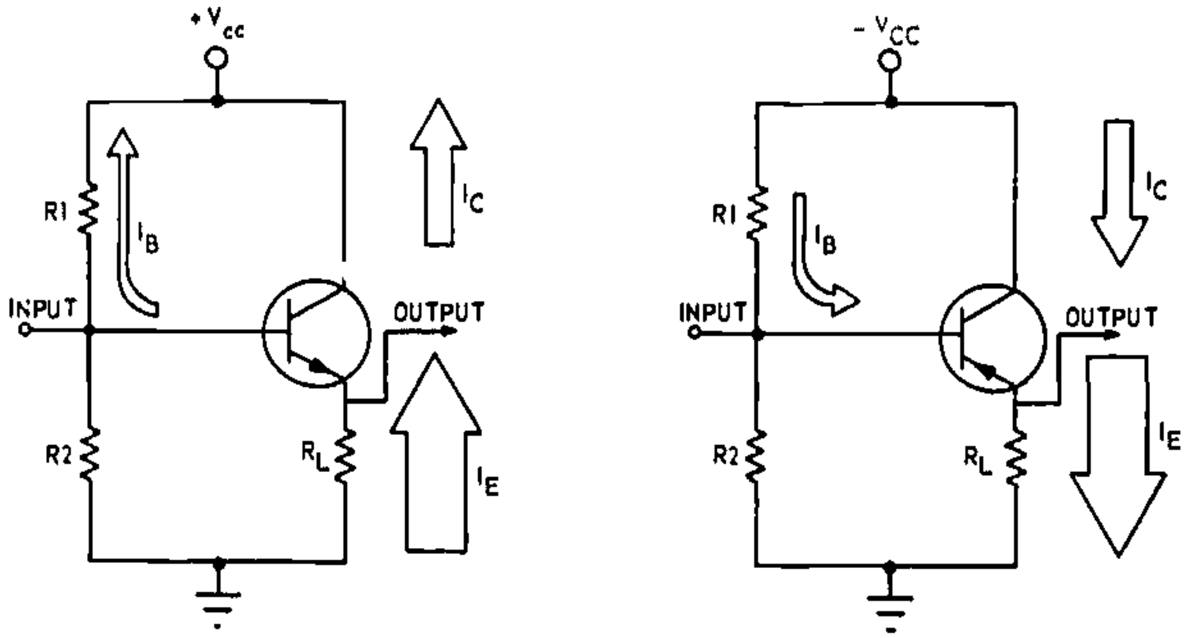
in the common-base configuration. While this graph may at first appear to be the same as the one for a CE configuration, there are several important differences you should note. The horizontal axis now indicates the collector-base voltages, since in this configuration, the output is taken from the collector with respect to the base. Also, since the input is now applied to the emitter with respect to the base, the various curves in the family are now labeled as emitter currents (I_E = 1 mA, 2 mA, etc). This family of curves is determined from a static common base configuration in much the same way as you saw in the common emitter static circuit of Figure 2-17A. Now, however, emitter current is held constant to produce each curve in the family.

2-72. Notice that the collector voltage (V_{CB}) has very little effect on collector current (I_C). Changes in emitter current, however, do produce corresponding changes in collector current. We can say, therefore, that changes in EMITTER CURRENT will have the controlling effect on the amount of collector current that will flow in the circuit.

2-73. In the COMMON-BASE configuration, this controlling effect of I_E on I_C is called ALPHA. Alpha is defined as the forward current transfer ratio of a common base configuration. The formula for alpha is:

$$\text{Alpha } (\alpha) = \frac{\Delta I_C}{\Delta I_E} \text{ with } V_{CB} \text{ constant}$$

2-74. This formula represents a theoretical current gain or amplification. The CB characteristic curves can be used to calculate alpha (see Figure 2-21). With the collector-base voltage (V_{CB}) held constant



A. NPN

B. PNP

Figure 2-22. Common Collector Configuration REP4-645

at 15 volts, emitter current is changed from 1 mA to 3 mA, for example, and I_C changed from 1 mA to 2.8 mA. So, for a 2 mA change in emitter current (3 mA - 1 mA), collector current changed by 1.8 mA (2.8 mA - 1 mA).

$$\text{Alpha } (\alpha) = \frac{\Delta I_C}{\Delta I_E} = \frac{1.8 \text{ mA}}{2 \text{ mA}} = 0.90$$

2-75. This is a current gain of less than one. Since a part of the change in emitter current (ΔI_E) will flow into the base circuit and not appear as a change in collector current (ΔI_C), the change in collector current will ALWAYS be less than the change in emitter current that causes it. This leads us to the following rule: ALPHA IS ALWAYS LESS THAN ONE.

2-76. Small changes in emitter current (forward bias) will produce large changes in the collector resistance, in the same manner as you already studied in the common emitter configuration. Simply use the formula $R_{DC} = V_{CB}/ I_C$ to calculate the resistance of the transistor at any point on the graph.

2-77. Common Collector Configuration

2-78. Figure 2-22 shows the common-collector configuration, with the resulting current paths showing direction and relative magnitude of electron flow. Notice that the direction of current is determined by the type of transistor (NPN or PNP), and not the circuit configuration. For the NPN transistor, electrons always flow into the emitter, out of the base, and out of the collector. For the PNP transistor, these directions are reversed.

2-79. The gain or forward current transfer ratio of the common collector configuration is called GAMMA. The formula for gamma is:

$$\text{Gamma } (\gamma) = \frac{\Delta I_E}{\Delta I_B} \text{ with } V_{CE} \text{ constant}$$

However, since output characteristic curves are seldom prepared for the common collector configuration, gamma is instead computed by calculating Beta and adding one. The formula then becomes:

$$\text{Gamma } (\gamma) = \text{Beta} + 1$$

For example, if a transistor with a Beta of 49 were used in a common collector configuration, Gamma would be 49 + 1 = 50.

2-80. Configuration Relationships

2-81. Since a given transistor may be connected in any of the three basic configurations, there must be a relationship between Alpha, Beta, and Gamma. Manufacturers usually specify a value of Alpha or Beta for a given transistor. The relationships between Alpha, Beta, and Gamma are given by the following formulas:

$$\text{Beta } (\beta) = \frac{\alpha}{1 - \alpha}$$

$$\text{Alpha } (\alpha) = \frac{\beta}{\beta + 1}$$

$$\text{Gamma } (\gamma) = \beta + 1$$

2-82. For example, a transistor has an Alpha of 0.95 but we wish to use it in a common emitter configuration. This means we must determine Beta.

$$\text{Beta} = \frac{\alpha}{1 - \alpha} = \frac{0.95}{1 - 0.95} = \frac{0.95}{0.05} = 19$$

2-83. Therefore, a change in base current in this transistor will produce a change in collector current that will be 19 times as large.

2-84. If we wished to use this transistor in a common collector configuration, we can find Gamma by:

$$\text{Gamma} = \text{Beta} + 1 = 19 + 1 = 20$$

2-85. If we wish to use a transistor with a Beta of 99 in a common base circuit, we can use the formula to find Alpha.

$$\text{Alpha} = \frac{\beta}{\beta + 1} = \frac{99}{1 + 99} = \frac{99}{100} = 0.99$$

Chapter 3

AMPLIFIER PRINCIPLES

3-1. In this chapter, we will concentrate on the capabilities of the transistor as an amplifying device. As you recall from your study of circuit configurations, the ratio of output changes to input changes determines gain. These changes could be in current, voltage, or power, and will be used in the calculation of an amplifier's current, voltage, and power gains. Amplification depends on the change in the transistor's resistance caused by an input signal. To illustrate this principle refer to Figure 3-1.

3-2. Figure 3-1A shows a voltage divider consisting of fixed resistor R1 and variable resistor R2 connected across a DC voltage source. The voltage at point A with respect to ground is determined by the size of the resistors and the applied voltage. Decreasing the resistance of R2 causes the voltage at point A to decrease. Increasing the resistance causes the voltage at point A to increase. The resistance of R2 provides a control of the voltage at point A.

3-3. Figure 3-1B uses the resistance of transistor Q1 to control the voltage at point A. We used characteristic curves to show that base current controls collector current in a t ransistor. For a small change in I_B, the coll. urrent changes a large amount. This large . ange in I_C results from a large resistance change in the transistor. In other words, base current controls the resistance of the transistor.

3-4. A transistor, then, acts like a variable resistor. If base current is small (Figure 3-1B) the resistance of Q1 would be large, and the voltage at point A would be almost equal to the applied voltage. If base current is a large value, the resistance of Q1 would be small, and the voltage at point A would be almost equal to zero volts. The result is that a change in base current controls the voltage at point A.

3-5. Figure 3-1C shows an amplifier circuit. The transistor Q1 and R1 are connected in series across the applied voltage source. Resistor R2 furnishes the forward bias for the transistor. Transistor resistance changes are controlled by signal generator G1. Capacitor C1 couples the output from the generator to transistor Q1. Notice that the signal is applied to the transistor's base and will cause base current to change at the same rate as the input signal. This causes a change in transistor resistance. The change in transistor resistance causes a relatively large voltage change at point A. The resulting signal output or waveform at point A will have the same characteristics as the input signal voltage, but will be much larger. This is how amplification is achieved in a transistor amplifier.

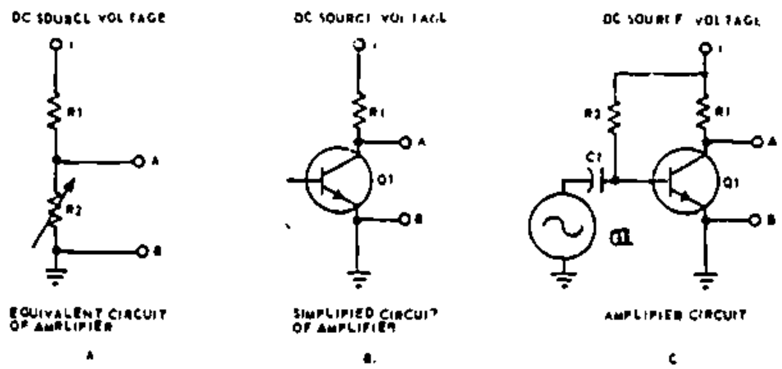


Figure 3-1. Development of an Amplifier

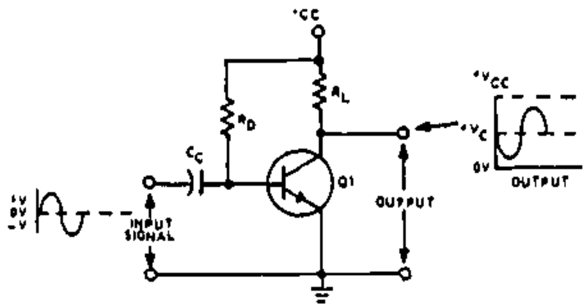


Figure 3-2. Common Emitter Configuration (NPN)

3-6. Amplification in a Common Emitter Configuration

3-7. A common emitter amplifier configuration is shown in Figure 3-2. Notice that the input signal is applied between the base and emitter, and the output signal is taken between the collector and emitter. The emitter is the electrode that is common to the input and output, hence the name common emitter. Resistor R_L is called the collector load resistor. Without R_L, the voltage on the collector would always be equal to V_{CC}. The collector load resistor makes the voltage on the collector (V_C) change as transistor resistance changes. The resistor R_D and the resistance of the base-emitter junction (R_{BE}) provide the necessary forward bias (I_B) for the transistor. Forward bias current flows from ground to the emitter, through R_{BE}, out the base lead and through R_D, to V_{CC}.

3-8. The coupling capacitor (C_C) in Figure 3-2 serves two purposes. It is used to COUPLE the AC signal to the amplifier input. Also, it blocks the DC voltages which are present on one side of the coupling capacitor from reaching the other side.

3-9. The input signal to the amplifier is a sinewave which causes the bias voltage to vary above and below the static bias level (no signal input). Figure 3-3 illustrates the static bias condition, with 600 millivolts of bias voltage and no signal input. The 600mv battery represents the bias voltage developed across R_{BE}. A static I_C of 2 mA will develop 10 volts across the collector load resistor (R_L). Since R_L and Q1 are in series with 25 volts (V_{CC}), applied, V_C will be equal to 15 volts. The voltage across R_L and the transistor must add up to V_{CC}.

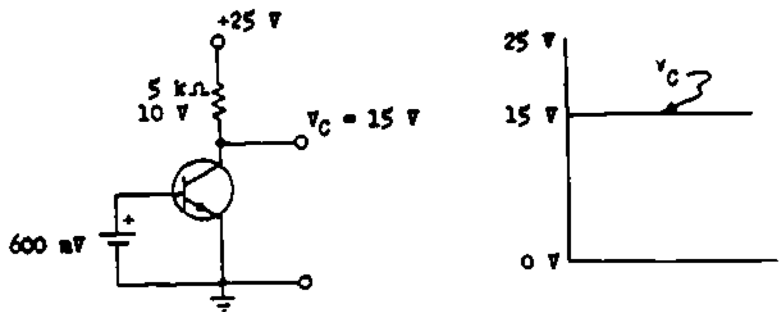


Figure 3-3. Static Conditions

385

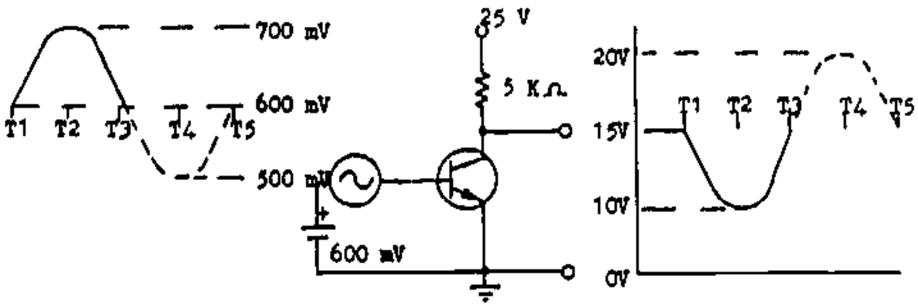


Figure 3-4. Input Signal Conditions

3-10. As the input signal goes positive, base voltage increases from 600mv to 700mv. See Figure 3-4. This increase in base voltage increases collector current. Assume I_C increases from 2 mA to 3 mA. The voltage across R_L will increase from 10 to 15 volts and V_C will decrease to 10 volts. Note that the output voltage is a negative alternation of voltage that is 180° out of phase and larger in amplitude than the input. In other words, a positive input signal will produce a decrease in output voltage.

3-11. During the negative alternation of the input signal, Figure 3-4, base voltage decreases from 600 mv to 500 mv. This decrease in base voltage decreases base current. Collector current will decrease from 2 mA to 1 mA. The voltage across R_L would decrease to 5 volts, and V_C would increase to 20 volts. The output is a positive alternation of voltage which is out of phase with and larger than the input. To summarize, with an input signal voltage amplitude of 200 mv peak-to-peak the base current changes caused output amplitude changes of 10 volts peak-to-peak. A small input signal voltage has been amplified to produce a large output signal voltage.

3-12. The PNP version of a common emitter configuration is shown in Figure 3-5. The primary difference between PNP and NPN common emitter configurations is the polarity of the source voltage. With a negative V_{CC}, the base voltage is negative with respect to ground and furnishes a forward bias for the base. This is represented by the 600 mv battery in Figure 3-6 and is the static bias.

3-13. On the positive alternation of the input signal, Figure 3-6, base current will decrease due to the fact that base voltage has decreased from 600 mv to 500 mv. The decrease in I_B causes I_C to decrease

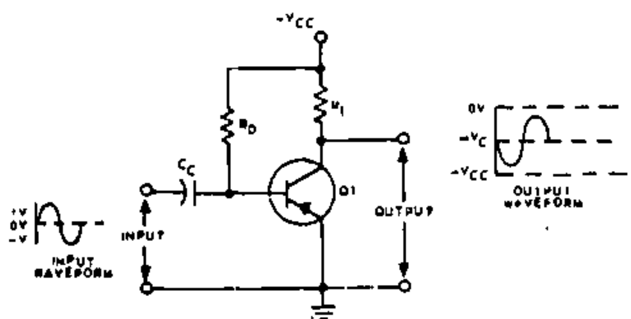


Figure 3-5. Common Emitter Amplifier (PNP)

377

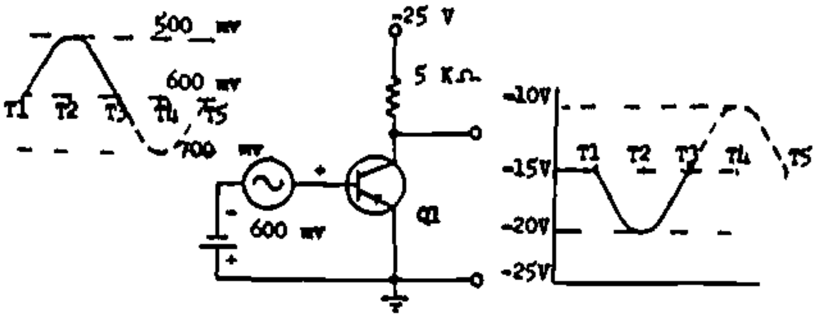


Figure 3-6. Common Emitter Signal Amplification (PNP)

from 2 mA to 1 mA. The voltage across R_L decreases from 10 volts to 5 volts. Collector voltage (V_C) then increases from -15 volts to -20 volts. Note that increasing I_B, increases I_C and increasing I_C, decreases V_C. The output signal varies at the same rate as the sinewave input, but is amplified.

3-14. When the negative alternation of the input signal is applied, Figure 3-6, base voltage increases to 700 mv which increases I_B. As I_B increases, I_C increases to 3 mA. As collector current increases, the voltage across R_L increases to 15 volts and V_C decreases to -10 volts. The change in V_C from it's static value (-15 volts) is the output signal voltage. This is the amplified version of the input signal.

3-15. Common Emitter Circuit Analysis

3-16. There are several methods of analyzing amplifier circuits. We will use the graphical method. It gives good results and is quite simple to do. This method is called LOAD-LINE ANALYSIS.

3-17. In order to use this method, we must first review common emitter characteristic curves. You should recall that this family of curves relates collector voltage V_C to collector current I_C for various values of base current I_B. Also, any point on one of the I_B curves shows three important values; base current, collector voltage, and collector current. Finally, each transistor has its own set of characteristic curves.

3-18. To predict the performance of a circuit, we can use characteristic curves and draw LOAD LINES to represent the circuit studied. A LOAD LINE is a line representing all the possible current - voltage relationships (I_C and V_{CE}) for a given circuit. In other words, the load line will show the values of I_C and V_{CE} (output) for any value of I_B (input). With a load line we can determine current, voltage, and power gains.

3-19. The circuit of Figure 3-7 will be used to demonstrate the use of a load line to analyze a transistor amplifier. A close inspection of the circuit diagram will reveal the following facts:

a. The circuit is a common-emitter configuration.

b. Transistor is a type 2N118 (NPN low power).

c. V_{CC}, the collector supply voltage, is 25 volts.

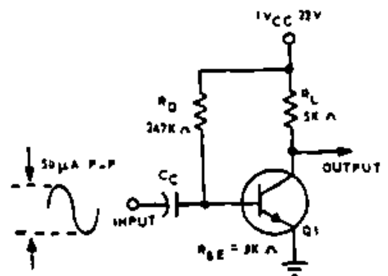


Figure 3-7. Transistor Amplifier Circuit

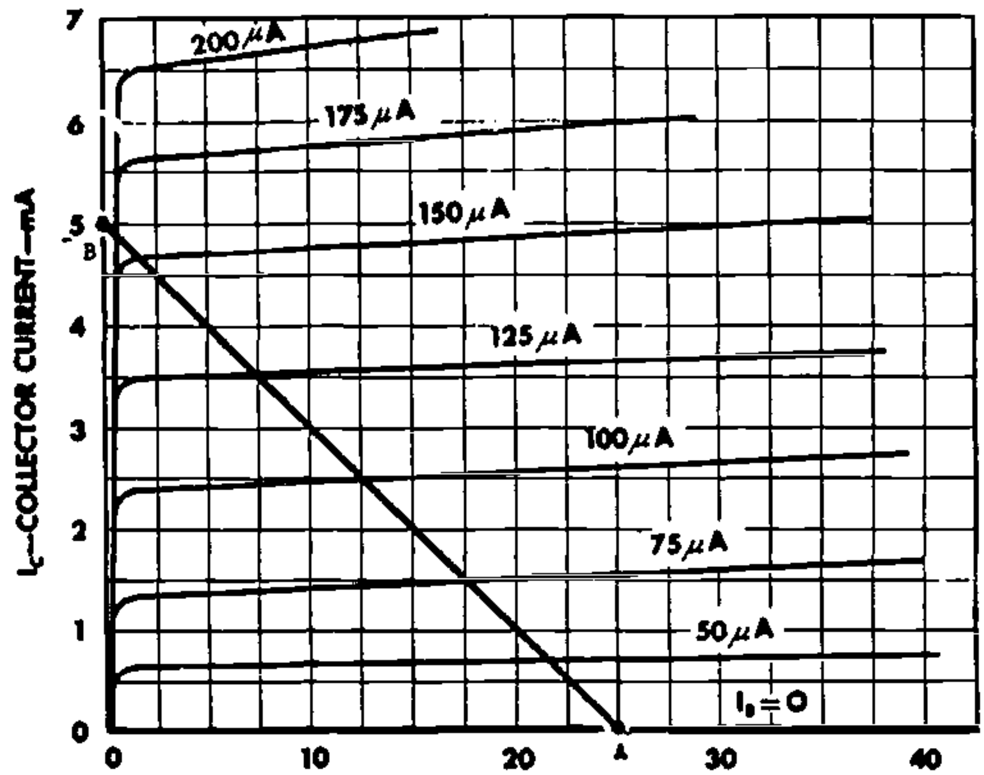


Figure 3-8. Common Emitter Characteristics

d. R_L, the collector load resistor, is 5 k ohms.

e. R_{BE}, the base-emitter junction resistance, is 3 k ohms.

f. R_D, the forward bias resistor, is 247 k ohms.

g. Input signal is 50 µA peak-to-peak.

3-20. We will also need the common emitter characteristic curves for the 2N118 transistor, as shown in Figure 3-8. With this information, we are ready to proceed with the circuit analysis.

3-21. Step 1: Plot the Load Line.

3-22. Two points establish a load line: maximum collector voltage and maximum collector current. To find the maximum collector voltage, let the transistor act as an OPEN circuit. Now there is no path for collector current. With no collector current through the load resistor R_L, there is no voltage drop across it to subtract from the supply voltage. We read the applied voltage across the transistor. The collector voltage will equal the supply voltage; we have one point of the load line. This point is on the collector voltage (horizontal) axis (V_C) at 25 volts and collector current (vertical) axis (I_C) at 0 mA. This is point A in Figure 3-8.

3-23. The second point is determined by letting the transistor appear as a SHORT

379

CIRCUIT. Now maximum collector current will flow, limited only by the value of the load resistor R_L. Use Ohm's Law to find collector current.

$$I_C = \frac{V_{CC}}{R_L} = \frac{25 \text{ volts}}{5 \text{ k ohms}} = 5 \text{ mA}$$

Since all the supply voltage is dropped across R_L, the collector voltage V_C is 0 volts. This information allows us to locate point B in Figure 3-8 on the collector current (vertical) axis at 5 mA, and the collector voltage (horizontal) axis at 0 volts.

3-24. To complete the load line, connect points A and B with a straight line. The resulting line is a LOAD LINE representing all of the possible collector voltage - collector current relationships for the circuit. We must now determine where on this load line the circuit is operating.

3-25. Step 2: Establish the Static Circuit Conditions.

3-26. The operating point Q (QUIESCENT point) represents the STATIC or no input signal condition for the circuit. The operating point on the load line will show the collector voltage and collector current for this static condition.

3-27. To find the operating point, the base current must be determined. Base current (I_B) flows through the base to emitter resistance R_{BE} and the forward bias resistor (R_D). The total resistance in the base current path is then:

$$R_T = R_{BE} + R_D$$

$$R_T = 3 \text{ k ohms} + 247 \text{ k ohms} = 250 \text{ k ohms.}$$

The applied voltage is 25 volts (V_{CC}). Now use Ohm's Law to find the base current:

$$I_B = \frac{V_{CC}}{R_T} = \frac{25 \text{ volts}}{250 \text{ k}\Omega} = 100\,\mu\text{a}$$

3-28. The operating point is located where the I_B = 100 μA curve crosses the load line, as shown in Figure 3-9, and is labeled Q. Now, the static collector voltage and current can be read from the graph. The collector voltage at the operating point is 12.5 volts (read from the horizontal axis), and the collector current is 2.5 mA (read from the vertical axis).

3-29. The emitter current is equal to the base current plus the collector current. Therefore, I_E is:

$$I_E = I_B + I_C = .100 \text{ mA} + 2.5 \text{ mA} = 2.6 \text{ mA}$$

3-30. This completes the analysis of the circuit in the static (no signal) condition. Next, the effect of the input signal on the circuit will be discussed.

3-31. Step 3: Apply the Input Signal.

3-32. Figure 3-10 illustrates the effect of the input signal on the base current of the transistor. Figure 3-10A shows the base current at the operating point Q. The input signal is illustrated in Figure 3-10B. Notice that the positive alternation of the input signal will increase base current. Figure

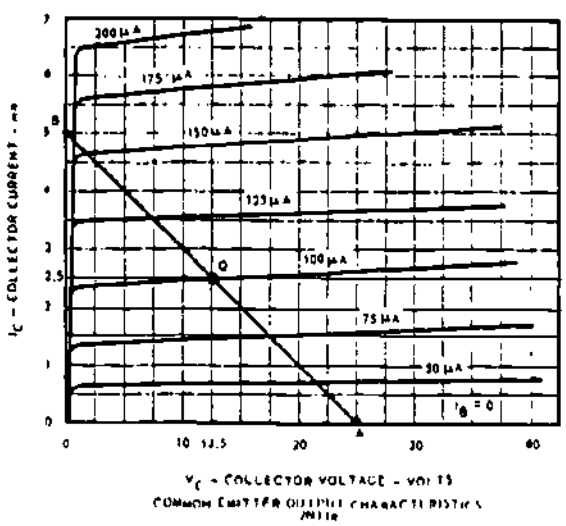


Figure 3-9. Load Line for 2N118 Transistor (Common Emitter Configuration)

359

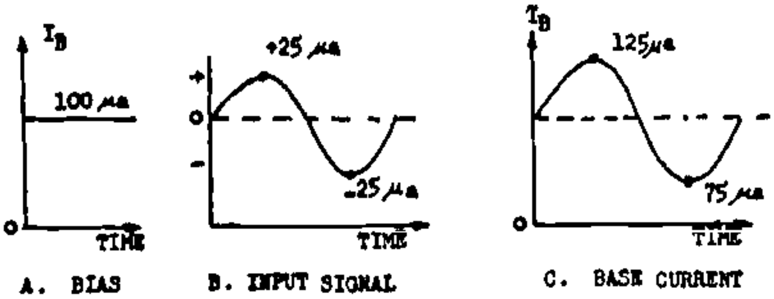


Figure 3-10. Effect of Input Signal

3-10C. On the negative alternation, the input signal will decrease base current. Notice the resulting base current in the transistor now varies, from 75 μA to 125 μA, in step with the input signal.

3-33. At the peak of the positive alternation of the input, the base current is 125 μAmp. At this instant, the circuit will be operating where the I_B = 125 μA curve crosses the load line (point C in Figure 3-11). The instantaneous operating point moves up along the load line to point C as the base current increases, then back down, as base current decreases, to the static operating point Q.

3-34. As the base current continues to decrease (due to the negative alternation of

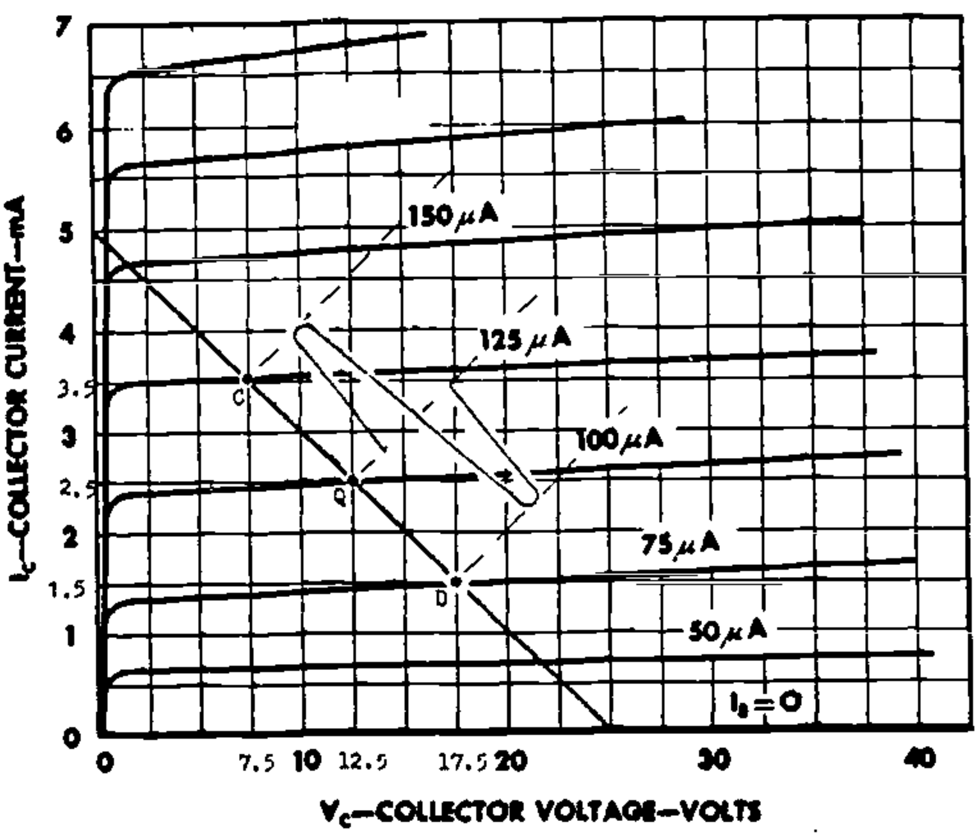


Figure 3-11. Common Emitter Characteristics

381

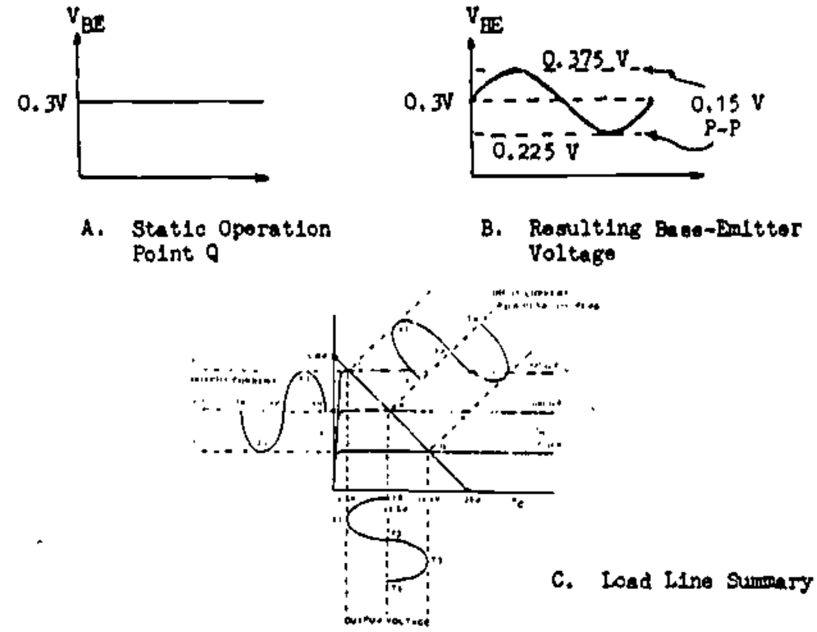


Figure 3-12. Effect of Input Signal

the input), the instantaneous operating point moves down along the load line to point D (Figure 3-11). At point D the base current reaches its minimum value of 75 μA; then moves back up the curve again to the static operating point Q (I_B = 100 μA). The total change in base current, which is called ΔI_B, is 50 μA (125 μA - 75 μA=50 μA).

3-35. The change in base current (ΔI_B) through the base-emitter junction resistance (R_{BE}) will produce a corresponding change in base-emitter voltage (ΔV_{BE}).

$$\Delta V_{BE} = \Delta I_B \times R_{BE}$$

3-36. In this circuit, the change in base current (given as the input signal) is 50μA p-p. The value of R_{BE} is 3 k ohms. Using the formula:

$$\Delta V_{BE} = \Delta I_B \times R_{BE}$$

$$= 50\ \mu A \text{ p-p} \times 3 \text{ k ohms} = 0.15\text{v p-p}$$

3-37. The effect of the input signal on base-emitter voltage is illustrated in Figure 3-12. In Figure 3-12A, the value of V_{BE} at the operating point Q is shown as 0.3 volt. Figure 3-12B shows the resulting V_{BE} when the input signal is applied.

Notice that the base-emitter voltage changes in response to the input signal. In the next step, we will determine the effect of the input signal on the collector circuit.

3-38. Step 4: Determine Output Current Change.

3-39. Figure 3-11 illustrates the effect of the input signal on the output current (I_C). At the operating point note that the I_C is 2.5 mA. This is found by drawing a line parallel to the horizontal axis at the operating point (Q). This line will cross the vertical axis (I_C) at the 2.5 mA level. At the peak of the positive alternation of the input signal, the base current is increased to 125 μA, located on the load line at point C. The collector current at point C is 3.5 mA. At the peak of the negative alternation, I_B decreases to 75 μA, located on the load line at point D. The decrease in I_B will cause I_C to decrease to 1.5 mA. The total change in I_C is called ΔI_C and is equal to 2 mA (3.5 mA – 1.5 mA = 2 mA)

3-40. Step 5: Determine Output Voltage Change.

3-41. Figure 3-11 also illustrates the effect of the input signal on the output voltage (V_C). At the operating point, the static V_C can be found by dropping a line from the operating point perpendicular to the horizontal axis. This line crosses V_C at 12.5 volts. At the peak of the positive alternation of the input signal, the base current increases to 125 μA, located on the load line at point C. A line dropped from point C would indicate a decrease in collector to emitter voltage from 12.5 volts to 7.5 volts. At the peak of the negative alternation of the input signal, I_B decreases to 75 μA (point D) and the collector to emitter voltage would increase to 17.5 volts. The total change in collector to emitter voltage is called ΔV_C and is equal to 10 volts (17.5v – 7.5v = 10 volts). From your analysis of the effects of the input signal or transistor operation, this important fact should now be more evident. As I_B increases, I_C increases, and V_C decreases.

3-42. Step 6: Determine Current Gain.

3-43. The gain of any device is the ratio of the output to the input. Expressed as a formula: Gain = $\frac{\text{output}}{\text{input}}$. We stated earlier that we can use the load line to calculate the current, voltage and power gains in an amplifier. The changes in an amplifier's output, divided by it's input changes, will give us the gain. The units used for this division must be the same.

3-44. The formula for current gain becomes: Current Gain = $\frac{\text{output current change}}{\text{input current change}}$. This current gain under operating conditions is called CURRENT GAIN (Ai). The A stands for gain and the subscript "i" stands for current. The total output current change (ΔI_C) in the circuit we have been discussing is 2 mA (Refer to Figure 3-11 and Step 4). The total input current change (ΔI_B) is 50 μA (Refer to Figure 3-10 and Step 3). We convert each of these changes to the same units, either mA or microamps, and use the formula:

$$Ai = \frac{\Delta I_C}{\Delta I_B} = \frac{2\text{ mA}}{50\ \mu A} = \frac{2000\ \mu A}{50\ \mu A} = 40$$

This means that the output current changes are 40 times greater than the input current changes.

3-45. Step 7: Determine Voltage Gain.

3-46. The VOLTAGE GAIN (Av) of an amplifier may be determined in the same manner as the current gain (Ai) using the formula:

$$\text{Voltage Gain (Av)} = \frac{\text{Output voltage changes}}{\text{Input voltage changes}}$$

The total output voltage change (ΔV_C) we found to be 10 volts. (Refer to Figure 3-11 and Step 5). The total input voltage change (ΔV_{BE}) is .15 volts. (Refer to Figure 3-12B and Step 3). The voltage gain is:

$$Av = \frac{\Delta V_C}{\Delta V_{BE}} = \frac{10\text{ volts}}{.15\text{ volts}} = 66.6$$

Observe that gain is not expressed in units such as volts, amperes, or watts. Gain simply means that the output is that many times greater than the input.

3-47. Step 8: Determine Power Gain.

3-48. The power gain (Ap) of an amplifier can be determined by multiplying the current gain by the voltage gain. The power gain for the amplifier we are discussing is:

$$A_p = Ai \times Av = 40 \times 66.6 = 2666$$

3-49. Power gain may also be determined by the ratio of output signal power to input signal power. Signal power is current change times the voltage change. The input signal power is:

$$Pi = \Delta I_B \times \Delta V_{BE}$$

$$= 50\ \mu A \times 0.15\text{ volts} = 7.5\text{ microwatts}$$

342

R_L = 4.2 KΩ

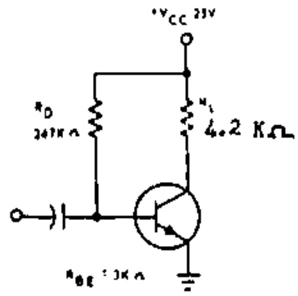
ΔI_C = 2.1 mA P-P

ΔV_C = 8 V P-P

Ai = 42

Av = 53.3

Ap = 2238



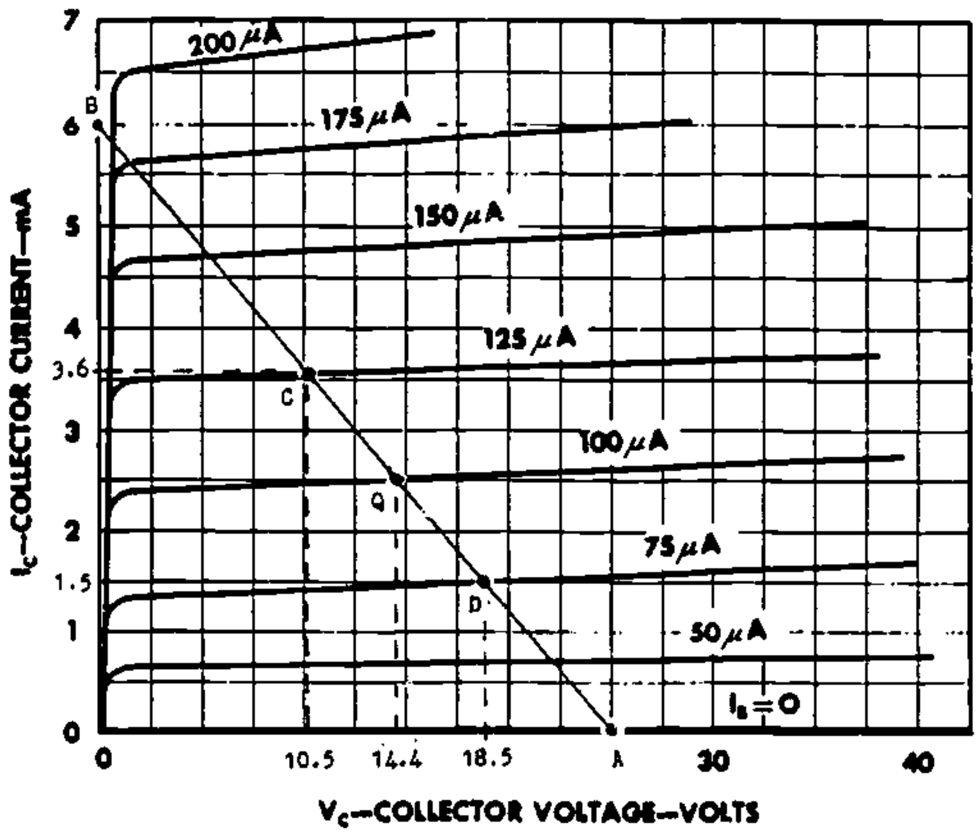


Figure 3-13. Common Emitter Amplifier

The output signal power is:

$$Po = \Delta I_C \times \Delta V_C$$

$$= 2mA \times 10 \text{ volts} = 20 \text{ milliwatts.}$$

Therefore, the power gain of the amplifier is found by using the formula:

$$A_p = \frac{Po}{Pi} = \frac{20 \times 10^{-3} \text{ watts}}{7.5 \times 10^{-6} \text{ watts}} = 2666$$

Notice that this is the same as the power gain calculated earlier.

3-50. Figure 3-12C shows a summary of the previous problem. The input signal is

393

projected onto the load line, showing the resulting change in I_B from point B to C. These points are projected to the vertical axis, showing the change in I_C. These points are also projected down to the horizontal axis, giving us the change in V_C. Following the points T0, T1, T2, T3, and T4 on the 3 sets of projected lines will show the relationship between input current, output current, and output voltage. As the input current increases from T0 to T1, output current increases, and output voltage decreases. Thus, input and output signal VOLTAGES are 180° out of phase. This 180° PHASE-SHIFT or PHASE INVERSION is a characteristic of the common emitter configuration ONLY.

3-51. Notice that the common emitter configuration develops a current gain (Ai) and a voltage gain (Av). Many factors govern the current and voltage gain of an amplifier. Some of these factors are the type of transistor and its characteristics, the amount of voltage applied to the circuit (V_{CC}), and the size of the collector load resistor R_L. The latter is the most important and useful to you as a technician. Figure 3-13 shows the same circuit as we studied before except that the value of R_L has been reduced from 5 k ohms to 4.2 k ohms. To find out what effect this change will have on circuit performance, we must construct a new load line following the steps previously outlined.

3-52. Step 1: Plot the Load Line.

Transistor OPEN:

$V_C = V_{CC} = 25\text{ V}$ when $I_C = 0\text{ mA}$ (Point A)

Transistor SHORT:

$I_C = \frac{V_{CC}}{R_L} = 6\text{mA}$ when $V_C = 0\text{ v}$ (Point B)

Join points with straight line.

3-53. Step 2: Establish Static Circuit Conditions.

$R_T = R_{BE} + R_D = 3\text{ K} + 247\text{ K} = 250\text{ k ohms}$

$I_B = \frac{V_{CC}}{R_T} = 100\ \mu\text{A}$

Point Q (operating point) is located where $I_B = 100\ \mu A$ curve and load line cross. We find that at the operating point:

$V_C = 14.4$ volts and $I_C = 2.5$ mA

3-54. Step 3: Apply the Input Signal.

The change in base current is:

$\Delta I_B = 50\ \mu\text{A p-p}$ (given)

This will cause the base current to go from a maximum of 125 μA (Point C) to a minimum of 75 μA (Point D). The change in base-emitter voltage is:

$\Delta V_{BE} = \Delta I_B \times R_{BE} = 50\ \mu\text{A} \times 3\text{K ohms} =$

0.15 volt p-p

3-55. Step 4: Determine Output Current Change.

$\Delta I_C = 3.6\text{ mA} - 1.5\text{ mA} = 2.1\text{ mA p-p}$
(read from graph, Figure 3-13)

3-56. Step 5: Determine Output Voltage Change.

$\Delta V_C = 18.5\text{v} - 10.5\text{v} = 8$ volts p-p
(read from graph, Figure 3-13)

3-57. Step 6: Determine Current Gain.

$$Ai = \frac{\Delta I_C}{\Delta I_B} = \frac{2.1\text{ mA p-p}}{0.05\text{ mA p-p}} = 42$$

Notice that when the load resistance R_L is reduced, the current gain INCREASES.

3-58. Step 7: Determine Voltage Gain.

$$Av = \frac{\Delta V_C}{\Delta V_{BE}} = \frac{8\text{ volts p-p}}{0.15\text{ volts p-p}} = 53.3$$

Note that making the load resistor R_L smaller REDUCES the voltage gain of the amplifier.

3-59. Step 8: Determine Power Gain.

$Ap = Ai \times Av = 42 \times 53.3 = 2238$

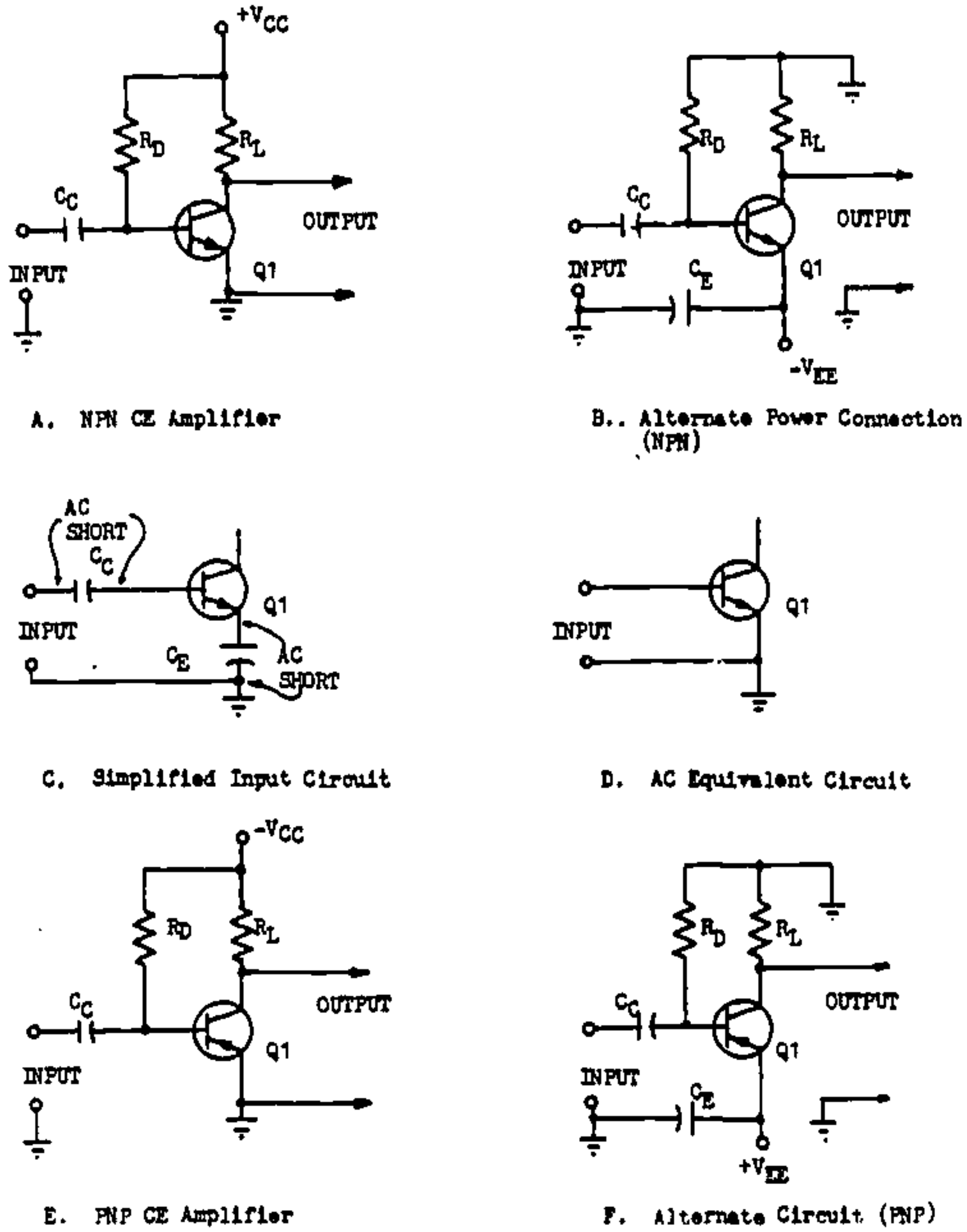


Figure 3-14. Common Emitter Configurations

NOTE: The power gain for this example DECREASED as R_L was reduced. Do not be misled into believing that this will always occur. Power gain is dependent on impedance matching, and will be maximum when the value of R_L is such that it matches the characteristic impedance of the transistor. Increases or decreases in this value of R_L will result in a reduced power gain (A_p). For this reason, the slope of the load line cannot be used to determine the effect of changes in R_L on A_p.

3-60. So, as the size of the collector load resistor decreases, current gain (Ai) increases, and voltage gain (Av) decreases. Likewise, when R_L is made larger, Av increases and Ai decreases.

3-61. It is not always necessary to have a $+V_{CC}$ for NPN transistors and a $-V_{CC}$ for PNP transistors. Figure 3-14 shows alternate methods of connecting the common emitter configuration. Figure 3-14B shows how an NPN transistor can be connected when only a negative power source voltage ($-V_{EE}$) is available. The input and output signal connections identify this circuit as a common emitter configuration. DC current flow is still from negative to positive; that is, $-V_{EE}$, through the transistor, to ground.

3-62. Figure 3-14C shows the simplified input circuit of Figure 3-14B. The coupling capacitor C_C acts as an AC short circuit (low reactance), and couples the input signal to the base of the transistor. Capacitor C_E is called a BYPASS or DECOUPLING capacitor and acts as an AC short circuit. This places the emitter at ground as far as the input AC signal is concerned. Figure 3-14D shows that the input signal is therefore developed across the base-emitter junction. This same technique can be applied to the PNP C_E amplifier (Figure 3-14E) to operate the transistor from a positive power source ($+V_{EE}$) as shown in Figure 3-14F.

3-63. The common emitter amplifier is often used because it is capable of producing current, voltage, and power gains. Decreasing the load resistor R_L causes A_i to increase and A_V to decrease, and vice versa. The input and output signals for the common emitter amplifier are 180° out of phase.

3-64. Common Base Amplifier

3-65. A common base amplifier configuration is shown in Figure 3-15. Notice that the input signal is applied between the emitter and base, and the output signal is taken between the collector and base. The base is the element which is common to both the input and output. Forward bias for the emitter-base junction is provided by the emitter supply voltage (V_{EE}), resistor R_E, and R_{BE}. The positive alternation of the input signal applied to the emitter of the NPN transistor in Figure 3-15A decreases forward bias and causes emitter current to decrease. A decrease in emitter current results in a decrease in collector current. A decrease in I_C causes collector voltage (V_C) to become more positive. The collector waveform is an amplified reproduction of the positive input alternation. Therefore, there is no phase shift in a common base circuit.

3-66. The negative alternation of the input signal adds to the forward bias and I_E will increase. Collector current will increase causing collector voltage to decrease. Notice the output voltage is going in a negative direction as the input signal goes negative.

3-67. Figure 3-15B illustrates the common base amplifier employing a PNP transistor. Note that V_{EE} and V_{CC} are opposite in polarity to that of the NPN in Figure 3-17A.

3-68. The positive alternation will add to the forward bias by making the "P" type emitter more positive. I_E and I_C will increase, causing V_C to go in a positive direction. Note the output waveform decreasing toward zero volts in Figure 3-15B.

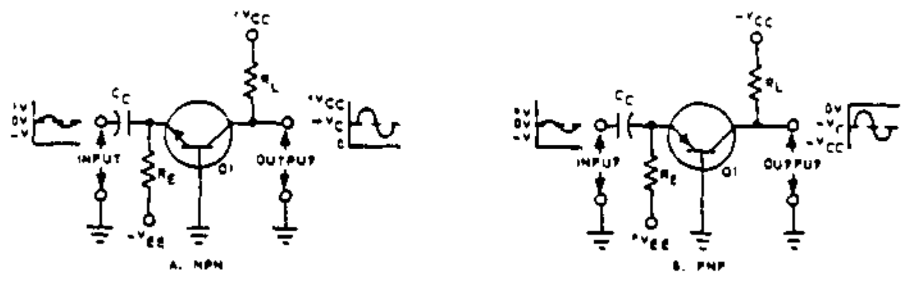


Figure 3-15. Common Base Configuration

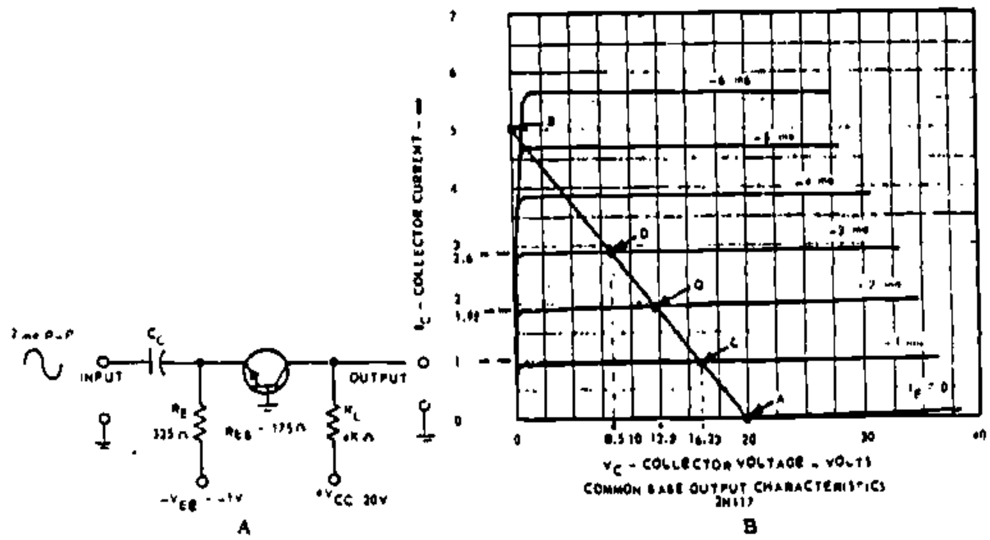


Figure 3-16. Load Line for 2N117 Transistor (Common Base Configuration)

3-69. On the negative alternation of the input signal, I_E and I_C will decrease due to the decrease in bias. Collector voltage will become more negative. Note that input and output signal voltages are in phase in the common base amplifier.

3-70. Figure 3-16 illustrates the common base amplifier circuit and its characteristic curves. We will now demonstrate the use of load line analysis on the common base circuit.

3-71. Step 1: Plot the Load Line.

3-72. With a V_{CC} of 20 volts and a load resistor of 4 k ohms, the amplifier's load line extends from point A (0 mA, 20 volts) for an open transistor to point B (5 mA, 0 volts) for a shorted transistor.

NOTE: The emitter resistor R_E has been disregarded in figuring maximum current of 5 mA. This is due to the fact that the resistance of R_E is less than one tenth R_L.

3-73. Step 2: Establish the Static Circuit Conditions.

3-74. The controlling element in a common base configuration is the emitter. Emitter current is controlled by the values of R_E, R_{BE}, and V_{EE}.

$$I_E = \frac{V_{EE}}{R_E + R_{BE}} = \frac{1 \text{ volt}}{500\ \Omega} = 2 \text{ mA}$$

The operating point (Q) is at the junction of the I_E = 2 mA curve and the load line. At the operating point, the static collector to base voltage V_{CB} is 12.5 volts and the static collector current I_C is 1.95 mA.

3-75. Step 3: Apply the Input Signal.

3-76. The positive alternation of the 2 mA p-p signal will oppose emitter current and I_E will decrease to 1 mA (point C of Figure 3-16). With a decrease in I_E, collector current decreases to 1 mA and collector voltage increases to 16.25 volts.

3-77. During the negative alternation, bias current (I_E) will increase to 3 mA at point D on the load line. I_C increases to 2.9 mA and V_{CB} decreases to 8.5 volts.

3-78. Step 4: Determine Output Current Change.

3-79. The change in collector (output) current can be read from the vertical axis of

388

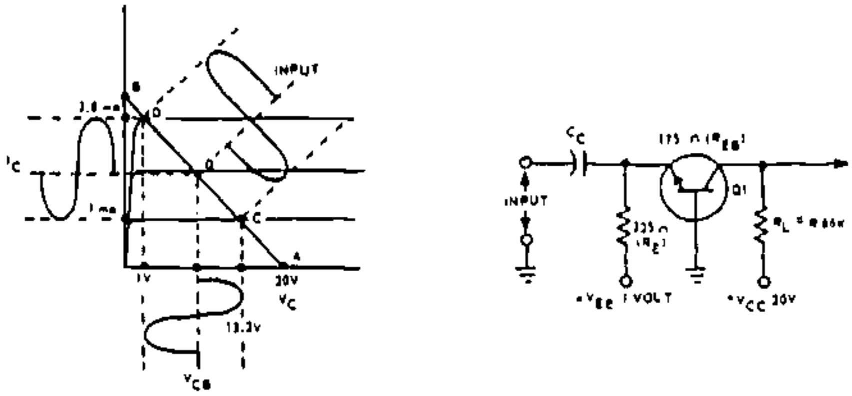


Figure 3-17. Load Line for 2N117 Transistor (Common Base Configuration)

the characteristic curves. At point C, collector current is 1 mA; at point D, I_C is 2.9 mA. The change in collector current is then:

$$\Delta I_C = 2.9 \text{ mA} - 1 \text{ mA} = 1.9 \text{ mA}$$

3-80. Step 5: Determine Output Voltage Change.

3-81. The change in collector to base (output) voltage can be read from the horizontal axis. At point C, V_C is 16.25 volts; at point D, V_{CB} is 8.5 volts. The change in collector to base voltage is:

$$V_{CB} = 16.25 \text{ v} - 8.5\text{v} = 7.75 \text{ volts}$$

3-82. Step 6: Determine Current Gain.

3-83. The current gain (Ai) for the common base amplifier is:

$$Ai = \frac{\Delta I_C}{\Delta I_E}$$

The peak -to -peak output current (ΔI_C is 2.9 mA minus 1 mA or 1.9 mA.

The peak-to-peak input current is 2 mA. Substituting these values into the formula, Ai is equal to 0.95.

$$Ai = \frac{\Delta I_C}{\Delta I_E} = \frac{1.9 \text{ mA}}{2 \text{ mA}} = 0.95$$

NOTE: This represents a current gain of less than one.

3-84. Step 7: Determine the Voltage Gain.

3-85. The voltage gain formula is:

$$Av = \frac{\Delta V_{CB}}{\Delta V_{BE}}$$

It is the ratio of change in output voltage to a change in input voltage. The ΔV_{CB} is 7.75 volts (refer to Figure 3-16). The input voltage (ΔV_{BE}) is:

ΔV_{BE} = Peak-to-Peak Signal Current x R_{BE} or $\Delta I_E \times R_{BE}$

Multiplying the input signal change by the base - emitter resistance results in an input signal voltage of 0.35 volts.

$$\Delta V_{BE} = \Delta 2 \times 10^{-3} \times 175\,\Omega = 0.35 \text{ volts},$$

the voltage gain is:

$$Av = \frac{\Delta V_{CB}}{\Delta V_{BE}} = \frac{7.75 \text{ volts}}{0.35 \text{ volts}} = 22.1$$

The output signal voltage is 22.1 times larger than the input signal voltage.

3-86. Step 8. Determine Power Gain.

38

3-87. The power gain for the common base, like that of the common emitter, can be calculated by one of two methods:

$$A_p = A_i \times A_v \quad \text{or } A_p = \frac{\text{output power}}{\text{input power}}$$

$$A_p = .95\ (A_i) \times 22.1\ (A_v) = 21$$

3-88. The gain of the common base configuration depends on many factors, as with the common emitter. One main factor is the size of the collector load resistor. Because the current gain of a common base amplifier is less than one, the circuit is not used as a current amplifier. The circuit is usually used for a large voltage gain. Figure 3-17 illustrates the effect on voltage and current gain when the collector load resistor is increased in size.

3-89. With a 8.66 k ohms resistor in the collector, the load line extends from 20V and 0 mA (point A) to 0V and 3 mA (point B). With the same amount of bias as before, the operating point will be at point Q. The input signal is still 2 mA peak-to-peak, so emitter current moves between points C and D during operation.

3-90. Collector current will vary from 1 mA to 2.8 mA. The current gain is now 0.9. Observe that current gain decreases as the size of the collector load resistor increases.

3-91. Collector voltage varies between 13.2 volts and 1 volt. The input voltage is the same as before (.35 volts) so the voltage gain is now 34.7. This represents an increase in voltage gain with the increase in collector load resistance. The power gain (A_p) of the common base amplifier is dependent on impedance matching, and will be maximum when the characteristic impedance of the transistor is equal in value to R_L. Changes in the resistance of R_L above or below this optimum value will result in a decreased power gain.

3-92. As with the common emitter, the common base configuration may appear in different arrangements. Figure 3-18 shows some typical examples. Part A shows a

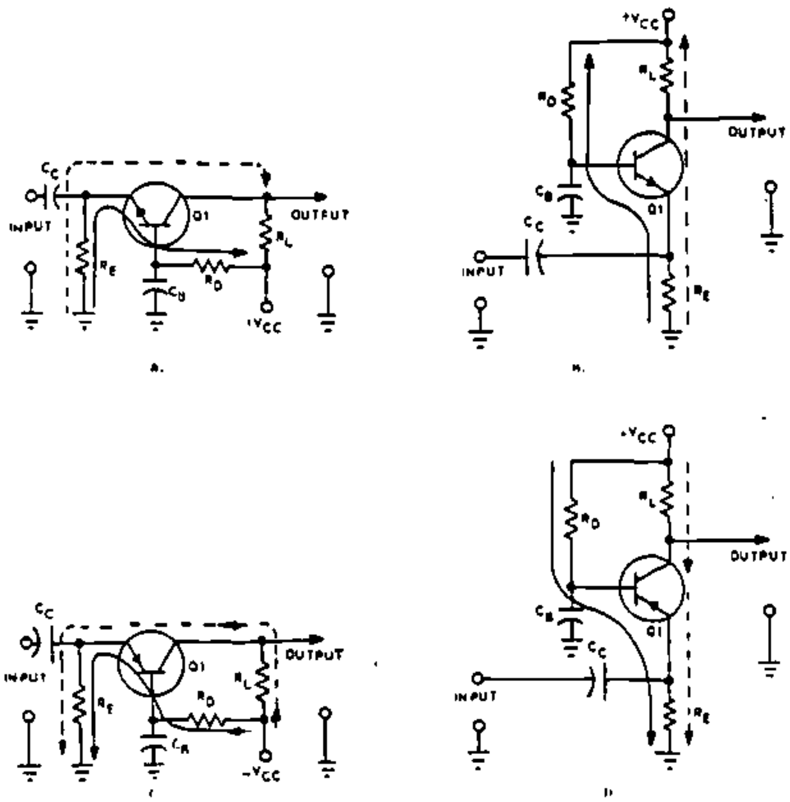


Figure 3-18. Common Base Configurations

399

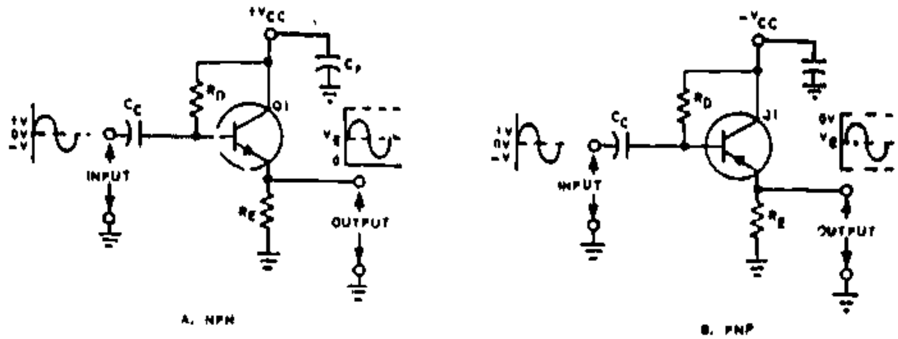


Figure 3-19. Common Collector Configuration

common base using a NPN transistor. Note that V_{EE} (emitter bias supply voltage) has been eliminated. Bias is now provided by R_D connected to the base. Because of this arrangement, C_B must be used to place the base lead at AC ground. Figure 3-18B is Figure 3-18A redrawn.

3-93. Figures 3-18C and D illustrate common-base drawings for PNP transistors. R_D furnishes the forward bias, R_E is the emitter resistor, R_L is the collector load resistor, and C_B is the base by-pass capacitor. The base current path is shown as a solid line while the collector current path is shown as a dashed line.

3-94. Common Collector Amplifier.

3-95. The third configuration in which we employ the NPN and PNP transistor as an amplifier is the common collector. Like the common emitter and common base configurations previously discussed, the common collector (C_C) has certain identifiable and useful characteristics, such as a relatively high current gain.

3-96. The common collector is also called an EMITTER FOLLOWER. In Figure 3-19, the collector is placed at AC GROUND or made common to both the input and output signals by the large by-pass capacitor, C_F.

3-97. In Figure 3-19, the input signal is applied between the base and ground. The output signal is developed between the emitter and ground. Thus, the collector (AC ground), is common to both the input and output. Note the output signal is developed across the emitter resistor (R_E) which is the load resistor. C_C is the input coupling capacitor and R_D provides forward bias for the transistor.

3-98. Let us now discuss the effect of the input signal on current through the common collector amplifier. Basically, as the positive alternation of a sinusoidal input signal is applied to the base of the NPN transistor in Figure 3-19A, an increase in base and emitter current occurs (forward bias increases). The increase in current through the emitter resistor (R_E) causes a corresponding increase in voltage across R_E. In other words, V_E (output signal) goes more positive with respect to ground. The negative alternation of the input signal causes base and emitter current to decrease, thus causing a corresponding decrease in output signal. Therefore, it can be seen from Figure 3-19A that the output signal voltage, developed across R_E, is controlled by a change in input signal, and the two signals are IN-PHASE.

3-99. The circuit operation of Figure 3-19B, using a PNP transistor, follows the operation of Figure 3-19A. The positive alternation of the input signal, applied to the base of the PNP transistor, causes base current to decrease (less forward bias). Therefore, emitter current decreases, the negative

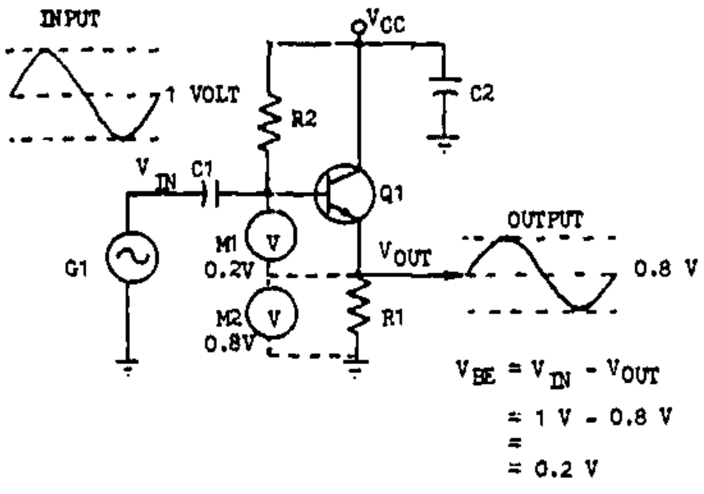


Figure 3-20. Voltage Gain - Common Collector

voltage across R_E decreases, and the output voltage goes in a positive (less negative) direction.

3-100. The negative alternation of the input signal causes base current to increase. Therefore, I_E increases and the voltage drop across R_E increases. The output voltage goes in a negative direction.

3-101. Another important characteristic of the common collector amplifier is the current gain. You recall from previous discussions on current gain in the three basic configurations, to calculate the gain of a common collector amplifier (Gamma), add the numerical value "1" to the current gain of the common emitter amplifier (Beta). Beta + 1 = Gamma. Of the three configurations, the common collector has the highest current gain and for this reason is often used as a CURRENT AMPLIFIER.

3-102. In terms of voltage gain, the common collector provides a gain of less than one. That is, the output voltage is SMALLER than the input voltage. This can best be explained by referring to Figure 3-20. As you recall, the output signal is developed across the emitter resistor (R-1) while the input signal is applied across both R_{BE} and R1 in series. The effective input voltage (base to emitter voltage) is the input voltage (V_{IN}) minus the output voltage (V_{OUT}). As the gain approaches one the effective input voltage approaches zero. Thus, the voltage gain of a common collector amplifier is always less than one, and is not normally used as a voltage amplifier. As with the common emitter and common base amplifiers, the power gain of the common collector amplifier is dependent on impedance matching.

3-103. Since the input signal is applied to the base in a common collector configuration and the output is taken across the emitter resistor, this causes both control elements (base and emitter) to feel a signal at the same time. As the voltage on the base goes in a positive direction, the voltage on the emitter goes in a positive direction. Likewise, as the voltage on the base goes in a negative direction, the voltage on the emitter goes in a negative direction.

3-104. This action is referred to as DEGENERATION. DEGENERATION is defined as the process of returning a part of the output of an amplifier back to its input in such a manner that it cancels part of the input signal.

3-105. Figure 3-20 illustrates what this means. An input signal of one volt peak-to-peak is applied at the input terminals and developed across the resistance of the

392

base-emitter junction (R_{BE}) and the emitter resistor (R1). Part of the input signal would be developed across R_{BE} and part across R1. With respect to controlling the emitter current, the transistor would "feel" and respond to the voltage across the base-emitter junction only. Part of the input signal to the amplifier has been lost, or cancelled. Refer back to the definition of degeneration. Degeneration is present because both control elements of the transistor (base and emitter) has a signal on them. The signal voltage on the emitter is in phase with and, therefore, cancels part of the signal voltage applied to the base.

3-106. One disadvantage of DEGENERATION which should be obvious at this time, is the reduction in signal voltage or gain in the output of the amplifier. However, there are advantages in using DEGENERATION, such as greater amplifier stability, and an increase in frequency response. These advantages will be discussed in a later chapter in more detail.

3-107. Stabilization.

3-108. Transistors are very sensitive to temperature variations. Heat, whether it comes from current carriers flowing through the transistor, or from the environment in which the transistor operates, affects transistor circuit operating characteristics. The process of preventing undesired changes in a transistor circuit caused by heat is called TEMPERATURE STABILIZATION.

3-109. In order to understand the operation of the various stabilization circuits, the effects of temperature on the transistor must first be examined in more detail. The circuit of Figure 3-21A will be used to illustrate the temperature effects. Figure 3-21B shows the characteristic curves for Q1 at 25 degrees Centigrade (about room temperature) with the load line for the circuit of Figure 3-21A. The operating point has been established so that collector current (I_C) is 1 mA, and collector voltage (V_C) is 10 volts. We would like to maintain the value of I_C constant over a wide range in temperature, as indicated in Figure 3-22A.

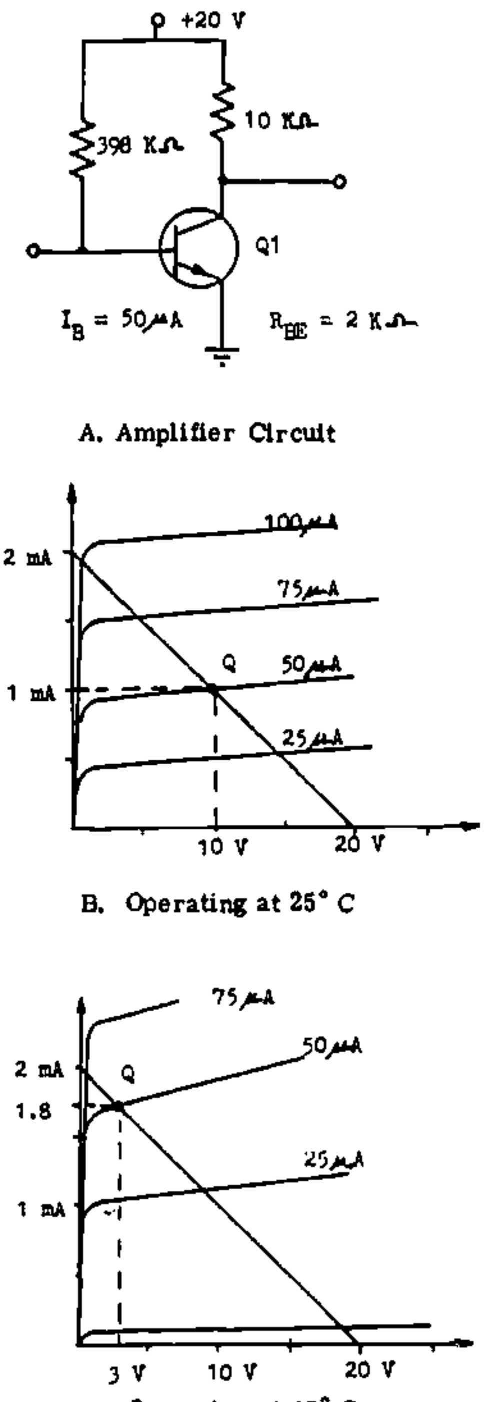


Figure 3-21. Effects of Temperature on Transistor Operation

3-110. Figure 3-21C shows what happens to the characteristic curves when the transistor is operated at a temperature of

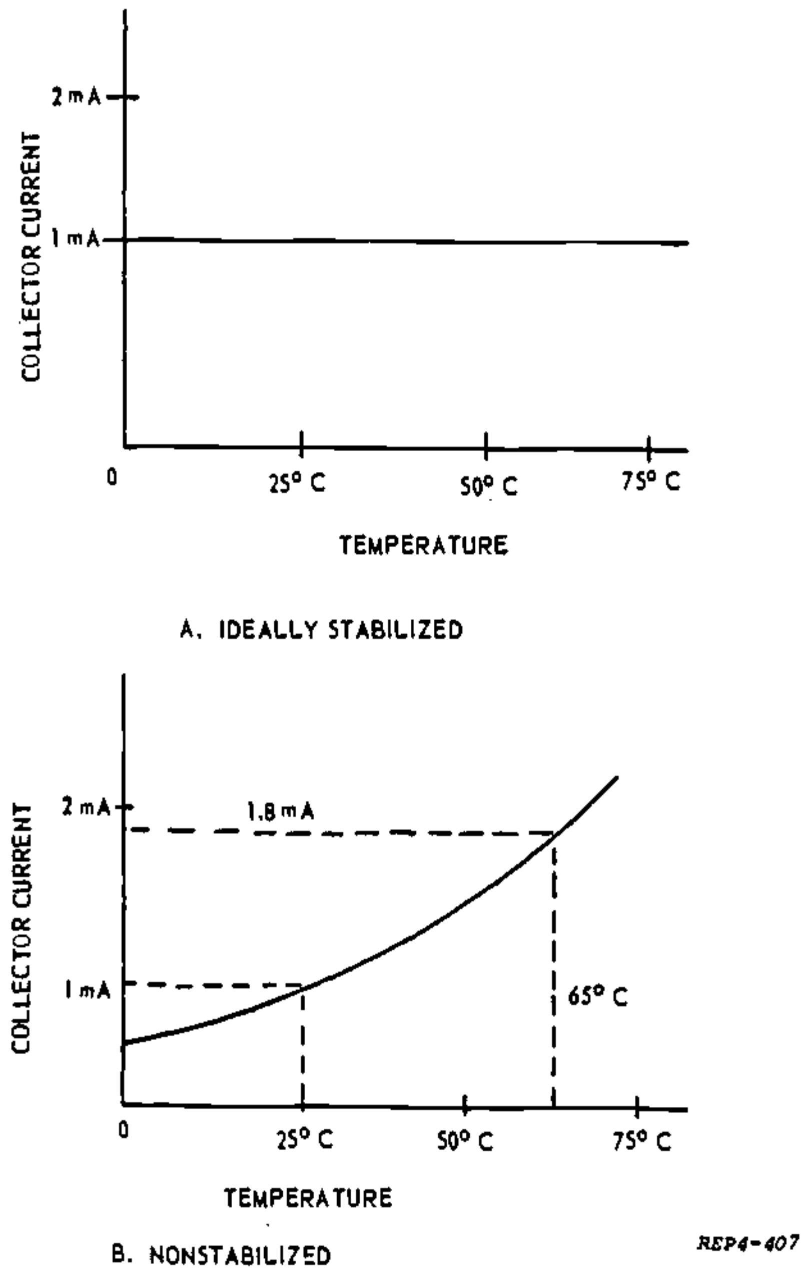


Figure 3-22. Collector Current versus Temperature

65 degrees Centigrade. Notice that the curves have changed due to the increase in operating temperature. So not only do the characteristic curves depend upon the type of transistor and circuit configuration (as you learned earlier), but also on the operating temperature of the transistor as well. The load line, as determined by the values of V_{CC} and R_L, remains the same. We see in Figure 3-21C that the operating point Q has moved to the saturation region. Collector current has increased to 1.8 mA and V_C is now only 3 volts. Since the saturation region is nonlinear, the amplifier will now severely distort the input signal. The relationship between I_C and temperature for this circuit is shown in Figure 3-22B.

3-111. As you recall, semiconductor devices have a NEGATIVE temperature coefficient of resistance. This means that the resistance of the base-emitter junction (R_{BE}) will decrease as temperature increases. The lower resistance will allow slightly more base current to flow, and therefore more collector current as well.

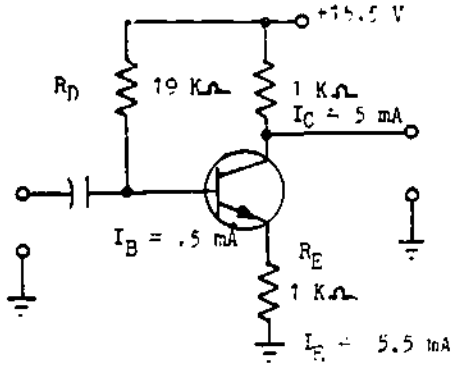
3-112. The reverse biased collector-base junction is also sensitive to temperature changes. Recall that I_{CBO} (collector-base reverse bias current) is due to the flow of minority current carriers. These minority current carriers are produced when covalent bonds are broken. Heat provides the energy to break covalent bonds, forming electron-hole pairs. A temperature increase of about 10° Centigrade causes the number of electron-hole pairs to double. In the NPN transistor, for example, this results in both majority and minority current carriers being created in the P-type base (electrons are minority carriers and holes majority carriers in P material). The electrons will move out of the base region, since they will be aided by the strong CB junction field. The holes, however, cannot leave the base. Therefore, the positively charged holes will attract electrons from the emitter, increasing I_E. A small portion of these additional electrons attracted from the emitter will become base current. Most will move on to the collector, aided by the strong CB junction field. Thus, an increase in the number of electron-hole pairs, generated by heat, will cause an increase in collector current.

3-113. We have seen that an increase in temperature in an unstabilized transistor circuit will cause an increase in collector current. The increase in current through the transistor will cause the transistor to increase in temperature, since power ($P = I^2R$) in the transistor is dissipated as heat. Unless these effects are controlled, the transistor may become excessively hot and be destroyed.

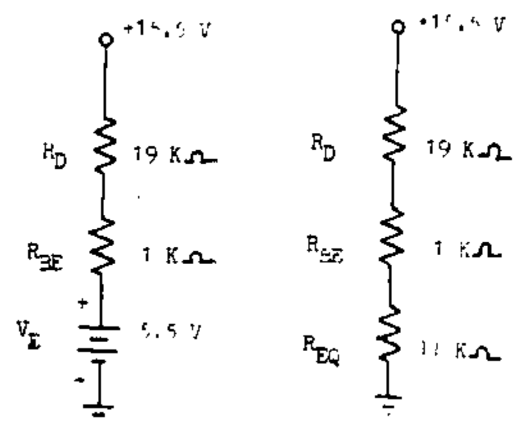
3-114. In order to properly stabilize a transistor circuit for temperature variations, we must compensate the circuit so that base current does not change appreciably as the emitter-base junction resistance varies with temperature. Also, the effects of I_{CBO} must be compensated for to keep the collector current constant. In most silicon transistors, the amount of I_{CBO} is not important unless the transistor will be operating at temperatures above 75°C. This is not true for germanium transistors, however, because of their much larger I_{CBO} (1 to 10 μA) at room temperature. Compensation for I_{CBO} effects is necessary at much lower operating temperatures (typically 50°C). Now we will discuss some of the various circuits devised to reduce the effects of temperature on transistor currents.

3-115. Emitter Resistor Stabilization

3-116. One of the most commonly used stabilization circuits is shown in figure 3-23A. An emitter resistor is placed in the emitter circuit. This resistor is often called a SWAMPING resistor, since it reduces or SWAMPS out the effects of changes in emitter-base junction resistance. To see how



A. Schematic



B. Equivalent Base Network

C. Equivalent Emitter Resistor

Figure 3-23. Emitter Resistor Stabilization

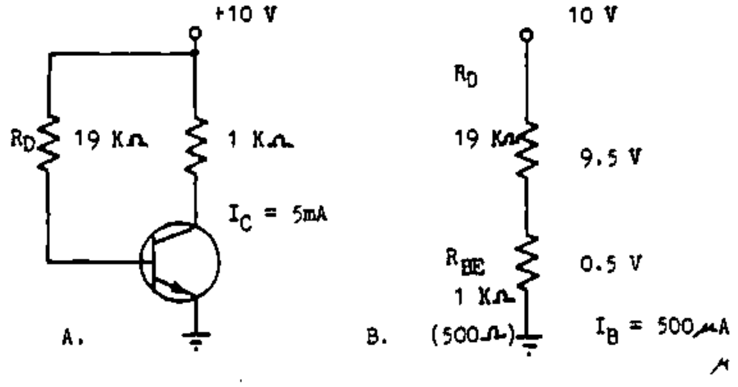


Figure 3-24. Effects of Changes in R_{EB} on Unstabilized Amplifier

this is accomplished, examine the bias network and base current path. Notice first that all of the current flowing into the transistor (emitter current, I_E) must flow through R_E. Recalling that I_E is I_B plus I_C, we find the emitter current to be:

$$I_E = I_C + I_B = 5 \text{ mA} + 500\,\mu\text{A} = 5.5 \text{ mA}$$

The emitter current (5.5 mA) flowing through R_E (1 k ohm) will produce a voltage drop V_E of 5.5 volts. We can draw an equivalent diagram of the base bias network as shown in Figure 3-23B, replacing R_E with a battery that provides the same emitter voltage. Resistors R_D and R_{BE} need only drop the 10 volt difference between V_E and V_{CC}. The bias circuit can be further simplified by replacing the battery with an equivalent resistance (R_{EQ}) that will produce the same voltage drop (V_E) due the flow of base current. This value of resistance is found by:

$$R_{EQ} = \frac{V_E}{I_B} = \frac{5.5V}{0.5 \text{ mA}} = 11 \text{ k ohms}$$

The bias circuit then becomes the circuit shown in Figure 3-23C. The emitter resistor R_E thus appears, to the base current, to be a much larger resistance (R_{EQ} = 11 k ohms) than the 1 kohm value given on the schematic. This will help reduce the effect of emitter-base junction resistance changes (caused by temperature changes) on base current.

3-117. To illustrate this fact, we will compare the unstabilized transistor amplifier shown in Figure 3-24A to the emitter resistor stabilized circuit of Figure 3-25A. Both amplifier circuits are biased for the same base current (I_B = 500 μA) and collector current (I_C = 5 mA) at the operating point. Figure 3-24B shows the base bias circuit for the unstabilized amplifier of Figure 3-24A. Let us assume that the emitter-base junction resistance decreases from 1 k ohm to 500 ohms due to an increase in operating temperature. The approximate circuit values with R_{BE} = 500 ohms are given in parenthesis. Notice that the base current increases from 500 micoramperes to 513 microamperes. The 13 microamperes increase in base current is a 2.6% increase.

3-118. Figure 3-25B shows the bias circuit for the circuit of Figure 3-25A. Again, assume R_{BE} decreases from 1 k ohm to 500 ohms due to an increase in operating temperature. This will produce the circuit values shown in parenthesis. Now the base current only increases from 500 microamperes to 508 microamperes. The 8 microampere increase represents a change of only 1.6%. This illustrates how the emitter resistor reduces or "swamps" out any changes that R_{BE} might produce in the circuit.

3-119. Remember that any change in base current will be amplified the same as an

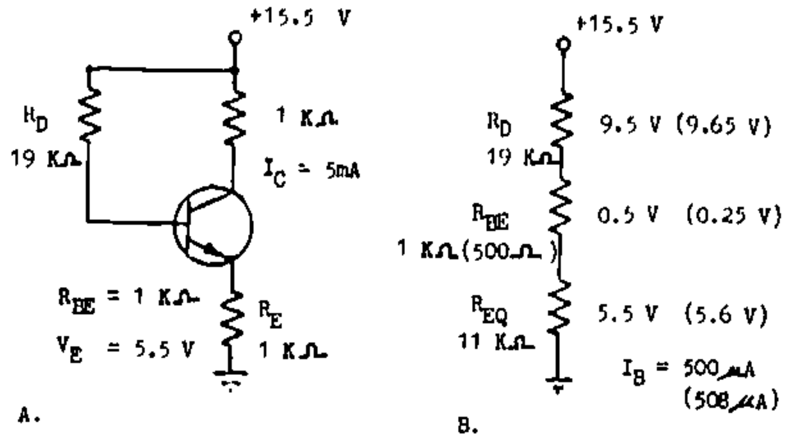


Figure 3-25. Effects of Changes in R_{EB} on Stabilized Amplifier

input signal. The emitter resistor stabilized circuit will therefore produce a smaller increase in I_C than the unstabilized circuit for the same decrease in R_{BE}.

3-120. The emitter resistor is also effective in reducing the effects of I_{CBO}. Recall that I_{CBO} adds to collector current, so as temperature increases, collector current will increase. Also, recall that the trapped holes in the base will draw electrons from the emitter, so I_E will increase as well. The increase in I_E will increase the voltage drop (V_E) across R_E. This will make the emitter more positive and decrease emitter-base current. Collector current will be reduced back toward its original value. Thus, the emitter resistor helps compensate for changes in I_{CBO}.

3-121. Although the emitter swamping resistor does help stabilize the common emitter amplifier for DC changes caused by temperature, it also causes degeneration of the input signal. As you recall from the discussion of the common collector configuration, the input signal will be divided between R_{BE} and R_E. Since only the signal felt across R_{BE} is amplified, the gain of the circuit is reduced. The DC operating point stability of the emitter resistor stabilized circuit can be maintained, without loss of gain, by placing the emitter at AC ground. This is done by placing a relatively large capacitor C_E across the emitter resistor (see figure 3-26). This emitter "bypass" capacitor allows the signal to "see" ground on the emitter, so all of the input signal will be felt across the emitter-base junction. Since no signal is developed across R_E, there will be no loss of gain. The value of C_E is chosen such that its reactance is small compared to R_{BE} for the lowest signal frequency to be amplified. This allows temperature stabilization without degeneration.

3-122. Voltage Divider Bias Stabilization

3-123. A very common modification of the emitter resistor stabilization circuit just

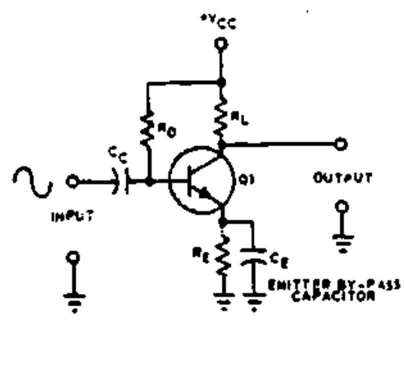


Figure 3-26. Temperature Stabilization Without Degeneration

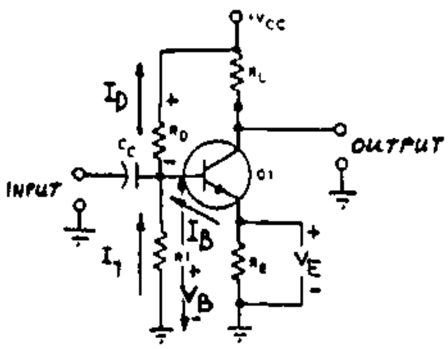


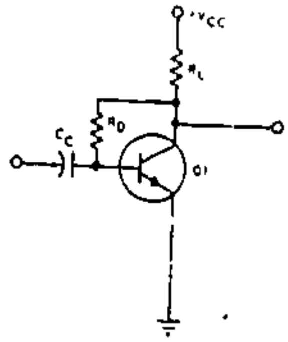
Figure 3-27. Voltage Divider Bias Stabilization

discussed is shown in Figure 3-27. Notice the addition of resistor R1 between base and ground. You may recall that this voltage divider (R1 and R_D) was one of the basic transistor bias circuits introduced earlier. This arrangement provides additional stability to the circuit for the effects of I_{CBO}, by holding the base-to-ground voltage V_B more constant. In this circuit, R1 provides a current (I_1) which is a large portion of the total current (I_D) that flows through R_D ($I_D = I_1 + I_B$). Thus, changes in base current will not cause a very large change in base voltage V_B. Now, when I_{CBO} causes an increase in I_E, as was described earlier, the increase in emitter voltage (V_E) will cause a larger decrease in base-emitter voltage (V_{BE}). This will cause a larger decrease in I_B, and a corresponding decrease in collector current, reducing I_C to a value closer to its original value.

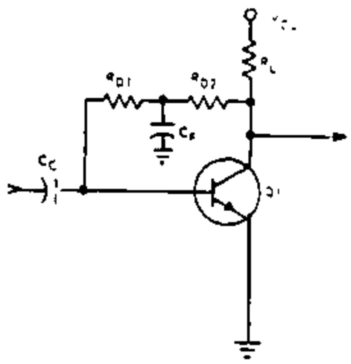
3-124. Self Bias Stabilization

3-125. The self bias arrangement, shown in Figure 3-28A, connects bias resistor R_D between the base and collector of the transistor. Resistor R_D was previously connected directly to V_{CC}. The collector voltage (V_C) now becomes the source voltage for the base bias network. When temperature causes an increase in collector current, collector voltage decreases. The decrease in V_C causes the voltage applied to the base (V_B) to decrease. A decrease in base voltage (V_B) will reduce forward bias, reducing base current, and therefore collector current is decreased. Summarizing the total effect using symbols:

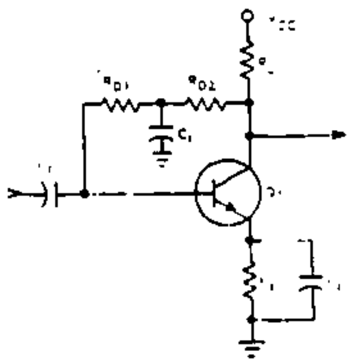
$I_C\uparrow$, $V_{RL}\uparrow$, $V_C\downarrow$, $V_B\downarrow$, $I_B\downarrow$, $I_C\downarrow$



A. Basic Self Bias Circuit



B. Self Bias Without Degeneration



C. Self Bias with Emitter Resistor

Figure 3-28. Self Bias Stabilization.

In other words, as I_C tends to increase due to temperature increases, the self bias network tends to cut I_C back down automatically.

3-126. A disadvantage of the self bias arrangement shown in Figure 3-28A, however, is that the amplified AC output signal on the collector also affects the base voltage. Since the collector and base signals are 180° out of phase, that part of the collector signal that gets back to the base through R_D cancels some of the input signal. This is degeneration, and reduces the gain of the amplifier.

3-127. To reduce this effect, the bias network is modified as shown in Figure 3-28B. The bias resistor R_D is now split into two resistors R_{D1} and R_{D2} that add up to the same resistance as R_D. A capacitor C_F is connected from the junction of R_{D1} and R_{D2} to ground. This arrangement provides the same DC temperature stability as the previous circuit. However, the AC output signal present on the collector cannot get back to the base, because the reactance of C_F is small, placing the junction of R_{D1} and R_{D2} at AC ground. Resistors R_{D1} and R_{D2} and capacitor C_F form a low-pass filter network which provides DC stabilization without AC signal degeneration. The self bias network is often used with an emitter resistor, as shown in Figure 3-28C, to provide even greater stabilization against the effects of temperature.

3-128. Thermistor Stabilization

3-129. Another method used to compensate for the effects of temperature uses a temperature-sensitive resistor called a THERMISTOR. The word THERMISTOR is short for thermal resistor, indicating that the resistance will change with temperature. As used in this example, it has a NEGATIVE temperature coefficient of resistance, as does the transistor. That is, its resistance DECREASES as its temperature INCREASES. The schematic symbol for the thermistor is a resistor with t°, representing temperature, as shown in the thermistor stabilized amplifier of Figure 3-29.

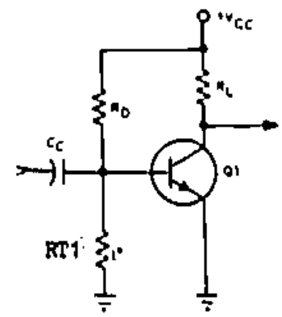


Figure 3-29. Thermistor Stabilization

3-130. As temperature increases, collector current starts to rise and the resistance of thermistor RT1 will decrease. As the resistance of RT1 decreases, more current will flow through RT1 and R_D. The increase in current through R_D causes a greater voltage drop across R_D. The voltage drop across RT1 will therefore decrease, reducing forward bias voltage. Reducing forward bias voltage will cause base current to decrease, thereby causing collector current to decrease back toward its normal (ideal) value.

3-131. To see the effectiveness of the thermistor as a stabilization component, refer to figure 3-30. Curve X shows the variation in collector current for a circuit that is not stabilized. Curve Y shows the variation in I_C for a circuit that is emitter resistor stabilized. Curve Z shows the variation in collector current for a circuit using thermistor stabilization. Notice the

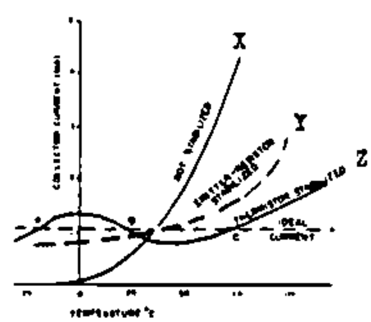


Figure 3-30. Collector Current versus Temperature (Emitter Resistor and Thermistor)

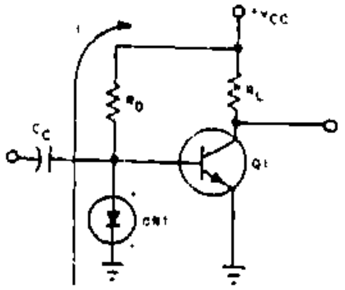


Figure 3-31. Forward-Biased Diode Stabilization

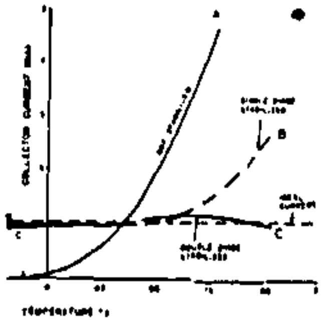


Figure 3-32. Collector Current Versus Temperature (Diode Stabilized)

improvement in stability with the circuit that is thermistor stabilized. This curve approaches the IDEAL CURRENT reference over a wider range of temperatures. However, thermistor stabilization achieves the ideal current value at only three points (A, B and C), because the thermistor resistance variation with temperature is not equal to the variation in transistor junction resistances. Since the material of the thermistor is not the same as the transistor, the two resistances will not react identically to changes in temperature.

3-132. Forward Biased Diode Stabilization

3-133. In order to more closely follow the resistance changes of the transistor, the thermistor can be replaced by a forward biased diode, as shown in Figure 3-31. Since the diode and transistor are made of the same materials and both have a negative temperature coefficient, the diode will be able to more closely compensate the circuit for changes in emitter-base junction resistance. The operation of this circuit is otherwise the same as the thermistor circuit just discussed.

3-134. The effectiveness of this form of circuit stabilization is shown in Figure 3-32. Notice on Curve B that, for temperatures less than approximately 50° Centigrade, the collector current is very close to the ideal constant collector current. Above 50° C., the effects of I_{CBO} become great, and the curve begins to rise rapidly. This indicates that additional compensation must be employed at the higher temperatures to offset the adverse effects of I_{CBO} on collector current.

3-135. Reverse Biased Diode Stabilization

3-136. Figure 3-33 shows how a reverse biased diode can be used to reduce the effects of ICBO on collector current. Since diode CR1 is reverse biased, there will be a small reverse current (I_R) due to minority current carriers. These minority current carriers are due to electron-hole pairs, generated by heat. Remember that I_{CBO} is also due to electron-hole pairs, generated by heat. If both PN junctions are identical and at the same temperature, then electron-hole pairs will be formed in CR1 and Q1 at the same rate.

3-137. As the reverse current of CR1 increases, it will cause a larger voltage drop across R_D. This will reduce the voltage across the base-emitter junction (V_{BE}), causing base current to decrease. Therefore,

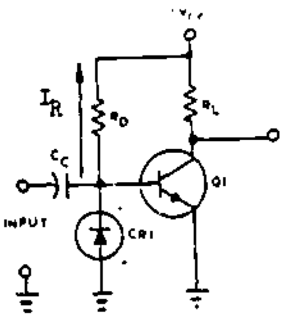


Figure 3-33. Reverse Biased Diode Stabilization

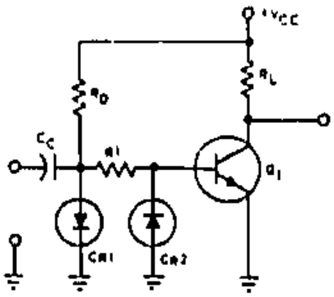


Figure 3-34. Double-Diode Stabilization

collector current will decrease by the same amount I_{CBO} increased. The result is that the collector current would remain almost constant with temperature.

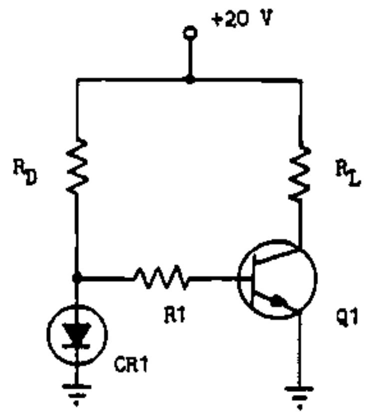
3-138. Double Diode Stabilization

3-139. It is not uncommon to find both a forward-biased and a reverse-biased diode in the same amplifier circuit. This arrangement is called DOUBLE-DIODE stabilization, and is shown in Figure 3-34. The forward-biased diode CR1 compensates for changes in the resistance of the forward-biased emitter-base junction due to temperature. The reverse-biased diode CR2 compensates for the effects of I_{CBO} in the reverse-biased collector-base junction. Curve C of Figure 3-32 shows the increased temperature stability of the double-diode stabilized amplifier. The collector current is maintained at very near the ideal value over a wide range of operating temperatures.

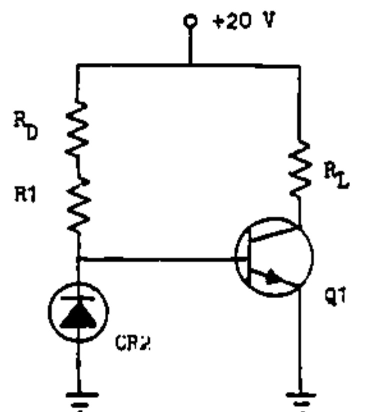
3-140. Notice resistor R1 in Figure 3-34. This resistor was not shown in either the circuit employing the forward-biased or the reverse-biased diode. In this circuit, R1 serves to isolate the two diodes, and also increases the effectiveness of each. Figure 3-35 shows how R1 fits into the forward-biased diode stabilization network employing CR1, while Figure 3-35B shows R1 in the reverse-biased diode stabilization network with CR2.

3-141. Figure 3-35A shows that R1 acts similar to a "swamping" resistor in that it increases the total resistance of the base current path. This will help reduce any change in base current due to changes in emitter-base junction resistance caused by temperature. Also, any increase in base current will produce a larger voltage drop across R1, thus reducing V_{BE}. This will aid the action of CR1 in reducing the forward bias voltage as temperature increases.

3-142. Figure 3-35B shows that R1 also aids the action of CR2. The resistance of R1 effectively adds to R_D, so that increases in reverse current from CR2 will produce a larger decrease in bias voltage. This will reduce base and collector current in transistor Q1 to better cancel the added I_{CBO} current. Collector current is still close to the ideal value.



A. Forward Bias Network



B. Reverse Current Network

Figure 3-35. Effect of R1 on Diode Stabilization Networks.

3-143. Throughout this section we have used NPN transistors to demonstrate the operation of the various stabilization circuits. However, all of the problems, effects, and stabilization techniques presented apply equally as well to circuits using PNP transistors.

3-144. Distortion

3-145. In general terms, DISTORTION is a change in waveform. It is the opposite of fidelity; a circuit that has high fidelity has low distortion. Amplifiers are subject to three major types of distortion: amplitude, frequency and phase.

3-146. By definition, AMPLITUDE DISTORTION is the result of changing a waveshape so that its amplitude is no longer proportional to the original amplitude. During the first alternation (increasing I_B), the output is varying at the same rate as the input. On the second alternation (decreasing I_B) the output does not vary at the same rate as the input, since emitter current is cut off for a portion of this alternation. The result is that the output signal waveshape is no longer proportional at all points to the input waveshape. Class AB, Class B, and Class C operation will cause amplitude distortion. Class A amplifiers can also cause amplitude distortion when they are operated in the nonlinear area of the dynamic transfer curve.

3-147. FREQUENCY DISTORTION occurs when all frequencies are not amplified equally. An amplifier designed to amplify frequencies in the audio band should amplify all frequencies from 15 Hz to 20 kHz equally. If it does not pass this band of frequencies equally it has frequency distortion. Inductance and capacitances cause frequency distortion because their reactances depend on frequency. These reactive components will cause the gain of an amplifier to change with frequency.

3-148. PHASE DISTORTION is also caused by reactive components. If two frequencies that have a specific phase relationship are applied to the input of an amplifier, and the phase relationship is changed at the output, the circuit has introduced phase distortion. Phase distortion occurs when some frequencies, applied to the amplifier, do not receive the same time delay as the other frequencies as they pass through the amplifier.

3-149. Distortion in an amplifier is not always undesirable. Often distortion is deliberately introduced to alter a waveshape for a specific purpose. Later in this course you will study several circuits that will use distortion to advantage. Only when a change in waveform characteristics is unwanted is distortion undesirable.

3-150. Methods of Coupling

3-151. Usually, amplifier systems have a series of amplifiers connected together. A small signal voltage is applied to the first or input amplifier and its output becomes the input to the next amplifier in the series. The purpose of each amplifier circuit or stage is to receive the signal, increase its strength, and pass it on to the next amplifier. The

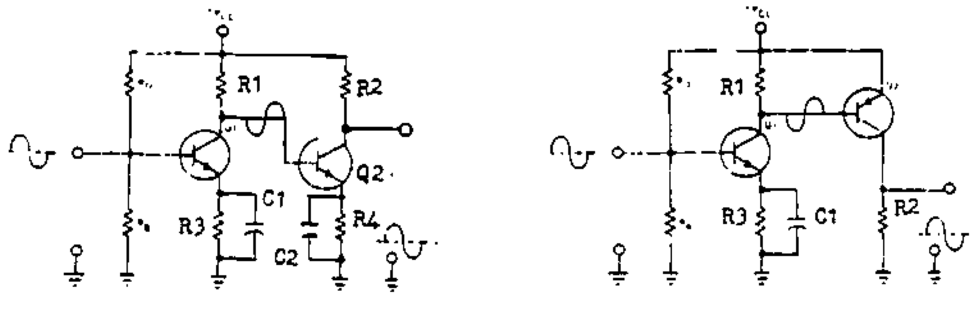


Figure 3-36. Direct Coupled Amplifiers

methods employed in connecting or coupling of the amplifier stages will be discussed in this section.

3-152. Direct, RC, impedance and transformer coupling are four methods commonly used to connect amplifier circuits together. Direct coupling is illustrated in Figure 3-36. Notice that the output of one stage (collector) is connected to the input of the next stage (base) in each circuit. Figure 3-36A shows NPN transistor Q1 directly coupled to NPN transistor Q2. Resistor R1 acts as the bias resistor R_D for Q2 as well as the collector load for Q1. The resistance of Q1 acts as bias resistor R_B for Q2. The input signal is amplified and inverted by Q1, then amplified and inverted again by Q2, since these are both common emitter configurations.

3-153. The circuit of Figure 3-36B is often used to decrease the number of components over the previous circuit. Transistors Q1 and Q2 are both common emitter amplifiers. The input signal is applied to the base and output signal is taken from the collector. This arrangement allows the use of both PNP and NPN transistors with a single power source, $+V_{CC}$ and eliminates the need for C2 and R4.

3-154. Transistor Q1 is forward biased by R_D and R_B. R1 is the collector load resistor for Q1, and it establishes the forward bias for Q2. R2 is the collector load resistor for Q2, where the output is taken with reference to ground.

3-155. The positive alternation of an input signal applied to the base of Q1 causes base and collector currents to increase. The voltage drop across R1 increases, which causes the base current of Q2 to increase. Collector current of Q2 increases, and the voltage across R2 increases. On the negative alternation of the input signal, all currents decrease and the output voltage goes negative (less positive).

3-156. Direct-coupled amplifiers require minimum circuit parts, resulting in economy of construction. The number of stages that can be directly coupled, however, is limited, because any undesired change in the first stage is amplified in succeeding stages.

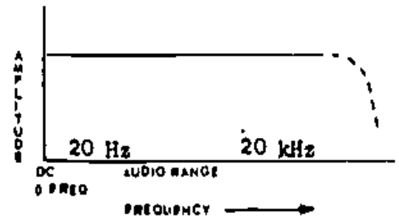


Figure 3-37. Frequency Response of Direct-Coupled Amplifier

3-157. Collector current changes due to temperature variations, for example, in the first stage are amplified by all the stages, resulting in very large I_C changes for small temperature variations, causing severe temperature instability. Notice that Q1 has two stabilization components, R_B and R3, to minimize effects of temperature change.

3-158. Figure 3-37 shows the frquency response curve, plotting amplifier output signal amplitude against input signal frequency, for a direct-coupled amplifier. The direct-coupled amplifier will amplify both DC and AC signals. For a given input amplitude, the output amplitude remains constant from zero hertz throughout the audio frequency range. Therefore, the amplifier has a flat frequency response throughout the audio frequency range. The reduction of amplitude at the high frequency end, as shown in figure 3-37 is due to the transistor's interelement capacitance and stray capacitance.

3-159. Figure 3-38 shows transistor INTERELEMENT CAPACITANCE. Although the capacitances C_{EB}, C_{CE}, and C_{CB} are shown

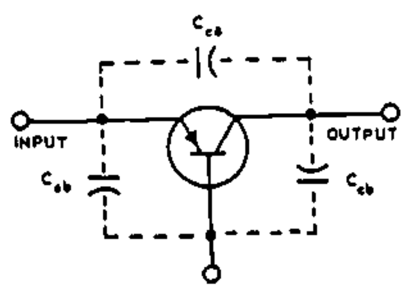


Figure 3-38. Interelement Capacitance

externally, the actual capacitive effects are produced by the PN junctions within the transistor. The collector and base form the plates for C_{CB} and the collector-base junction depletion region is the dielectric or the distance between the capacitor plates. As the frequency applied to the amplifier increases, the reactance of the transistor's interelement capacitance decreases. The low reactance will shunt both input and output amplifier signals, resulting in a reduced output amplitude.

3-160. STRAY CAPACITANCE is that capacitance which exists between circuit components and wiring. The stray capacitance between 2 conductors could provide a shunting effect and cause output signal amplitude to decrease. Stray capacitance is not normally a problem in audio amplifiers. The highest frequency involved is about 20 kHz, which makes the capacitive reactance high and reduces its shunting effect on the signal.

3-161. The RC coupling network, shown in Figure 3-39, couples two amplifier stages. The network consists of collector load resistor R2 of the first stage, coupling capacitor C2, and forward bias resistor R3 for the base of Q2.

3-162. Capacitor C2 blocks or isolates the DC collector voltage of Q1 from the DC base voltage of Q2. However, signal voltage variations (output signal) at the collector of Q1 will be coupled through C2 to the base of Q2. Since C2 is in the signal path from Q1 to Q2, its reactance must be very low to prevent any signal loss (reduction in signal amplitude).

3-163. The signal path or route the signal follows through the amplifier in Figure 3-39 is as follows: the input signal voltage is coupled through the coupling capacitor C1 to the base of Q1. Bias voltage changes cause I_B and I_C changes. The collector current changes of Q1 cause V_C changes at the signal rate. These output signal voltage changes are coupled through C2 to the base of Q2. This signal on the base of Q2 is amplified and appears on the collector of Q2 as the output signal.

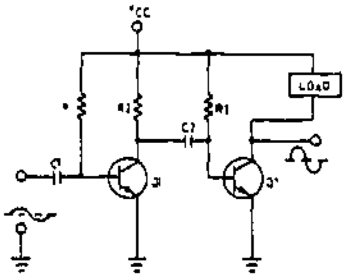


Figure 3-30. RC Coupled Amplifier

3-164. Two primary factors limit the frequency response of RC coupled amplifiers. The first is the coupling capacitor. The reactance of the coupling capacitor and the input resistance of transistor Q2 form a series voltage divider. The reactance of a capacitor varies inversely with frequency. At low frequencies the reactance of the capacitor is large in comparison to the input resistance of the transistor. Therefore, the coupling capacitor will drop a large amount of the signal voltage, resulting in a reduced signal to the base of Q2. The output signal amplitude then would be reduced.

3-165. The other limiting factor in the frequency response of RC coupled amplifiers is interelement and stray capacitance. The high frequency response is limited by these capacitances, causing a loss in amplitude at the high frequency end of the curve.

3-166. Figure 3-40 shows a typical frequency response curve of an RC coupled audio amplifier. The high reactance of the coupling capacitor causes loss of amplitude at the low frequency end of the curve. The size of the coupling capacitor is chosen so that the low frequency half power point (peak x .707)

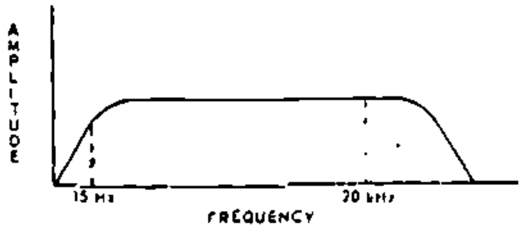


Figure 3-40. Frequency Response of RC Coupled Amplifier

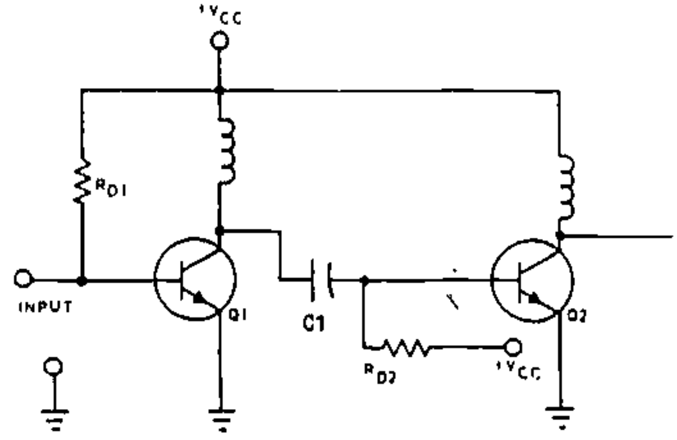


Figure 3-41. Impedance Coupling

occurs at about 15 hertz. The interelement and stray capacitances cause the loss above 20 kHz.

3-167. Impedance (or LC) coupling between two amplifiers is shown in Figure 41. This type of coupling is similar to RC coupling except that the load resistor is replaced with an inductor. Operation of the impedance coupled amplifier circuit is the same as the RC coupled amplifier circuit.

3-168. Impedance coupling is normally used at frequencies above the audio range. The chief advantage is that the reactance of the inductor increases as frequency increases. This increase in load impedance will increase the amplifier's voltage gain which will compensate for loss in gain due to the interelement capacitance of the transistor.

3-169. The main disadvantage of impedance coupling is that it is limited to high frequency use. The reactance of the inductor at low frequencies is not large enough to produce good voltage gain. Referring to Figure 3-42, the loss in gain at low frequencies is due to low inductive reactance and high coupling capacitor reactance. The low gain at high frequencies is due to the interwinding capacitive reactance of the inductor and interelement capacitance of the amplifier. These capacitances shunt the amplifier, resulting in a decrease in signal amplitude. The peak in the curve is due to the LC resonance of the inductor and the interelement capacitance of the transistor.

3-170. Interstage coupling of amplifiers by means of a transformer is shown in Figure 3-43. The primary winding of transformer T1 is the collector load of the first stage Q1. The secondary winding of transformer T1 couples the AC signal to the base of Q2. R_B and R_{D2} form a forward bias voltage divider for Q2. The low DC resistance of the secondary of T1 does not affect the forward bias (base current) appreciably. C1 is used to place one side of the transformer secondary at AC ground allowing all of the input signal to be applied between base and emitter of Q2.

Figure 3-42. Response Curve (Impedance Coupling)

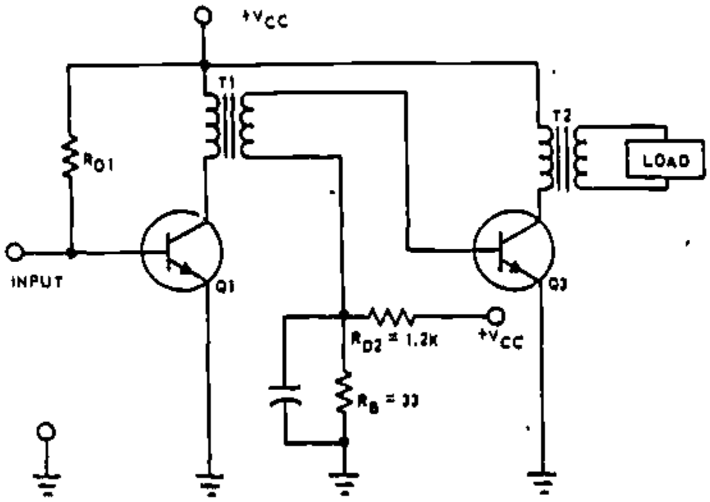


Figure 3-43. Transformer-Coupled Amplifier

3-171. Figure 3-44 shows the frequency response of a transformer-coupled amplifier. The low reactance of the windings at low frequencies causes the low frequency response to fall off. At high frequencies, the response is reduced by the transistor interelement capacitance and the interwinding capacitance of the transformer.

3-172. Troubleshooting

3-173. As a maintenance man, the technique of troubleshooting is of primary importance to you. A malfunction of a component in an amplifier system will produce specific symptoms. With a good troubleshooting technique, the technician will be able to analyze these symptoms and determine the faulty component. The amount of time and work required for the isolation of the faulty component depends upon your knowledge of normal operation. The discussion of troubleshooting will begin with the analysis of the single-ended Class A, CE amplifier of Figure 3-45 and progress to the two-stage amplifier.

3-174. During normal operation, the following DC voltages are present in the amplifier: Base-emitter voltage (V_{BE}) would be a small voltage (approximately 0.6 volts); collector voltage (V_C), measured from collector to ground, would be approximately 1/2 V_{CC} (+10 volts). In Figure 3-45, V_{BE} is dependent upon the values of V_{CC}, R1, and R_{BE}. Changing any of these factors would change the measured voltage. V_C is dependent upon the values of V_{CC}, R2, and the resistance of Q1. The equivalent circuits are shown

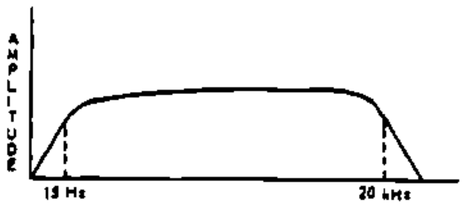


Figure 3-44. Frequency Response of Transformer-Coupled Audio Amplifier

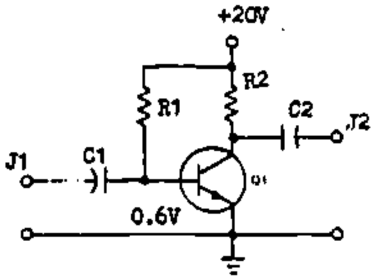


Figure 3-45. Single-Ended Amplifier

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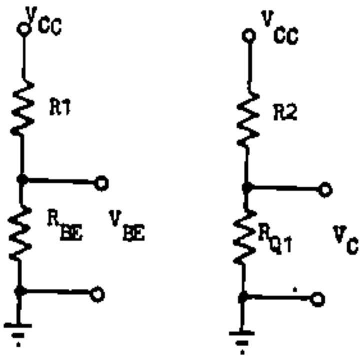

Figure 3-46. Equivalent Bias and Collector Circuit

in Figure 3-48. Figure 3-47 shows another single-ended amplifier. Figure 3-48 shows the equivalent circuits. The base-emitter voltage is controlled by V_{CC}, R1, R3, R4, and R_{BE}. NOTE: The bias network is a series parallel network. The voltage from base to ground (V_B) is +2.5 volts, and the voltage from emitter to ground (V_E) is +2 volts. The base-emitter voltage (V_{BE}) is +0.5 volts, or the difference between V_B and V_E. Collector voltage is controlled by the values of V_{CC}, R2, R_{Q1} and R4.

3-175. The normal DC voltages which are present in the amplifier circuit can be found in the Technical Order for the equipment you are troubleshooting. The Technical Order

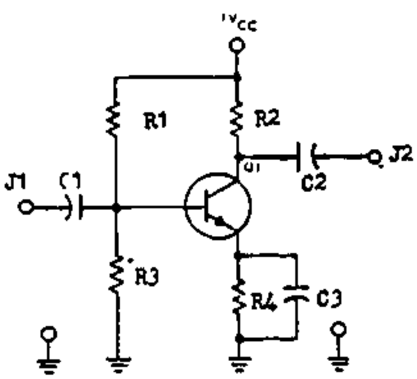

Figure 3-47. Single-Ended Amplifier

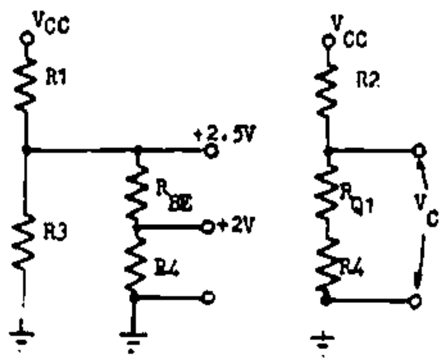

Figure 3-48. Equivalent Bias and Collector Circuit

is a complete maintenance manual giving operating instructions, circuit analysis, alignment and troubleshooting procedures for an electronic system. These voltages can be measured with the multimeter or the oscilloscope. The measured values of voltage can be compared with the normal voltages to aid in the analysis of circuit operation.

3-176. The AC signal which the amplifier is designed to pass and amplify can be observed at various points in its path with the oscilloscope. The signal can be traced as it progresses through the amplifier from the input at J1 to the output at J2. Figure 3-49 illustrates the signal path through the amplifier circuit.

3-177. The signal observed at J1 is small (millivolts). As the signal passes through the coupling capacitor C1, little or no loss in signal amplitude should be observed. The AC signal on the collector should be an amplified reproduction of the input signal with a 180° phase reversal and no distortion. This signal passes through the coupling capacitor C2 and essentially the same amplitude and quality of signal should be observed at J2. These voltage measurements and waveshapes indicate the amplifier is operating normally.

3-178. Now, let us observe the effects a malfunctioning component will have on the voltages in the amplifier.

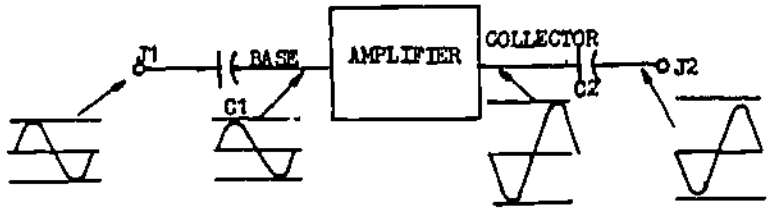

Figure 3-49. Amplifier Signal Path

3-179. A component which is malfunctioning can deviate from its normal characteristics to one of two extreme conditions, an open or a short. A malfunction can occur at any point between these extremes, and the symptoms which appear may vary. To simplify our troubleshooting explanation, we will use the extreme conditions. An open will be an infinite resistance, and a short will be zero resistance. A short may cause damage to other circuit components. However, for our explanation, we will assume that circuit components can withstand the increased current without damage. Becoming familiar with the symptoms for these conditions will aid you in the analysis of malfunctions which occur to a lesser degree.

3-180. In Figure 3-50, if R2 were open, collector current would be zero because there is now an incomplete path for current flow. The voltage drop across the open resistor, R2, would be the applied voltage V_{CC}. The voltage on the collector of Q1 would be zero.

3-181. Figure 3-51 shows a simplified collector circuit with R2 open and the voltage which will appear at the collector. A signal applied to the amplifier will appear at the collector as a very weak signal. This signal is due to the coupling through the transistor's interelement capacitance. The signal is reduced due to the high reactance of the transistor interelement capacitance. Figure 3-51 shows the signals present in the amplifier for an open collector load resistor.

3-182. With R2 shorted, Q1 becomes the only resistance in the circuit, and the supply voltage will be measured on its collector. See Figure 3-52A. With no amplifier load resistance, no signal would appear on the collector. However, the base signal would be near normal amplitude. See Figure 3-52B.

3-183. The effect an open transistor will have on the measured voltages is shown in Figure 3-53.

3-184. The effects of this malfunction on the signal is illustrated in Figure 3-53B. With Q1 open there would be no output signal at J2.

3-185. A shorted transistor can be the result of an internal or an external short. The effect of an internal short is illustrated

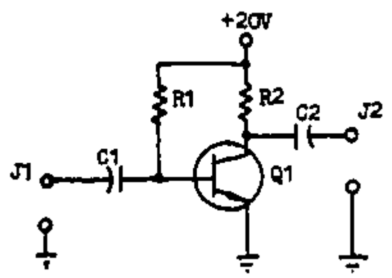

Figure 3-50. Single-Ended Amplifier

408

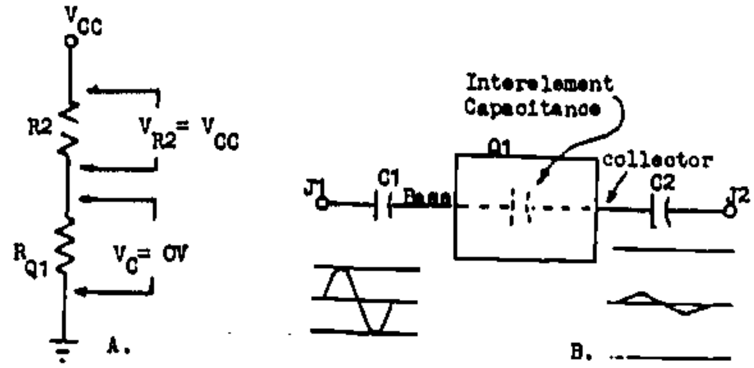

Figure 3-51. R2 Open

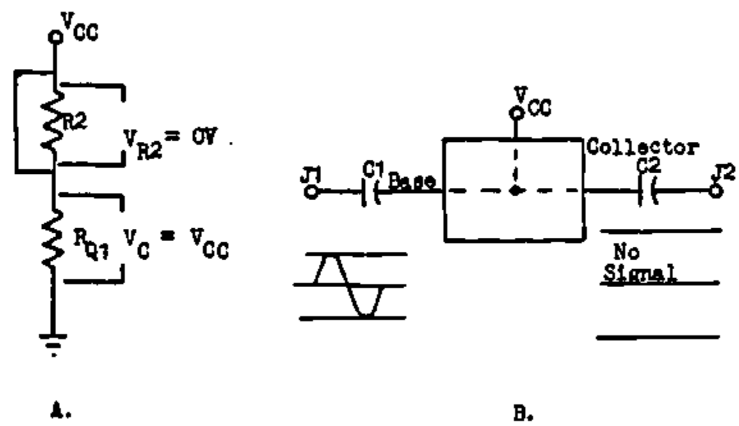

Figure 3-52. R2 Short

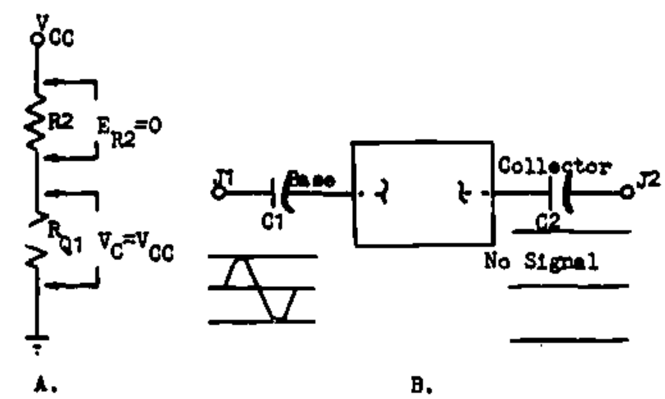

Figure 3-53. Q1 Open

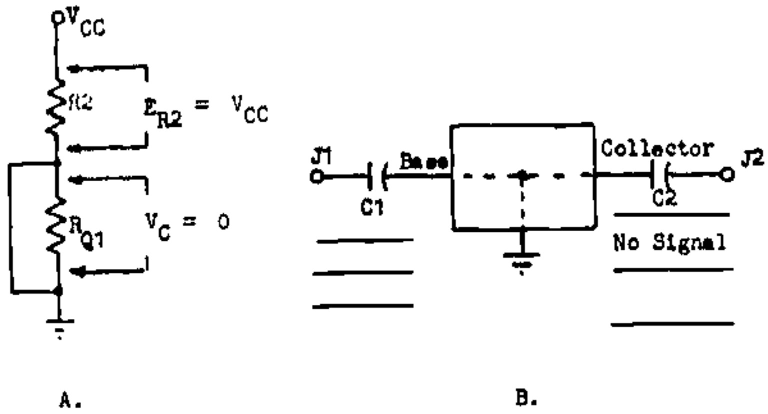

Figure 3-54. Q1 Shorted

in Figure 3-54. The input and output will be shorted to ground and no output waveshape will be observed. A large collector current will flow and all of the applied voltage (V_{CC}) will be dropped across R2. If an external short occurs in the transistor, the symptoms will be somewhat different. Consider, for instance, that the collector and emitter leads short together. The current and voltage symptoms would be the same, but the input waveshape will still be present at the base.

3-186. Finally, let's observe the effects of R1 on the DC voltages and signals in the amplifier. Figure 3-55 shows the DC bias voltage when R1 opens or shorts.

3-187. If R1 opens, bias voltage decreases to zero and Q1 will not conduct. I_C decreases to zero, and V_C will increase to V_{CC}. Q1 is operating in its cutoff region. The transistor has no bias and is operating approximately Class B. With sufficient input signal, a weak and distorted signal would be present in the output.

3-188. If R1 shorts, bias voltage increases and I_C will increase, causing V_C to decrease. Q1 will be operating in the saturation region. Increasing the bias voltage to V_{CC} would cause excessive transistor currents to flow. This in all probability would destroy the transistor. However, for our analysis, we will assume that the transistor can withstand the increased current. With R1 completely shorted there would be no signal present at the base of Q1 or at its collector, since the input signal would be shorted to AC ground (V_{CC}).

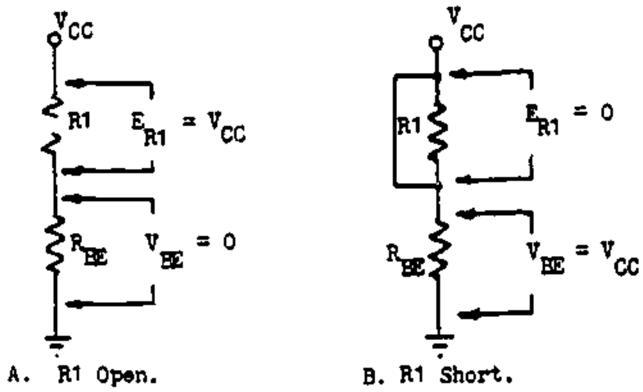

Figure 3-55. Effects of Faulty R1 on Bias Voltage

410

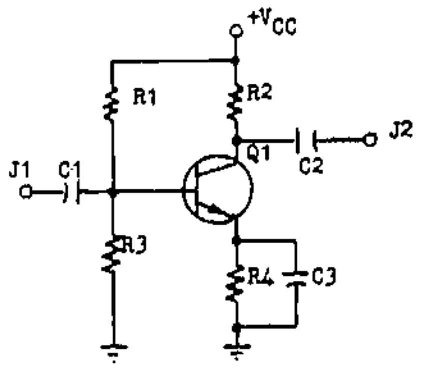

Figure 3-56. Single-Ended Amplifier

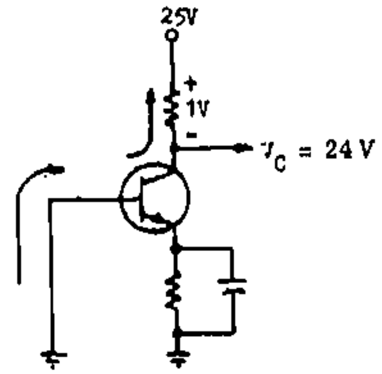

Figure 3-58. Reverse Bias Collector-Base Current Flow

3-189. Figure 3-56 is basically the same amplifier we have been discussing with the exception of R3, R4, and C3, which are stabilization components. We will now discuss the effects these components have on circuit operation when they malfunction.

Refer to Figure 3-57, which shows the equivalent bias and collector networks.

3-190. If R3 opens, the base-to-ground voltage (V_B) would increase. This would increase the bias voltage (V_{BE}). As you recall, as bias voltage increases, I_C would increase. This would cause V_C to decrease to a value lower than normal, and V_E to increase due to the increased current through R4. The effect this malfunction has on the signal current cannot be definitely

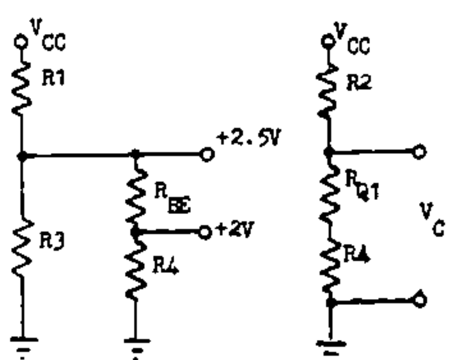

Figure 3-57. Equivalent Bias and Collector Circuit

stated. Due to the increase in bias voltage, the amplifier's operating point has moved closer to the saturation region of the dynamic transfer curve. This may cause a decrease in gain and saturation distortion. The degree to which the symptoms would appear is dependent upon how much bias voltage change is experienced when R3 opens. The base signal would be normal; however, the collector signal may show distortion.

3-191. If R3 shorts, the V_{BE} and V_E drop to zero volts and the amplifier is cutoff. Refer to Figure 3-57. Collector current in this amplifier will decrease to zero. Due to minority current through the collector base junction, V_C will be very close to V_{CC}, but not equal to it. Refer to Figure 3-58.

3-192. The signal input to the amplifier is now shorted to ground. Therefore, you would observe no signal either in its input or output circuits.

3-193. Since R4 is in the DC current path for Q1, if it were open, I_E would cease, I_C would drop to near zero (minority current still present), and V_C would increase to near V_{CC}. See Figure 3-56 and 3-57. The base to ground voltage would be higher than normal, since less current will flow through R1. The emitter voltage (V_E) would be nearly the same as the base voltage. Since the amplifier is not functioning, the normal signal on the base would be coupled through Q1 interelement capacitance and a very weak, distorted signal would appear in the output.

3-194. If R4 shorts, the V_{BE} would increase ($V_{BE} = V_B - V_E$) since the voltage across R4 (V_E) drops to zero. I_C would increase and V_C would be lower than normal. Since Q1 is now operating with a greater amount of bias voltage, operation is approaching saturation. The amplifier output signal may experience a decrease in amplitude and an increase in distortion. R4 is employed for temperature stabilization and, shorting would decrease circuit temperature stability. Its swamping action on bias current changes are no longer felt, and the increase in bias results in greater heat which further reduces circuit stability.

3-195. C3 is utilized in the amplifier to prevent degeneration of the input signal appearing between base-emitter of Q1. An open capacitor would decrease the gain of the amplifier. The input signal is normal. However, due to the degeneration, the output signal will be lower than normal. The static operating point of the amplifier will not be changed by this malfunction; therefore, V_C and V_{BE} will be normal.

3-196. Refer to Figure 3-57. C3 is in parallel with R4. When C3 shorts, it will place a short across R4, producing the same effects as R4 shorting. V_E would decrease to zero and V_{BE} would increase. This increase in bias voltage may cause a decrease in output signal amplitude and an increase in distortion.

3-197. Classification of Amplifiers

3-198. Amplifiers may be classified or grouped in a number of ways. The methods we will discuss are classification by use, frequency range, and class of operation.

3-199. Classification by use. Amplifiers may be grouped by the way they are used in a circuit. Recall that the current, voltage, and power gains of an amplifier are dependent on several factors, namely configuration, size of the load resistor, transistor type, etc. An amplifier designed to produce a large current gain is called a current amplifier, and one that provides a large voltage gain is called a voltage amplifier. A power amplifier is one which must deliver large amounts of output powe.

3-200. Classification by frequency. An amplifier may be classified also by the range of frequencies it is capable of amplifying properly. A DC AMPLIFIER is one which is able to amplify DC (0 Hertz) applied to its input. DC amplifiers are often found in oscilloscopes and computer circuits. An AUDIO AMPLIFIER, as the name implies, operates in the audio range, which is about 15 Hz to 20 kHz.

3-201. RADIO FREQUENCY AMPLIFIERS are operated in the radio frequency (RF) spectrum from about 10 kHz to 300 GHz or higher. RF amplifiers are commonly used in radio receivers and transmitters.

3-202. Lastly, the VIDEO AMPLIFIER, which is also called a wide-band amplifier, can amplify all frequencies from a few hertz to several megahertz. They are used in television and radar systems.

3-203. Classification by class of operation. There are four classes of operation for amplifiers. They are CLASS A, CLASS AB, CLASS B, and CLASS C. The class of operation is determined by the amount of bias and the amplitude of the input signal.

3-204. All of the amplifiers you have seen so far in this chapter have been CLASS A amplifiers. Amplifiers operated CLASS A are biased in such a manner as to allow collector current to flow during the complete 360 degree cycle (100%) of the input signal. CLASS B amplifiers are biased to allow collector current to flow one half, or 50%, of the input signal cycle. Class AB falls between Class A and Class B. Collector current is zero for a portion of one alternation of the input signal; thus I_C flows for more than 180 degrees, but less than 360 degrees (51% to 99%) of the input cycle. Finally CLASS C amplifiers are biased to allow I_C to flow for less than 180 degrees of the input cycle (less than 50%). Each of

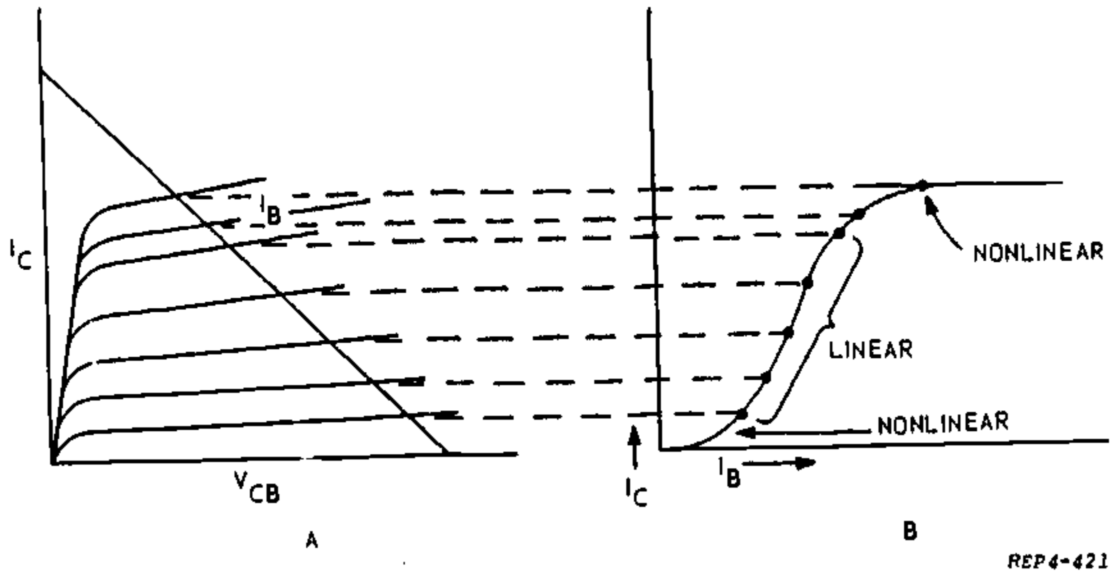

Figure 3-59. Development of Dynamic Transfer Curves

these classes of operation has certain advantages and disadvantages, and will now be explained in detail.

3-205. Amplifiers operated Class A are biased in such a manner as to allow collector current flow during a complete 360 degrees of the input signal. Collector current also flows when no signal is present. The initial operating point is established, by proper biasing, so that the transistor will operate within the linear portion of its collector characteristics, thus providing an output waveform which is a replica of the input waveform.

3-206. To aid the discussion of classes of operation, we use a "dynamic transfer" curve. Figure 3-59A shows a typical common emitter family of curves with a load line. These curves, however, do not give a clear picture of the linearity between the input current (I_B) and output current (I_C). To show the linearity characteristics of a circuit, a transfer curve, shown in figure 3-59B is constructed. This curve is a plot of I_C (vertically) against I_B (horizontally). By extracting values of I_C versus I_B at various points on the load line, and transferring this information to the chart on the right, a dynamic transfer curve is developed.

3-207. Notice that the center portion of the transfer curve is almost a straight line. This is the LINEAR operation region for the amplifier. The top and bottom of the curve is not straight, indicating the NON-LINEAR operation of the amplifier as saturation or cutoff is approached.

3-208. Class A amplifiers operate within the linear portion of the collector characteristic curves. Figure 3-60 uses a transfer curve to illustrate Class A operation. The initial operating point is established in the middle of the linear portion of the curve. The input signal will cause the base current to vary up and down along the curve. This will cause a corresponding change in collector current. For Class A operation, the amplifier current never goes beyond the linear portion of the curve. The input signal will cause the base current to vary up and down along the curve. This will cause a corresponding change in collector current. For Class A operation, the amplifier current never goes beyond the linear portion of the curve. This results in an output signal which is an exact replica of the input. Notice that collector current flows during 100% (or 360 degrees) of the input cycle.

3-209. For Class AB operation, the amplifier is biased so that I_C is zero (cutoff) for a

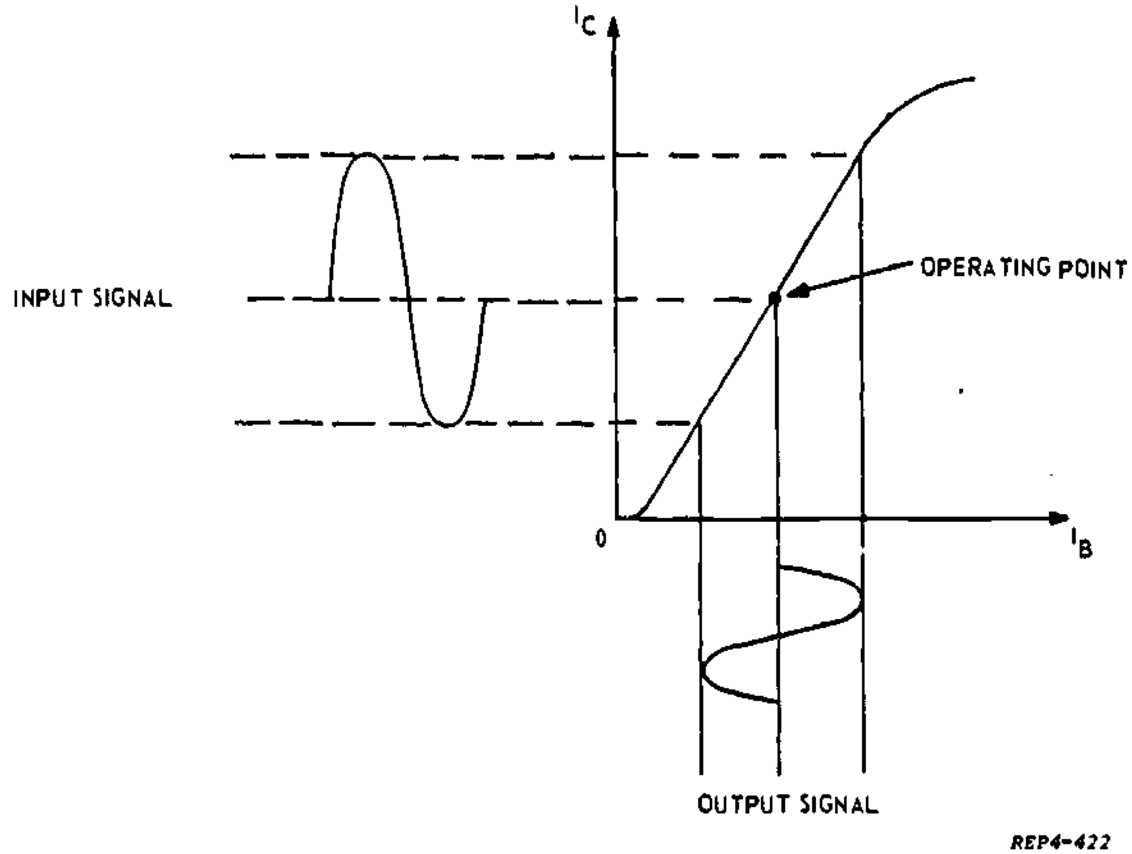

Figure 3-60. Class A Operation

portion of one alternation of the input signal. Thus collector current will flow for more than 180 degrees but less than 360 degrees. To operate Class AB, forward bias current is made less than the peak value of the input signal current. Therefore, the input junction will be reverse biased during one alternation for the amount of time that the signal current peak opposes and exceeds the value of forward bias current. Figure 3-61 shows the characteristics of a Class AB amplifier. An examination indicates that the operating point has been moved downward along the curve toward cutoff as compared to Class A. Collector cutoff current is very small during the time I_B is zero, because collector current during this period is due to I_{CBO}. Notice also that the collector current (or output signal) waveform is not an exact replica of the input with Class AB operation.

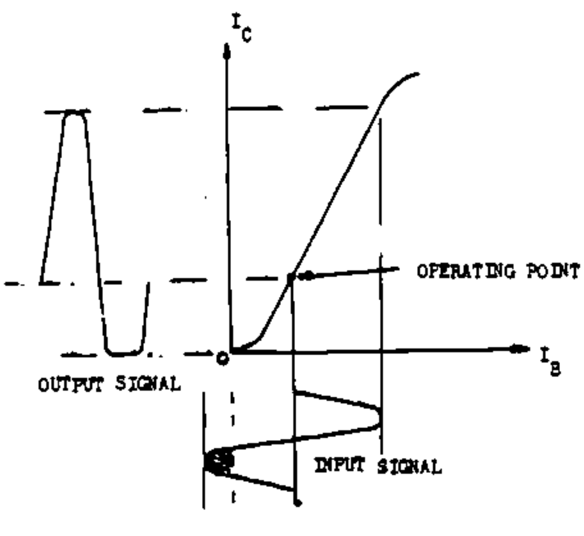

Figure 3-61. Class AB Operation

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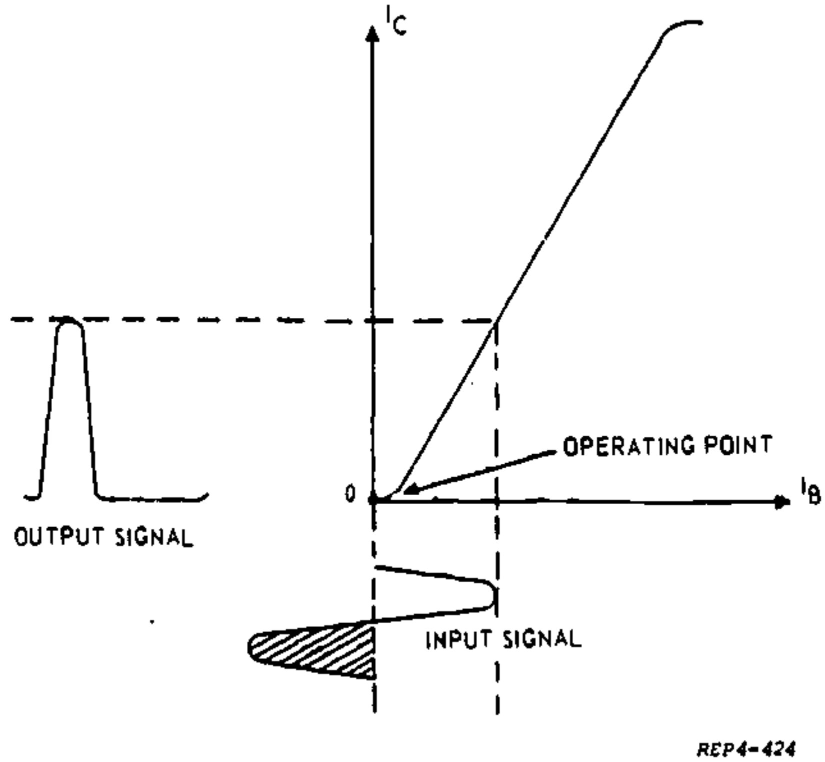

Figure 3-62. Class B Operation

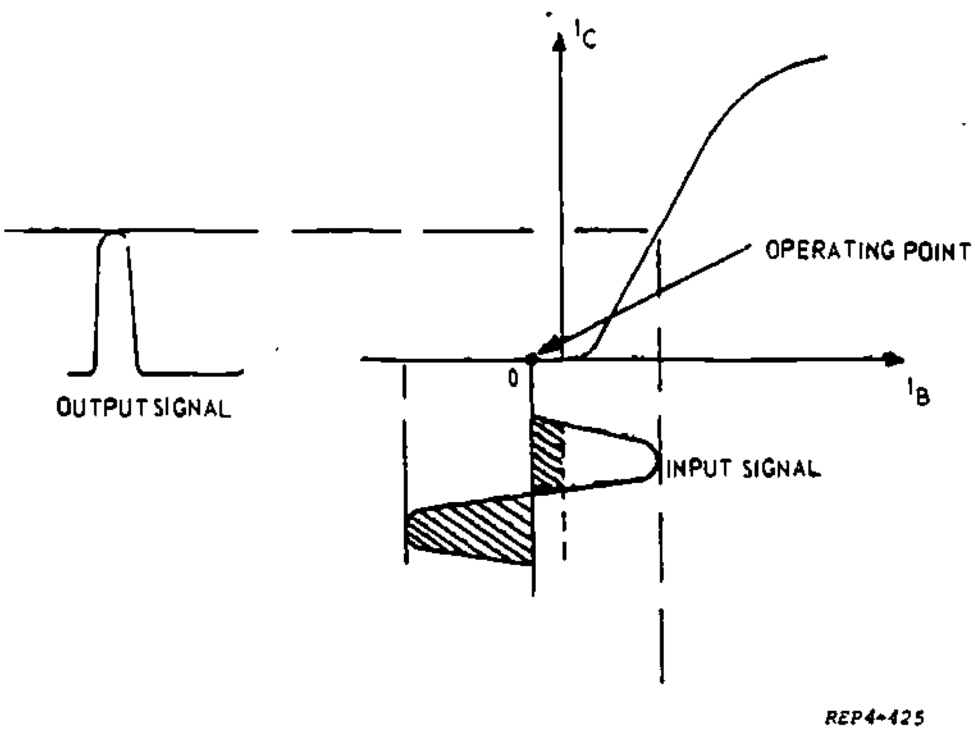

Figure 3-63. Class C Operation

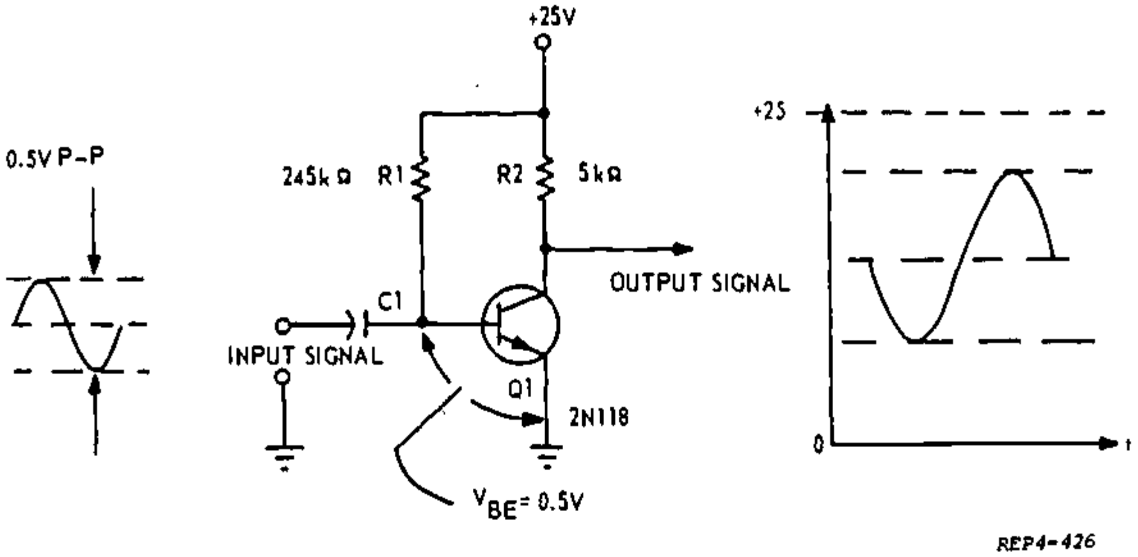

Figure 3-64. Class A Amplifier

3-210. Figure 3-62 shows a curve with the initial operating point at zero base current ($I_B = 0$). This amplifier is biased for Class B operation, with collector current cutoff during one half cycle (50%) of the input signal. The initial operating point is established so that base current is zero under NO SIGNAL conditions. When a signal is applied, one half cycle will forward bias the base-emitter junction and I_C will flow. Since the operating point must move through the non-linear region near cutoff, the collector current does not exactly follow the shape of the input signal. On the other half cycle of the input signal, the base-emitter junction will be reverse biased, and I_C will be cut off. Thus, in Class B operation, collector current will flow for approximately 180 degrees of the input signal, and there will be no collector current flow with no input signal applied.

3-211. Class C amplifiers are biased so that collector current flow is zero for more than 180 degrees of the input signal. In other words, the transistor remains in a cut-off condition for all but a small portion of the input signal. To establish an operating point below cutoff in a transistor requires that the base-emitter junction be reverse biased. Only the portion of the input signal that overcomes this reverse bias will cause collector current to flow.

3-212. Figure 3-63 shows the characteristics of a Class C amplifier. Notice that the operating point is established beyond the collector cutoff level. Only the portion of the input signal that overcomes the reverse bias will cause an output signal. During the rest of the cycle the input junction is rverse biased, as shown by the shaded area. Notice that the output signal bears little resemblance to the input signal waveform.

3-213. From the previous discussion, you can conclude that two primary items determine the class of operation of an amplifier. These are the AMOUNT OF BIAS and the AMPLITUDE OF THE INPUT SIGNAL. Figure 3-64 shows a common emitter amplifier. We can determine its class of operation from the information given on the schematic diagram, or in the actual circuit by using an oscilloscope and multimeter.

3-214. Notice first that the bias resistor R1 places the base of the NPN transistor at a positive 0.5 volts with respect to the emitter ($V_{BE} = +0.5V$), indicating that the

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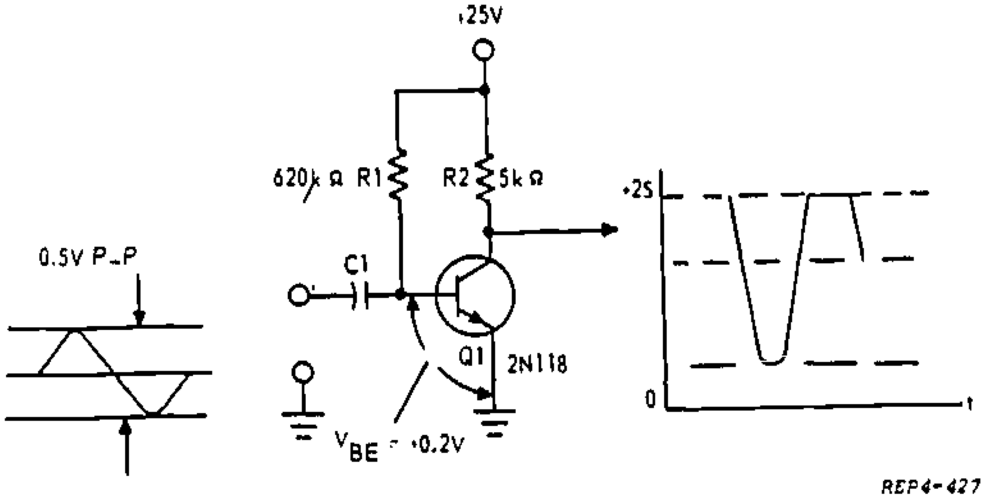

Figure 3-65. Class AB Amplifier

transistor has forward bias. This voltage of the multimeter across the base and emitter leads of the transistor and measuring the DC bias voltage.

3-215. Next we compare the PEAK value of the input signal to the amount of bias voltage. The input signal is given as 0.5 volts p-p, which is 0.25 volts peak. The input signal voltage can be measured with an oscilloscope by placing the probe on the base lead of the transistor. Recall that the negative alternation of the input will oppose forward bias in this circuit. Since the peak value of the input (0.25 volts) is less than the bias voltage, the transistor will have forward bias for the entire input cycle, and collector current will flow for the entire cycle. Therefore, this amplifier is operating class A.

3-216. Class A operation can also be verified by observing the waveform at the collector of the transistor with the oscilloscope. As long as the transistor operates in the linear region of the dynamic transfer curve, the output waveform will be an exact replica of the input waveform.

3-217. We can apply the same techniques to the circuit of figure 3-65 to determine the class of operation. Note that the bias voltage (V_{BE}) is less than in the previous example. Now the peak value of the input signal is more than the bias voltage. The input signal will completely cancel the forward bias for a portion of one alternation of the input signal, and collector current will be cutoff during this time. Collector current is cut off for only a portion of one alternation (less than 180 degrees), hence the amplifier is operating Class AB.

3-218. So far we have illustrated the effect of the amount of bias on class of operation. To illustrate the effect of signal amplitude, consider the circui of figure 3-65, but with an input signal of 0.2 volts p-p. Now, comparing peak signal amplitude (now 0.1 volts peak) to bias voltage (0.2 volts) we see that the input signal will no longer completely cancel forward bias. Therefore, collector current will flow during the entire input cycle, and the amplifier circuit is now operating Class A.

3-219. Now consider the amplifier circuit of figure 3-64 (which we determined earlier to be operating Class A), but with a larger input signal amplitude of 1.2 volts p-p. The peak value of the input signal (0.6 volts)

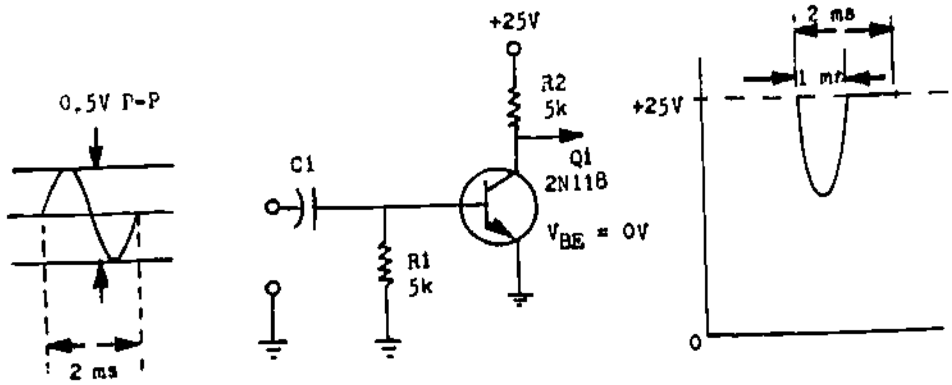

Figure 3-66. Class B Amplifier

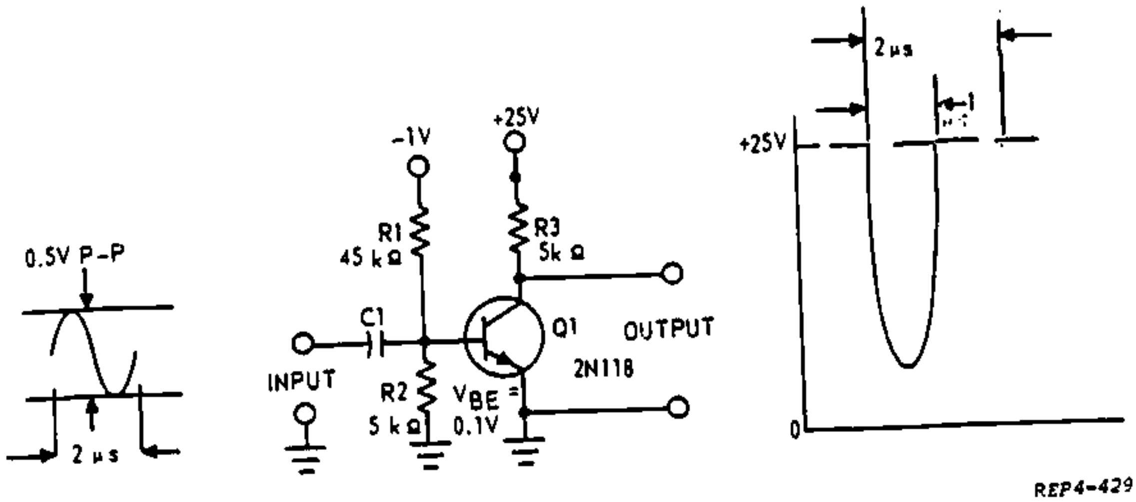

Figure 3-67. Class C Amplifier

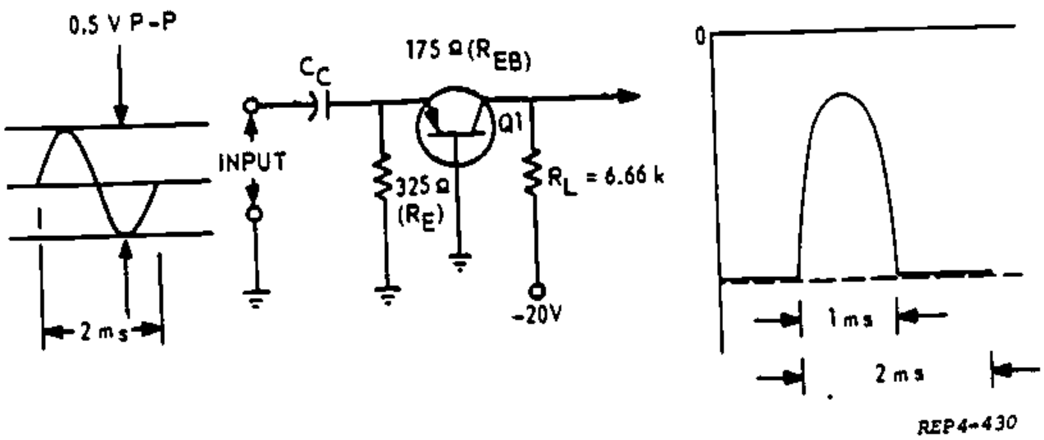

Figure 3-68. Class B Common Base Amplifier

is somewhat greater than the bias (0.5 volts) so collector current will be cut off for a protion of the negative alternation of the input signal. The amplifier is now operating Class AB. On the positive alternation, the input signal will aid bias to the extent that the transistor will be driven into saturation for a portion of the positive alternation. If the input signal to an amplifier is large enough so that it goes alternately into cutoff and saturation, the amplifier is called an OVERDRIVEN AMPLIFIER.

3-220. Figure 3-66 shows a Class B amplifier. Notice that the bias voltage (V_{BE}) is 0 volts. Resistor R1 is used to place the base at zero volts, and to develop the input signal. Only the positive alternation of the input signal will allow the transistor to conduct and collector current would flow for only 50% of the input cycle.

3-221. The oscilloscope can be used to verify Class B operation. The time for one cycle of the input is measured (2 ms) and compared to the time an output signal is produced (1 ms). A ratio of 1 to 2, or 50% indicates Class B operation.

3-222. To illustrate Class C operation we will use the circuit of figure 3-67. Resistors RI and R2 form a voltage divider which places -0.I volts on the base. This is reverse bias for the emitter-base junction. The input signal must first overcome this reverse bias before collector current can flow. Therefore, the transistor will conduct for only a portion of the positive alternation of the input cycle. The negative alternation will aid the reverse bias already present, and collector current will remain cut off. Collector current flows for less than 50% of the input cycle, indicating Class C operation.

3-223. The techniques just studied can also be applied to other transistor circuit configurations. Figure 3-66 shows a common base amplifier using a PNP transistor. By comparing the time collector current flows (developing an output signal) with the input signal period, we see that this amplifier is operating Class B. These measurements are easily made using the oscilloscope. Similarly, the common collector circuit of figure 3-69 can be determined to be operating Class AB. Remember that I_E and I_C cease when the input signal cuts off the transistor.

3-224. Two terms used in conjunction with amplifiers are FIDELITY and EFFICIENCY. FIDELITY is defined as the degree to which a device accurately reproduces, at its output, the waveform characteristics of a signal applied to its input. In other words, if a sine wave of a certain frequency is applied to the input of an amplifier and a sine wave at the same frequency is developed in the output, the amplifier has a high degree of fidelity.

3-225. A class A amplifier, then, has a high degree of fidelity. A Class AB amplifier has less fidelity, and Class B and Class C amplifiers have low or POOR fidelity.

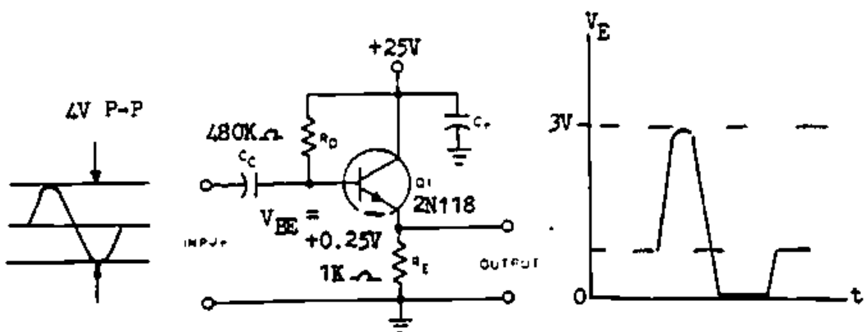

Figure 3-69. Class AB Common Collector Amplifier

3-226. EFFICIENCY is defined as the ratio between the output signal power and the total input power. An amplifier has two input power sources, one from the signal and one from the power supply. Power furnished by the power supply is determined by voltage and current required at the operating point. The input signal power is determined by the current-voltage values of the input signal. The output power is determined by the current-voltage values of the output signal.

3-227. A Class A amplifier has a relatively large input power from the power supply. This is because Class A amplifiers are biased near the middle of the dynamic transfer curve, where both voltage and current are relatively large. Even with no input signal, the circuit is using considerable power from the power supply. The amplitude of the output signal is limited by the nonlinear areas of the transfer curve. Therefore, the output signal will be relatively small. Comparing the total input power to the output signal power reveals the efficiency to be very low.

3-228. Class AB amplifiers are biased lower on the dynamic transfer curve, so I_C is smaller than in a Class A amplifier. Further, during the time the transistor is cut off by the input signal, no collector current flows. The total input power to the amplifier in Class AB is less than in Class A. This leads to better efficiency.

3-229. Class B amplifiers are biased with little or no I_C at the operating point. With no input signal there is little wasted power. The efficiency of Class B is higher still.

3-230. The efficiency of Class C is the highest of the four classes, since collector current is cutoff during all but a small portion of one-half cycle of the input cycle.

3-231. We have discussed three methods of classifying amplifiers; by use, frequency range, and class of operation. It should now be apparent that an amplifier can be described in detail by these methods. For example, an amplifier designed for a high power gain, capable of amplifying frequencies in the audio range, and operating such that collector current flows during the entire cycle of the input signal would be called a CLASS A AUDIO POWER AMPLIFIER.

3-232. Harmonic Generation

3-233. A sine wave is the basis of all other waveforms. It is the only waveform that contains only one frequency. When any outside source changes the shape of a sine wave, other frequencies are generated. The resultant waveform is a composite of these other frequency components. To illustrate this principle, refer to figure 3-70.

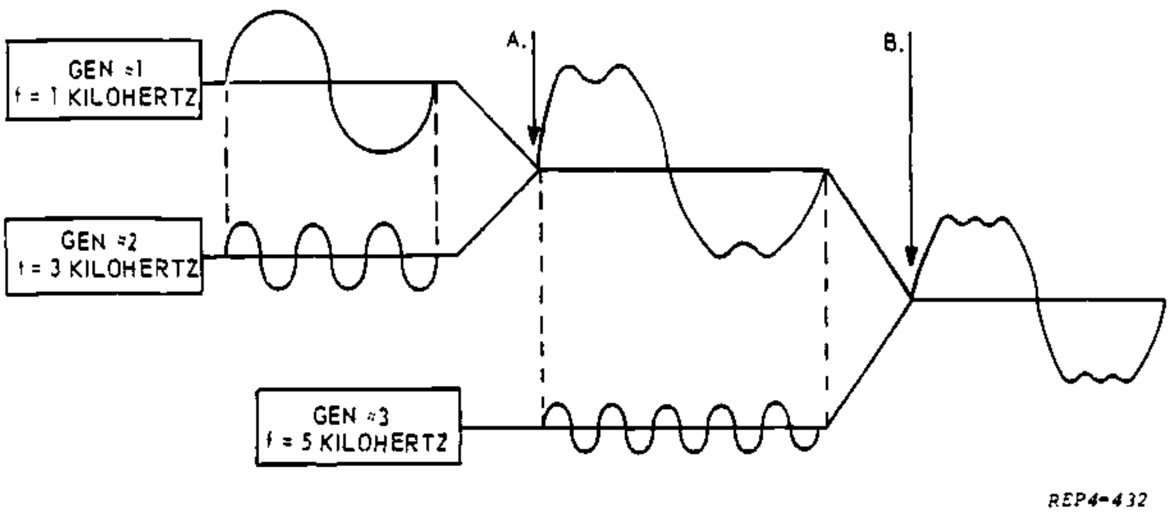

Figure 3-70. Complex Wave Generation

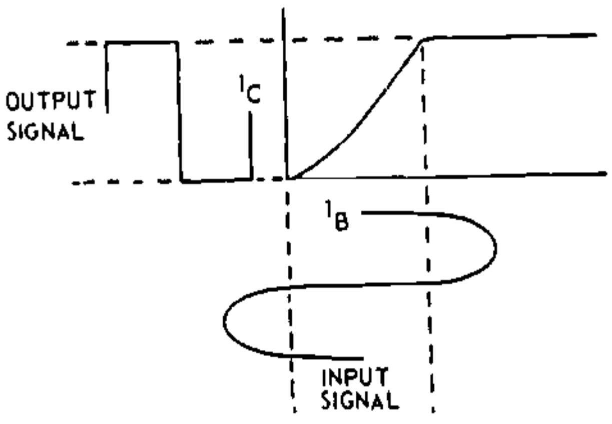

Figure 3-71. Harmonic Generation

3-234. generator No. 1 is producing a sine wave signal of 1 kHz. Generator No. 2 is producing a sine wave signal of 3 kHz, which is the third harmonic of the 1 kHz. A HARMONIC is an integral (whole number) multiple of the fundamental frequency. That is, the second harmonic is two times the fundamental, the third harmonic is three times the fundamental, etc. Those harmonics that are odd multiples of the fundamental frequency are called odd harmonics, and the even multiples are called even harmonics.

3-235. By combining the fundamental frequency and the third harmonic frequency (Point A, figure 3-70), a resultant wave is formed that is considerably different than either of the originals. When the fifth harmonic frequency (Generator No. 3) is added with the fundamental and the third harmonic, the resultant wave at Point B is obtained. Both waves (Point A and B) are called nonsinusoidal waves. A nonsinusoidal wave is any wave that does not vary as a sine curve. Further, as seen above a nonsinusoidal wave contains more than one frequency component.

3-236. It is not necessary to have three generators to produce the waveform shown at point B of figure 3-70. Figure 3-71 illustrates how an amplifier can do the same thing. If a sine wave input signal were large enough to drive an amplifier alternately into saturation and cutoff (overdriven), the output waveform would be nearly flat on the top and bottom. Since the output is nonsinusoidal, it now contains fundamental and harmonic frequencies. The harmonic frequencies have been generated by the nonlinear operation of the transistor (cutoff and saturation).

3-237. When a sine wave is applied to a non-linear device, harmonically related frequencies are generated. Any waveform that is not a sine wave contains more than one frequency.

3-238. A Class A amplifier is designed to operate on the linear portion of its transfer curve. Thus, no harmonics will be generated and the output will contain only the frequency applied to the input of the amplifier. Class AB, Class B, and Class C amplifiers do generate harmonics because, at some time during their operation, they use the non-linear portion of the curve.

3-239. The type or class of operation will determine the type of harmonics generated. In Class B operation, the predominant harmonics generated are even harmonics. Some odd harmonics will be generated, but their amplitudes are small compared to the even harmonics. In Class C operation, however, both odd and even harmonics have large values. Overdriven amplifier operation will generate odd harmonics.

Chapter 4

SELECTED SOLID STATE DEVICES AND INTEGRATED CIRCUITS

4-1. The introduction and application of semiconductor devices into the field of Electronics has enabled us to successfully launch a space vehicle. This is only one of thousands of things which have either been improved or made possible by semiconductor devices. The large, high power consuming, heat generating vacuum tube amplifiers have been replaced, to a large degree, by the transistor, tunnel diode, or field effect transistor. The slow acting, heavy, large, unreliable control devices such as switches and relays have been replaced by special semiconductor devices. This has, to a great extent, aided in the development of miniature computers. As man's knowledge of the application of semiconductors increased, he was able to produce components such as resistors, capacitors and inductors from semi-conductor materials. In fact, it is now possible to produce entire electronic circuits known as integrated circuits. These circuits can be as small or smaller than the letter "0." The development of these micro-miniature semiconductor circuits has greatly reduced the size and weight of electronic systems and has increased their reliability. The schematic symbols, biasing characteristics, and applications of some of these semiconductor devices will be discussed in this chapter.

4-2. Unijunction Transistors

4-3. The unijunction transistor (UJT) is the first one of the selected solid state devices we will discuss. It basically is a variable resistance which is voltage controlled. It does not amplify, but it does serve as an electronic switch. Like a switch, the unijunction can go from a high resistance (switch open) to a low resistance (switch closed).

4-4. Figure 4-1A shows the construction of a unijunction transistor using an N-type bar. Fused into the N-type material is a piece of P-type material which is the emitter. Ohmic contacts are connected at opposite ends of the bar, called BASE 1 and BASE 2. Observe that the position of the emitter is closer to BASE 2, about two-thirds the distance from BASE 1 to BASE 2. Other unijunctions use a P-type bar with an N-type emitter. The N region has a specific resistance

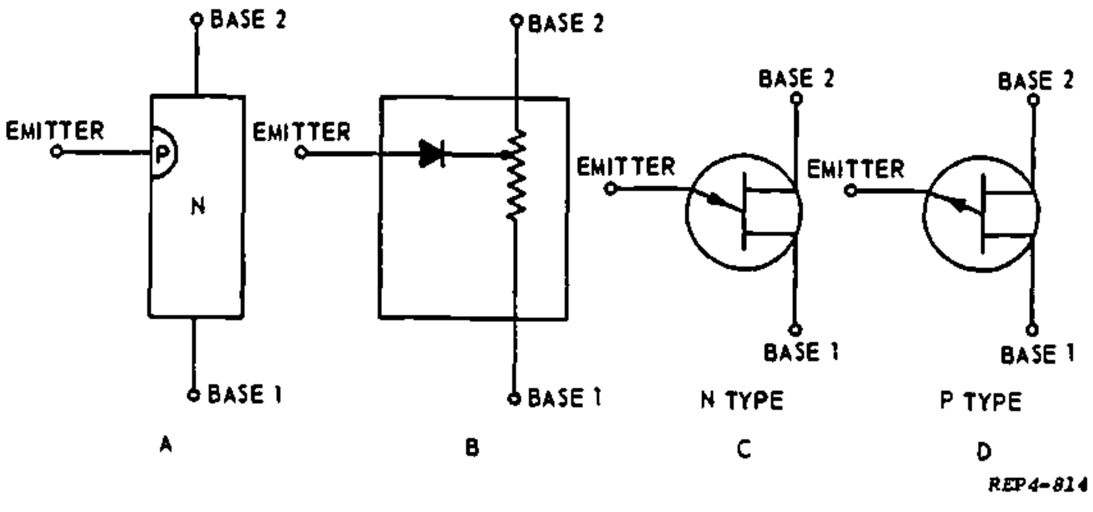

Figure 4-1. Unijunction Transistor (UJT)

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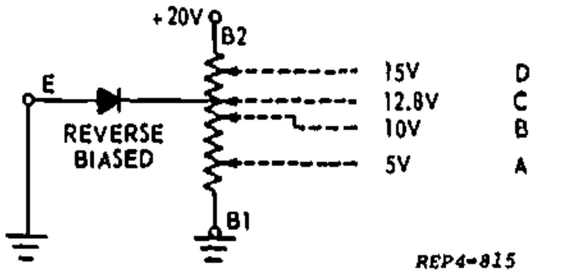

Figure 4-2. Voltage Distribution or Gradient in the Unijunction Transistor

because it is a semiconductor. Figure 4-1B shows the equivalent circuit for the three terminals. The N-type bar appears as a resistor between BASE 1 and BASE 2. This resistance is called "interbase" resistance and can have typical values of 5k to 10k ohms. The P-type emitter fused to the N-type bar forms a PN junction diode as shown. Figure 4-1C shows the schematic symbol for an N-type unijunction and 4-1D is the symbol for the P-type unijunction transistor.

4-5. When a voltage is applied across the two bases (Figure 4-2), a small current will flow from BASE 1 to BASE 2. The voltage applied will be evenly distributed across the interbase resistance which appears as a voltage divider. This distribution is called the "voltage gradient." One-fourth the distance from B1 to B2 represents one-fourth of the interbase resistance. Therefore, one-fourth of the voltage applied will appear at point A with respect to B1 or ground. Point B represents one-half of the resistance; therefore 10 volts would appear at point B. Three-fourths of the applied voltage appears at point D. Increasing or decreasing the voltage applied would change the voltage at these points but the distribution or voltage gradients would remain the same. For 40 volts applied, point A would be 10 volts, point B would be 20 volts, and 30 volts at point D.

4-6. In Figure 4-2, the voltage at the junction of the emitter and bar (Point C) is positive 12.8 volts with respect to BASE 1 or ground. The emitter at point E is at ground potential; therefore the emitter is reverse biased by 12.8 volts. The emitter junction is "cutoff" and will remain at cutoff as long as the emitter is less positive than point C. In the cutoff condition, there is very little current through the emitter-BASE 1 junction. The impedance of the emitter is very high (from 1 to 65 megohms) and the emitter circuit acts like an open switch.

4-7. Figure 4-3A shows an equivalent circuit of a cutoff unijunction. R1 and R2 provide only positive 10 volts at the emitter and the emitter junction is reverse biased. Current flows from BASE 1 to BASE 2, but this current is small and is only used to develop the voltage for biasing one side of the junction. When the voltage on the emitter exceeds the voltage at point C, the junction will become forward biased, and the UJT will "FIRE" or turn on.

4-8. Refer to Figure 4-3B. With forward bias, the emitter to B1 resistance will

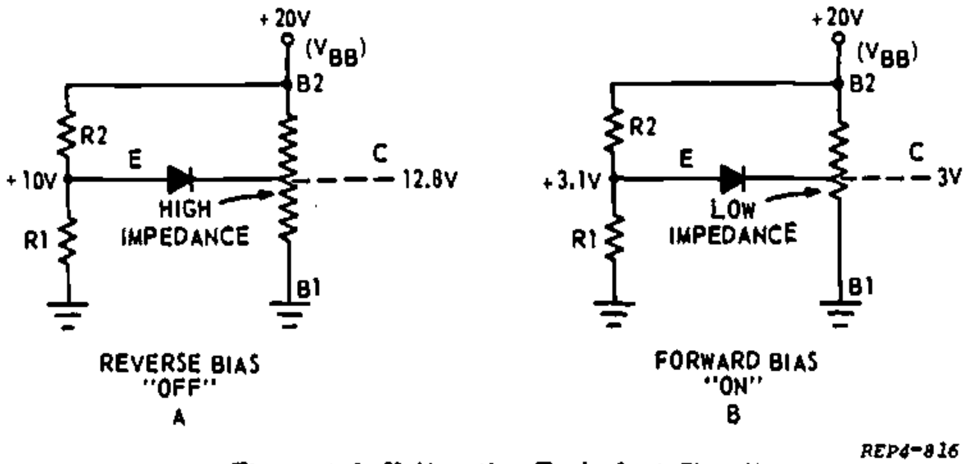

Figure 4-3. Unijunction Equivalent Circuits

423

decrease to a very low value. The decrease in resistance causes the voltage at point C to drop to a low value (3 volts in this example). The low emitter-B1 resistance acts like a closed switch and a large current will flow through the junction. The current will flow from B1 to the emitter, through R2 to V_{BB}. This large current through R2 will cause the voltage at point E to drop to positive 3.1 volts. The emitter is forward biased by .1 volt and will remain on as long as forward bias is applied. In the "ON" state (forward biased) the UJT is operating at saturation (maximum current).

4-9. The R1 and R2 divider is used to represent any sensing device which can change the emitter voltage. To simulate the action of the sensing device and its effect on the UJT, we will increase the value of R1. The voltage across R1 would increase which will forward bias the UJT and fire it. If its resistance is then decreased, the forward bias is removed and the UJT will turn off. The time required to change states from on to off or vice versa is called the "switching time." The switching time for the unijunction is only a fraction of a microsecond or a million times faster than conventional switching devices.

4-10. Figure 4-4 shows a characteristic curve of a unijunction transistor, plotting emitter voltage versus emitter current. From 0 to 12.8 volts (point A to point B) at the bottom of the chart is the area of emitter cutoff. During cutoff, a very small amount of reverse bias current (leakage current) will flow in the emitter. However, this current is from .2 to 12 microamperes and cannot be plotted on the graph which is calibrated in milliamperes. Forward bias occurs at the peak voltage point (point B). The unijunction fires and emitter current increases. The emitter voltage will decrease to point C called the valley voltage point. The area between points B and C is called the "negative resistance area" because the emitter current increases as the emitter voltage decreases. The time required to change from point B to point C is the switching time. When the UJT is fired, the negative resistance properties of the device

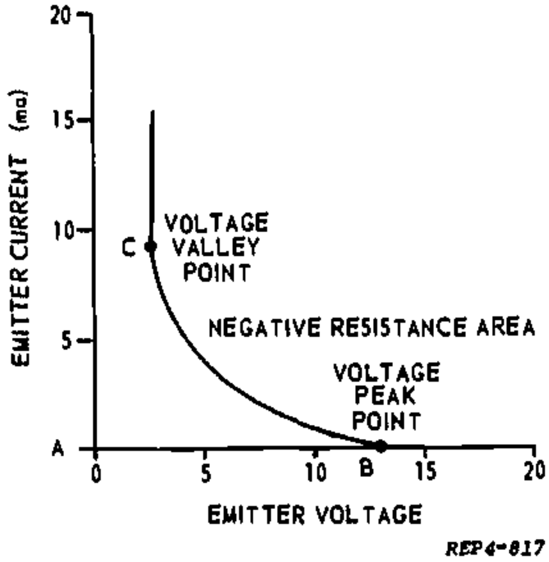

Figure 4-4. Unijunction Characteristic Curve

cause a very rapid change from the "off" to "on" conditions or vice versa and accounts for its fast switching time.

4-11. From our discussion of the unijunction it can be seen that it is merely a voltage controlled switch. It may be used in many applications requiring a switching or control device. One application of the UJT is as a waveform generator and will be discussed later.

4-12. Field Effect Transistors

4-13. NPN and PNP transistors are current-controlled devices, and have a low input impedance. The field effect transistor (FET) is a voltage-controlled device, and has a high input impedance. This semiconductor device operates on electrostatic principles, and is used in transmitters, receivers, test instruments, and other electronic devices.

4-14. The FET devices can be divided into two main groups: the Junction Field Effect Transistor (JFET) and the Metal Oxide Semiconductor Field Effect Tranststor (MOSFET). We will first discuss the characteristics of the Junction Field Effect Transistor.

4-15. JFETs are either N-type or P-type. For discussion purposes, we use the N-type

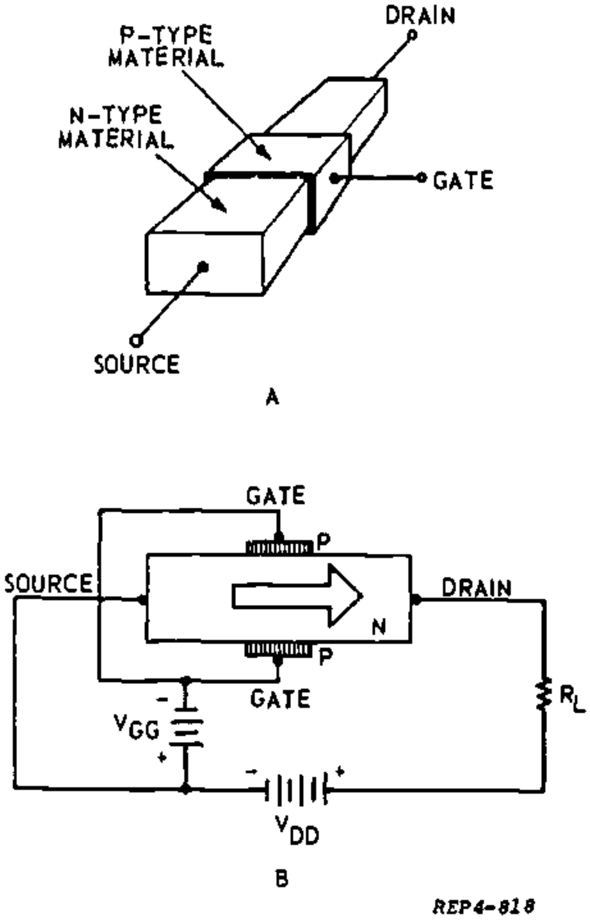

Figure 4-5. N-Type Junction (JFET) Field Effect Transistor

JFET, although the P-type construction and operation use the same basic principles. Let's start with a bar of N-type silicon crystal, shown in Figure 4-5A.

4-16. The two connections labeled "source" and "drain" are simply ohmic type connections to each end of the N-type crystal. A P-type region is processed into the bar (Figure 4-5A and B), and an ohmic contact is made to this region. This connection is called the "gate." The gate can be compared to the base of a conventional transistor.

4-17. Figure 4-5B shows how an N-bar JFET is connected to external power sources for proper operation. The drain is connected through R_L to the positive terminal of the drain supply (V_{DD}), and the source to the negative terminal of V_{DD}. The drain current, I_D, flows through the JFET from source to drain and through the external circuit as shown by the arrows. Ignoring the action of the gate for the moment, I_D is limited by R_L and the resistance of the N-type material.

4-18. The gate is connected to the negative terminal of the gate supply, V_{GG}. The positive terminal of V_{GG} is returned to the source. This connection reverse biases the gate-source PN junction. With the gate reverse biased, the only gate current flowing is an extremely small reverse current. For the moment, let's assume the gate voltage is zero. As drain current flows through the JFET, a voltage gradient is produced along

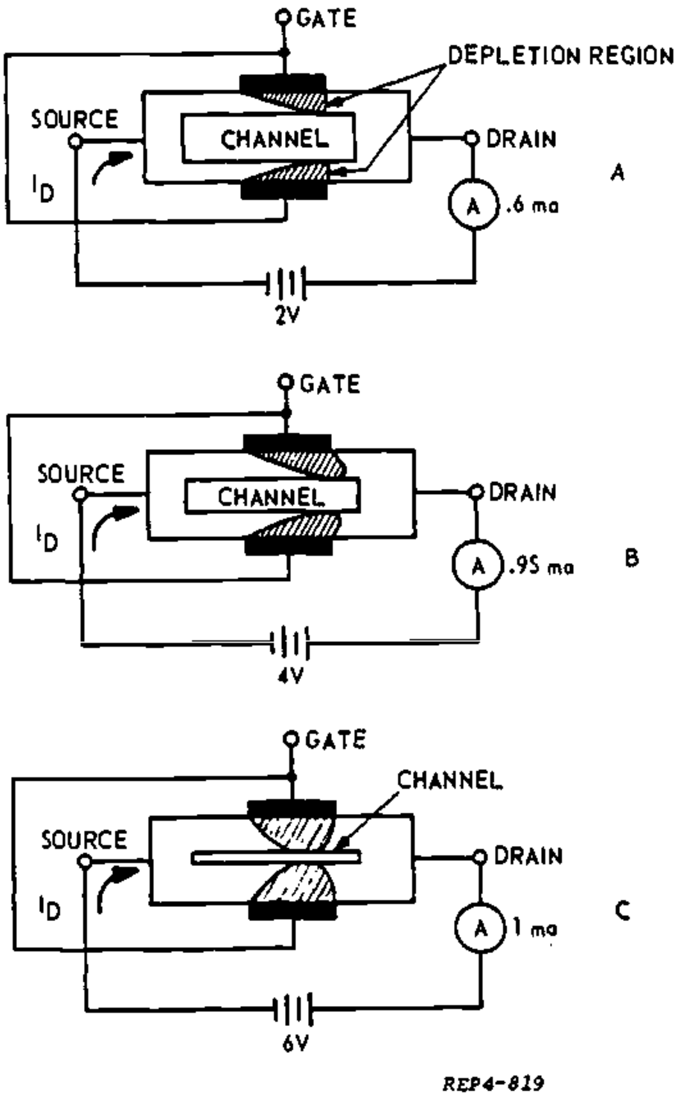

Figure 4-6. Effects of Changing V_{DS} on Channel and Drain Current

the bar with voltages that are positive with respect to the source. This will also reverse bias the gate PN junction. Whenever a PN junction is reverse biased, a depletion region, void of current carriers, is set up around the junction. This is shown in Figure 4-6A. The drain current cannot flow in the depletion regions, since no current carriers are available. Therefore, drain current is confined in the space between the depletion regions. This space is referred to as the "channel." As the drain-source voltage (V_{DS}) is increased, the drain current increases. However, the increase in drain current is nonlinear.

4-19. Refer to Figure 4-6B. Note that a change in drain-source voltage from 2 to 4v results in a change of drain current from .6 to .95 mA (ΔI_D = 0.35 mA). However, a change in V_{DS} from 4-6v produced a change in I_D from .95 to 1 mA (ΔI_D = 0.05 mA). This is because the reverse bias on the gate PN junction increases as the drain current increases. This causes an increase in the size of the depletion regions, causing them to extend further into the channel as shown in Figure 4-6B. Thus, as drain current increases, it causes a decrease in channel width, which tends to oppose an increase in drain current.

4-20. Increasing the drain-source voltage even further causes the depletion regions to almost come together, as shown in Figure 4-6C. When this condition is present, further increases in drain-source voltage cause little increase in drain current. Thus, drain current is at its saturated value.

4-21. The point where drain current reaches its saturated value is referred to as "channel pinch-off." If the drain-source voltage is increased too far, breakdown of the reverse biased gate junction occurs. This causes a high I_D and the JFET is destroyed. This action can be seen on the characteristic curve for an N-type JFET in Figure 4-7. With zero gate-source voltage (V_{GS}), pinch-off occurs when V_{DS} is approximately 4 volts and I_D is .95 mA.

4-22. Control of the channel pinch-off point can be obtained by varying the negative gate potential with respect to the source. As the gate voltage is increased (made more negative in respect to source) the depletion regions are extended further into the channel. This causes channel pinch-off to occur at a lower drain-source voltage, and thus causes a lower drain current. Therefore, drain current can be controlled by gate voltage. Making the gate more negative decreases current, and vice versa.

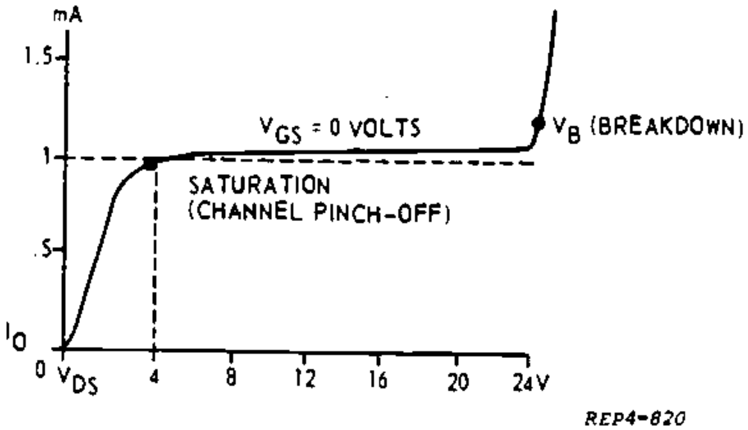

Figure 4-7. N-Type JFET Characteristic Curve

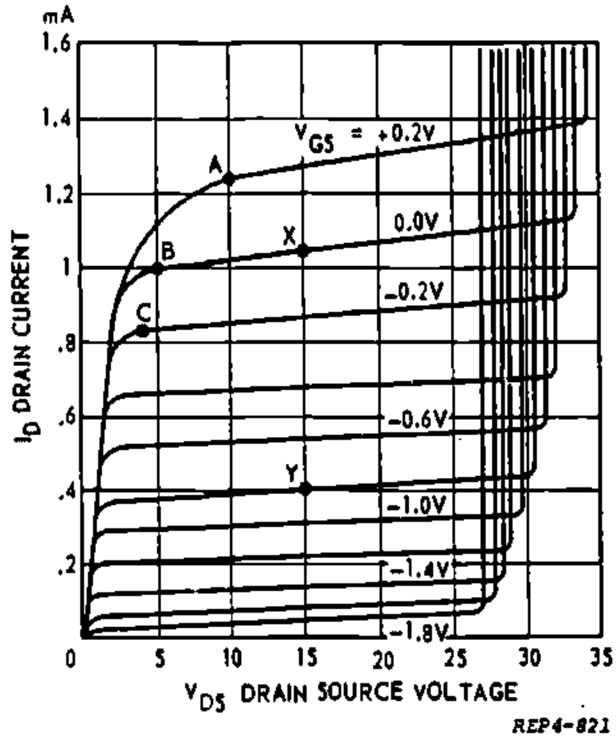

Figure 4-8. N-Type JFET Characteristic Curves

4-23. Figure 4-8 shows the family of curves for the N-type JFET. Point A, B, and C on the curves show where the channel pinch-off occurs. Note that making the gate more negative reduces channel pinch-off and also drain current. If V_{GS} is made negative enough, drain current becomes almost zero. This value of V_{GS} is called the "pinch-off voltage" (V_P). You will notice that small changes in gate voltage (V_{GS}) produce large changes in drain current (I_D). The gate is therefore used as the controlling element of the JFET.

4-24. The designation "unipolar" is often given to a FET device. Unipolar specifies a device which essentially contains one type of current carriers, either holes or electrons, but not both as in the bipolar NPN and PNP transistors.

4-25. The term "field effect" stems from the fact that the resistance of the silicon bar and the resultant drain current are affected by varying the electrostatic field at the gate.

4-26. Figure 4-9 shows the standard symbol for the N-type and P-type junction FETs, with their electrodes and polarities labeled. The bar is P material on the P-type JFET, and the bar is N material in the N-type JFET.

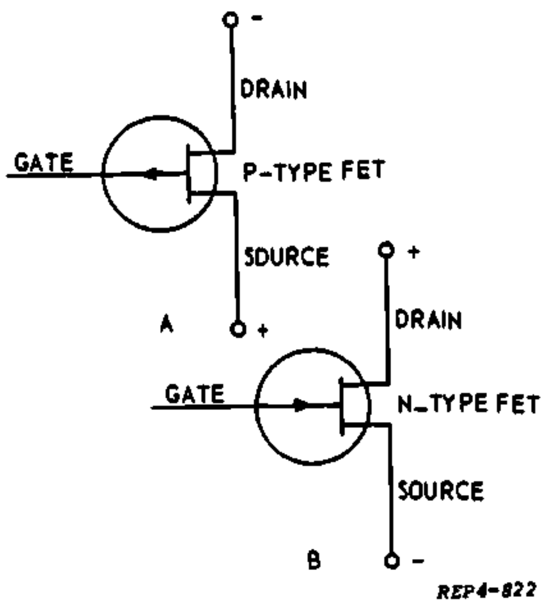

Figure 4-9. Junction FET Symbols

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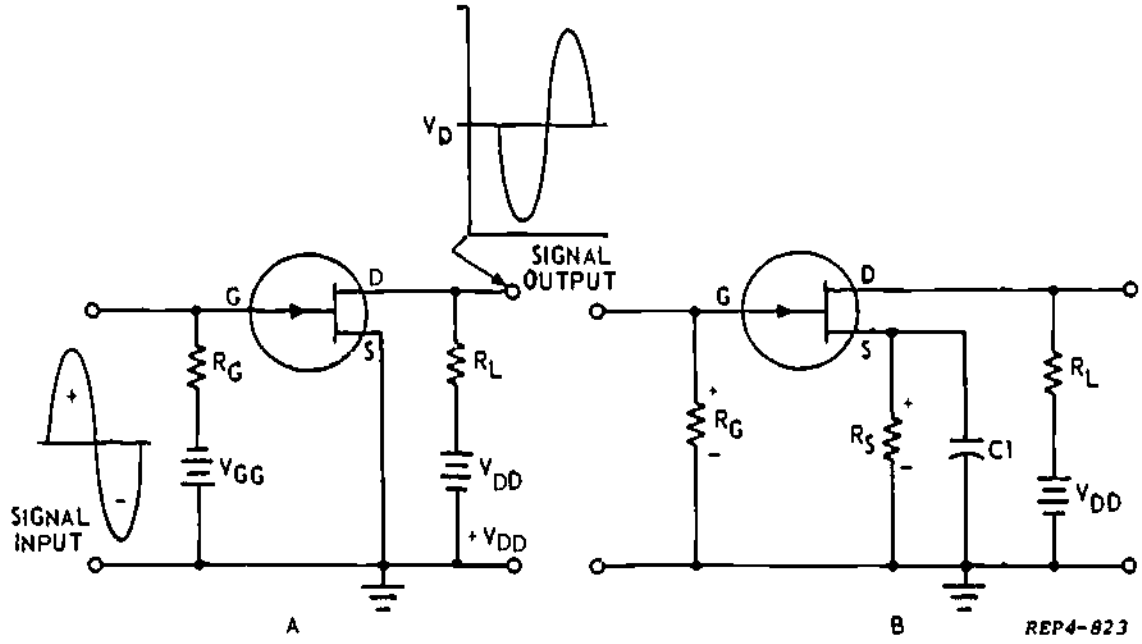

Figure 4-10. Common Source Amplifier

4-27. Figure 4-10 shows the JFET amplifier circuit in one of the three circuit configurations that may be employed, the common source amplifier. In Figure 4-10A, the input signal is applied to the gate, and the output is taken from the drain, with the source common to input and output. Resistor R_G is used to develop the input signal, V_{GG} is the gate supply voltage. R_L is the drain load resistor, and V_{DD} is the drain supply voltage. With the application of a positive input signal, the negative gate voltage will decrease, which increases drain current. This would cause drain voltage (V_D) to decrease causing the output signal to go in a negative direction. A negative input signal would increase gate voltage, drain current would decrease and the output signal would go more positive. Thus, the signal is shifted 180° as it passes through the JFET. Figure 4-10B shows the common source amplifier with V_{GG} removed and R_S added. R_S is placed in the source lead to develop the gate-source bias voltage as a self biasing network. C1 bypasses the signal around R_S preventing degeneration. Drain current through R_S will develop a voltage drop of the - 'arity shown. The gate is connected to the negative end of R_S while the source is on the positive end. Thus the gate is made negative with respect to the source, providing the desired reverse bias for the gate.

4-28. As with conventional transistors, the JFET may be connected in a common source, common gate, or common drain configuration. These may be compared to the common emitter, common base, and common collector configurations respectively. Each configuration has the same input-output signal phase relationship as the conventional transistor. In contrast however, the input signal of the JFET is applied to a reverse biased junction, while in the transistor the input is applied to a forward biased junction.

4-29. The input impedance for the JFET therefore is much higher than conventional transistors. Due to the reverse biased input of the JFET, its interelement capacitance is very low. As you recall the input interelement capacitance is one factor which limits the high frequency response in conventional transistor amplifiers. Two characteristics of the JFET therefore are its high input impedances which make it useful in test equipment and its low interelement capacitance enabling operation in high frequency circuits.

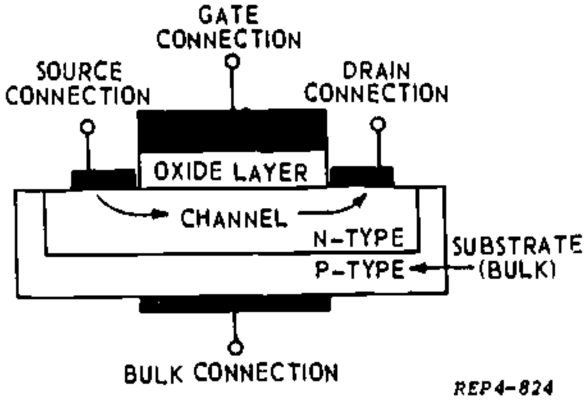

Figure 4-11. Cut-Away View of MOSFET (N-Channel)

4-30. The field effect transistor is a constant current device. That is, beyond a certain point (channel pinch-off) changes in drain voltage cause almost no change in drain current. Drain current is controlled entirely by gate voltage. Therefore, one of the most important dynamic characteristics of a JFET is how much change in drain current is produced by a given change in gate voltage. This characteristic is referred to as "trans-conductance" (gm). It is the ratio of a change in drain current to a change in gate voltage, holding V_{DS} constant.

$$gm = \frac{\Delta I_D}{\Delta V_{GS}},\ V_{DS} \text{ constant}$$

The unit for transconductance is the mho, and is equal to 1 ampere divided by 1 volt. As an example, refer to points X and Y in Figure 4-8. A change in V_{GS} from 0 volts (point X) to -.8 volts (point Y) causes a change in drain current from 1.05 mA to .4 mA. The gm is therefore:

$$gm = \frac{\Delta I_D}{\Delta V_{GS}} = \frac{.65 \times 10^{-3} \text{ amperes}}{0.8 \text{ volts}}$$

$$= .8125 \times 10^{-3} \text{ mho}$$

The unit "mho" is generally too large for most specifications. Generally, gm is expressed in milli- or micromhos. Thus $.8125 \times 10^{-3}$ mho becomes 812.5 micromhos. Transconductance (gm) is a figure of merit for the JFET. The higher the value of gm the greater the amplifying ability of the JFET.

Although the JFET is a great improvement over the conventional transistor, it also has limitations. The small amount of reverse bias gate current which is drawn from a signal source would produce some loading of that source. To reduce this loading effect and to improve frequency response, an improved type FET was developed.

4-31. The second type of FET is the Metal Oxide Semiconductor (MOS), usually referred to as a MOSFET. The basic operation is

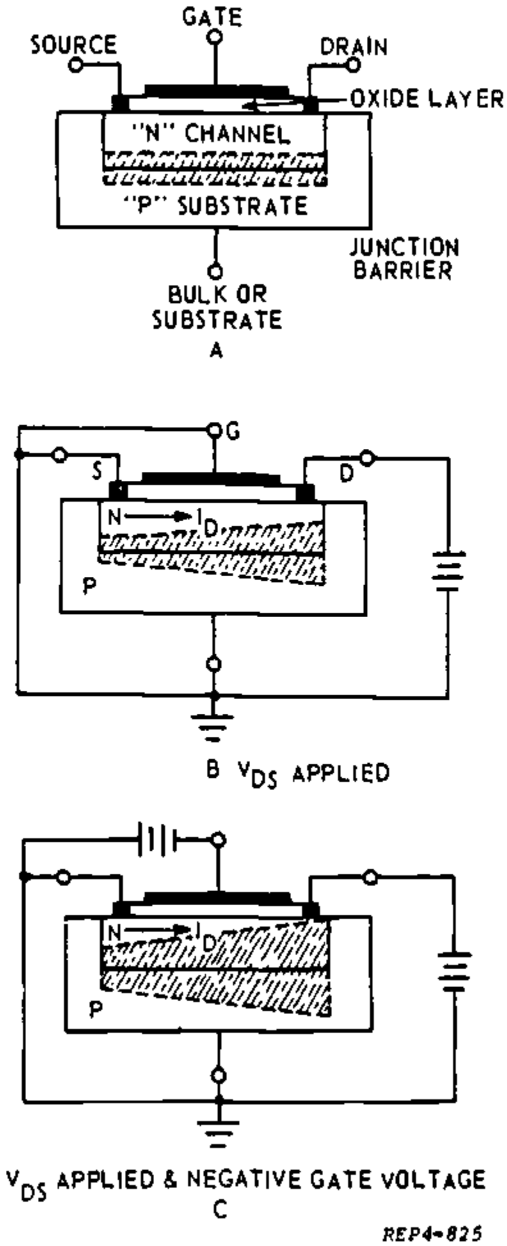

Figure 4-12. N-Channel Depletion Type MOSFET

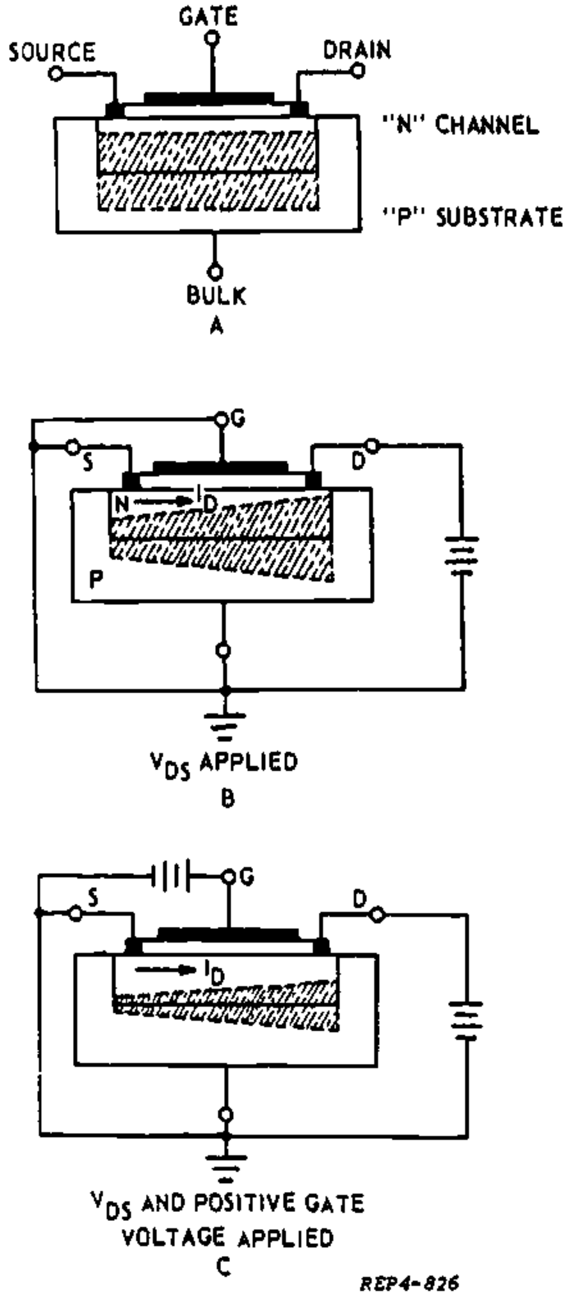

Figure 4-13. N-Channel Enhancement Type MOSFET

similar to the JFET. However, due to design characteristics, the MOSFET has a higher input impedance and a lower input capacitance than the JFET. The physical construction of a MOSFET is shown in Figure 4-11. Ohmic contacts are made to a section of N-type material to form the source and drain. This is called the channel material. The channel material is chemically joined with P-type material called the BULK or substrate. The N-channel and P-substrate form a PN junction and have all the characteristics of the PN junction. An insulator consisting of an oxide layer is placed between the source and drain. A metal gate is deposited over the oxide layer and a connection is made to the gate. MOSFETs are sometimes referred to as "insulated gate" FETs or IGFETs. The metallic gate and channel material form the plates of a very small capacitor. Current flows from the source to the drain through the channel immediately below the gate. The amount of current will depend on channel doping, gate, and drain-source voltages.

4-32. MOSFETs are classified as depletion or enhancement types. The depletion type has its channel doped heavily to allow a large amount of drain current flow with a small drain-source voltage applied. The enhancement type has a very lightly doped channel which allows a small amount of I_D flow.

4-33. Figure 4-12A and 4-13A show the N-channel depletion and enhancement MOSFETs with no circuit connections. Note that there is a depletion region at the junction between the channel and substrate. This will form a channel through which I_D will flow. As you recall from the discussion of PN junctions, the width of the depletion region is dependent upon percentage of doping. Since the enhancement MOSFET is lightly doped, its barrier width is large and the resultant channel is small.

4-34. When a voltage is applied to the MOSFET drain and source, drain current will flow in the channel. In Figures 4-12B and 4-13B, note that a large amount of I_D will flow in the depletion type and a small I_D flows in the enhancement type. Drain current through the channel will produce a voltage drop in the channel which becomes more positive as we go from source to drain. This changes the amount of reverse bias and the barrier width from source to drain.

4-35. In Figure 4-12C, we can see the effect of applying a negative voltage to the gate. This negative gate potential makes the N-channel more positive. Remember, the gate is one plate of a capacitor and the N-channel

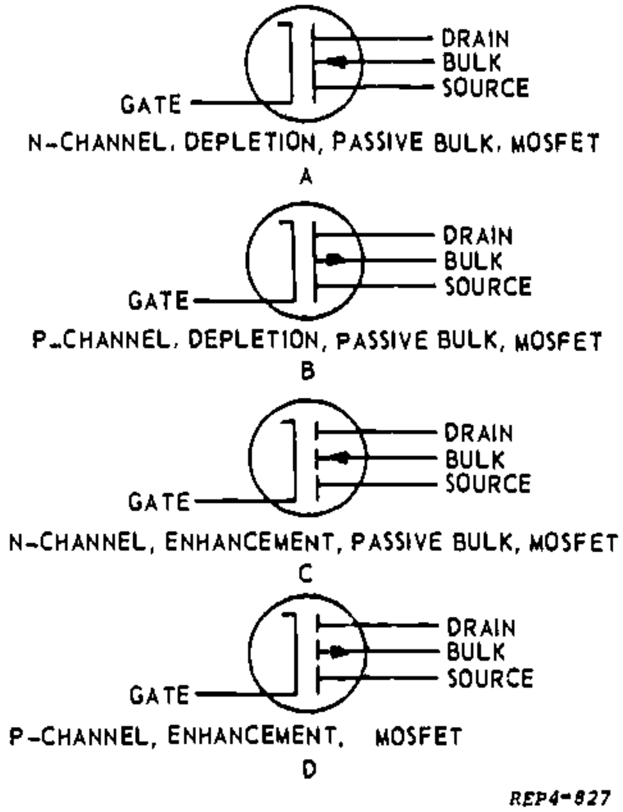

Figure 4-14. MOSFET Symbols

is the other plate. Making the gate negative increases the reverse bias between the channel and substrate. The junction barrier increases, channel width decreases, and drain current decreases. Therefore, in the depletion N-type MOSFET, a negative gate voltage will decrease drain current.

4-36. Figure 4-13C shows the enhancement type MOSFET with a positive gate voltage. This causes the channel to become less positive, reducing the reverse bias between channel and substrate. Notice barrier width decreases, channel width increases, and a larger drain current will flow. The gate voltage for both types of MOSFETs will establish the operating point. The input signal applied to the gate will alternately add to and subtract from the gate voltage, and will cause I_D to vary accordingly. The schematic symbols for MOSFETs are shown in Figure 4-14. You will note that the MOSFET can be manufactured with the N-channel, as we've discussed, or with the P-channel. With P-Channel MOSFET, all voltage polarities will be reversed, and drain current will flow in the opposite direction. The arrow on the Bulk lead pointing "in" represents an N-Channel device, and pointing "out," the P-Channel. The solid line between the source and drain represents a depletion type and a broken line the enhancement type. The gate, which does not touch the other elements, represents the insulated gate.

4-37. Basic circuit applications for the MOSFET are the same as the JFET. Figure 4-15 shows the N-Channel depletion MOSFET in a common source configuration.

4-38. Due to the insulated gate, the input impedance for the MOSFET is extremely high (10^{14} ohms) and the interelement capacitance is extremely low. This makes the MOSFET very useful for frequencies well above the range of the ordinary transistor and in circuits requiring high input impedance amplifiers. For this reason, MOSFETs are employed in electronic voltohmmeters and other electronic test equipment.

4-39. Tunnel Diodes

4-40. THE TUNNEL DIODE is a two-element device which can operate as a conventional diode, amplifier, or oscillator. Like the unijunction, JFET, and MOSFET previously discussed, the Tunnel Diode is also a special semiconductor device. Some of the advantages of the tunnel diode over transistors are smaller size, greater temperature range, and higher resistance to radiation. The tunnel diode takes its name from a "tunnel" effect - a process wherein a particle can disappear

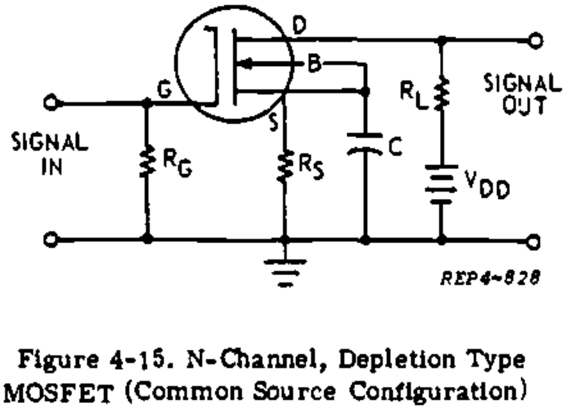

Figure 4-15. N-Channel, Depletion Type MOSFET (Common Source Configuration)

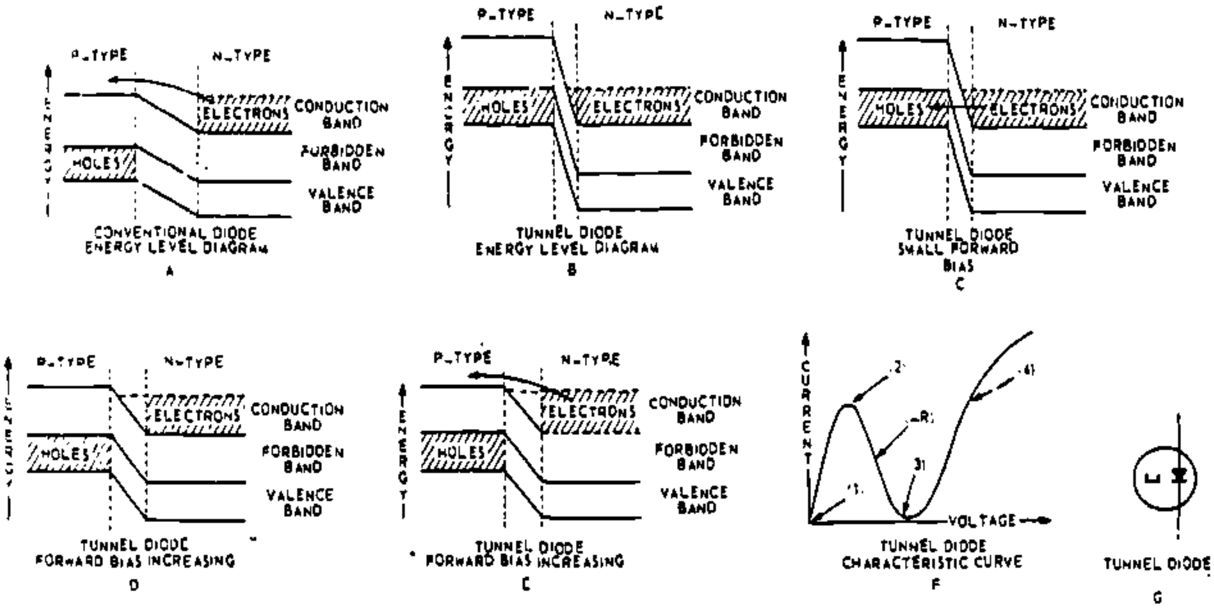

Figure 4-16. Tunnel Diode Energy Levels and Curve

from one side of potential barrier and appear instantaneously on the other side, even though it does not have enough energy to surmount the barrier. It is as if the particle "tunnels" underneath the barrier. In discussing the operation of the tunnel diode, refer to Figure 4-16G.

4-41. In the case of the tunnel diode, the barrier is the space charge or depletion region of a PN junction. This is the same barrier which prevents current from flowing in the reverse direction in the ordinary PN junction diode. In the tunnel diode, this barrier is made extremely thin (less than a millionth of an inch) by doping it very heavily. Compare the barrier of a conventional diode in Figure 4-16A to the barrier of the tunnel diode in Figure 4-16B. The barrier of the tunnel diode is so thin that penetration by means of the tunnel effect becomes possible with a small forward bias voltage (Figure 4-16C). With a further increase in forward bias voltage, current decreases, giving the effect of "negative resistance." Negative resistance, from our preceeding discussion on the unijunction, appears when an increase in voltage across a resistor results in a decrease in current through the resistance.

4-42. Recall that in an atomic structure, electrons cannot exist in the forbidden band. Also, recall that the number of holes in the valence band, or electrons in the conduction band, can be controlled by adding either acceptor or donor impurities to the semiconductor crystal. Acceptor impurities add to the number of holes in the valence band, and donor impurities add more electrons to the conduction band. In this way, P-type (holes in the valence band) and N-type (electrons in the conduction band) material can be built into a single crystal lattice structure. As we already know, the intersection of these two regions is called a PN junction.

4-43. Figure 4-16A illustrates the energy level diagram of a conventional diode. The N-type material has many free electrons in the conduction band, and the P-type material has many holes in the valence band, the diode having been properly doped for this effect. The barrier height is relatively small and the barrier width is relatively large compared to those in Figure 4-16B.

4-44. Figure 4-16B illustrates an energy level diagram of a tunnel diode. Because it is doped much more heavily than the conventional diode in Figure 4-16A, the barrier height is very large and the barrier width is extremely narrow. Further, notice that the energy level of the holes in P-type material are aligned with the free electrons of the N-type material. This situation exists with no bias voltage on the diode. There is, for all practical purposes, no current at this time. The condition with zero bias voltage and no current flow is designated (1) in Figure 4-16F.

4-45. When a small forward bias voltage is applied to a tunnel diode, as shown in Figure 4-16C, the free electrons of the N-type material are raised in energy. Even though they appear not to have sufficient energy to travel up the "potential hill" (or overcome the junction barrier), they will now "tunnel" through the barrier and recombine with holes in the P-type material. This "tunneling" action results in a relatively high current through the tunnel diode (Refer to (2) in Figure 4-16F).

4-46. As forward bias is increased further, the free electrons are raised in energy and become more aligned with forbidden band of the P-type material. The current flow due to tunneling now decreases. When the free electrons are exactly aligned with the forbidden band of the P-type materials, Figure 4-16D, current through the tunnel diode is at a minimum (Figure 4-16F Point 3). The region where increasing forward bias (E increasing) causes current to decrease through the device (I decreasing) is referred to as the "negative resistance" (-R) region (Figure 4-16F). This region is also referred to as the normal operating region.

4-47. Figure 4-16E illustrates the energy level diagram when the forward bias on the tunnel diode is increased still further. Notice the similarity between the conventional diode of Figure 4-16A and the tunnel diode of Figure 4-16E. The tunnel diode now acts as a convnetional diode. (Note characteristic curve marked (4) in Figure 4-16F.)

4-48. To summarize the discussion, refer to the characteristic curve for a tunnel diode (Figure 4-16F). Point (1) represents zero current and zero voltage, as shown in the energy level diagram in Figure 4-16B. As forward bias increases (point (1) to point (2), the tunnel diode current increases rather rapidly. Point (2) on the curve represents the "peak point" where the current reaches a maximum value. This is represented in Figure 4-16C. As forward bias is increased still further, moving from point (2) to point (3) on the curve, current begins to decrease. This is because the free electrons are aligning themselves with the forbidden band of the P-type material (Figure 4-16D). At point (3) the current is minimum (valley point) because the free electrons are opposite the forbidden band of the P-type material. The area between point (2) and point (3) is called the negative resistance region because as voltage (forward bias) increases, current decreases.

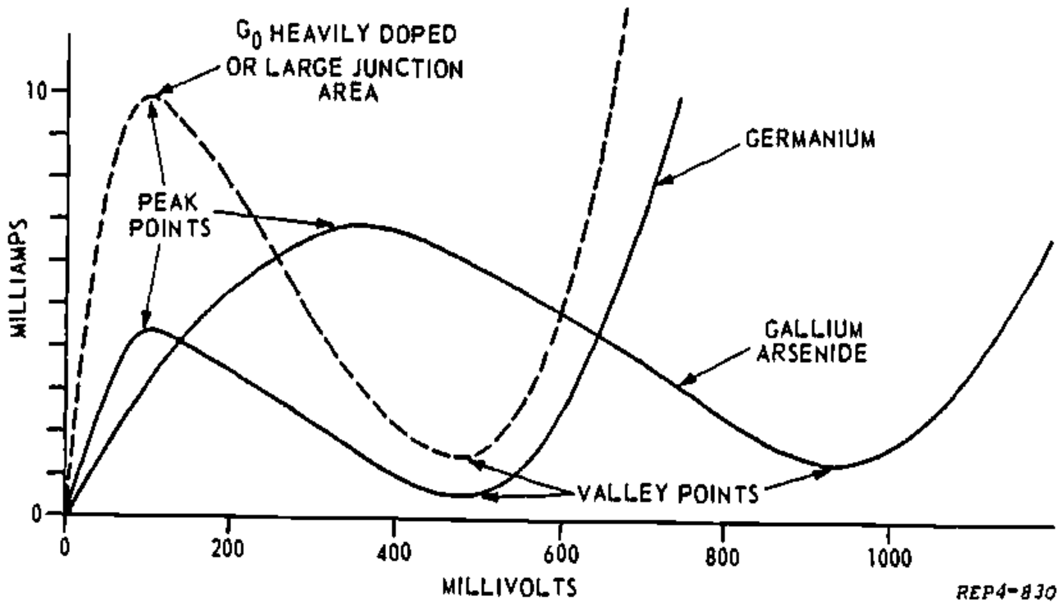

Figure 4-17. Comparison of Volt Ampere Curves for Germanium and Gallium Arsenide Tunnel Diodes

4-49. As forward bias is increased beyond point (3), current again increases. The tunnel diode from here on will act as a conventional diode, (Figure 4-16A). To get some idea of the magnitude of voltage and currents involved, look at Figure 4-17. Germanium tunnel diodes reach their first peak at about 0.1 volts. The total negative resistance region covers approximately 400 mv, with a power level of 10^{-6} to 10^{-3} watts.

4-50. Varactor

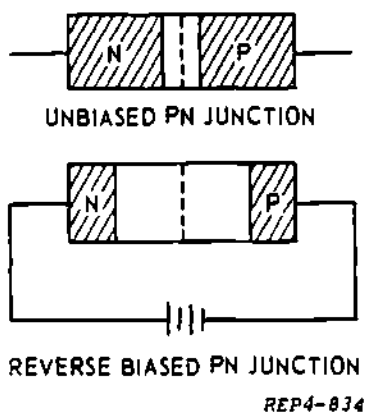

Figure 4-18. Unbiased and Reverse Biased PN Junction

4-51. The varactor is a voltage controlled semiconductor capacitor. To understand its principle of operation, let's review the PN junction. As you recall, when a PN junction is biased in the reverse direction, the electrons in the N-type material are drawn toward the positive battery terminal. The holes in the P-type material are drawn toward the negative battery terminal. Assuming an ideal diode, all of the carriers would be pulled away from the junction; therefore, no carriers would exist in the barrier region. This situation will remain as long as a reverse-bias voltage of constant amplitude is applied to the PN junction (refer to Figure 4-18).

4-52. Electrical charges are held captive in the diode, separated by an area where no carriers are present. In other words, the semiconductor diode forms a capacitor with the N- and P-type materials acting as plates, and the barrier as the dielectric.

4-53. As you recall, the formula for capacitance is $C = K \frac{A}{D}$

A = plate area
K = dielectric constant
D = distance between plates

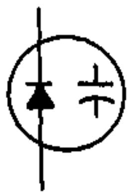

Figure 4-19. Varactor Symbol

4-54. If the value of the reverse-bias voltage is increased from its previous value, carriers move farther away from the junction, (distance between plates increased) and the value of the resulting capacitor decreases. If the value of the reverse-bias voltage is decreased from a previous value, carriers move closer to the junction, and the value of the resulting capacitance increases. Thus, the value of the capacitor is dependent upon the value of the applied reverse-bias voltage.

4-55. This capacitive effect is present in all semiconductor diodes; it is increased by suitable doping and manufacturing control to produce a VARACTOR. We can now see from our discussion that a varactor is a special type of semiconductor diode which produces a capacitive effect that is dependent upon the value of the applied reverse-bias voltage. The schematic symbol is shown in Figure 4-19.

4-56. The relationship between reverse bias voltage (V_R) and capacitance for a typical varactor is shown in Figure 4-20. The ratio of maximum to minimum capacitance that can

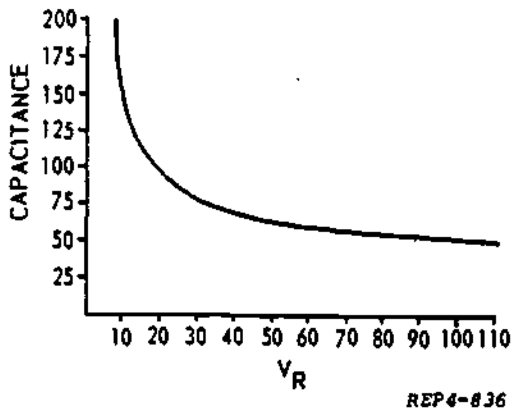

Figure 4-20. Varactor Reverse Bias Versus Capacitance

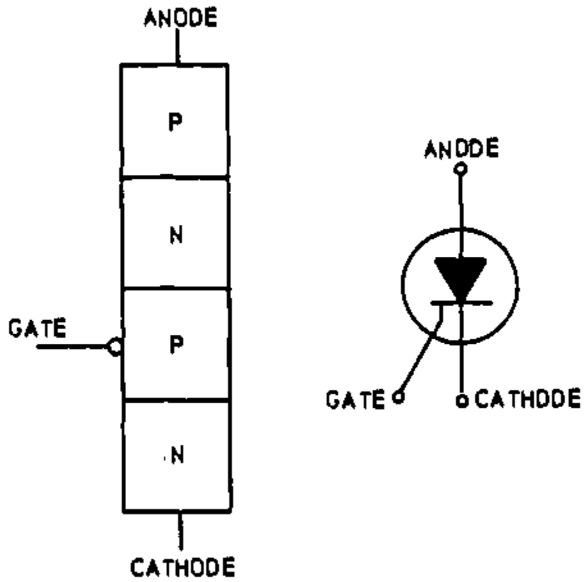

Figure 4-21. Silicon Controlled Rectifier (SCR) Structure and Schematic Symbol

be obtained from a varactor is determined by the range of the reverse voltage V_R. Observe that greatest capacitance values occur at low values of V_R. The upper V_R limit is fixed by the breakdown voltage rating of the diode, and the lower V_R limit is fixed by zero volts reverse bias. The varactor can be used in almost any application requiring a variable capacitor.

4-57. Silicon Controlled Rectifier

4-58. Just as P- and N-type semiconductor materials can form a two-layer PN device (diode), other semiconductor devices are built up of three or more alternate layers of P and N materials. Most transistors are three-layer devices of either PNP or NPN structure and contain two PN junctions. Four layers create a PNPN device, which has three junctions. A large number of applications have been found for the various four-layer devices, since these units have certain characteristics which make them superior to the two- and three-layer devices for certain control actions.

4-59. The SILICON CONTROLLED RECTIFIER (SCR) is basically a 4 layer (PNPN)

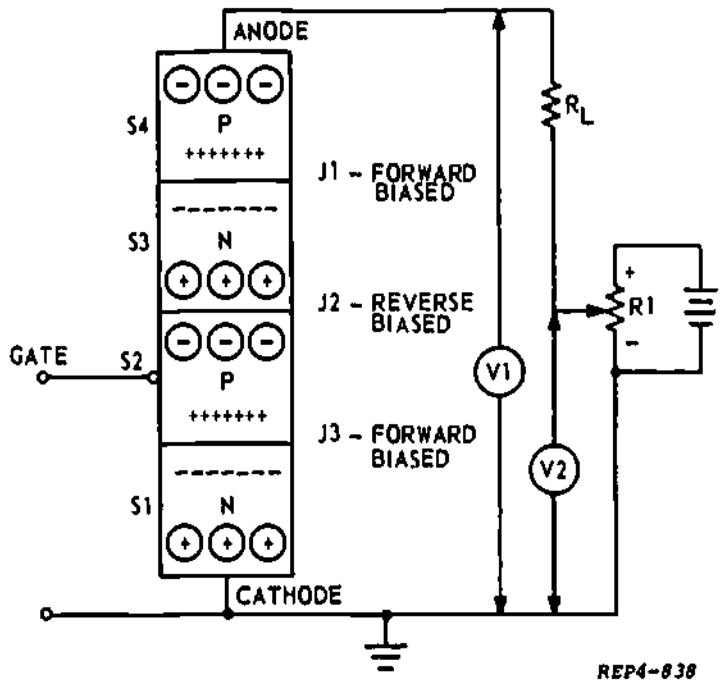

Figure 4-22. Bias on SCR Junctions

semiconductor device having three electrodes: a CATHODE, an ANODE, and a control electrode called the GATE, as shown in Figure 4-21 along with its schematic symbol. The term RECTIFIER is commonly used in referring to circuits or devices which conduct current primarily in one direction, such as the junction diode. The SCR differs from conventional rectifiers in that it will not conduct a substantial amount of current when forward bias is applied to the anode and cathode until a certain minimum voltage is reached. The value of this potential can be varied or controlled by the use of an external signal at the control electrode (gate) of the SCR. This unique control characteristic makes the SCR particularly useful in power-controlling devices, especially in high-power circuits.

4-60. Figure 4-22 shows the SCR properly connected in a circuit that can be used to determine its forward biased characteristics. The supply voltage causes the anode to be positive with respect to the cathode (forward bias). The resulting electrostatic field through the device causes electron carriers to be attracted toward the anode, and hole carriers to be attracted toward the cathode. At junction J_1, holes in section S_4 are repelled by the positive anode potential and move toward J_1. In section S_3, electrons are attracted toward the positive anode and move toward J_1. A similar action takes place in sections S_1 and S_2 to bias J_3. Since majority carriers moved toward the junctions, we speak of these junctions as being forward biased. Majority carriers move away from junction J_2 and so it is reverse biased. Conduction from cathode to anode would occur if J_2 were not reverse biased. The movement of carriers is only a momentary condition, and will cease when the reverse-biasing potential across J_2 equals the anode-to-cathode potential. The SCR is now in its non-conducting or OFF state.

4-61. Conduction (or the ON state) can be achieved by one of two means. The first is to increase the anode-to-cathode potential until the device breaks over into conduction. The potential at which this breakover occurs is called the FORWARD BREAKOVER POTENTIAL. Once breakover occurs and conduction results, the anode-to-cathode voltage (V_1 in

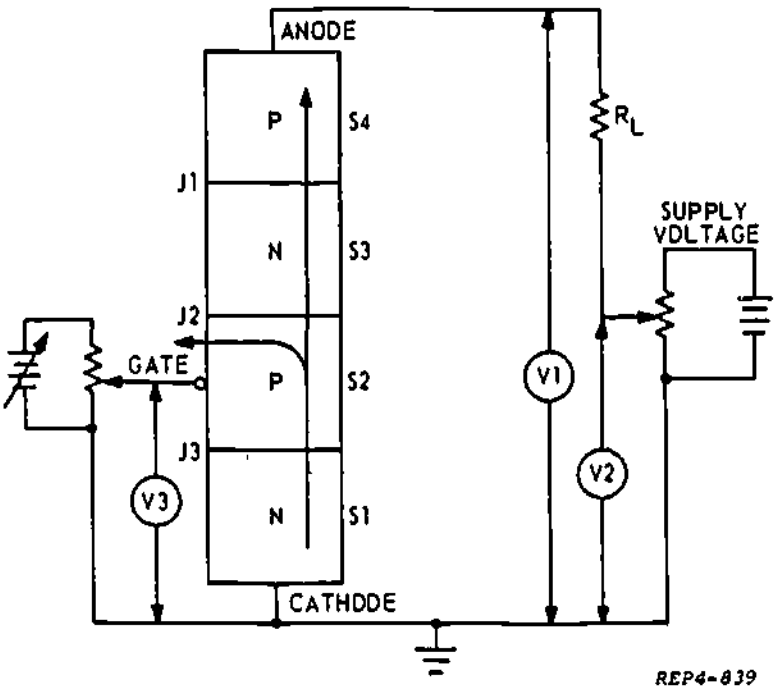

Figure 4-23. Achieving Conduction by Gating

Figure 4-22) decreases, due to the increased voltage drop across R_L. At first glance, it would appear that there is no longer enough potential across the SCR to maintain the breakover condition. However, this conducting condition will continue. Recall that a junction is said to be reverse-biased when MAJORITY carriers are attracted away from the junction. Recall also that reverse bias for majority carriers is forward bias for MINORITY carriers (holes in N-type material, free electrons in P-type material). Forward breakover is based on the following concept. Electrons (from section S_1) cross J_3, attracted by the positive anode potential. If S_1 is more heavily doped than is S_2, and the anode potential is sufficiently large, some of the electrons crossing J_3 will NOT meet holes and combine, because all the holes will have already combined with electrons. This condition is called "saturation." Those that do not combine act like minority carriers, since they are electrons in P-type material. These electrons then "see" J_2 as being forward-biased, and they cross on over J_2 into the N-type section S_3. J_1 is also forward biased for them, and they move on to the anode and out into the circuit, completing the path for current flow. If electrons continue to be in excess in S_2, (S_2 now has many electrons and no holes), sections S_1, S_2, and S_3 will act like a single piece of N-type material. Since the anode (S_4) is P-type material, the overall effect is as if we now have a single forward biased PN junction at J_1.

4-62. The SCR remains in the high conduction (ON) condition until the current drops to a value below that necessary to supply more than enough electrons from S_1 to S_2 to combine with and cancel out all of holes in S_2. This minimum current is called HOLDING CURRENT. When the holes in S_2 outnumber the free electrons arriving from S_1, the number of these electrons reaching J_2 is insufficient to maintain conduction and conduction stops. J_2 reverts to a simple reverse-biased junction until the forward breakover potential is again exceeded.

4-63. The second means of achieving conduction involves the use of the gate electrode. A positive potential on the gate is used to cause conduction. This potential is much less than the anode-to-cathode breakover potential, usually only a few volts. To understand the operation of the gate electrode, study Figure 4-23. You will notice that the gate terminal is tied to the P-type section S_2. With a positive potential at the gate, electrons will be

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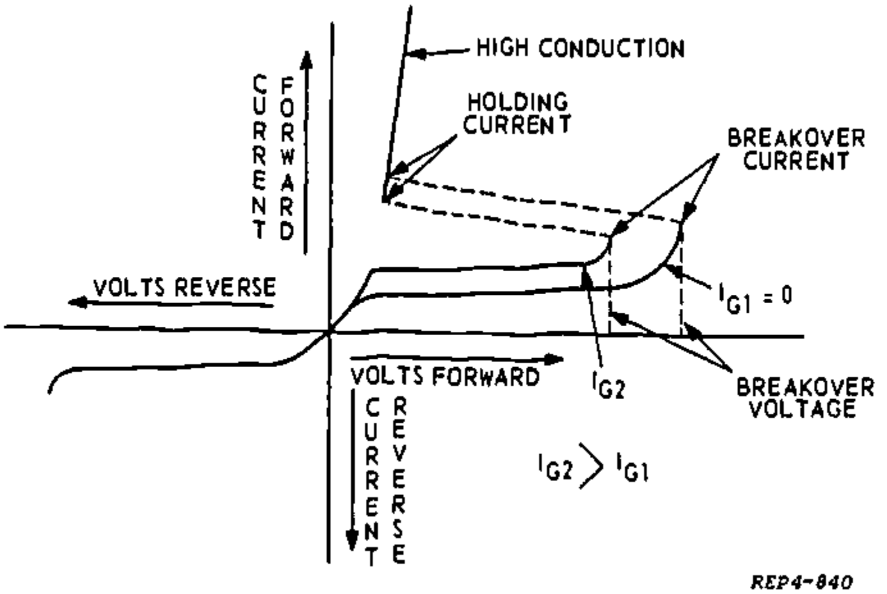

Figure 4-24. E-I Curves for Different Values of Gate Current

drawn out of S_1 and into S_2. Thus, the positive gate potential is aiding the anode potential. Some of these electrons will combine with holes in S_2 and gate current (I_G) will flow. Others will feel the positive anode potential and move toward the anode. If enough electrons are drawn to cancel all the holes in S_2, conduction will occur. The SCR has been gated ON. The more positive the gate potential is made, the lower the anode-to-cathode voltage required for conduction.

4-64. Figure 4-24 shows two curves, one with zero gate current($I_G = 0$) and one with gate current (I_{G2}) which is greater than zero($I_{G2} > I_{G1}$). Observe that the breakover voltage point with I_{G2} is at a lower voltage than with I_{G1}. The VOLTS FORWARD represents the anode-to-cathode voltage measured by V1 in Figure 4-23. If the gate current is increased sufficiently to saturate section S_2, current flows through the SCR even with very low anode-to-cathode voltages applied.

4-65. After the silicon controlled rectifier is triggered (turned ON) by the gate signal, the current flow through the device is independent of gate voltage or gate current. It remains in the high conduction state until the anode current is reduced to a level below that required to sustain conduction (holding current). The device can also be turned off by application of a reverse bias from anode to cathode. With reverse bias, J1 and J3 become reverse biased and only a small leakage current (due to minority carriers) will flow. If an excessive reverse bias is applied, structure breakdown will occur due to avalanche current, and the SCR will be destroyed.

4-66. Zener Diode

4-67. The zener diode is a PN junction diode that is specially designed to withstand operation in the reverse breakdown region without structure damage. Its schematic symbol is shown in Figure 4-25. The zener diode is also referred to as the AVALANCHE diode or BREAKDOWN diode, since it normally is operated in the breakdown voltage/avalanche current region of the PN junction characteristic.

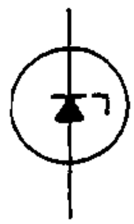

Figure 4-25. Zener Diode Schematic Symbol

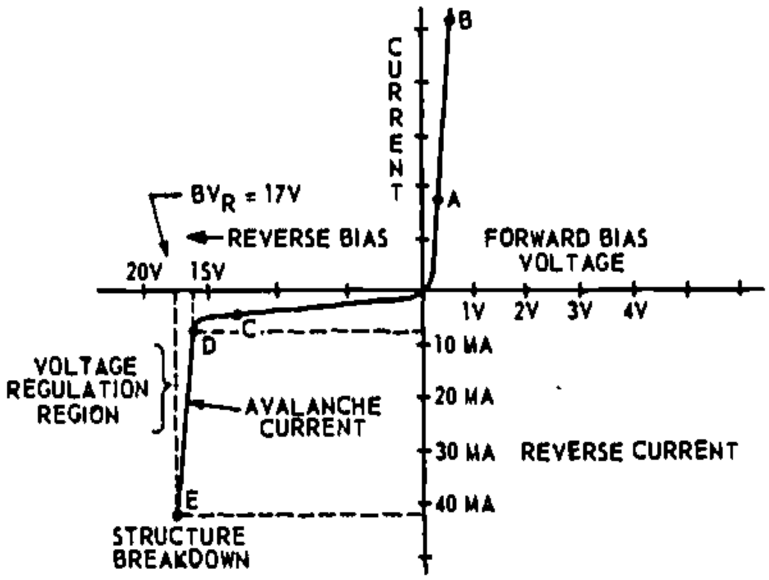

Figure 4-26. Zener Diode Characteristic Curve

4-68. The characteristic curve for the zener diode is basically the same as the PN junction diode. With forward bias applied, the zener diode operates the same as a regular junction diode (points A & B). Notice that, with reverse bias, the zener diode is able to operate with a large amount of avalanche current before structure breakdown occurs (point E, Figure 4-26), whereas the regular PN junction diode is destroyed as soon as the breakdown voltage (BV) is reached.

4-69. Between points D and E in Figure 4-26, the voltage changes very little (from 17 to 17.5 volts) for a wide variation in current (from 7 mA to 40 mA). This region is therefore called the VOLTAGE REGULATING REGION, since the voltage across the zener diode remains relatively constant, or is REGULATED, over a wide range of currents. However, if an excessive amount of current is allowed to flow, the diode will be destroyed due to structure breakdown. Therefore, a current limiting resistor, R_S, is used in series with the diode and the power source, as shown in Figure 4-27.

4-70. The primary purpose of the zener diode should be evident. The zener diode is used to REGULATE VOLTAGE. Later in the course you will study several circuits that make use of the constant voltage properties of this device to provide a constant voltage from a power source over a wide range of currents.

4-71. The physical appearance of a zener diode is the same as an ordinary junction diode. Recall that the voltage regulating effect takes place at some reverse bias voltage (BV). This voltage is determined

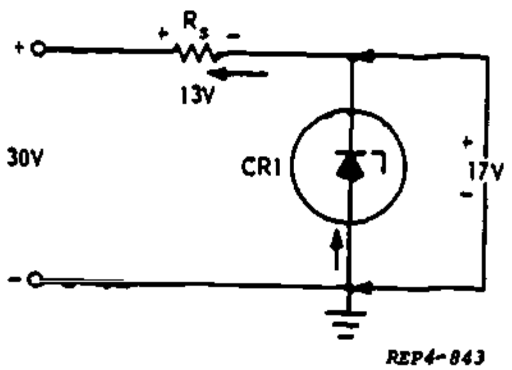

Figure 4-27. Zener Diode Current

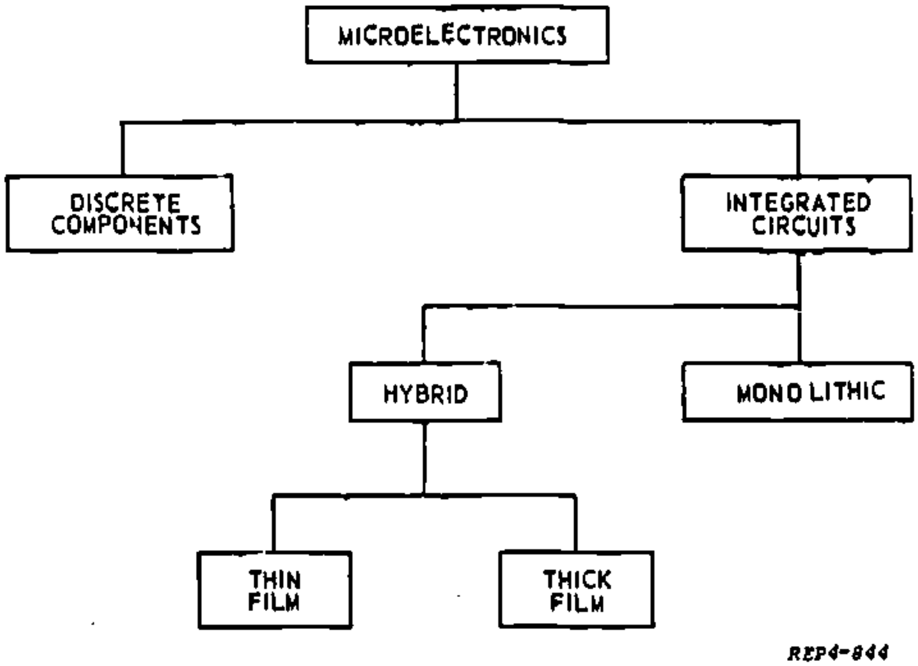

Figure 4-28. Microelectronics

(by doping) when the diode is manufactured, and can be from about 3 volts to twenty volts. More than one zener diode may be connected in series if necessary to provide the correct regulated voltage.

4-72. Microelectronics

4-73. Microelectronics is a broad term used to describe the use of extremely miniaturized components and techniques, usually in transistors or other solid state devices and circuits. Use Figure 4-28 in studying the following paragraphs.

4-74. Integrated Circuits

4-75. Up to now the various semiconductors, resistors, capacitors, etc. have been considered as separately packaged components, called DISCRETE COMPONENTS. In this section we will introduce some of the more complex devices that contain complete circuits or systems as a single packaged component. These devices are referred to as INTEGRATED CIRCUITS.

4-76. Integrated circuits (ICs) almost eliminate the use of individual electronic parts (resistors, capacitors, transistors, etc.) as the building blocks of electronic circuits. Instead, we have tiny CHIPS (tiny slices or wafers of a semiconductor crystal or insulator) whose functions are not that of a single part, but of dozens of transistors, resistors, capacitors, and other electronic elements, all interconnected to perform the task of a complex circuit. Often these comprise a number of complete conventional circuit stages, such as a multistage amplifier, in one extremely small component.

4-77. The family of integrated circuits have several advantages over conventionally wired circuits of discrete components. These advantages include (1) a drastic reduction in size and weight, (2) a large increase in reliability, (3) lower cost, and (4) possible improvement in circuit performance. However, they are composed of parts so closely associated with one another that repair becomes almost impossible. In case of trouble, the entire circuit is replaced as a single component.

4-78. Basically, there are two general classifications of integrated circuits: HYBRID and MONOLITHIC, as shown in Figure 4-28. In the monolithic integrated circuit, all ele-

440

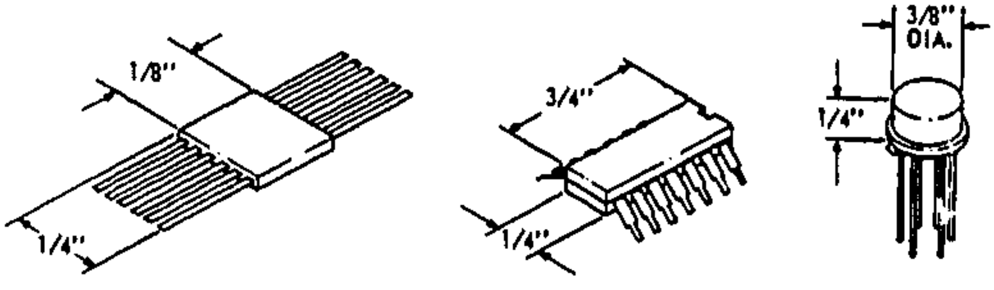

Figure 4-29. Package Styles for Integrated Circuits

ments (resistors, transistors, etc.) associated with the circuit are fabricated inseparably within a continuous piece of material (called the SUBSTRATE), usually silicon. This type is made very much like a single transistor. While one part of the crystal is being doped to form a transistor, other parts of the crystal are being acted upon to form the associated resistors and capacitors. Thus, all the elements of the complete circuit are created in the crystal with the same processes and in the same time required to make a single transistor. This produces a considerable cost savings over the same circuit made with discrete components by lowering assembly costs.

4-79. Hybrid integrated circuits are constructed somewhat differently from the monolithic devices. The PASSIVE components (resistors, capacitors) are deposited onto a substrate (foundation) made of glass, ceramic, or other insulating material. Then the ACTIVE components (diodes, transistors) are attached to the substrate and connected to the passive circuit components on the substrate using very fine (.001 inch) wire. The term "hybrid" refers to the fact that different processes are used to form the passive and active components of the device.

4-80. Hybrid circuits are of two general types: (1) thin film, and (2) thick film. "Thin" and "thick" film refer to the relative thickness of the deposited material used to form the resistors and other passive components. Thick film devices are capable of dissipating more power, but are somewhat more bulky.

4-81. Integrated circuits are being used in an ever increasing variety of applications. Small size, weight, and high reliability make them ideally suited for use in airborne equipment, missile systems, computers, spacecraft, and portable equipment. They are often easily recognized because of the unusual packages that contain the integrated circuit. Some of the most common package styles are shown in Figure 4-29. These tiny packages protect and help dissipate heat generated in the device. One of these packages may contain one or several stages, often having several hundred components.

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Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 29

PN JUNCTIONS AND DIODES

1 October 1975

AIR TRAINING COMMAND

7-8

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ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 29

PN JUNCTIONS AND DIODES

This Guidance Package is designed to guide you through this module of the Electronics Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

OVERVIEW

1. SCOPE: This module will instruct you in the basic structure of semiconductor material and how it is modified to produce P and N type materials. It will further explain the formation of PN junctions and discuss the characteristics of PN junction diodes.

2. OBJECTIVES: Upon completion of this module, you should be able to satisfy the following objectives:

a. Given an energy level diagram of semiconductor material, identify:

(1) Valence band.

(2) Forbidden band.

(3) Conduction band.

(4) Current carrier produced by heat.

(5) Current carrier produced by doping.

b. Given an energy level diagram of a PN junction diode and a list of statements, select the statement(s) that describe(s):

(1) Junction recombination.

(2) Depletion region characteristics.

(3) Forward bias conduction.

(4) Reverse bias conduction.

(5) Effect of temperature changes on conduction.

c. Given a PN junction diode characteristic curve and values of forward and reverse bias voltage, compute:

(1) Forward bias resistance.

(2) Reverse bias resistance.

Supersedes KEP-GP-29, 1 May 1974. Present supplies will be used.

d. Given a PN junction diode characteristic curve, identify:

(1) Points of structural breakdown.

(2) Operating region.

e. From a group of PN junction circuit diagrams, select the arrangement that identifies proper:

(1) Forward bias.

(2) Reverse bias.

f. Given a circuit diagram of PN junction diodes indicating direction of current paths, select the arrangement that identifies:

(1) Majority current.

(2) Minority current.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following.

READING MATERIALS:

Digest
Adjunct Guide with Student Text IV

AUDIOVISUALS:

Television Lesson 30-231, Solid State Principles

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK. CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the back of this Guidance Package.

Contact your instructor if you experience any difficulty.

Begin the program.

The major voltage requirement in electronic circuit operation is DC, yet the generation of AC voltages is much more efficient and economical. Because of this, many electronic devices have been developed to be used in converting the economical AC voltage to required DC voltage. One of these devices is the PN junction diode. Therefore, it is extremely important for you to gain an understanding of its characteristics and operation.

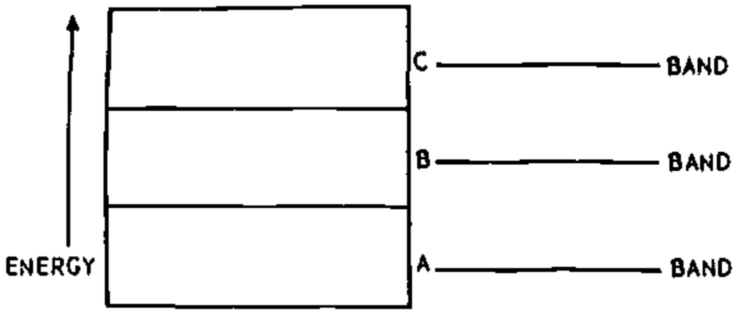
A. Turn to Student Text, Volume IV, and read paragraphs 1-1 through 1-17. Return to this page and answer the following questions.

1. Electrons in the outermost shell of an atom are referred to as ______________ electrons.

2. The outermost shell of an atom that contains electrons is called the ______________ shell.

3. Two common semiconductor materials are ______________ and ______________.

4. The electrons that enter into electrical conduction or chemical combination are the ______________ electrons.



Energy Level Diagram

5. Before an electron becomes a free electron available for conduction, it must be

elevated from the ____________________

to the ______________________ band.

6. Label the energy bands on the energy level diagram.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

B. Turn to Student Text, Volume IV, and read paragraphs 1-18 through 1-22. Return to this page and answer the following questions.

1. The sharing of valence electrons in a crystal lattice structure is referred to as

____________________ bonding.

2. When an electron breaks a covalent bond and is elevated to the conduction band, a/an

______________ ______________ pair is generated.

3. Free electrons in an intrinsic (pure) material will respond to an external EMF and enter into electrical conduction through the conduction band. (True) (False)

4. Electron hole pairs are generated by heat. (True) (False)

5. Hole flow does not occur in an intrinsic material. (True) (False)

6. Holes act as positive charges equal in charge but opposite in polarity to the electron. (True) (False)

7. Holes will respond to an external EMF and move from positive to negative through the valence band of a material. (True) (False)

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

C. Turn to Student Text, Volume IV, and read paragraphs 1-23 through 1-35. Return to this page and answer the following questions.

1. The process of adding impurities to a crystal structure is referred to as

____________________ .

2. When an impurity has been added to a crystal, the crystal is called ____________.

3. The addition of a donor impurity to silicon or germanium creates ____________ type semiconductor material.

4. The addition of a donor impurity to a semiconductor material creates many free electrons in the material which appear in

the ____________________ band.

5. The addition of an acceptor impurity to germanium or silicon creates

_________________ type semiconductor material.

6. The addition of an acceptor impurity to a semiconductor material creates many free holes in the material which appear in the

_________________ band.

7. Conduction in P type semiconductor material is mainly due to the movement of

_________________ carrier in the

_________________ band.

8. Conduction in N type semiconductor material is mainly due to the movement of

_________________ carrier in the

_________________ band.

9. Electron hole pair generation occurs in P and N type materials. (True) (False)

10. In P type material, there will be a limited number of (majority) (minority) carrier electrons in the _________________ band which will contribute to conduction.

11. In N type material, there will be a limited number of (majority) (minority) carrier holes in the _________________ band which will contribute to conduction.

12. In P type material, the majority current carrier is the _________________ and the minority current carrier is the

_________________.

13. In N type material, the majority current carrier is the _________________ and the minority current carrier is the

_________________.

14. In P type material, the density of the majority carrier holes is controlled by

_________________ and the density of the minority carrier electrons is controlled by

_________________.

15. In N type material, the density of the majority carrier electrons is controlled by

_________________ and the density of the minority carrier holes is controlled by

_________________.

16. Increasing the temperature of a semiconductor material will increase the number of majority and minority current carriers in both N and P type materials. (True) (False)

17. All semiconductor material exhibits a (negative) (positive) temperature coefficient of resistance.

18. If the temperature of a semiconductor is increased, its resistance will _________.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

D. Turn to Student Text, Volume IV, and read paragraphs 1-36 through 1-42. Return to this page and answer the following questions.

1. A PN junction diode is manufactured by chemically joining a section of P type semiconductor material to a section of N type semiconductor material and attaching metallic contacts to each end. (True) (False)

2. Immediately upon manufacture, there will be a PN junction formed at the point where the P material meets the N material. (True) (False)

3. Through a process called diffusion, electrons from the conduction band of the N material cross the PN junction into the P material, and holes from the valence band of the P material cross the PN junction into the N material. (True) (False)

4. Junction recombination results in the development of a ______________ region between the P and N materials in a PN junction diode.

5. The depletion region is an area between the P and N materials that contains no majority current carrier. (True) (False)

6. The depletion region is an ionized area between the P and N materials which has an electrostatic field that projects from the ______________ material toward the ______________ material.

7. Another name for the depletion region is the ______________.

8. The physical distance from one side of the depletion region to the other side is often referred to as barrier ______________.

9. Increasing the amount of doping in a PN junction diode will (increase) (decrease) the width of the depletion region.

10. The difference of potential across the depletion region is often referred to as the barrier ______________.

11. The difference of potential across the depletion region (increases) (decreases) as doping is increased.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

E. Turn to Student Text, Volume IV, and read paragraphs 1-43 through 1-58. Return to this page and answer the following questions.

1. Connecting a battery across a PN junction diode so that its electrostatic field opposes the junction electrostatic field is referred to as ______________ bias.

2. Connecting a battery across a PN junction diode so that its electrostatic field aids the junction electrostatic field is referred to as ______________ bias.

3. Proper forward bias is provided for a PN junction diode when the (negative) (positive) battery terminal is connected to the P type material, and the (positive) (negative) battery terminal is connected to the N type material.

4. Reverse bias is provided for a PN junction diode by connecting the ______________ battery terminal to the P material and the ______________ terminal to the N material.

5. When a PN junction diode is forward biased, electrons in the conduction band of the N material cross the junction into the P material and holes in the P material cross the junction into the N material. (True) (False)

6. When a PN junction is forward biased, conduction is due to the movement of (majority) (minority) current carriers.

7. Increasing the amount of forward bias (within limits) will (increase) (decrease) conduction in a PN junction diode.

8. When a PN junction is reverse biased, conduction will be due to the movement of (majority) (minority) current carriers.

9. What effect will an increase in ambient temperature have on reverse bias conduction in a PN junction diode? ______________

10. What effect does applying forward bias have on barrier height and width of a PN junction diode? ______________

11. What effect does applying reverse bias have on barrier height and width of a PN junction diode? ______________

44

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F. Turn to Student Text, Volume IV, and read paragraphs 1-59 through 1-75. Return to this page and answer the following questions.

1. Draw the symbol for a PN junction diode and label the leads.

2. If 1 volt forward bias is applied to a PN junction diode and the current flow is 5 mA, what is the resistance of the diode? _______

3. If 3 volts of forward bias causes 50 mA of current flow in a PN junction diode, the resistance of the diode is ________ ohms.

4. Compute the resistance of a PN junction diode that has 10 microamps of current flow with 100 volts reverse bias applied. _______

5. Draw a schematic symbol for a PN junction diode showing proper battery connections for forward and reverse bias.

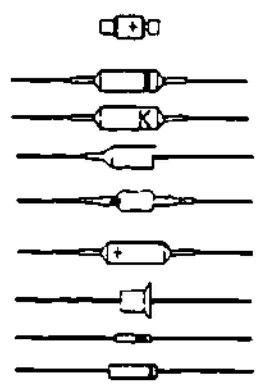
6. Draw a schematic symbol for a PN junction diode and indicate the direction of majority and minority current flow.

7. The forward bias resistance of a PN junction diode is (low) (high) and the reverse bias resistance is (low) (high).

8. If excessive forward bias is applied to a PN junction diode, it will be destroyed because of heat. This action is referred to as ____________ __________________.

9. Excessive reverse bias will cause structural breakdown of a PN junction diode. The voltage at which structural breakdown occurs is referred to as ______________ voltage and the current that flows after breakdown is referred to as ____________ current.

10. Identify the cathode leads on the following PN junction diodes with a checkmark.



Semiconductor Diode Physical Appearance

11. Name the three current ratings and the one voltage rating assigned to PN junction diodes by the manufacturer.

____

____

____

____

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

QUESTIONS:

1. On an energy level diagram, the gap between two permissible energy levels is called the ________________ band.

2. In a given atom the highest energy level which normally contains electrons is called the valence shell. (True) (False)

3. The first unoccupied energy level of an atom is called the ________________.

4. Free electrons are those which have been given enough energy to cross the forbidden band to the conduction band. (True) (False)

5. Conductors have a relatively wide forbidden band outside the valence band. For this reason, it takes considerable energy to free electrons from the influence of the nucleus. (True) (False)

6. An insulator has (many) (few) free electrons.

7. A material whose conductivity is greater than rubber but less than copper might be called a ________________.

8. The sharing of outer orbit electrons between two or more atoms is called:

   a. Pair bonding.

   b. Covalent bonding.

   c. Adhesive bonding.

   d. Junction bonding.

9. Figure 29-1 represents the energy level diagram of a semiconductor material. Identify the forbidden band, conduction band, and valence band.

10. Electron hole pair generation is caused by ____________________.

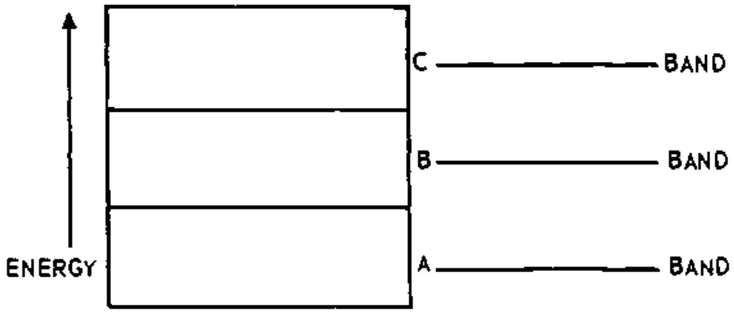


Figure 29-1. Energy Level Diagram

11. A HOLE is a mobile positive charge. (True) (False)

12. Electron flow occurs in the conduction band and hole flow in the ______________.

13. The process of adding impurities to semiconductor material such as germanium is called ______________________.

14. When germanium is doped with (donor) (acceptor) impurity, N type material is formed.

15. P type material has an excess of ________________ caused by doping with acceptor impurities.

16. In figure 29-2, identify the carriers produced by heat and those produced by doping.

a. ______________________________

b. ______________________________

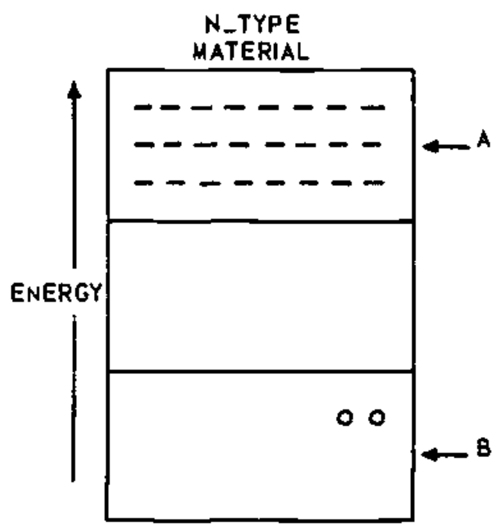


Figure 29-2. Energy Level Diagram

17. Figure 29-3 represents a PN junction diode as the junction barrier is being formed. Select the statement which describes junction recombination.

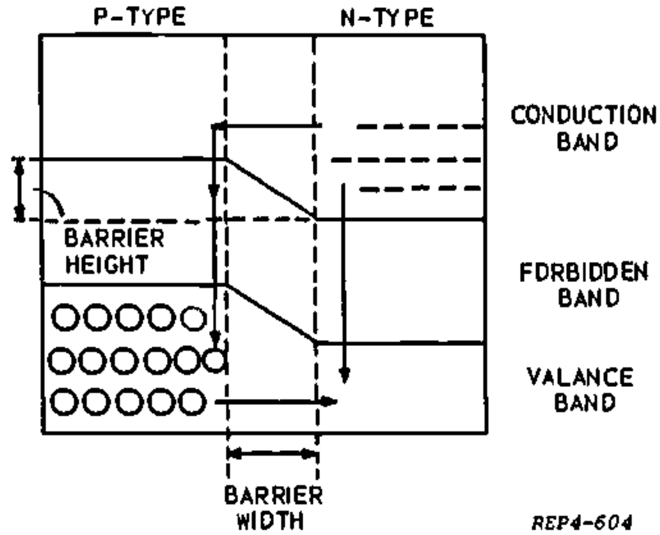


Figure 29-3. Energy Level Diagram of Junction Barrier Formation

a. The diffusion of holes and electrons across the junction, forming a layer of fixed charges on the two sides of the junction.

b. The recombining of minority carriers in either N or P type material which determine the barrier or junction width.

c. The depletion of electrons in the P type material of the junction and their recombining with majority carriers in the N type material.

d. Electron hole pair generation in the depletion area which causes the minority carriers to recombine, forming the barrier height.

18. Refer to figure 29-3. Barrier width is the ________________ distance across the junction and depends on the amount of doping. Barrier height can be measured in ________________.

19. The application of an external potential which opposes the junction field is called ______________________________.

20. Reverse bias (increases) (decreases) barrier width and height.

21. When a PN junction is reverse biased, there is no current flow in either direction. (True) (False)

22. Minority current (increases) (decreases) as temperature increases.

Refer to figure 29-4 for questions 23 through 27.

23. Calculate the forward bias resistance at point B. ______________________

24. The reverse bias resistance at point C would be:

a. 800 ohms.

b. 80 k/ohms.

c. 800 k/ohms.

d. 80 ohms.

25. What would occur if more than 4 volts of forward bias were applied?

____

26. Avalanche current is caused by excessive ______________________.

27. To prevent damage to the diode, it must be operated between points:

a. A-C.

b. A-B.

c. D-C.

d. D-E.

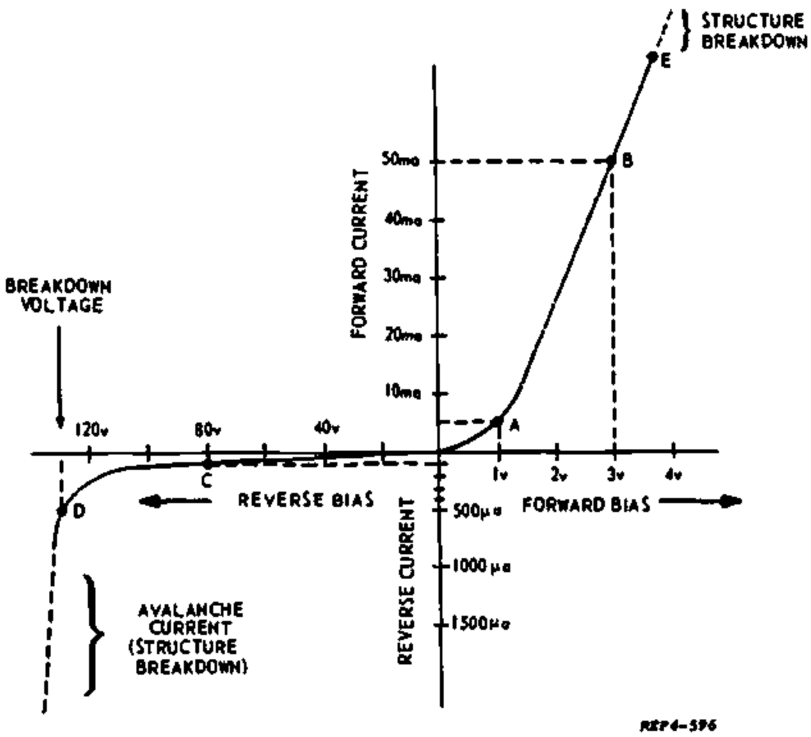


Figure 29-4. Voltage Current Characteristics of a Diode

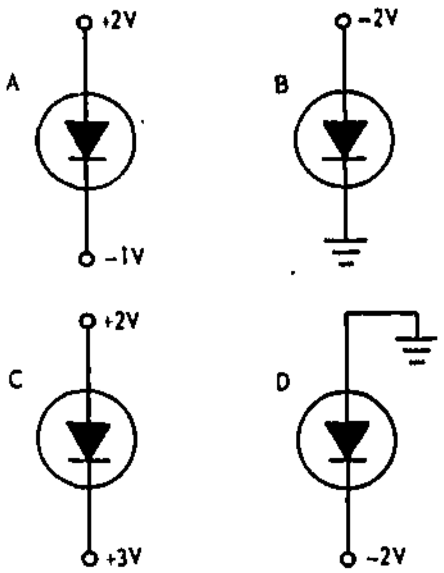


Figure 29-5. PN Junction Diodes

28. Select the circuit arrangement(s) in figure 29-5 which identify proper forward bias.

A B C D

29. Refer to figure 29-5. Select the arrangement(s) which identify proper reverse bias.

A B C D

30. Which arrow in figure 29-6 represents minority current flow?

A B

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

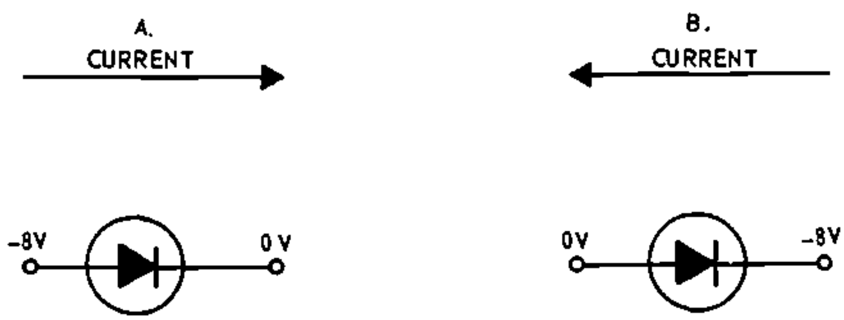


Figure 29-6. PN Junction Diodes

ANSWERS TO A:

1. valence
2. valence
3. silicon, germanium
4. valence
5. valence, conduction
6. a. valence
   b. forbidden
   c. conduction

If you missed ANY questions, review the material before you continue.

ANSWERS TO B:

1. covalent
2. electron hole
3. True
4. True
5. False
6. True
7. True

If you missed ANY questions, review the material before you continue.

ANSWERS TO C:

1. doping
2. extrinsic
3. N
4. conduction
5. P
6. valence
7. hole, valence
8. electron, conduction
9. True
10. minority, conduction
11. minority, valence
12. hole, electron
13. electron, hole
14. doping, temperature
15. doping, temperature
16. True
17. negative
18. decrease

If you missed ANY questions, review the material before you continue.

ANSWERS TO D:

1. True
2. True
3. True
4. depletion
5. True
6. N, P
7. junction barrier
8. width
9. decrease
10. height
11. increases

If you missed ANY questions, review the material before you continue.

ANSWERS TO E:

1. forward

2. reverse

3. positive, negative

4. negative, positive

5. True

6. majority

7. increases

8. minority

9. increase conduction

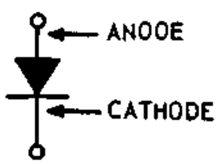
10. barrier height decreases, barrier width decreases

11. barrier height increases, barrier width increases

If you missed ANY questions, review the material before you continue.

ANSWERS TO F:

1.

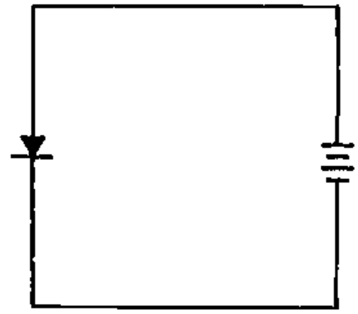


2. 200 ohms

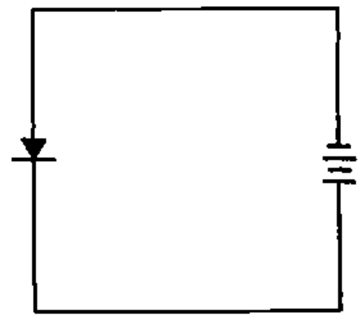
3. 60

4. 10 megohms

5.

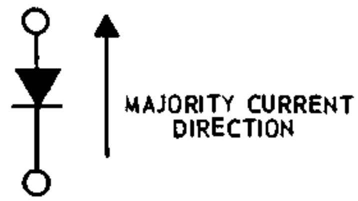


FORWARD BIAS



REVERSE BIAS

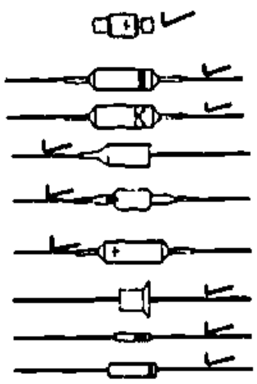
6.



7. low, high

8. thermal runaway

9. breakdown, avalanche

10. 

11. maximum average forward current

    peak recurrent forward current

    maximum surge current

    peak reverse voltage (PRV)

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK:

1. forbidden
2. True
3. conduction
4. True
5. False
6. few
7. semiconductor
8. b
9. A - valence band

   B - forbidden band

   C - conduction band
10. heat
11. True
12. valence
13. doping
14. donor
15. holes
16. a. doping

    b. heat
17. a
18. physical, volts
19. forward bias
20. increases
21. False
22. increases
23. 60 ohms
24. c
25. structure breakdown
26. reverse bias
27. d
28. A, D
29. B, C
30. A

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER INSTRUCTION.

455

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Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 30

TRANSISTORS

1 August 1975

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KEP-GP-30
1 August 1975

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 30

TRANSISTORS

This Guidance Package is designed to guide you through this module of the Electrónic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

OVERVIEW

1. SCOPE: This module will instruct you on the basic construction and biasing for NPN and PNP transistors, and on conduction in a three element two junction device. It will further explain how a control advantage is attained and discuss the characteristics of transistors.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given an energy level diagram of a properly biased NPN or PNP transistor and a list of statements, select the statement(s) that describe(s)

(1) junction operation.

(2) conduction.

(3) effect of temperature changes on conduction.

b. Given the schematic diagram for a properly biased NPN or PNP transistor, determine the effect bias changes have on I_E, I_B, I_C, and I_{CBO}.

c. Given a group of NPN or PNP circuit diagrams, select the arrangement that identifies the proper biasing method.

d. Given schematic diagrams for grounded emitter NPN or PNP transistor in static configurations indicating direct current paths, select the arrangement that identifies the proper direct current path.

e. Given a list of statements, select the statement that describes the forward current transfer ratio (Beta) for the grounded emitter configuration.

f. Given schematic diagrams for grounded base NPN or PNP transistor configurations indicating direct current paths, select the arrangement that identifies the proper current paths.

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g. Given a list of statements, select the statement that describes the forward current transfer ratio (Alpha) for the grounded base configuration.

h. Given circuit diagrams for grounded collector NPN or PNP transistor in static configurations indicating direct current paths, select the arrangement that identifies the proper direct current paths.

i. Given a list of statements, select the statement that describes the forward current transfer ratio (Gamma) for the grounded collector configuration.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following.

READING MATERIALS:

Digest
Adjunct Guide with Student Text IV

AUDIOVISUALS:

Television Lesson 30-353, Transistor Triodes (Construction)
Television Lesson 30-354, Transistor Triodes (Operation)
Narrated Illustration Lesson 0502A & B, Basic Transistor Amplifier (Configuration)

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK. IF NOT, SELECT ONE OF THE RESOURCES AND BEGIN STUDY.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced material as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the back of this text.

If you experience any difficulty, contact your instructor.

Begin the program.

In your experiences in life you have often come in contact with devices which are used to develop a control advantage. The transmission of your automobile gives the engine a control advantage over the rear end. A block and tackle allows a small amount of power to lift a heavy object. In electronics the transistor has a similar function; that is, it is an electronic device which is used to develop an electrical control advantage. The transistor is designed so that it can control a large amount of power from a small power source. In the world of electronics today, the transistor is used to develop an electrical control advantage. The transistor is used in a wide variety of applications ranging from the pocket transistor radio to complex circuitry capable of landing a man on the moon.

A. Turn to Student Text, Volume IV, and read paragraphs 2-1 through 2-19. Return to this page and answer the following questions.

1. Name the three elements of a junction transistor.

____

____

____

2. The two junctions of a transistor are the ________ ________ junction and the ________ ________ junction.

3. Draw a pictorial diagram of an NPN and a PNP transistor showing proper forward and reverse bias for normal operation.

4. The majority current carrier tn PNP transistors is the ____________, and the NPN transistors is the ____________.

5. Draw a pictorial diagram for properly biased NPN and PNP transistors showing direct current paths. Label the transistor currents.

6. Base current is made minimum in a transistor by constructing the base region very (thick) (thin) and (lightly) (heavily) doping it.

7. When a hole is placed under the influence of an electrostatic field it will move (with) (against) the field.

8. In an NPN transistor, majority carrier electrons that move from the emitter into the base region become minority carriers and come under the influence of the intense reverse biased collector base junction electrostatic field and move into the collector region where they again become majority carriers. (True) (False)

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

B. Turn to Student Text, Volume IV, and read paragraphs 2-21 through 2-34. Return to this page and answer the following questions.

1. Emitter current (I_E) is equal to _____% of total transistor current.

2. Complete the following formulas stating the relationships between I_C, I_E, and I_B.

I_E = ______________________________

I_C = ______________________________

I_B = ______________________________

3. In a transistor, the voltage that controls the magnitude of I_E, I_C, and I_B is the __________ __________ voltage.

4. Increasing the forward bias voltage applied to the emitter base junction of a transistor will increase I_E, I_B, and I_C. (True) (False)

5. Decreasing the reverse btas voltage applied to the collector base junction will decrease I_E, I_B, and I_C. (True) (False)

6. Forward bias applied to the emitter base junction of a transistor will (increase) (decrease) the barrier height and (increase) (decrease) the barrier width.

7. The relationship between the forward bias voltage (V_{EB}) and base current is nonlinear. What two transistor values exhibit a linear relationship?

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

C. Turn to Student Text, Volume IV, and read paragraphs 2-36 through 2-55. Return to this page and answer the following questions.

1. Leakage current (I_{CBO}) is the current between the collector and base of a transistor measured with the emitter lead open. (True) (False)

2. Increasing the reverse bias collector base voltage will increase I_{CBO}. (True) (False)

3. The magnitude of leakage current is dependent on junction temperature. (True) (False)

4. Leakage current (I_{CBO}) consists of the movement of minority current carriers across the collector base junction. (True) (False)

5. I_{CBO} aids base current and opposes collector current. (True) (False)

6. Draw the schematic symbol for an NPN and a PNP transistor. Label the leads and indicate the direction of external electron flow.

7. Draw a circuit diagram of a properly biased NPN and PNP transistor using two batteries. Show the current paths and indicate direction. Label I_C, I_E, and I_B.

8. Name the three basic configurations a transistor can be used in.

____

____

____

9. Draw a circuit diagram of a properly biased NPN and PNP transistor using a single power source. Show current paths and indicate direction. Label I_E, I_B, and I_C.

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

____

D. Turn to Student Text, Volume IV, and read paragraphs 2-56 through 2-87. Return to this page and answer the following questions.

1. Draw a schematic diagram for a common (grounded) emitter (NPN) configuration. Draw in and label transistor currents.

2. The control advantage of the CE configuration is the control that base current (I_B) exhibits over ______________ current.

3. The formula for the control advantage (theoretical current gain) for the CE configuration is:

Beta (β) = ________________

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

____

E. Turn to Student Text, Volume IV, and read paragraphs 2-68 through 2-76. Return to this page and answer the following questions.

1. Draw a schematic diagram for a common (grounded) base (PNP) configuration. Draw in and label transistor currents.

2. The control advantage of the CB configuration is the control that emitter current

(I_E) exhibits over ____________ current.

3. The formula for the control advantage (theoretical current gain) for the CB configuration is:

Alpha (α) = ________________

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

F. Turn to Student Text, Volume IV and read paragraphs 2-78 through 2-85. Return to this page and answer the following questions.

1. Draw a schematic diagram for a common (grounded) collector (NPN) configuration. Draw in and label transistor currents.

2. The control advantage of the CC configuration is the control that base current

(I_B) exhibits over ____________ current.

3. The formula for the control advantage (theoretical current gain) for the CC configuration is:

Gamma (γ) = ______________

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

QUESTIONS:

1. Transistors have ______________ PN junctions.

2. The _____________ junction is normally forward biased while the collector base junction is _____________.

3. The resistance of the collector base junction is low. (True) (False)

4. The reverse biased collector base junction of a transistor represents forward bias to _____________ carriers in the base.

5. Figure 30-1 is a pictorial and energy level diagram of a properly biased NPN transistor. The 10V battery is connected so as to apply _____________ to the collector base junction.

For questions 6 through 9 refer to figure 30-1.

6. Select the correct statement.

____ a. Battery V_{CC} causes the collector base resistance to decrease.
____ b. Battery V_{EE} causes the emitter base resistance to decrease.
____ c. The two batteries are connected in series opposing.
____ d. Barrier height of the emitter base junction is greater than that of the collector base junction.

7. Base current is greater than emitter current. (True) (False)

8. A change in base current has no effect on collector current. (True) (False)

9. An increase in the temperature of the emitter base junction would cause an increase in

____ a. emitter current.
____ b. base current.
____ c. collector current.
____ d. all of the above.

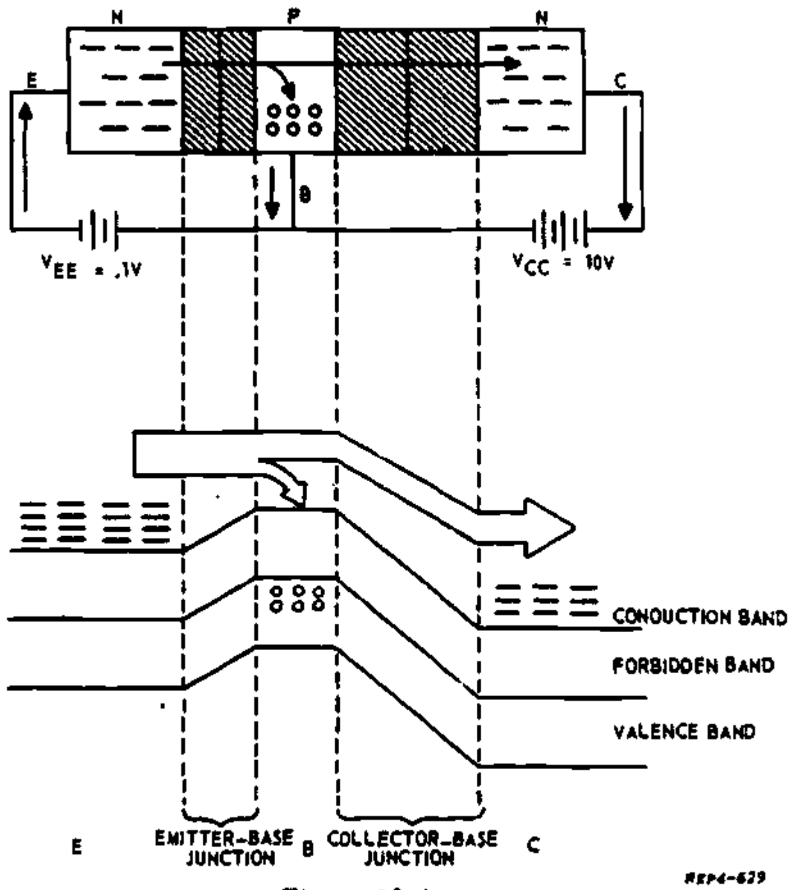


Figure 30-1

10. The term I_{CBO} means

____ a. collector current with base open.

____ b. collector-base current with emitter open.

11. I_{CBO} is caused by heat. (True) (False)

Use figure 30-2 for questions 12 and 13.

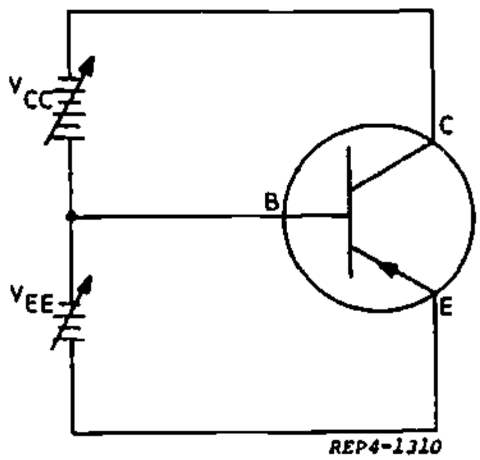


Figure 30-2

12. Assuming no temperature change, what effect would an increase in battery V_{EE} have on the following transistor currents?

I_E ____________

I_B ____________

I_C ____________

I_{CBO} ____________

13. A change in V_{CC} has more/less effect on collector current than a change in V_{EE}.

14. From the group of circuit diagrams in figure 30-3, select the arrangement/arrangements that identify the proper biasing method.

____

____

____

____

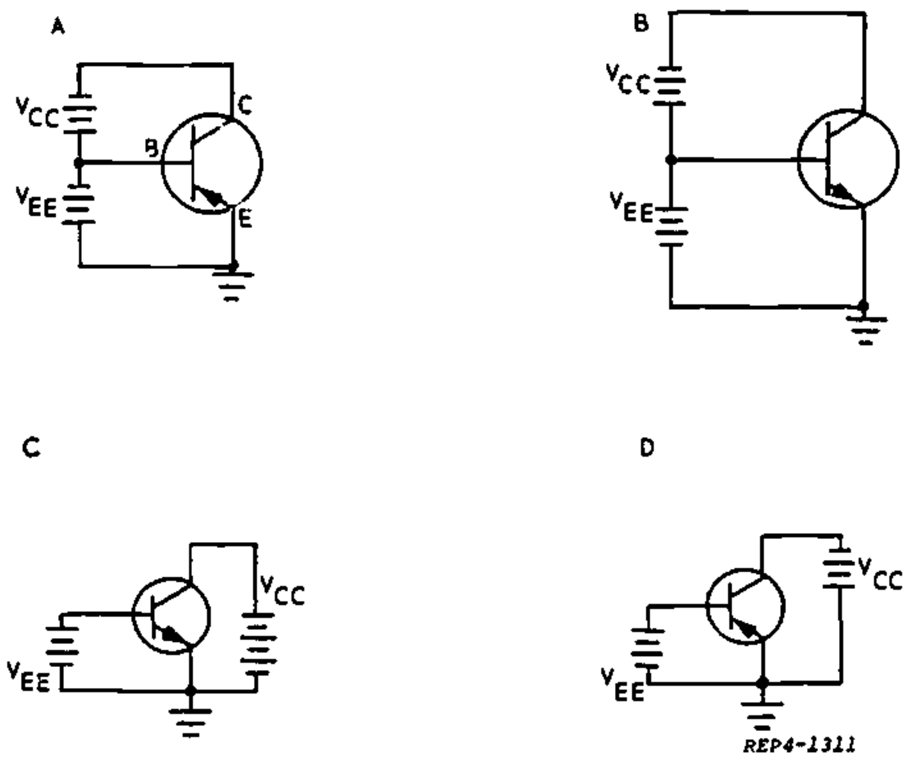


Figure 30-3

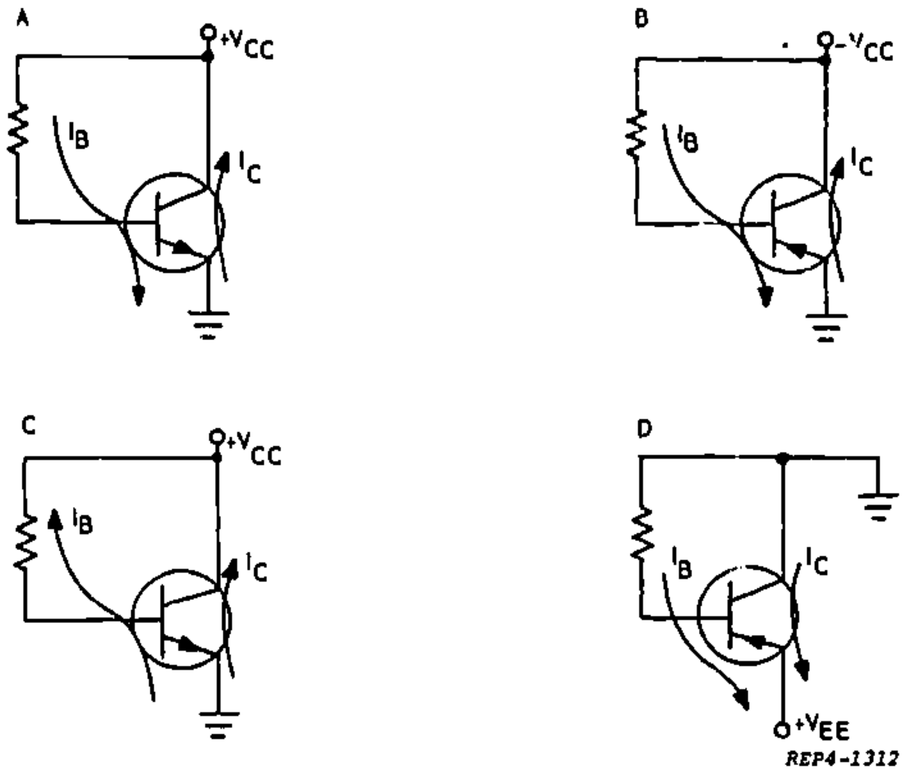


Figure 30-4

15. When a transistor is connected in the grounded emitter configuration, the emitter is common to both the input and output signal path. (True) (False)

16. From figure 30-4, select the circuit/ circuits which show the correct current paths.

____

____

____

____

17. Forward current transfer ratio (beta) for a common emitter configuration is the ratio of changes in

____a. collector current to base current.
____b. emitter current to base current.
____c. collector current to emitter current.

18. A common base configuration can be identified by the fact that the

____a. input is on the base and output from the collector.

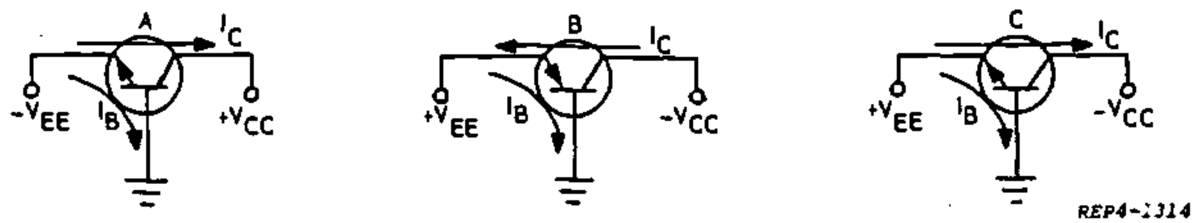


Figure 30-5

____b. input is on the base and output from the emitter.

____c. input is on the collector and output from the base.

____d. input is on the emitter and output from the collector.

19. From the group of diagrams in figure 30-5, select the one which identifies the correct current paths in a grounded base configuration.

____

20. Forward current transfer ratio (Alpha) for a grounded base configuration is the ratio of changes in

____a. collector current to emitter current.

____b. collector current to base current.

____c. emitter current to base current.

21. Alpha is always (greater) (less) than one.

22. In a grounded collector configuration,

____a. input is on the base and output from the collector.

____b. input is on the base and output from the emitter.

____c. input is on the emitter and output from the collector.

23. Forward current transfer ratio (Gamma) for the grounded collector configuration is the ratio of changes in

____a. emitter current to collector current.

____b. collector current to base current.

____c. emitter current to base current.

24. Gamma is (greater) (less) than Beta.

25. In the group of diagrams in figure 30-6, select the one which indicates the correct DC paths.

____

CONFIRM YOUR ANSWERS ON THE BACK PAGES.

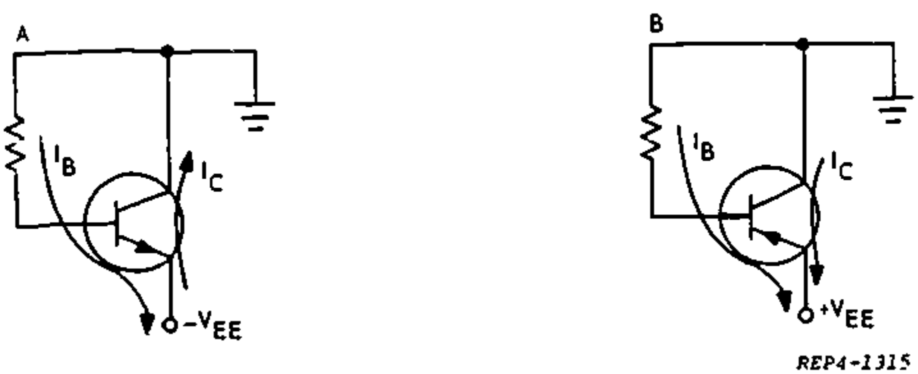


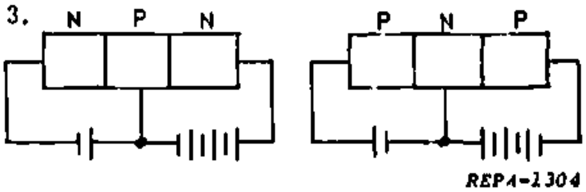
Figure 30-6

ANSWERS TO A:

1. emitter, base and collector

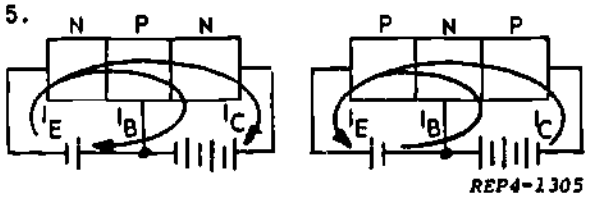
2. emitter base, collector base

3.



4. hole, electron

5.



6. thin, lightly

7. with

8. True

If you missed ANY questions, review the material before you continue.

ANSWERS TO B:

1. 100

2. $I_E = I_B + I_C$

$I_C = I_E - I_B$

$I_B = I_E - I_C$

3. forward bias or emitter base

4. True

5. False

6. decrease, decrease

7. Base current and collector current

If you missed ANY questions, review the material before you continue.

ANSWERS TO C:

1. True

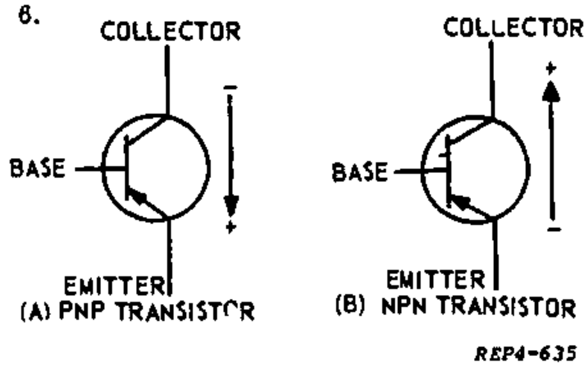
2. False

3. True

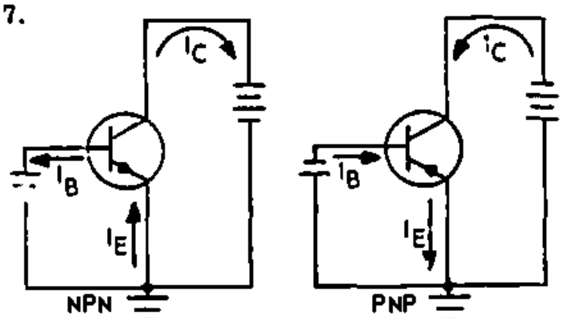
4. True

5. False

6.

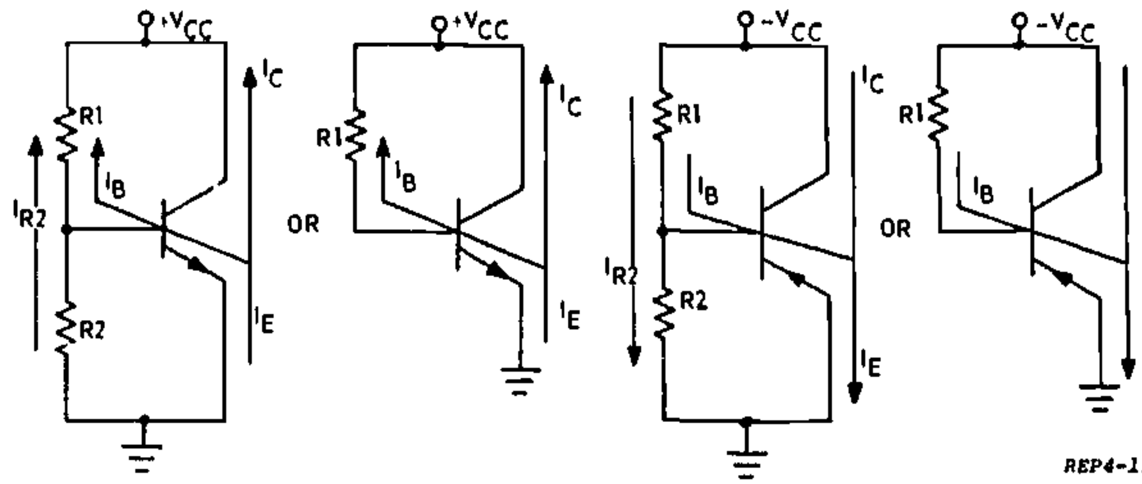


7.



8. Common (grounded) emitter, common (grounded) base, common (grounded) collector

9



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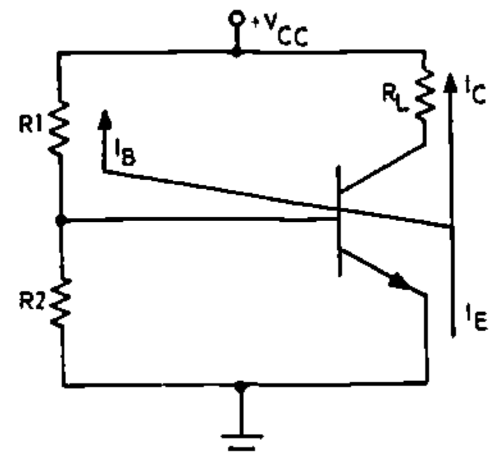
If you missed ANY questions, review the material before you continue.

ANSWERS TO D:

1.



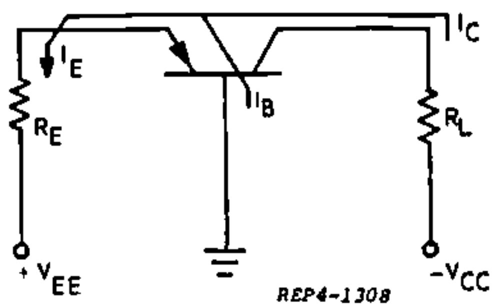
2. collector

3. $\beta = \frac{\Delta I_C}{\Delta I_B}$ with V_{CE} constant.

If you missed ANY questions, review the material before you continue.

ANSWERS TO E:

1.



REP4-1308

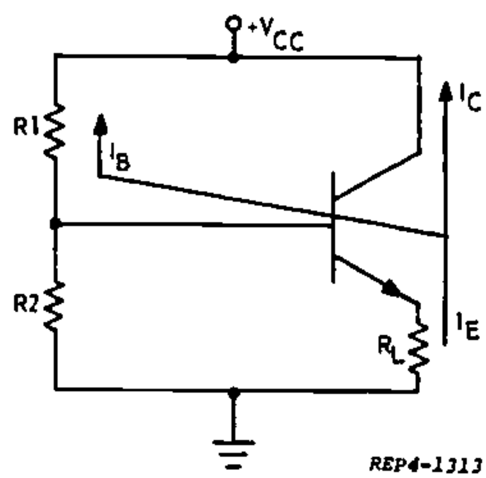
2. collector

3. $\alpha = \frac{\Delta I_C}{\Delta I_E}$ with V_{CB} constant.

If you missed ANY questions, review the material before you continue.

ANSWERS TO F:

1.



REP4-1313

2. Emitter

3. $\gamma = \frac{\Delta I_E}{\Delta I_B}$ with V_{CE} constant

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK:

1. 2
2. emitter base, reverse biased
3. False
4. minority
5. reverse bias
6. b
7. False
8. False
9. d
10. b
11. True
12. I_E increase

    I_B increase

    I_C increase

    I_{CBO} none
13. less
14. a, c
15. true
16. c, d
17. a
18. d
19. a
20. a
21. less
22. b
23. c
24. greater
25. b

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER INSTRUCTIONS.

ATC ST 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-31

Technical Training

Electronic Principles (Modular Self-Paced)

Module 31

AMPLIFIER PRINCIPLES

November 1975

AIR TRAINING COMMAND

7-8

Designed For ATC Course Use

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Radar Principles Branch
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GUIDANCE PACKAGE 3AQR30020
KEP-GP-31
November 1975

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 31

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

OVERVIEW

1. SCOPE: This module will instruct you in the principles of voltage, current, and power amplification as it applies to each transistor configuration. It will further discuss class of operation, distortion, coupling, and temperature stabilization characteristics of the basic transistor amplifier.

2. OBJECTIVES: Upon completion of this module, you should be able to satisfy the following objectives:

a. Given the schematic diagram for NPN or PNP common emitter amplifier configuration and a list of statements, select the statement(s) which describe(s) the effect of input signal current and input signal voltage changes on current in each element and collector voltage; of load resistor changes on actual voltage, current, and power gain.

b. Given the schematic diagram for NPN or PNP common base amplifier configuration and a list of statements, select the statement(s) which describe(s) the effect of input signal current and input signal voltage changes on current in each element and collector voltage; of load resistor changes on actual voltage, current, and power gain.

c. Given the schematic diagram for NPN or PNP common collector amplifier configuration and a list of statements, select the statement(s) which describe(s) the effect of input signal current and input signal voltage changes on current in each element and emitter voltage; of load resistor changes on actual voltage, current, and power gaun.

d. Given a transistor amplifier schematic diagram and a list of statements, select the statement that describes the cause of amplitude distortion; of frequency distortion; of phase distortion.

e. Given temperature stabilized transistor amplifier schematic diagrams and a list of statements, select the statement(s) that describe(s) how collector current variations are minimized.

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480

f. Given a list of statements, select the statement that describes the capabilities of direct, RC, impedance, and transformer coupling as related to frequency and gain.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text IV

AUDIOVISUALS:

Television Lesson 30-323A, Amplifier Principles

Television Lesson 30-325, Distortion

Television Lesson 30-358, Transistorized Audio Amplifiers

Television Lesson 30-413, Construction of Load Lines

Television Lesson 30-435, Transistor Stabilization

LABORATORY EXERCISE:

Laboratory Exercise 31-1, Transistor Amplification

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Confirm your answers at the back of this guidance package.

Contact your instructor if you experience any difficulty.

Begin the program.

The basic amplifier is the heart of all electronic equipment. Without it the world of electronics, as it is known today, would be non-existent. There would be no radio, television, communications, or space travel possible without the basic amplifier. All electronic circuitry depends on the principles of amplification for their existence. The radio waves that a car antenna intercepts are extremely weak (in the order of millivolts) and must be amplified (made larger) to be heard. The signal from a tapehead of a tape recorder is too small to be heard and must be amplified. An electronics technician must have a basic knowledge of the principles of amplification. Without this knowledge, it will be impossible to comprehend the complex circuitry that will be encountered during the sets portion of this course, and later in a field environment.

A. Turn to Student Text, Volume IV, and read paragraphs 3-1 through 3-14. Return to this page and answer the following questions:

1. The resistance of a transistor is controlled by the voltage applied between the emitter-base junction. (True)(False)

2. In a common emitter amplifier, the input is applied between the ______________ and ______________ and the output is taken between the __________ and __________.

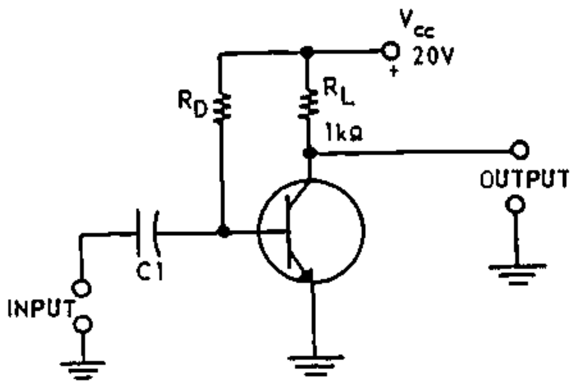
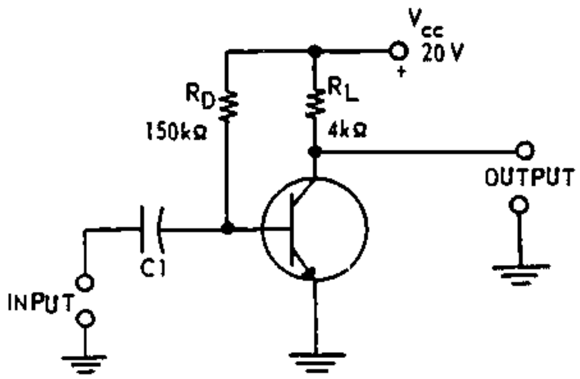


Figure 31-1. Common Emitter Amplifier (NPN)

3. Refer to figure 31-1. If I_C was 5 mA, what would be the voltage measured between the collector and emitter?

____



C

Figure 31-2. Common Emitter Amplifier (NPN)

Refer to figure 31-2 for questions 4 and 5.

4. If a voltage change of 200 mV at the input causes a change in collector current of 3 mA, what would be the change in collector to emitter voltage?

____

5. If the voltage applied to the input terminals is made more positive, what effect will this have on:

(a) I_B ______________________________

(b) I_C ______________________________

(c) I_E ______________________________

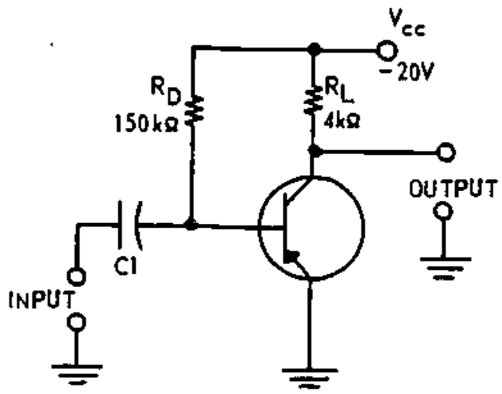
(d) V_{CE} ______________________________

(e) Transistor resistance

____

(f) E_{RL} ______________________________

Refer to figure 31-3 for questions 6 and 7.



D

Figure 31-3. Common Emitter Amplifier (PNP)

6. If the voltage applied to the input is made more negative, what effect will this have on:

(a) I_B ______________________________

(b) I_C ______________________________

(c) I_E ______________________________

(d) V_{CE} ______________________________

(e) Transistor resistance

____

(f) E_{RL} ______________________________

7. If a base current change of 20 μA causes a collector current change of 4 mA, what is the change in collector-to-emitter voltage?

____

8. What is the phase relationship of the input signal voltage to the output signal voltage in a common emitter amplifier?

____

CONFIRM YOUR ANSWERS.

B. Turn to student text, Volume IV, and read paragraphs 3-15 thr .ugh 3-63. Return to this page and answer the following questions.

Refer to figure 31-4 for questions 1 through 6.

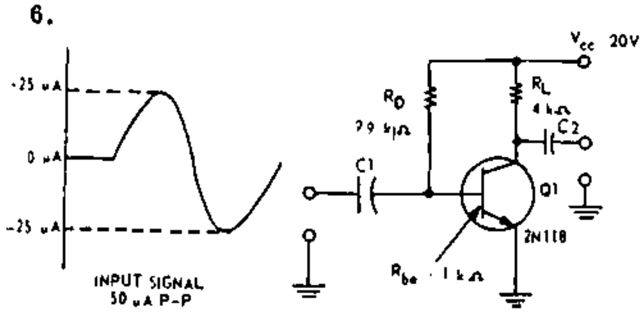


Figure 31-4. Common Emitter Amplifier

1. The base current (I_B) will be

______________________________ μA.

2. The forward bias voltage (V_{EB}) will be

______________________________ V.

3. If the input base current change of 50 μA causes a collector current change of 4 mA, the current gain (A_i) would be

______________________________.

4. If a base to emitter voltage change of .05 V causes a collector-to-emitter voltage change of 10V, the voltage gain (A_v) of the circuit would be

______________________________.

5. Using the values obtained in questions 3 and 4, compute power gain (A_p).

$A_p = A_i \times Av$

A_p = ________

6. The output waveshape of a common emitter amplifier is (180° out of) (in) phase with the input waveshape.

7. What effect would increasing the resistive value of the collector load resistor have on A_i or Av?

A_i ________

Av ________

CONFIRM YOUR ANSWERS

C. Turn to Student Text, Volume IV, and read paragraphs 3-64 through 3-93. Return to this page and answer the following questions.

Refer to figure 31-5 for questions 1 through 6.

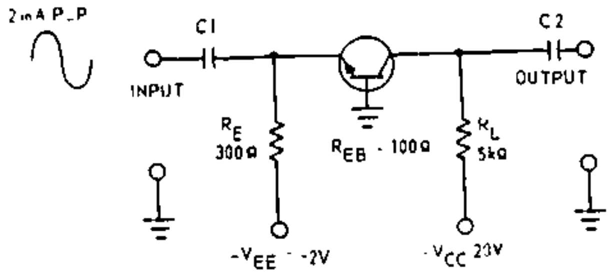


Figure 31-5. Common Base Amplifier

1. The emitter current (I_E) will be

______________________________ mA.

2. The forward bias voltage (V_{EB}) will be

______________________________ V.

3. If the input emitter current change of 2 mA causes a collector current change of 1.95 mA, the current gain (A_i) would be

______________________________.

4. If a change in emitter/base voltage of .2V causes a change in collector-to-base voltage of 12V, the voltage gain (A_V) is ________

5. Using the values obtained in questions 3 and 4, compute the power gain (A_p).

$A_p = A_i \times A_v$

A_p = ________

6. The output waveshape of a common base amplifier is (in) (out of) phase with the input waveshape.

7. What effect would increasing the resistive value of the collector load resistor have on A_I or A_V?

A_I ________

A_V ________

CONFIRM YOUR ANSWERS

D. Turn to Student Text, Volume IV, and read paragraphs 3-94 through 3-106. Return to this page and answer the following questions.

Refer to figure 31-6 for questions 1 through 3.

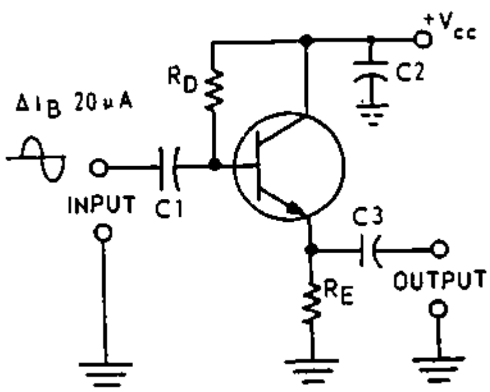


Figure 31-6. Common Emitter Amplifier

1. The output signal voltage will be (greater) (smaller) than the input signal voltage.

2. The voltage developed across R_E (aids) (opposes) the forward bias voltage.

3. (Degenerative) (Regenerative) feedback developed across R_E causes the voltage gain of the common collector amplifier to be (more) (less) than one.

4. The output signal waveshape of the common collector amplifier is (in) (out of) phase with the input signal waveshape.

CONFIRM YOUR ANSWERS.

E. Turn to Student Text Volume IV, and read paragraphs 3-107 through 3-114. Return to this page and answer the following questions.

1. Increasing the temperature surrounding a transistor will cause the resistance of the emitter/base junction (R_{EB}) to (decrease) (increase).

2. Increasing the temperature surrounding a transistor will cause a/an (increase) (decrease) in I_{CBQ}.

3. Why do transistor amplifiers require temperature stabilization?

____

____

____

4. A transistor amplifier has a (negative) (positive) temperature coefficient of resistance.

5. In an unstabilized transistor amplifier, an increase in temperature will cause a/an (increase) (decrease) in collector current.

6. What would happen to the density of minority current carrier in a transistor if an increase in temperature occurred?

____

____

7. What change in I_{CBO} would be realized if a ten degree (10°) increase in a transistor temperature occurred?

____

____

CONFIRM YOUR ANSWERS.

F. Turn to Student Text, Volume IV, and read paragraphs 3-115 through 3-121. Return to this page and answer the following questions.

1. A series emitter lead resistor is often referred to as a __________ resistor.

2. The use of a series emitter lead resistor for temperature stabilization results in (regenerative) (degenerative) feedback.

3. How can the effect of this feedback be prevented?

____

____

4. In an unstabilized amplifier, an increase in temperature will result in an increase in base current which will be amplified and produce a much larger increase in collector current. (True)(False)

5. The series emitter lead resistor prevents R_{EB} changes from occurring in conjunction with temperature charges. (True)(False)

6. Use of the series emitter lead resistor will prevent I_C changes from occurring when a change in temperature occurs. (True) (False)

CONFIRM YOUR ANSWERS

G. Turn to Student Text, Volume IV, and read paragraphs 3-122 through 3-143. Return to this page and answer the following questions.

1. In a voltage divider stabilized transistor amplifier, an increase in ambient temperature would have what effect on the following: (increase)(decrease)(remain the same)

a. R_{EB} __________

b. I_B __________

c. V_{EB} __________

d. I_C __________

2. What is the disadvantage of using the self-bias arrangement for bias stabilization?

3. What can be done to the self-bias arrangement to eliminate the disadvantage referred to in question #2?

4. What is the temperature coefficient of resistance of a thermistor used for temperature stabilizing a transistor amplifier?

5. Why doesn't a thermistor provide perfect temperature stabilization?

6. A forward bias PN junction diode provides bias stabilization for changes in R_{EB} caused by temperature changes.(True)(False)

7. The reverse biased diode stabilizing circuit compensates for changes in (R_{EB}) (I_{CBO}) caused by temperature changes.

8. Which temperature stabilizing circuit is the most effective for temperature changes above as well as below 50° C?

CONFIRM YOUR ANSWERS.

H. Turn to Student Text, Volume IV, and read paragraphs 3-144 through 3-149. Return to this page and answer the following questions.

1. There are three major types of distortion. Briefly describe each type in your own words:

a. Amplitude distortion:

b. Frequency distortion:

c. Phase distortion:

2. What is the primary cause of

a. Amplitude distortion?

b. Frequency distortion?

c. Phase distortion?

CONFIRM YOUR ANSWERS.

I. Turn to Student Text, Volume IV, and read paragraphs 3-150 through 3-171. Return to this page and answer the following questions.

1. Which type of coupling has the poorest temperature stability?

2. The frequency response for direct coupling is flat for the audio frequency range. What causes it to drop off above 20 kHz?

3. In an RC coupled amplifier, the amplitude of the output signal drops below a usable level for input frequencies below 15 Hz and above the audio range. What are the primary reasons for this loss of amplitude?

4. Why is an impedance coupled amplifier limited to use above the audio frequency range?

5. The frequency response curve for transformer coupling is similar to that for an RC coupled amplifier. Why would transformer coupling be preferred to RC coupling?

CONFIRM YOUR ANSWERS.

J. Turn to Student Text, Volume IV, and read paragraphs 3-197 through 3-231. Return to this page and answer the following questions.

1. Amplifiers can be classified in many different ways. Three common ways are by its:

a. ______________________

b. ______________________

c. ______________________

2. Briefly describe the classes of operation of a transistor amplifier:

a. Class A: ______________________

b. Class AB: ______________________

c. Class B: ______________________

d. Class C: ______________________

3. The two primary items that determine the class of operation of an amplifier are:

a. ______________________

b. ______________________

4. What would be the class of operation of an OVER-DRIVEN amplifier?

5. Define FIDELITY as it relates to transistor amplifier.

6. Define EFFICIENCY as it relates to a transistor amplifier.

7. The class of operation of an amplifier that provides the best fidelity is class ____________.

8. The class of operation of an amplifier that provides the best efficiency is class ____________.

CONFIRM YOUR ANSWERS

K. Turn to Student Text, Volume IV, and read paragraphs 3-232 through 3-239. Return to this page and answer the following questions.

1. Any waveshape that is NOT sinusoidal contains harmonics. (True)(False)

2. The output of an amplifier operated class B would contain (odd)(even) harmonics.

3. The output of an overdriven amplifier contains (odd)(even) harmonics.

4. What harmonics are present in the output of a class C amplifier?

CONFIRM YOUR ANSWERS.

L. Turn to Laboratory Exercise 31-I. The objectives of this laboratory exercise are to determine the voltage and current gain of a transistor amplifier. The effect of load resistance changes and degenerative feedback on gain will also be investigated.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

LABORATORY EXERCISE 31-I

OBJECTIVES:

1. Using a transistor amplifier trainer, multimeter, oscilloscope, signal generator, ammeter panel, and formulas, determine actual:

a. current gain (A_i).

b. voltage gain (A_v).

c. power gain (A_p)

2. Using a transistor amplifier trainer, multimeter, oscilloscope, signal generator, and ammeter panel, determine the effect of:

a. load resistance changes on gain.

b. effect of degenerative feedback on voltage gain.

EQUIPMENT:

Transistor voltage amplifier trainer.

Oscilloscope

Multimeter

Ammeter Panel

Signal Generator

REFERENCES: Student Text, Volume IV, paragraphs 3-1 through 3-106.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

1. Trainer Analysis: The transistor voltage amplifier trainer is extremely versatile and can be used to determine many characteristics of a transistor amplifier. The first thing to do is become thoroughly familiar with the trainer shown in figure 31-7. Locate the following trainer functions and components:

a. Selection of two fixed collector load resistors. (S3)

b. Selection of ground or a series emitter lead resistor. (S4)

c. Selection of a by-pass capacitor to be used in conjunction with the series emitter lead resistor. (S6)

d. Selection of a fixed or variable biasing arrangement. (S1 and S2).

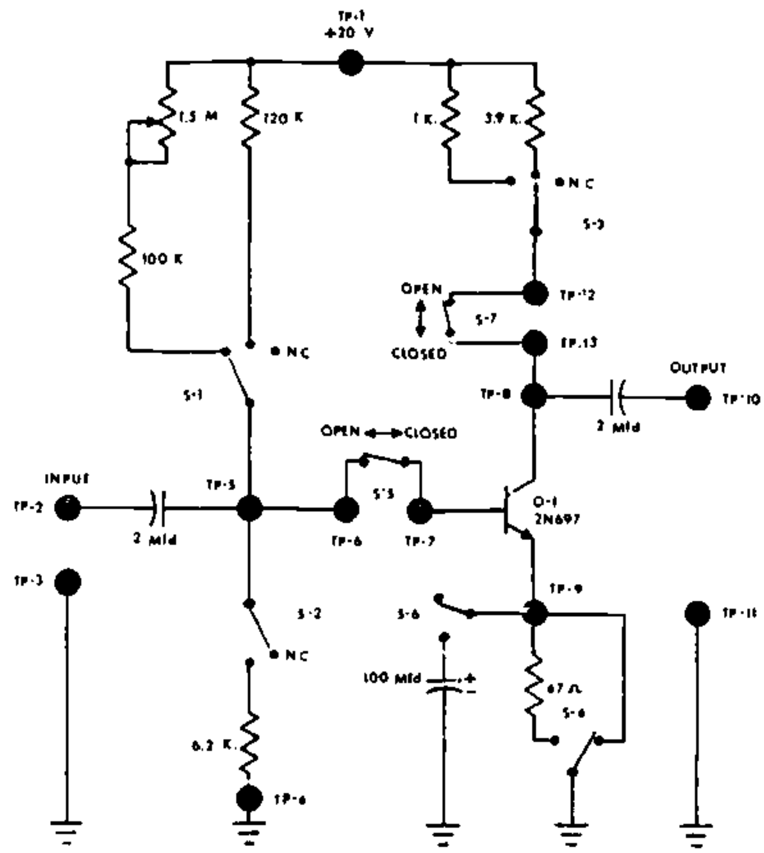


Figure 31-7. Transistor Voltage Amplifier

e. Input test points (TP2 and TP3) and output test points (TP10 and TP11).

f. Jacks (test points) for inserting ammeter for measurement of collector (TP12 and TP13) and base (TP6 and TP7) currents.

g. Test points for measuring or observing emitter voltage (TP9), bias voltage (TP5), collector voltage (TP8) and supply voltage (TP1).

2. Equipment Preparation.

a. The first exercise will be to determine the current gain of a transistor amplifier connected in the common emitter configuration. This means that the control advantage that base current exhibits over collector current will be determined. The formula for current gain for the CE configuration is:

$$A_I = \frac{\Delta I_C}{\Delta I_B}$$

The effect of load resistance changes on A_I will also be investigated.

b. Preset the switches on the transistor voltage amplifier trainer to select the circuit shown in figure 31-7.

(1) Select the 1.5 M ohm variable biasing resistor using switch S1.

(2) Rotate switch, S2, to the open position (NC).

(3) Select the 3.9 k ohm collector load resistor using switch S3.

(4) Select ground on the emitter lead using S4 (move right).

(5) Plug the trainer into a 110 VAC bench outlet.

3. Exercise #1, Current Gain

a. Rotate the 1.5 M ohm biasing resistor fully clockwise (CW). This provides maximum resistance, minimum bias for the transistor.

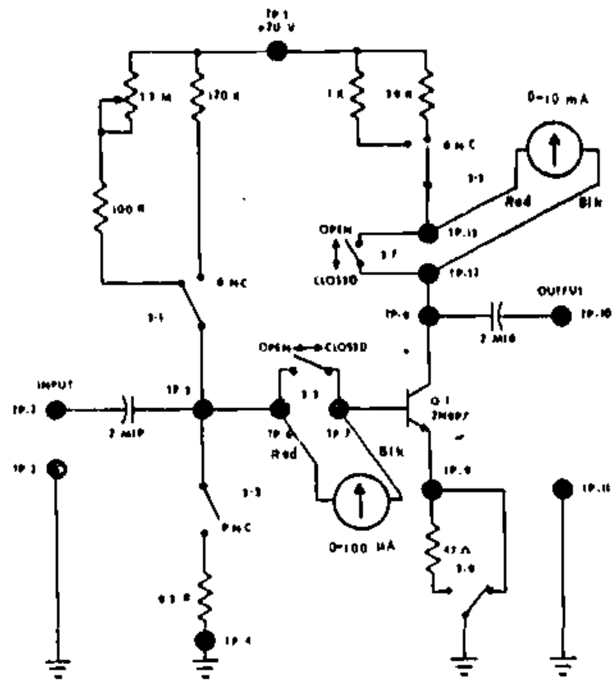


Figure 31-8

NOTE: Refer to figure 31-8 for meter connections.

b. Using the test lead provided, connect the 0-10 mA ammeter on the meter panel to TP 13 (black lead) and TP 12 (red lead) on the trainer. Move switch S7 to the OPEN position. The ammeter is now in series with the collector lead and reads collector current (I_C).

c. Connect the multimeter in series with the base lead to read base current. This is accomplished in the following manner.

(1) Rotate the FUNCTION switch on the multimeter to the 100µA SPECIAL position. In this position, the multimeter will read from 0-100 µA DC on the 0-10 DC scale of the meter.

(2) Connect the BLACK lead of the multimeter to TP7 and the RED lead to TP6.

(3) Move switch S5 on the trainer to the open position. The meter is now in series with the base lead and reads base current (I_B).

d. Rotate the 1.5 M ohm biasing resistor counterclockwise (CCW) until a reading of 2 mA collector current (I_C) is obtained.

Measure and record base current (I_B) as read on the multimeter.

I_B = ______________________ μA

e. Rotate the 1.5 M ohm biasing resistor CCW until I_C = 4 mA.

Measure and record I_B.

I_B = ______________________ μA

f. Determine the change in base current by subtracting the base current obtained in step 3d from the value obtained in step 3e.

ΔI_B = ______________________

g. Determine the change in collector current by subtracting the value obtained in step 3d from the collector current value in step 3e.

$\Delta I_C = 4\ mA - 2\ mA = 2\ mA$

h. Using the formula $A_i = \frac{\Delta I_C}{\Delta I_B}$, compute the current gain (A_i) of the amplifier.

A_i = ______________________

i. The A_i just determined is for an R_L of 3.9 k ohm and would be representative of the load line in figure 31-9.

(1) What should happen to A_i if the slope of the load line were increased?

Ai would (increase) (decrease) (remain the same).

(2) What would happen to the current gain if R_L was changed from 3.9 k ohm to 1 k ohm?

A_i would (increase) (decrease) (remain the same).

Confirm your answers to questions (1) and (2) before proceeding

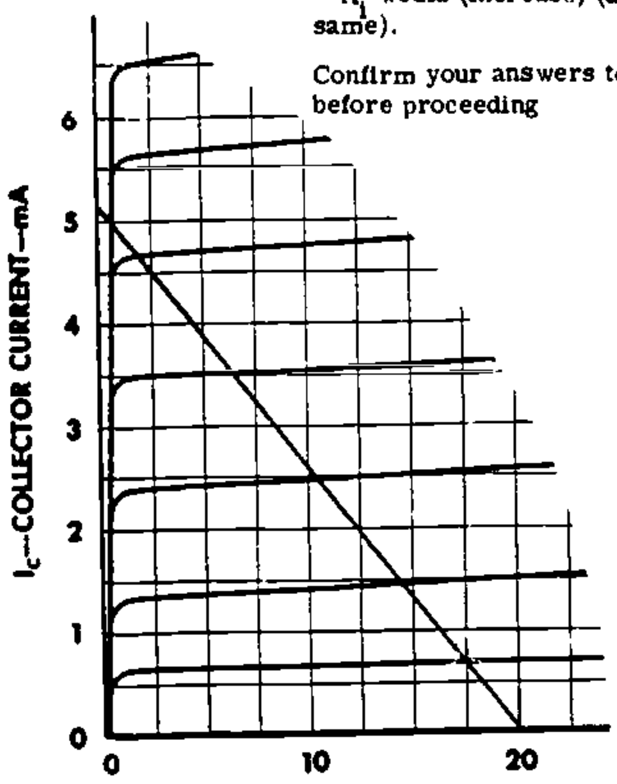


Figure 31-9. Load Line

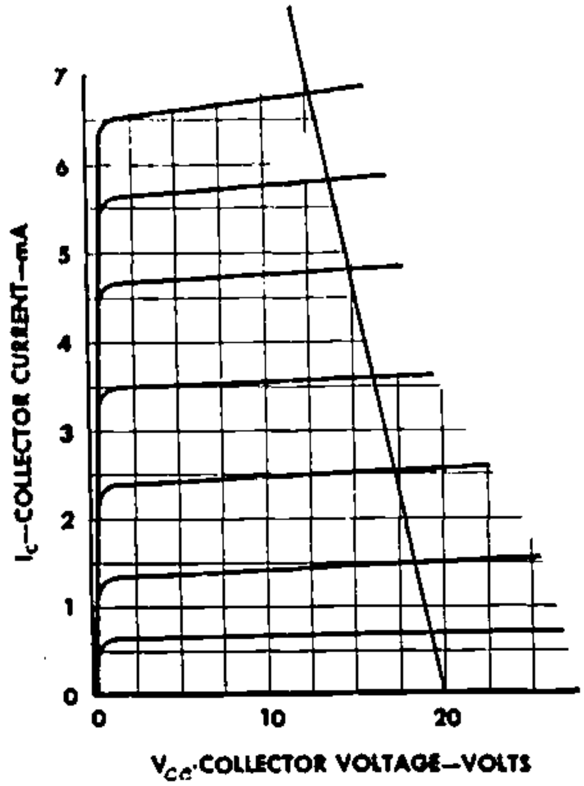


Figure 31-10. Load Line

j. Using S3, select the 1 k ohm load resistor.

k. With the 1.5 M ohm biasing resistor, adjust for the following collector current readings and record the base currents.

I_C = 2 mA, I_B = ______________ μA

I_C = 4 mA, I_B = ______________ μA

The change in I_B is: ΔI_B = ________

l. Compute the current gain for the 1 k ohm load resistor.

$$A_i = \frac{\Delta I_C}{\Delta I_B} = \_\_\_\_\_\_\_\_\_\_$$

The A_i just determined is for an R_L of 1 k ohm and would be representative of the load line in figure 31-10.

CAUTION: Do not attempt to achieve 20 mA collector current.

CONFIRM YOUR ANSWERS

4. Equipment Preparation (Exercise #2)

NOTE: Before beginning the second exercise, plug in the oscilloscope and signal generator and turn them on.

a. You will now determine the voltage gain (A_V) of a transistor amplifier connected in the common emitter configuration. This means that the ratio of input voltage change to output voltage change will be determined and expressed as

$$A_V = \frac{\Delta V_{CE}}{\Delta V_{EB}}.$$

The effect of load resistance changes on A_V will also be investigated.

Remove the multimeter and meter panel test leads from the trainer.

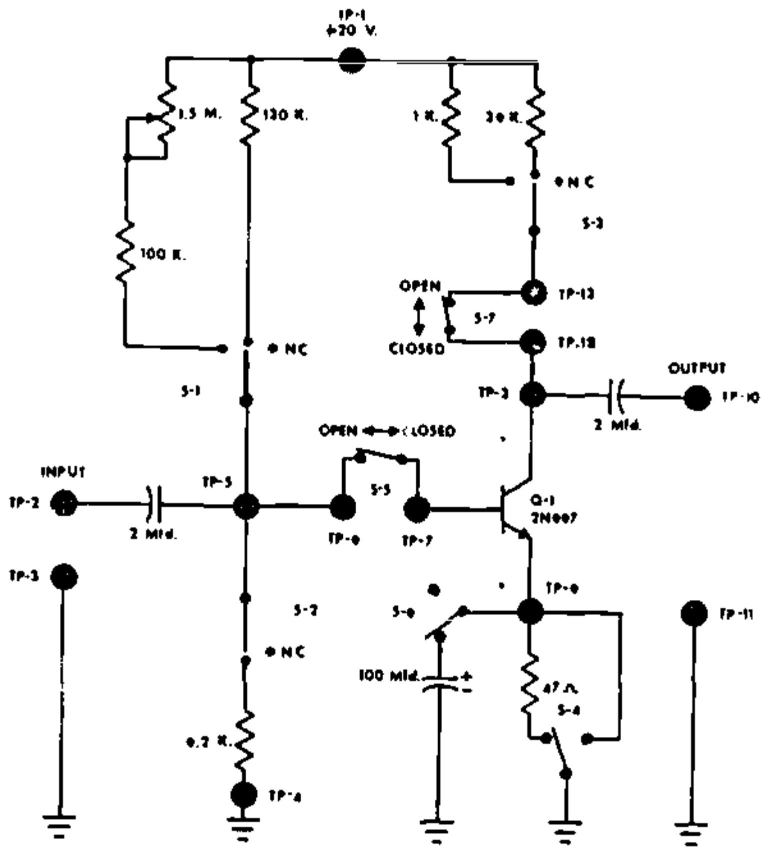


Figure 31-11.

b. Preset the switches on the trainer for the circuit configuration shown in figure 31-11.

(1) Close S-5 and S-7 in the base and collector circuits.

(2) Select the 120 k ohm biasing resistor using switch S1.

(3) Select the 6.2 k ohm biasing resistor using switch S2.

(4) Select the 3.9 k ohm collector load resistor using switch S3.

(5) Select the 47 ohm series emitter lead resistor using S4 (move left).

(6) Select the emitter by-pass capacitor with S6 (move right).

c. Signal Generator

CONTROL	POSITION
(1) MULTIPLIER	100
(2) FREQUENCY	100
(3) RANGE	.1V
(4) AMPLITUDE	Counter Clockwise

d. Connect the sine wave output of the signal generator to the input of the trainer between TP2 and GND. (TP3).

482

e. OSCILLOSCOPE CONTROLS	POSITION
(1) TRIG SELECT	EXT +
(2) LEVEL	AUTO
(3) TIME/CM	.1 mS (CAL)
(4) SEPARATE - CH1 & CH2	SEPARATE
(5) CHOP - ALT	ALT
(6) AC-ACF-DC	AC
(7) Vertical Position CH1 and CH2	Mid-position
(8) CH1 VOLTS/CM	50mV (CAL)
(9) AC-GND-DC CH1	AC
(10) CH2 VOLTS/CM	5V (CAL)
(11) AC-GND-DC CH2	AC
(12) PULL X10 MAG	Pushed in
(13) PULL TO INVERT CH2	Pushed in
(14) Vertical position CH1	Position trace at top center
(15) Vertical position CH2	Position trace at bottom center

5. Exercise #2 Voltage

a. Using the coaxial test lead with a ground (shield), connect the CH1 input of the oscilloscope between TP5 and GND (TP4) on the trainer.

b. Connect the EXT TRIG of the oscilloscope to TP8 on the trainer.

c. Adjust the sine wave output amplitude control of the signal generator until the CH1 trace on the oscilloscope indicates an input amplitude of 50 mV pk-to-pk.

d. Using a coaxial test lead with a ground (shield), connect the CH2 input of the oscilloscope between TP10 and GND (TP11) on the trainer.

NOTE: At this time, CH1 of the oscilloscope should be displaying the input to the trainer and CH2 should be displaying the amplified output of the trainer. If clear displays are not visible or if there is no display on the oscilloscope, call the instructor for assistance.

e. The voltage gain of the amplifier is the ratio of a change in input voltage to a change in output voltage. The peak-to-peak amplitude of the input to the trainer is 50 mV as displayed on the CH1 of the oscilloscope. The output amplitude displayed on the CH2 is

__________________ V Pk-Pk

f. Using the formula for voltage gain and the output voltage obtained in step 5e, compute the A_V of the amplifier:

$$A_v = \frac{\Delta V_{CE}}{\Delta V_{EB}} = \frac{\_\_\_\_}{50mV} = \_\_\_\_\_\_\_\_$$

6. Exercise #3 Power Gain

a. The voltage gain obtained in step 5f was obtained using a 3.9 k ohm load resistor. Recall that the current gain of the amplifier as calculated in step 3k was approximately 57 for a 3.9 k ohm load resistor. Using these two facts the power gain of the amplifier can be determined as follows:

Power Gain (A_P) = $A_I \times A_V$

A_P = 57 x ________ (A_V) = ________

(Use the value of A_V obtained in step 5f.)

b. By observing the input and output waveshapes on the oscilloscope, the phase relationship between them can be determined. The output is (in phase) (out of phase) with the input.

c. Observe the effect on gain when the emitter by-pass capacitor is removed from the circuit. This is accomplished by opening S6 (move left). Voltage gain (increased) (decreased). The change in gain was due to (regenerative)(degenerative) feedback.

d. Replace the bypass capacitor by closing S6 (move right).

e. Select the 1 k ohm collector load with S3, and readjust the signal generator for 50 mV Pk-Pk input to the trainer.

f. Read the output voltage from the oscilloscope and calculate Av for a 1 k ohm collector load.

$$(1)\quad A_v = \frac{\Delta V_{CE}}{\Delta V_{EB}} = \frac{\_\_\_\_}{50mV} = \_\_\_\_\_\_$$

(2) As the collector load resistor decreases in value, the voltage gain (increases) (decreases).

g. The power gain of the amplifier with a 1 k ohm load resistor is calculated as follows:

$A_p = A_I \times A_v$

(A_I as obtained in step 3 is 64.5.)

$A_p = 64.5 \times A_v$

A_p = ________________

NOTE: Do not be misled by the power gain values obtained with the 1 k ohm and 3.9 k ohm collector load resistor. The power gain drops off for values of load above and below this value. Impedance matching will be discussed later in the course.

h. Remove the emitter by-pass capacitor by switching S6 to the left and observe the effect on gain. Gain (increased)(decreased).

CONFIRM YOUR ANSWERS.

MODULE SELF-CHECK

QUESTIONS:

For questions 1 through 5, refer to figure 31-12.

1. In an NPN common emitter amplifier, as the input signal goes positive, base, emitter and collector current ____________ and transistor resistance ____________

2. In a PNP common emitter amplifier, as collector current increases, collector voltage goes positive/negative.

3. In any common emitter amplifier, the phase relationship of the output signal to the input signal is ____________

4. Gain is the ratio of a change in ____________ to a change in ________.

5. Using the circuit in figure 31-12 and characteristic curves for a 2N118 transistor, figure 31-13 compute A_V A_I, and A_P.

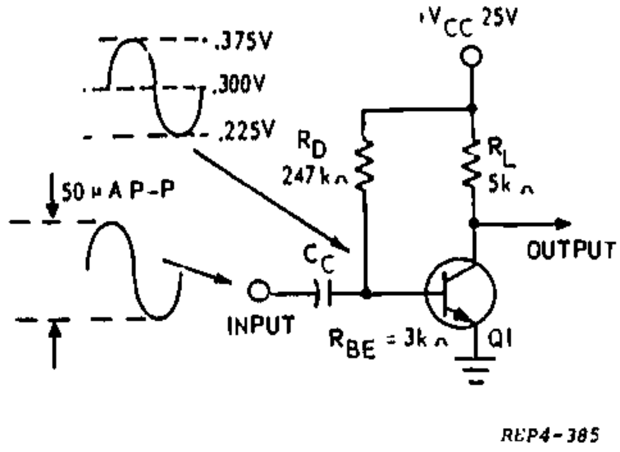


Figure 31-12. Common Emitter Amplifier

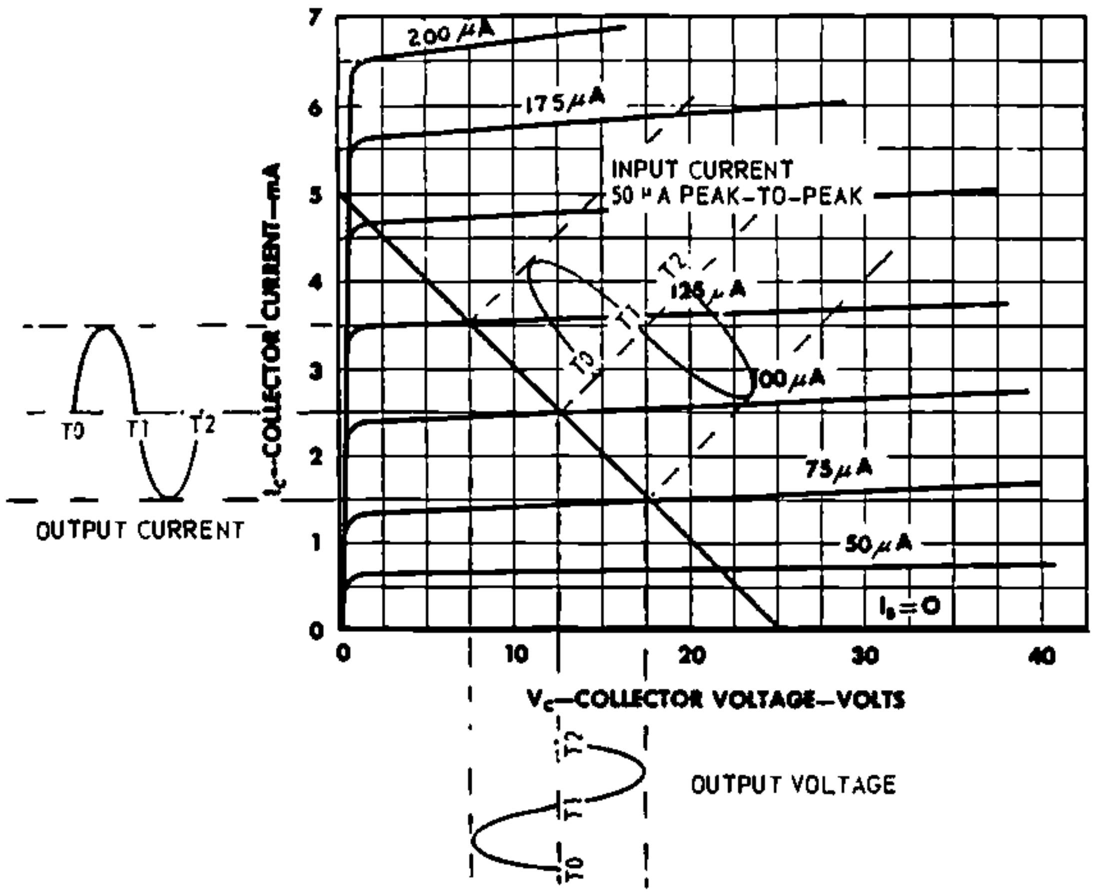


Figure 31-13. Common Emitter Output Characteristics

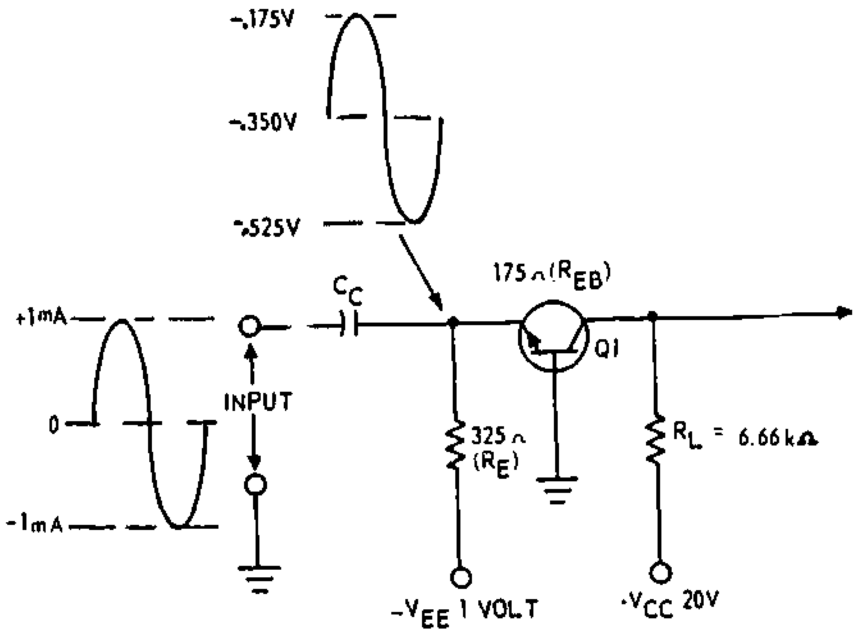


Figure 31-14. Common Base Amplifier

For questions 6 through 10 refer to figure 31-14.

6. In an NPN common base amplifier, as the input signal goes positive, base, emitter, and collector current ________________ and transistor resistance ________________

7. In any common base amplifier, the phase relationship of the output signal voltage to the input signal voltage is

____

8. The current gain of a common base amplifier is always (more)(less) than one.

9. Using figures 31-14 and 31-15, compute A_i, A_v, and A_p.

10. In a common base amplifier, as the collector load resistance is increased in size, A_I (increases) (decreases), and Av increases) (decreases).

For questions 11 through 16, refer to figure 31-16.

11. There is a 180° phase difference between the input and output signals in a common collector amplifier. (True) (False)

12. The voltage gain of a common collector amplifier is always (more)(less) than one.

13. Another name for a common collector configuration is ________________

14. In an NPN common collector amplifier, as the base signal goes positive, base, emitter, and collector current (increases) (decreases) and emitter voltage goes (positive) (negative).

15. In a common collector amplifier, as the emitter load resistance is increased, A_V (increases) (decreases), and A_I (increases) (decreases).

16. Degeneration is the process of returning part of an amplifier output back to the input in such a way that it cancels part of the input. (True) (False)

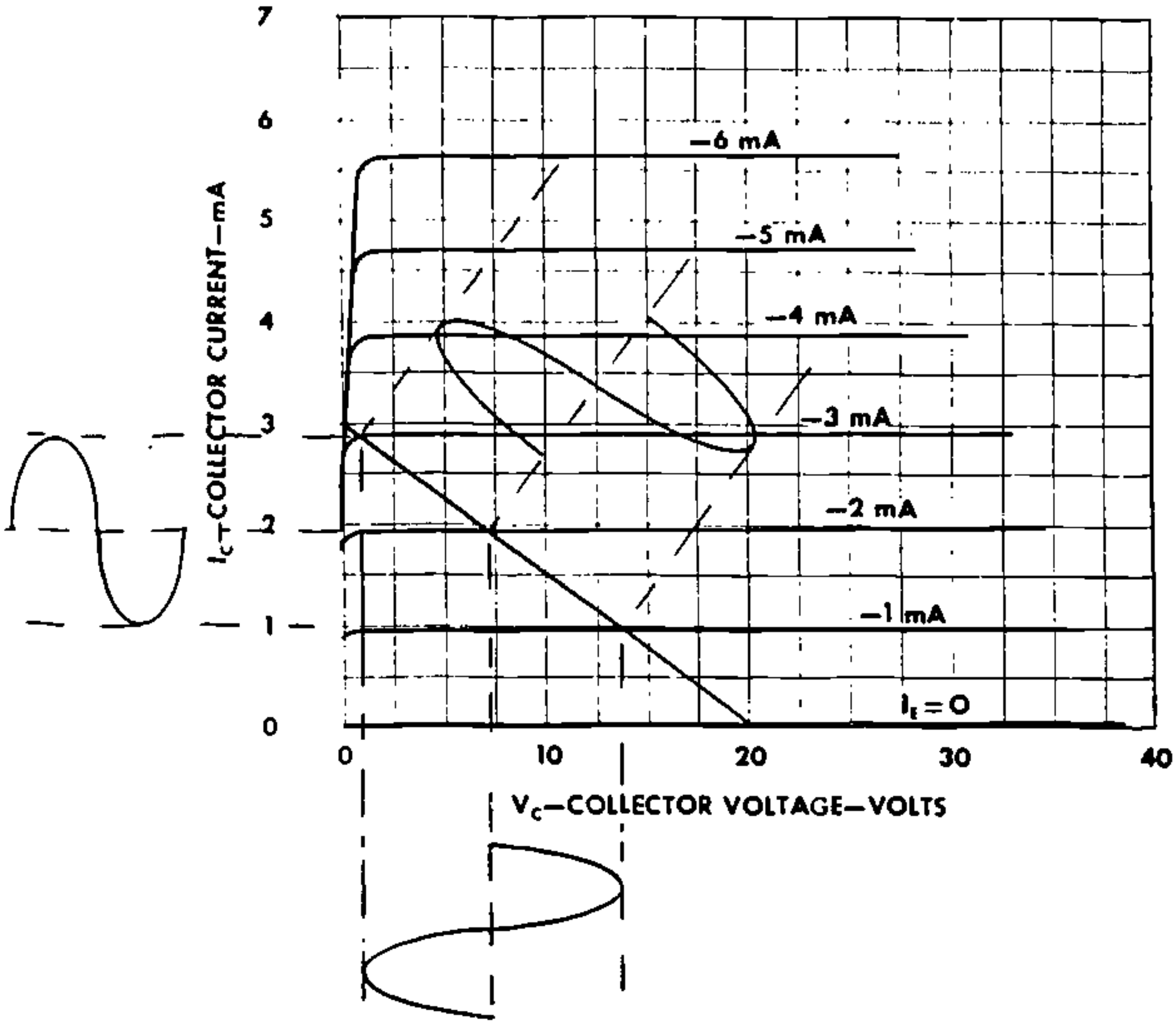


Figure 31-15. Common Base Output Characteristics 2N117

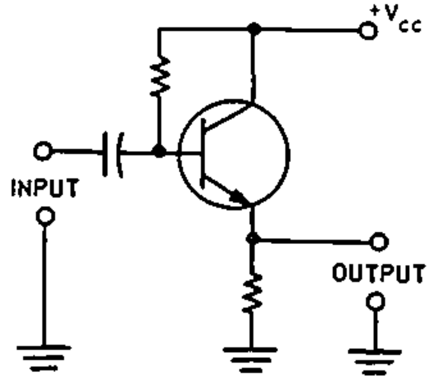


Figure 31-16. Common Collector Amplifier

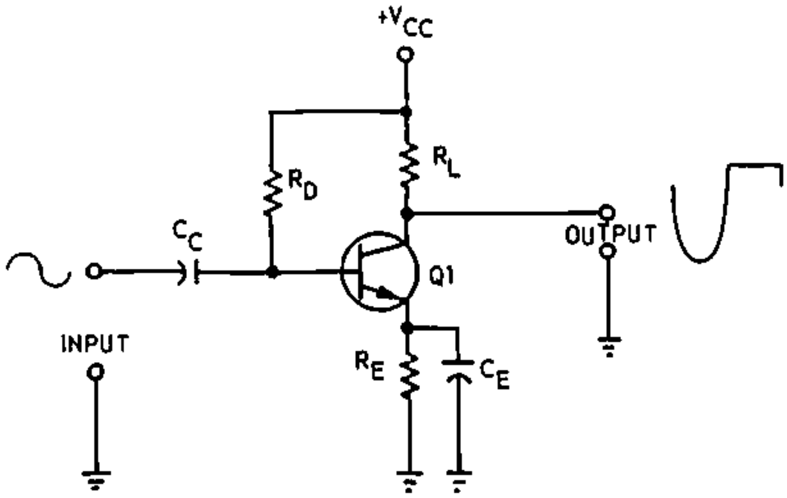


Figure 31-17. Common Emitter Amplifier

17. Power gain is dependent on impedance matching. (True) (False)

18. The effect of changing R_L on A_p (power gain) cannot be determined from the load line (True) (False)

19. Refer to figure 31-17. The type of distortion shown is ____________ distortion. It is caused by (too much) (too little) forward bias.

20. Phase distortion occurs when some frequencies applied to an amplifier do not receive the same time delay as other frequencies. (True) (False)

21. Both frequency and phase distortion are caused by ____________ components.

22. A transistor amplifier operating at 65° C will have (more) (less) collector current flowing than it will if it is operated at 25° C.

23. Causing collector current to remain the same over a wide range of temperature is called ____________

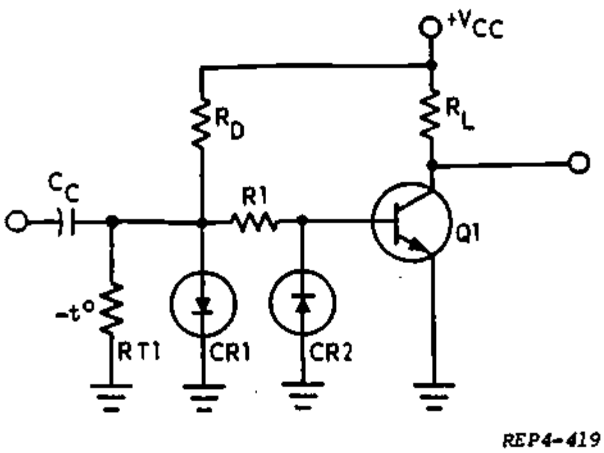


Figure 31-18. Common Emitter Amplifier

24. Figure 31-18 shows a transistor amplifier with several methods of stabilizing collector current for temperature changes. List the components used to stabilize I_C for changes in R_{EB} and those used to compensate for changes in I_{CBO}:

____

____

____

25. The frequency response of direct coupled amplifiers is flat from __________ Hz to 20 kHz.

26. The reduced amplitude at the high frequency end of the response curve for direct coupled amplifiers is due to interelement and stray capacitance. (True) (False)

27. Refer to figure 31-19. The loss of amplitude at the low end of the response curve is caused by the ________________ and at the high end by the ________________.

28. Impedance coupling is limited to ________________ frequency use.

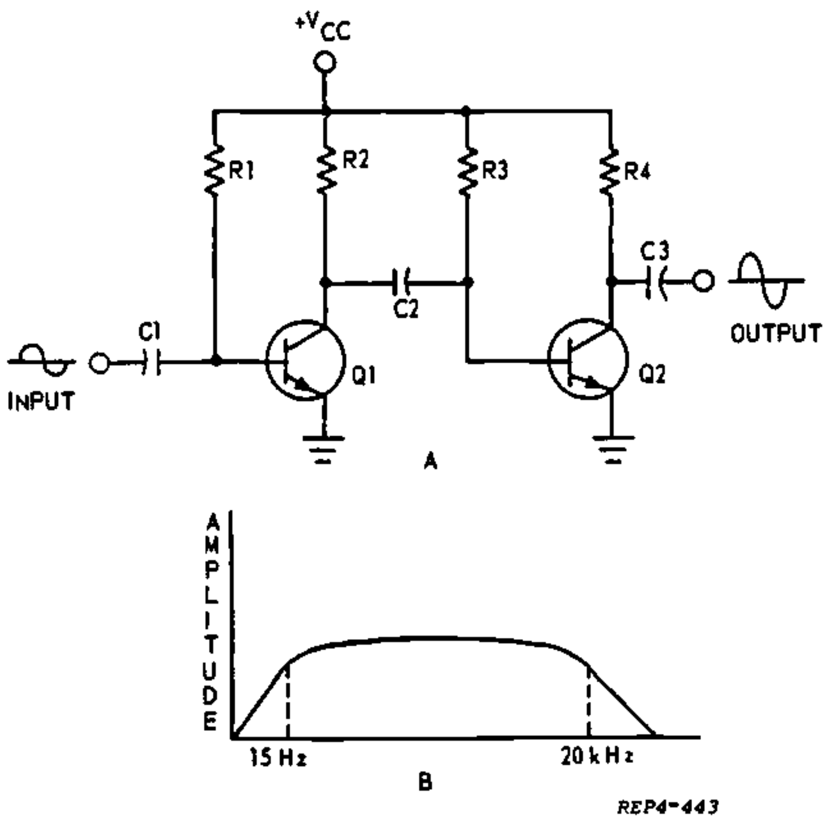


Figure 31-19. Two Stage Common Emitter Amplifier

20. Match the type of inter-stage coupling to the response curves shown in figure 31-20.

a. ______________ Direct Coupled.   c. ______________ Impedance coupled.

b. ______________ RC Coupled.   d. ______________ Transformer coupled.

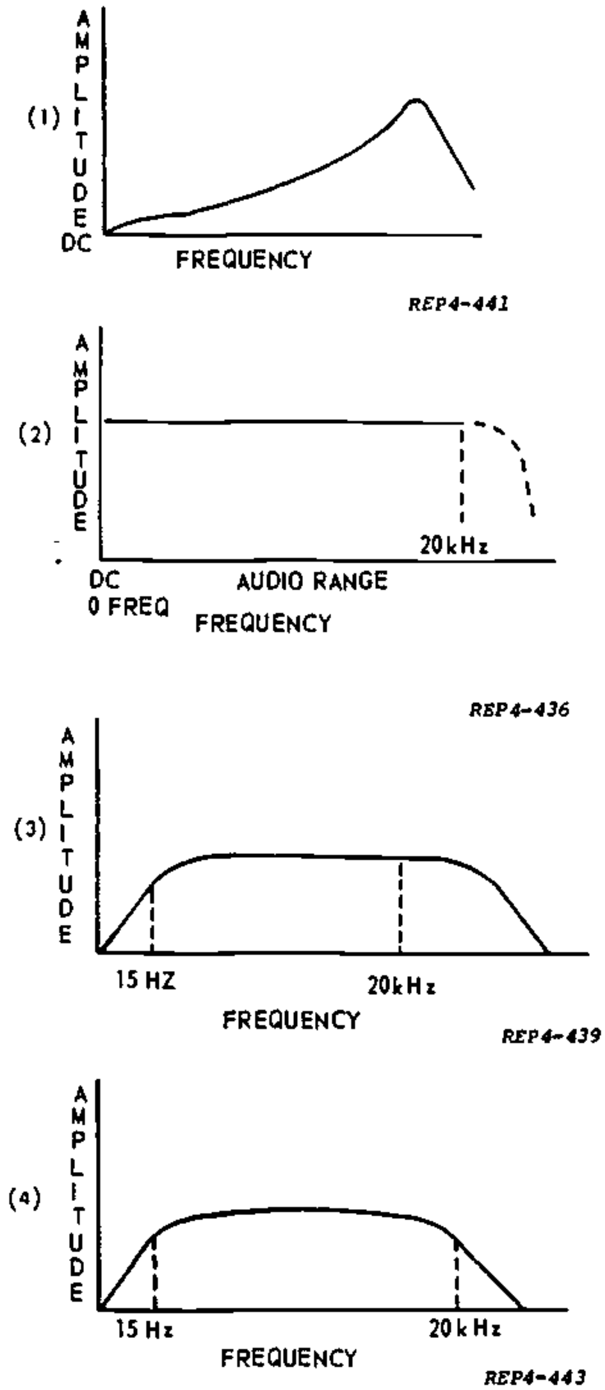


Figure 31-20. Frequency Response Curves

CONFIRM YOUR ANSWERS

ANSWERS TO A - ADJUNCT GUIDE

1. true
2. emitter, base
   collector, emitter
3. 15 V
4. 12 V
5. (a) increase
   (b) increase
   (c) increase
   (d) decrease
   (e) decrease
   (f) increase
6. (a) increase
   (b) increase
   (c) increase
   (d) decrease
   (e) decrease
   (f) increase
7. 16 V
8. 180 degrees out of phase.

If you missed ANY questions, review the material before you continue.

ANSWERS TO B - ADJUNCT GUIDE

1. $I_B = 200\ \mu A$
2. $V_{EB} = .2V$
3. $A_I = 80$
4. $Ap = 200$
5. $Ap = 16000$
6. 180° out of phase
7. A_I decrease
   A_V increase

If you missed ANY questions review the material before you continue.

ANSWERS TO C - ADJUNCT GUIDE

1. $I_E = 5\ mA$
2. $V_{EB} = .5V$
3. $A_I = .975$
4. $A_V = 60$
5. $A_p = 58.5$
6. in phase
7. A_I decrease
   A_V increase

If you missed ANY questions, review the material before you continue.

ANSWERS TO D - ADJUNCT GUIDE

1. smaller
2. opposes
3. degenerative, less
4. in

If you missed ANY questions, review the material before you continue.

ANSWERS TO E - ADJUNCT GUIDE

1. decrease
2. increase
3. To prevent collector current (I_C) variations from occurring in conjunction with temperature variations
4. negative
5. increase
6. minority carrier density would increase
7. I_{CBO} would approximately double

If you missed ANY questions, review the material before you continue.

ANSWERS TO F - ADJUNCT GUIDE

1. swamping

2. degenerative

3. by placing a by-pass capacitor in parallel with the swamping resistor

4. true

5. false

6. false, I_C changes will be minimized, but not prevented.

If you missed ANY questions, review the material before you continue.

ANSWERS TO G - ADJUNCT GUIDE

1. R_{EB} would decrease

   I_B would increase

   V_{EB} would decrease

   I_C would increase, but not as much as it would in an unstabilized circuit

2. Degenerative feedback

3. Use a low pass filter network

4. Negative

5. The thermistor resistance variations do not equal the transistor emitter/base junction resistance changes.

6. true

7. I_{CBO}

8. double diode

If you missed ANY questions, review the materials before you continue.

ANSWERS TO H - ADJUNCT GUIDE

1. a. Amplitude distortion is the result of changing a waveform so that its amplitude is no longer proportional to the original amplitude.

   b. Frequency distortion results when not all frequencies are amplified or attenuated equally.

   c. Phase distortion results when some frequencies applied to an amplifier do not receive the same time delay as other frequencies.

2. a. Amplitude distortion is caused by the operation of an amplifier in the nonlinear area of the characteristic curve.

   b. Frequency distortion is caused by the reactive components in an amplifier's circuitry.

   c. Phase distortion is also caused by the reactive components in an amplifier's circuitry. When phase distortion is present, frequency distortion will also be present.

If you missed ANY questions, review the material before you continue.

ANSWERS TO I - ADJUNCT GUIDE

1. Direct coupling

2. The interelemental and stray capacitances.

3. Low frequency loss of gain is because of the coupling capacitor and the higher frequency loss of gain is because of the interelement and stray capacitances.

492

4. The X_L of the inductor is directly proportional to frequency. ($X_L = 2\pi fL$). Because the inductor is being used in place of the load resistor, the amplifier gain will decrease as the input frequency decreases. (R_L decrease causes A_V decrease).

5. For impedance matching

If you missed ANY questions, review the material before you continue.

ANSWERS TO J - ADJUNCT GUIDE

1. a. use
   b. frequency
   c. class of operation

2. a. Class A: Collector current flows during the entire input cycle.

   b. Class AB: Collector current flows for more than 180° of an input cycle but less 360°.

   c. Class B: Collector current flows for exactly half of an input cycle.

   d. Class C: Collector current flows for less than one half of an input cycle.

3. a. amount of forward bias

   b. amplitude of the input signal

4. Class of operation cannot be determined.

5. Fidelity: The degree that the amplifier accurately reproduces at its output the waveform characteristics of the signal applied to its input.

6. Efficiency: The ratio of an amplifier output signal power to total input power.

7. Class A

8. Class C

If you missed ANY questions, review the material before you continue.

ANSWERS TO K - ADJUNCT GUIDE

1. true

2. even

3. odd

4. both odd and even

If you missed ANY questions, review the material before you continue.

ANSWERS TO LABORATORY EXERCISE 31-3, EXERCISE #1 CURRENT GAIN

(The answer obtained should be approximately the same as below. Do not expect them to be exactly identical.)

d. $I_B = 42\ \mu A$ (approx)

e. $I_B = 77\ \mu A$ (approx)

f. $\Delta I_B = 35\ \mu A$ (approx)

h. $A_i = 57$ (approx)

i. (1) increase
   (2) increase

k. $I_C = 2$ mA, $I_B, = 38\ \mu A$ (approx)
   $I_C = 4$ mA, $I_B, = 69\ \mu A$ (approx)

l. I_B = 31 μA (approx)

m. A_i = 64.5 (approx)

If you missed ANY questions, review the reference material before you continue.

ANSWERS TO LABORATORY EXERCISE 31-1, EXERCISE #2 & #3 VOLTAGE AND POWER GAIN

5e. 9.5 V Pk-Pk (approx)

5f. 190

6a. 10830 (approx)

6b. out of phase

6c. decreased, degenerative

6f. (1) 64
(2) decreases

6g. 4128 (approx)

6h. decreased.

If you missed ANY questions, review the reference material before you continue.

ANSWERS TO MODULE SELF-CHECK

1. increases, decreases

2. positive

3. 180°

4. output, input

5. A_v = 66.7, A_i = 40, A_p = 2668

6. decreases, increases

7. zero degrees-in phase

8. less than one

9. A_i = .95, A_v = 34.9, A_p = 33.2

10. A_i decreases, A_v increases

11. false

12. less

13. emitter follower

14. increase, positive

15. A_v increases, A_i decreases,

16. True

17. True

18. False

19. amplitude, too little

20. True

21. reactive

22. more

23. stabilization

24. For I_C -RT1, R_D and CR1
For I_{CBO} -R_D, R1 and CR2

25. zero

26. True

27. high reactance of the coupling capacitors, low reactance of the stray or interelement capacitance

28. high

29. a. 2, b. 3, c. 1, d. 4

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER INSTRUCTION.

495

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-32

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 32

TROUBLESHOOTING SOLID STATE AMPLIFIERS

1 August 1974

AIR TRAINING COMMAND

7-8

Designed For ATC Course Use

ATC Keesler 5-359

DO NOT USE ON THE JOB

496

Basic and Applied Electronics Department
Keesler Air Force Base, Mississippi

GUIDANCE PACKAGE 3AQR30020-1
KEP-GP-32
1 August 1974

ELECTRONIC PRINCIPLES

MODULE 32

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

Supersedes KEP-GP-32 dated 1 November 1973, stocks on hand will be used.

TROUBLESHOOTING SOLID STATE AMPLIFIERS

1. SCOPE: This module will instruct you in the basic techniques of troubleshooting solid state amplifiers. It will further provide practical experience in the use of test equipment to determine the cause of a malfunction in a transistor voltage amplifier.

2. OBJECTIVE: Upon completion of this module you should be able to satisfy the following objective:

Given a trainer having an inoperative transistor voltage amplifier circuit, schematic diagram, multimeter, signal generator, and oscilloscope, determine the faulty component two out of three times.

TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

LIST OF RESOURCES

TROUBLESHOOTING SOLID STATE AMPLIFIERS

To satisfy the objective of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Adjunct Guide with Student Text.

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

TROUBLESHOOTING SOLID STATE AMPLIFIERS

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

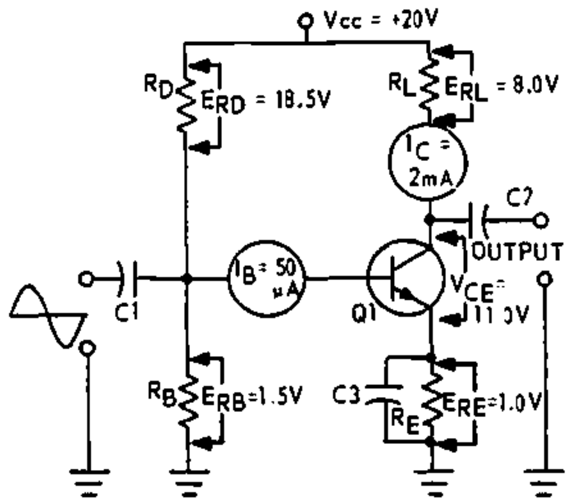
Check your answers against the answers at the top of the next even numbered page following the questions.

If you experience any difficulty, contact your instructor.

Begin the program.

The ability of an electronic technician to TROUBLESHOOT is essential to all electrical maintenance. If you desire to become a productive technician, you must develop this ability. It does not come naturally, nor can it be learned from a book. The technique of troubleshooting is learned through practice. This module provides extensive practice and will prepare you for the more complex troubleshooting problems you will encounter later in this course, and subsequently as a technician in a maintenance shop.

A. Turn to Student Text Volume IV and read paragraphs 3-173 thru 3-196. Return to this page and answer the following questions.



REP4-1267

Refer to the above diagram for the following questions.

1. The amplifier has malfunctioned and the following symptoms are present: Collector current and collector voltage are zero. The voltage drop across R_L equals the supply voltage. The collector waveshape is extremely small. The trouble is ______________________ .

ADJUNCT GUIDE

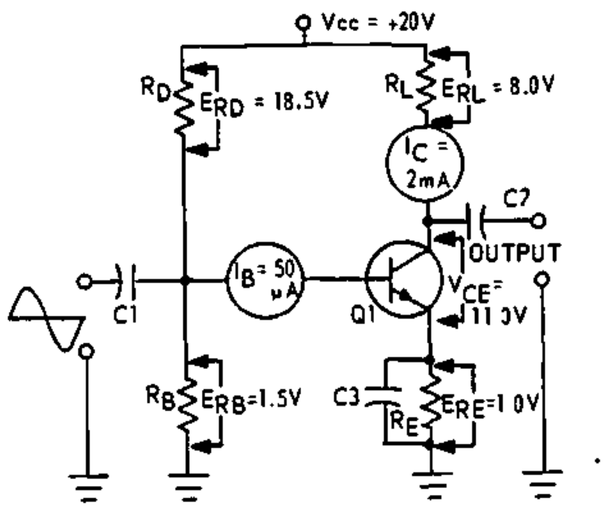
2. The amplifier has malfunctioned and the following symptoms are present: The collector voltage equals the supply voltage. There is no waveshape at the collector. The base waveshape and the base current are near normal. The trouble is ______________________.

3. The amplifier has malfunctioned and the following symptoms are present: Collector current has increased to near 5 mA and the voltage across R_L is approaching the supply voltage. There are no collector waveshapes and the collector voltage is near zero. The base voltage is near normal. The trouble is ______________________.

4. The amplifier has failed and the following symptoms are present: The collector voltage equals the supply voltage, the collector current is zero and there is no collector waveshape. The base waveshape is near normal. The trouble is ______________________.

5. The amplifier has malfunctioned and the following symptoms are present. E_{R_L} and I_C are near zero. V_C is near V_{CC}. The collector waveshape indicates class B operation. The trouble is ______________________.

6. The amplifier has malfunctioned and the following symptoms are present: The base voltage equals the supply voltage. The collector current has increased to near 5 mA and the collector voltage is near zero. There are no base or collector waveshapes. The trouble is ______________________.



REP4-1267

7. The amplifier has malfunctioned and the following symptoms are present: I_C is above normal and the collector voltage is below normal. V_{EB} is high. The base waveshape is near normal. The collector waveshape indicates that saturation distortion is present. The trouble is ________________.

8. The amplifier has malfunctioned and the following symptoms are present: I_C is near zero and the collector voltage is near V_{CC}. The base voltage is zero. There are no base or collector waveshapes. The trouble is ________________.

9. The amplifier has malfunctioned and the following symptoms are present: All voltages and currents are normal. There is no base or collector waveshape. The trouble is ________________.

10. The amplifier has malfunctioned and the following symptoms are present: All voltages and currents are normal. The base and collector waveshapes are normal. There is no waveshape at the output terminals. The trouble is ________________.

11. The amplifier has malfunctioned and the following symptoms are present: All voltages and currents are normal. The collector waveshape is lower than normal in amplitude but is not distorted. The base waveshape is normal. The trouble is ________________.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

B. Turn to Laboratory Exercise 32-1. This exercise will provide valuable experience troubleshooting a transistor voltage amplifier. It will also provide practice in the correct use of test equipment for the purpose of troubleshooting. Return and continue with this program.

ANSWERS TO A:

1. R_L open
2. R_L shorted
3. Q_1 shorted
4. Q_1 open or R_E open
5. R_D open
6. R_D shorted
7. R_B open or R_E or C3 shorted
8. R_B shorted
9. C_1 open
10. C_2 open
11. C_3 open

If you missed ANY questions, review the material before you continue.

32-1

TROUBLESHOOTING SOLID STATE AMPLIFIERS

OBJECTIVE: Given a trainer having an inoperative transistor voltage amplifier circuit, schematic diagram, multimeter, signal generator, and oscilloscope, determine the faulty component two out of three times.

EQUIPMENT: Transistor Voltage Amplifier Trainer, #5960.
Oscilloscope, LA-261
Multimeter, PSM-6
Signal Generator, #4664.

REFERENCES: Student Text, Volume IV, Chapter III, Paragraphs 3-172 through 3-196.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

The transistor amplifier trainer has built-in troubleshooting capabilities. The compartment at the rear of the trainer allows access to the switches to be used for inserting the troubles. The following troubles are available.

a. Open collector circuit.

b. Open emitter circuit.

c. Open Biasing arrangement.

d. Open output.

e. Open input.

f. Shorted transistor.

Troubleshooting involves the use of test equipment to obtain voltage measurements, current measurements, and to observe voltage waveshapes. These measurements and observations are then analyzed to determine the probable cause of a malfunction. It is important to realize that no test equipment can be used to make measurements or to observe waveshapes without modifying the circuit characteristics to some degree. Because of this, it is important that only one measurement or observation be made at a time.

This laboratory exercise will provide practice in associating symptoms of a malfunction to a specific trouble and will be conducted in the following sequence:

a. The normal voltage, current, and waveshape measurements will be taken and recorded on the troubleshooting summary chart (Figure 16).

b. A known trouble will then be placed in the trainer. The current, voltage and waveshape measurements will be taken and recorded in the appropriate blocks on figure 16 for that specific trouble.

c. Next you will be questioned to assure association of the abnormal readings to the inserted trouble.

LABORATORY EXERCISE

d. This procedure will be repeated for all six troubles.

NOTE: Before beginning the exercise detach figures 15 and 16 from the rear of this guidance package. Figure 15 illustrates the proper test equipment connections for this practice exercise and figure 16 is the troubleshooting summary chart.

An answer sheet with a conclusion and a troubleshooting summary chart for each exercise is in the back of this guidance package. Answer the questions carefully before comparing with the answer sheet. Your instructor will help you with any points that are not clear.

PRELIMINARY INSTRUCTIONS FOR TRANSISTOR VOLTAGE AMPLIFIER

a. Plug in the oscilloscope and signal generator and turn them ON.

b. Preset the switches on the trainer to obtain the following circuit configuraton and plug the trainer into a 110V AC outlet.

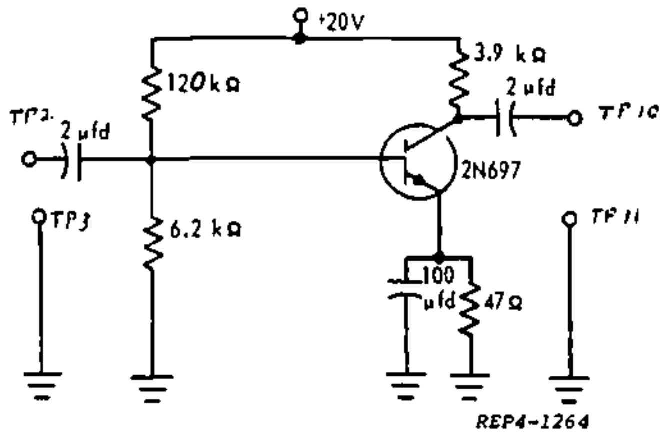


Figure 1. Schematic Diagram of Trainer Circuit

c. Connect the output of the signal generator (sine wave output) to TP2 and TP3 on the trainer.

d. Connect the "A" channel input of the oscilloscope to the output of the signal generator (TP4 and TP5).

e. Connect the trigger input to TP13. Adjust the output of the signal generator for a 10 kHz sine wave with an amplitude of .05 V pk-pk as read on the oscilloscope. (Set trigger selector to EXT+ and mode selector to AUTO).

PROCEDURES FOR MEASURING CURRENT, VOLTAGE, AND WAVESHAPES

1. The first step in the exercise will be to establish what the NORMAL currents, voltages, and waveshapes are for the Transistor Voltage Amplifier. Follow the sequence and procedures outlined below to measure and record the values for the circuit. Record the values and draw the waveshapes in column 1, Figure 16, Troubleshooting Summary Chart.

CURRENT MEASUREMENTS

a. Base Current (I_B) (TP6 to TP7) Place the PSM6 on the Special 100μ Amp function and insert the leads in TP6 and TP7. Place S-5 in the open position and read the base current. Remove the PSM6 and place S5 in the closed position.

NOTES

505

LABORATORY EXERCISE

NOTE: TO PREVENT DAMAGE TO METER, change function and range switches before inserting leads in TP-12 and TP-13 (Below)

b. Collector Current (I_C). (TP12 to TP13). Place the PSM6 on the mAmp function and the range switch on 10. Insert the leads in TP12 and TP13. Place S7 to the open position and read the collector current. Remove the PSM6 leads and place S7 to the closed position.

DC VOLTAGE MEASUREMENTS

c. Voltage Drop across R_L (E_{RL}). (TP1 to TP12). Place the PSM6 function switch on the 20k/Volt function and the range switch on 50. Measure and record the voltage between TP1 and TP12 (E_{RL}).

d. Collector Voltage (V_C) TP8 to TP11). Insert leads of PSM6 between TP8 and TP11. Measure and record the DC voltage (V_C).

e. Emitter-Base Voltage (V_{EB}). (TP7 to TP9). Insert leads of PSM6 in TP7 and TP9. Measure and record the DC voltage (V_{EB}).

PK/PK VOLTAGE AND WAVESHAPE MEASUREMENTS

f. Sinewave Signal Input (TP2). Measure the Pk/Pk amplitude of the input signal from the signal generator. Re-adjust to .05V Pk/Pk if necessary. Draw the waveform observed at TP2.

g. Base Voltage and Waveform (TP7). Measure and record the Pk/Pk amplitude of the sinewave signal observed at TP7. Draw the waveform observed at TP7.

h. Collector voltage and Waveform (TP8). Measure and record the Pk/Pk amplitude of the sinewave signal observed at the collector (TP8). Draw the waveform observed at TP8.

i. Output Voltage and Waveform (TP10). Measure and record the Pk/Pk amplitude of the sinewave signal observed at the output of Transistor Voltage amplifier (TP10). Draw the waveform observed at TP10.

NOTE: Before continuing with the exercise, compare your recorded results with those indicated on figure 2. There is an allowance for slight differences due to the trainer used and the associated test equipment. If your measurements differ greatly with those indicated as correct, call the instructor. If your measurements are the same or similar, continue with the next part of the exercise.

2. The trainer has the capability of simulating six different troubles as indicated at the top of Figure 16. These troubles can be simulated by selecting the proper switch located on the trainer. Access to the compartment may be made by opening the door. We will treat each problem separately and in two steps. The first step will be to insert the trouble and then measure and record the currents, voltages, and waveforms in the same sequence as was followed when the measurements were made for normal circuit operation. The second step will be to compare these readings with the normal readings in an effort to establish an insight to circuit malfunctions.

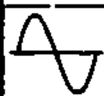
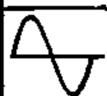
	Measurement Points	1. Normal Voltage, Current& Waveshape	2. Open Collector	3. Open Emitter	4. Open Biasing Arrangement	5. Open Output	6. Open Input	7. Shorted Transistor
	TP-2 to TP-3 (E_{IN})	ADJUST THE OUTPUT OF THE SIGNAL GENERATOR TO .05 VOLTS Pk-Pk ON THE OSCILLOSCOPE FOR EACH MALFUNCTION						
a.	TP-6 to TP-7 (I_B)	38 μa						
b.	TP-12 to TP-13 (I_C)	2 ma						
c.	TP-1 to TP-12 (E_{R_L})	8.5 V						
d.	TP-8 to TP-11 (V_C)	10.5 V						
e.	TP-7 to TP-9 (V_{EB})	.6 V						
f.	TP-2 to TP-3 Input Waveshape							
g.	TP-7 to TP-4 Base Voltage Pk-Pk	.05 V Pk-Pk						
	TP-7 to TP-4 Base Waveshape							
h.	TP-8 to TP-11 Collector Voltage Pk-Pk	13 V Pk-Pk						
	TP-8 to TP-11 Collector Waveshape							
i.	TP-10 to TP-11 (E_{OUT}) Pk-Pk	13 V Pk-Pk						
	TP-10 to TP-11 (E_{OUT}) Waveshape							

Figure 2. Normal Voltage, Current and Waveshapes

508

LABORATORY EXERCISE

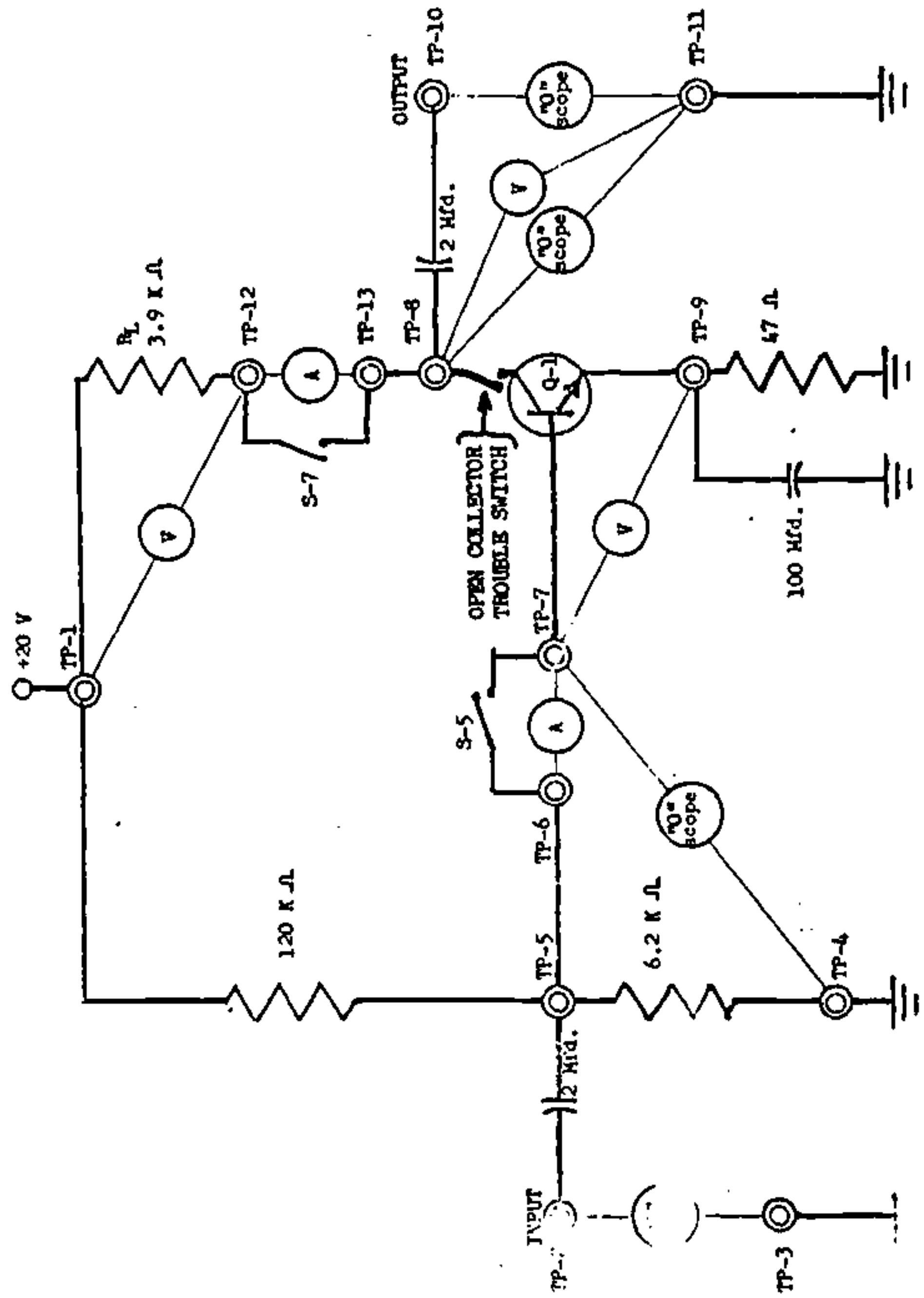


Figure 3. Trouble switch location for an open collector circuit.

TROUBLE #1: OPEN COLLECTOR CIRCUIT.

Insert the trouble "Open Collector Circuit" by raising the switch in the compartment. (Note Figure 3 for electrical location of switch.) Adjust the output of the signal generator for a .05 volt Pk/Pk signal with the oscilloscope. Record and draw the waveform on figure 16, at item f, column 2, "Open Collector Circuit."

518

Following the same procedures and sequence that you followed for obtaining the normal currents, voltages, and waveforms, measure and record the values.

After recording the data, compare the results with those that were obtained and recorded in column 1, "Normal Voltages, Currents, and Waveshapes."

Answer the following questions pertaining to the trouble "Open Collector Circuit." When answering the questions, refer to both Figure 3 and the Troubleshooting Summary Chart in order to arrive at your answer.

1. Why did the base current increase with an open collector?

Answer:

2. Why did the collector current decrease to zero?

Answer:

3. Why did the collector voltage increase to the applied voltage?

Answer:

4. Why did the Pk/Pk sinewave signal decrease to zero?

Answer:

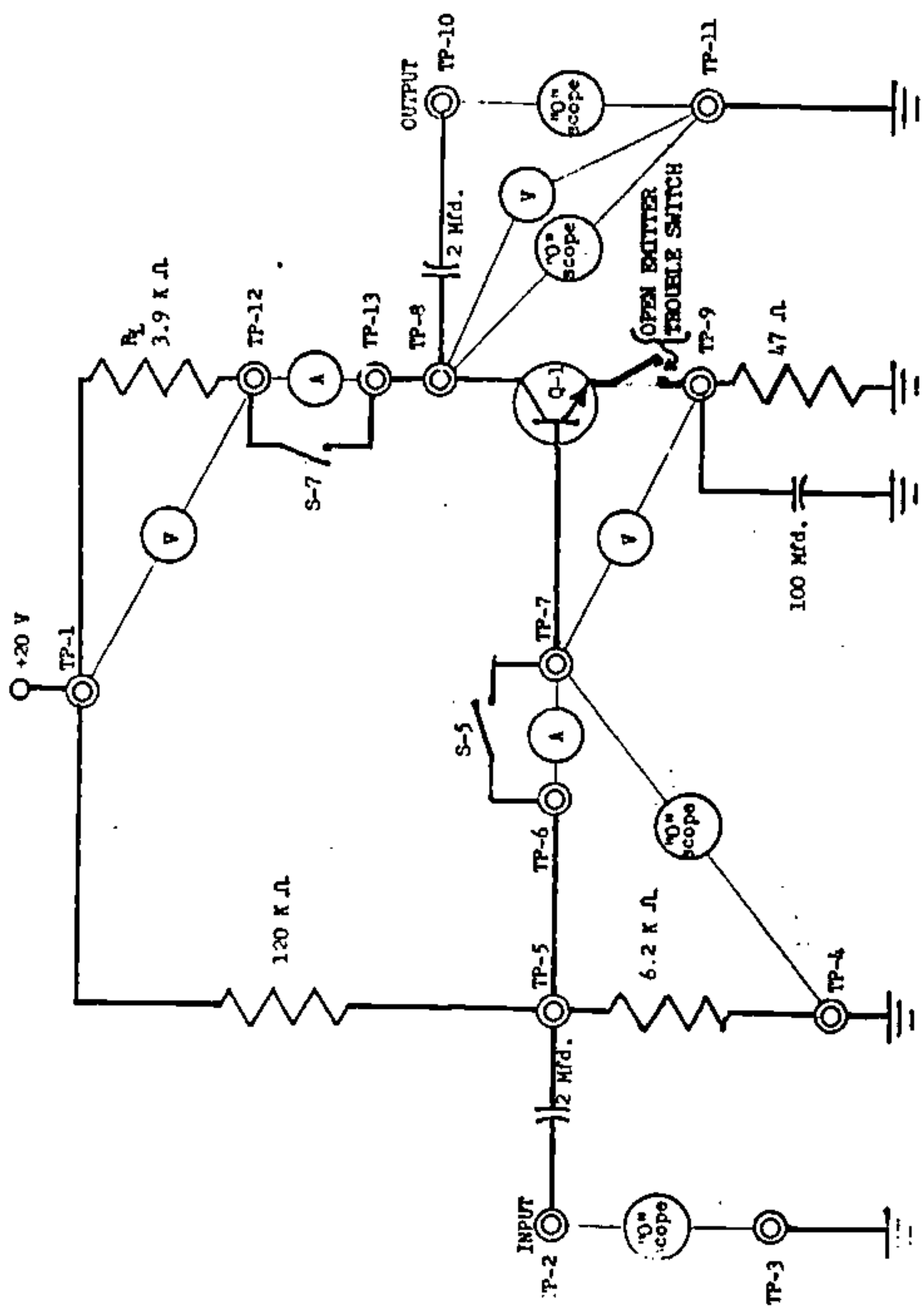


Figure 4. Trouble switch location for an open emitter circuit.

TROUBLE #2: OPEN EMITTER CIRCUIT

Insert the trouble in the trainer by raising the switch marked "Open Emitter Circuit" in the compartment on the trainer. Before taking your measurements, adjust the output of the signal generator for .05 volts Pk/Pk. Refer to Figure 4 for the electrical location of the switch that simulates the trouble "Open Emitter Circuit."

LABORATORY EXERCISE

Follow the procedures for taking current and voltage measurements, and obtaining waveshapes used when you obtained the normal measurements on pages 8 and 9. Record your measurements and draw the waveforms that you observe in column 3 under "Open Emitter Circuit" on the Troubleshooting Summary Chart.

After completing column 3, compare your results with the NORMAL readings in column 1 and answer the following questions. Use both the troubleshooting summary chart and figure 4 when answering the questions.

1. Why is I_B and I_C zero with an open emitter circuit?

Answer:

2. What value of V_C did you read? ________ Why should V_C be this value?

Answer:

3. Were you able to observe an output sinewave signal at the collector of the transistor (TP8)?

____________ If not, why? ______________________________________

4. Was there an output signal sinewave observed at TP10? ________ If none was observed, why?

LABORATORY EXERCISE

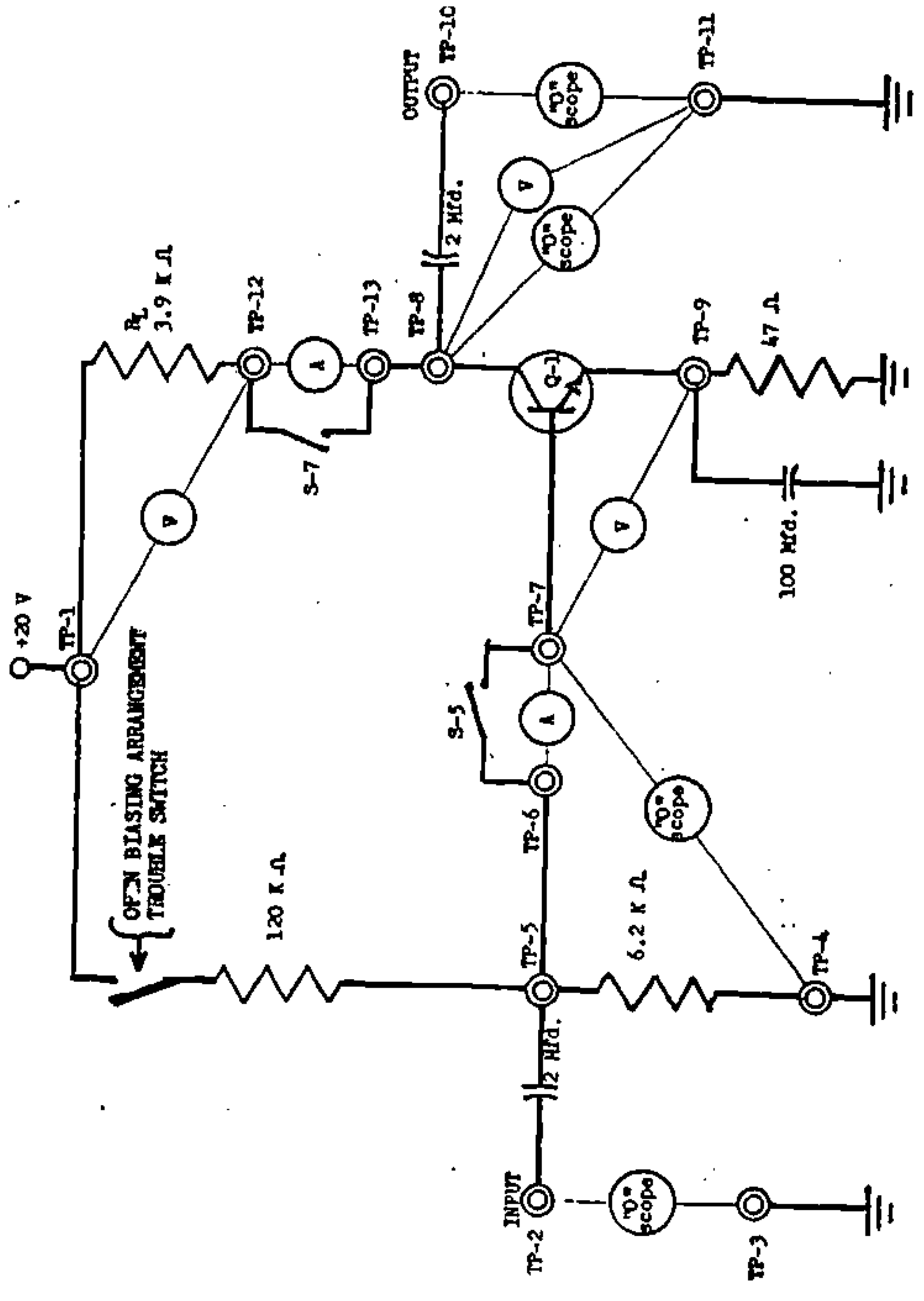


Figure 5. Trouble switch location for open biasing arrangement.

TROUBLE #3: OPEN BIASING ARRANGEMENT

Insert the trouble in the trainer by raising the switch marked "Open Biasing Arrangement" in the compartment on the trainer. Before taking your measurements, adjust the output of the signal generator for .05 volts Pk/Pk. Refer to Figure 5 for the electrical location of the switch that simulates the trouble "Open Biasing Arrangement."

522

Follow the procedures for taking current and voltage measurements, and obtaining waveshapes located on pages 8 and 9. Record your measurements and draw the waveforms that you observe in column 4 under "Open Biasing Arrangement" on the Troubleshooting Summary Chart, Figure 16.

After completing column 4, compare your results with the NORMAL readings in column 1, and answer the following questions. Use both the troubleshooting summary chart and figure 4 when answering the questions.

1. Why did I_C, I_B, and V_{EB} reduce to Zero?

2. What value of V_C did you read? ________ Why did V_C increase to this value?

3. Why isn't there a signal observed at the collector or at the output of the trainer?

514

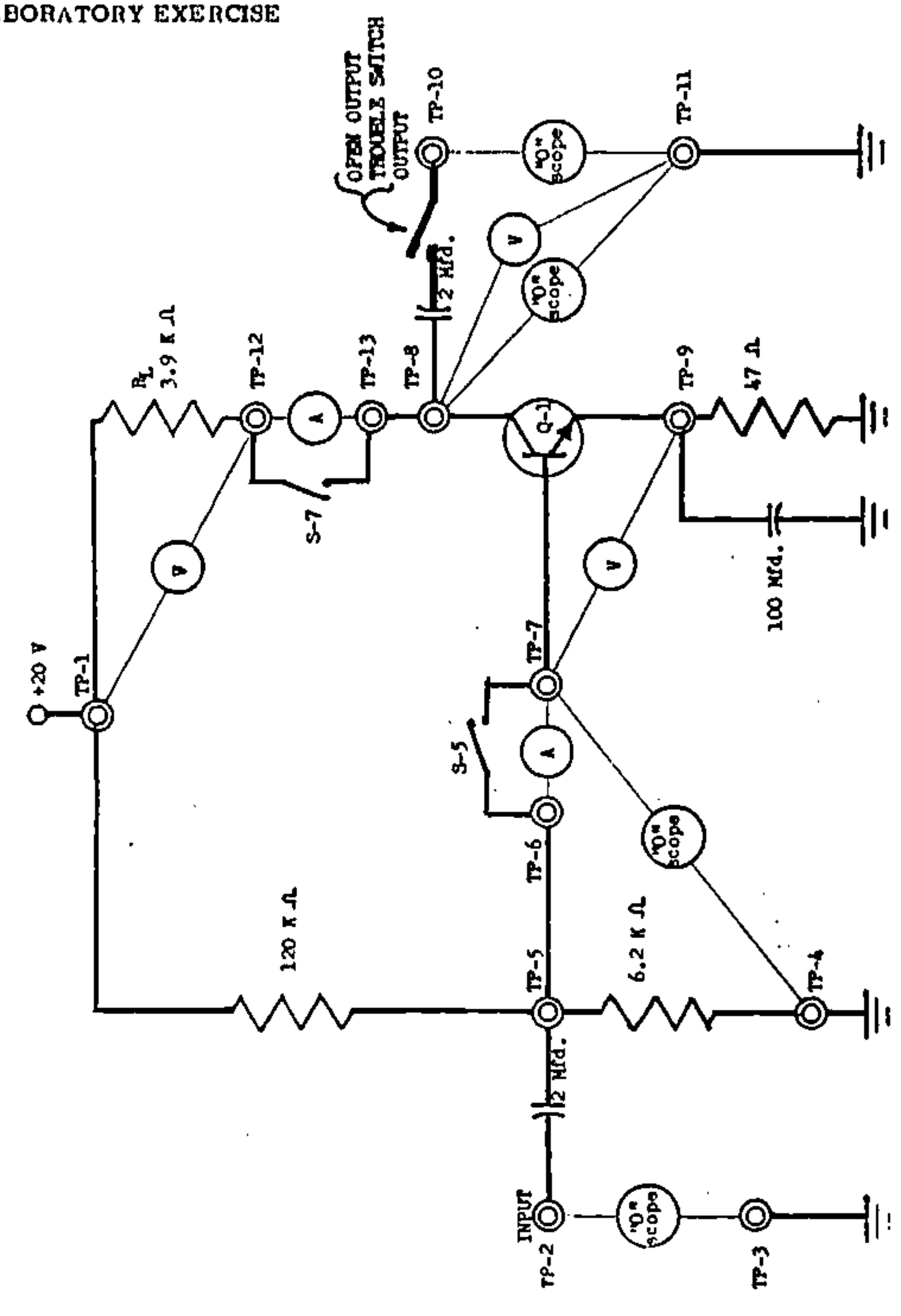


Figure 6. Trouble switch location for an open output

TROUBLE #4: OPEN OUTPUT.

Insert the trouble in the trainer by raising the switch marked "Open Output" in the compartment on the trainer. Before taking your measurements, adjust the output of the signal generator for .05 volts Pk/Pk. Refer to figure 6 for the electrical location of the switch that simulates the trouble "Open Output." At this point, attempt to predict what type of readings you should obtain and what waveforms should be present.

524

Follow the same procedures for taking current and voltage measurements, and obtaining waveshapes used when you obtained the normal measurements on pages 8 and 9. Record your measurements and draw the waveforms that you observe in column 5 under "Open Output" on the Troubleshooting Summary Chart, Figure 16.

After completing column 5, compare your results with the normal readings in Column 1 and answer the following questions. Use both the Troubleshooting Summary Chart and figure 8 when answering the questions.

1. Was there any major difference between the voltages and currents that you measured for this exercise compared to normal volages and currents? ______________ Why?

2. Was there a waveform observed at the collector?

3. Was there a waveform observed at the output of the trainer? ______________ What component would prevent an output from being observed at the output of the trainer?

516

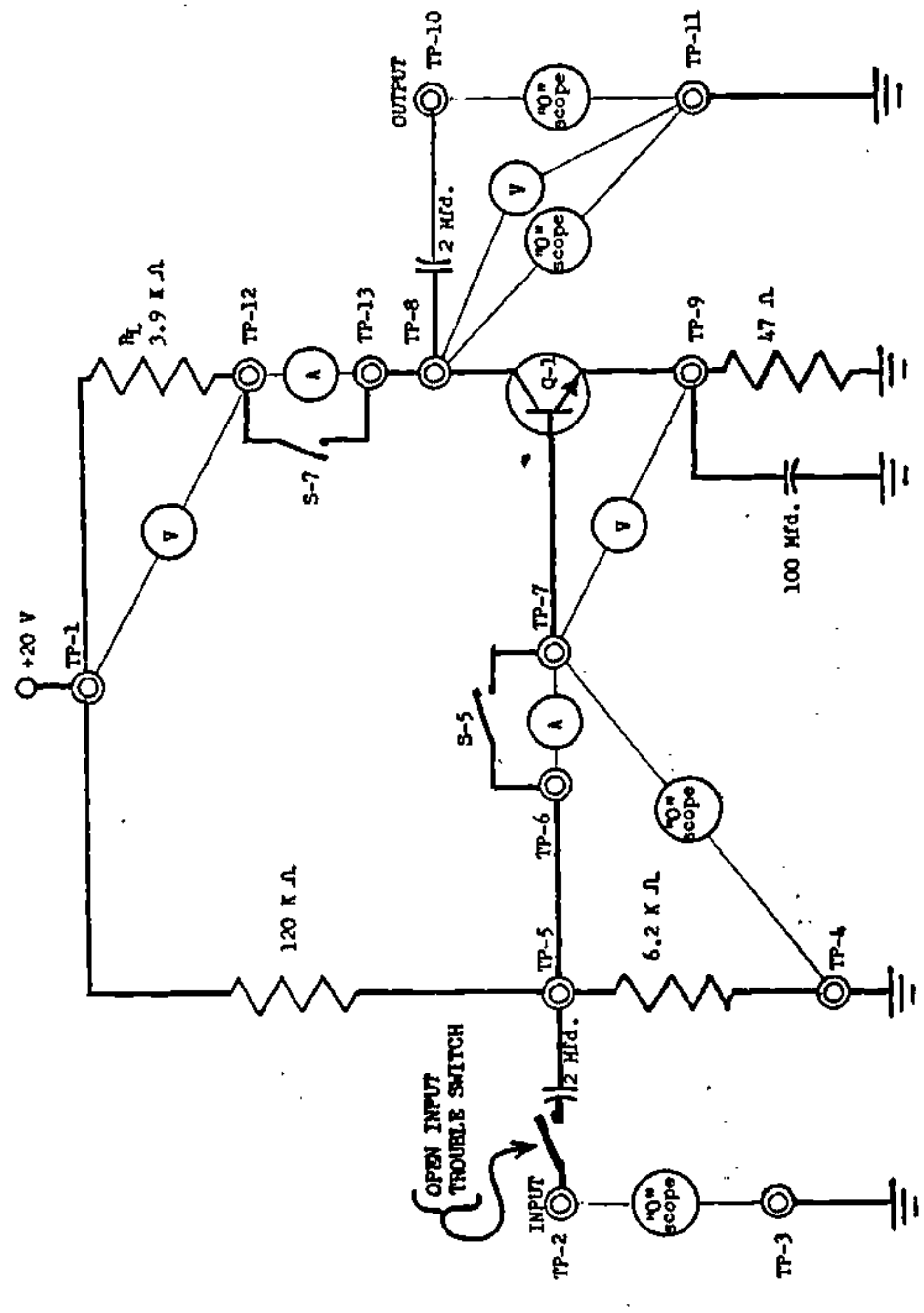


Figure 7. Trouble switch location for an open input

TROUBLE #5: OPEN INPUT

Insert the trouble in the trainer by raising the switch marked "Open Input" in the compartment on the trainer. Before taking your measurements, adjust the output of the signal generator for .05 volts Pk/Pk. Refer to figure 7 for the electrical location of the switch that simulates the trouble "Open Input." While observing figure 7, attempt to predict the outcome. Analyze

526

which waveforms should be present and which ones should be absent. Follow the procedures for taking current and voltage measurements and obtaining waveshapes used when you obtained the normal measurements on pages 8 and 9. Record your measurements and draw the waveforms that you observe in column 6 under "Open Input" on the Troubleshooting Summary Chart, Figure 16.

After completing column 6, compare your results with the readings in column 1 and answer the following questions. Use both the Troubleshooting Summary Chart and Figure 7 when answering the questions.

1. Why isn't there a waveform present at the base, collector, or at the output of the trainer?

2. Why were all of the voltages and currents measured close to the normal values?

3. How could you pinpoint the problem to an open coupling capacitor?

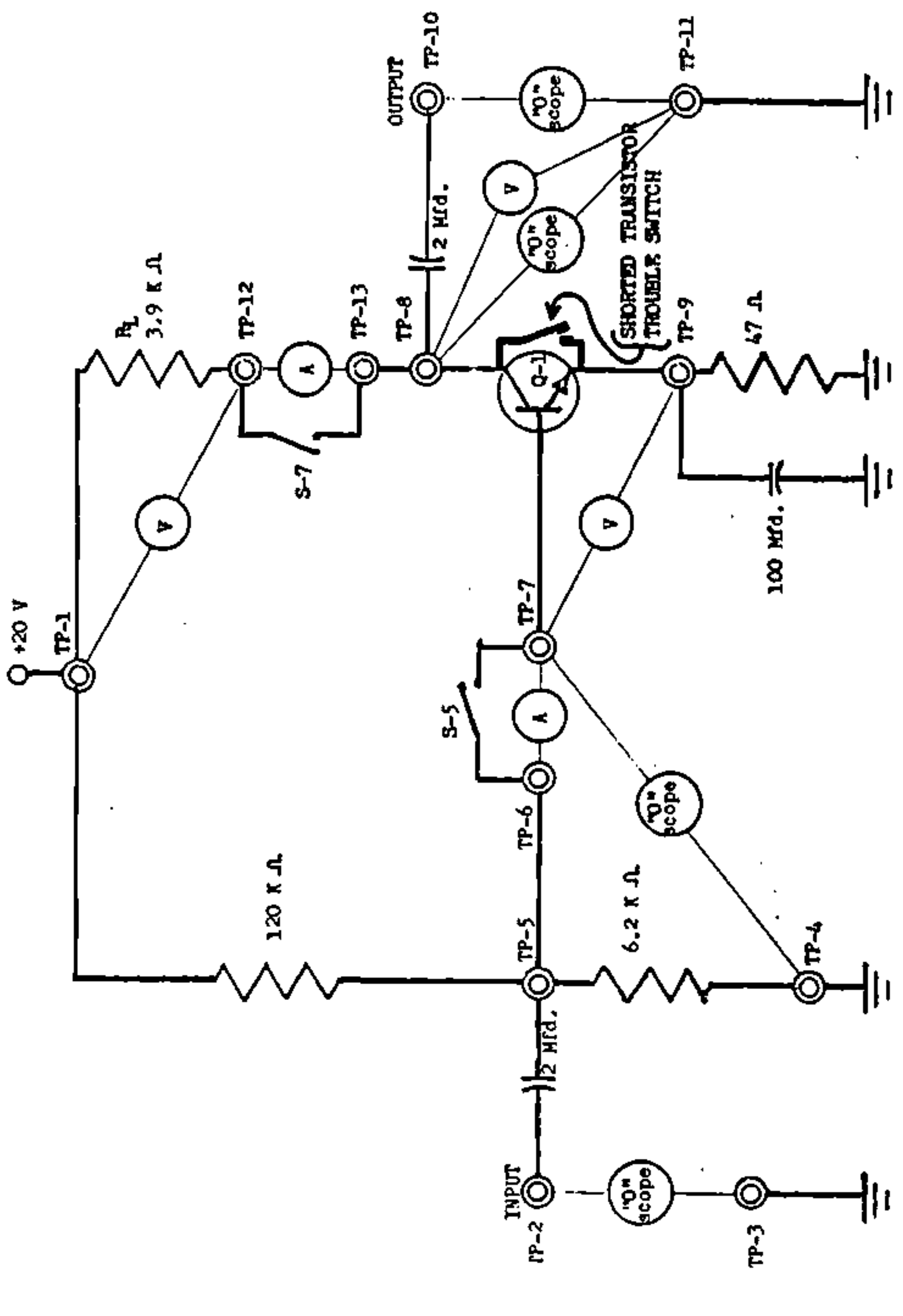


Figure 8. Trouble switch location for a shorted transistor

TROUBLE #6: SHORTED TRANSISTOR

Insert the trouble in the trainer by raising the switch marked "Shorted Transistor" in the compartment on the trainer. Before taking your measurements, adjust the output of the signal generator for .05 volts Pk/Pk. Refer to figure 8 for the electrical location of the switch that simulates the trouble "Shorted Transistor."

Follow the procedures for taking current and voltage measurements and obtaining waveshapes used when you obtained the measurements on pages 8 and 9. Record your measurements and draw the waveforms that you observe in column 7 under "Shorted Transistor" on the Troubleshooting Summary Chart, Figure 18. While observing figure 8, see if you can predict what abnormal readings will be present and whether or not you will be able to obtain an output from the amplifier with a shorted transistor.

After completing column 7, compare your results with the readings in column 1 and answer the following questions. Use both the Troubleshooting Summary Chart and Figure 8 when answering the questions.

1. Why did collector current almost double in value?

2. Why is E_{RL} almost the same value as V_{CC}?

3. What prevents an output from being observed at the output of the trainer?

520

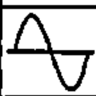
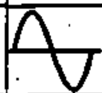
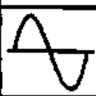
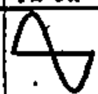
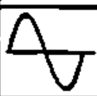
	Measurement Points	1. Normal Voltage, Current& Waveshape	2. Open Collector	3. Open Emitter	4. Open Biasing Arrange-ment	5. Open Output	6. Open Input	7. Shorted Tran-sistor
	TP-2 to TP-3 (E_{IN})	ADJUST THE OUTPUT OF THE SIGNAL GENERATOR TO .05 VOLTS Pk-Pk ON THE OSCILLOSCOPE FOR EACH MALFUNCTION						
a.	TP-6 to TP-7 (I_B)	38 µa	62 µa					
b.	TP-12 to TP-13 (I_C)	2 ma	0					
c.	TP-1 to TP-12 (E_{R_L})	8.5 V	0					
d.	TP-8 to TP-11 (V_C)	10.5 V	20 V					
e.	TP-7 to TP-9 (V_{EB})	.6 V	.6 V					
f.	TP-2 to TP-3 Input Waveshape							
g.	TP-7 to TP-4 Base Voltage Pk-Pk	.05 V Pk-Pk	.05 V Pk-Pk					
	TP-7 to TP-4 Base Waveshape							
h.	TP-8 to TP-11 Collector Voltage Pk-Pk	13 V Pk-Pk	0					
	TP-8 to TP-11 Collector Waveshape		—					
i.	TP-10 to TP-11 (E_{OUT}) Pk-Pk	13 V Pk-Pk	0					
	TP-10 to TP-11 (E_{OUT}) Waveshape		—					

Figure 9. Voltage, Current and Waveshapes with Open Collector

530

EXERCISE 1 ANSWERS AND EXPLANATION (OPEN COLLECTOR)

See Figure 9 for Voltage, Current, and Waveforms

1. No electrons can flow through the base to the collector when the collector is open. Therefore there are more electrons to flow out of the base increasing the base current.

2. There must be a continuous circuit from ground to V_{CC} through the emitter resistor, transistor, and load resistor in order for current to flow. If any element is open there will be no current flow. Collector current will be zero when the collector is open.

3. Normally part of the voltage is dropped across each element. When the collector is open all of the voltage is dropped across the open element as this is now an infinitely large resistance. The load resistor is small by comparison and drops no voltage, so collector voltage (V_C) becomes equal to V_{CC}.

4. The sine wave signal is blocked by the open collector and cannot be seen beyond the open element. Pk-Pk voltage is the result of changes in voltage and as collector voltage is now a constant V_{CC} no waveform appears on the oscilloscope.

CONCLUSION: With an open collector circuit, I_C decreases to zero, V_C increases to V_{CC}, and there is no sinewave signal observed at the output.

EXERCISE 2 ANSWERS AND EXPLANATION (OPEN EMITTER)

See Figure 10 (next page) for voltage and current values, and waveforms.

1. Current to both base and collector must flow through the emitter. When there is an open emitter no current can flow through the emitter to either the base or collector so I_B and I_C must be zero.

2. The open emitter acts like a very large resistor so all of the voltage is dropped across the open and very little across the load resistor so voltage measured at the collector (V_C) is equal to the applied voltage (V_{CC}).

3. There is no sine wave at the collector because with the emitter open the transistor is cut off and does not pass the signal from base to collector. The collector voltage (V_C) remains at V_{CC} and shows on the oscilloscope as a straight horizontal line.

4. There will be no sine wave at TP-10 (Output) because the signal was interrupted at the transistor. If there is no sine wave at the collector there will be none beyond that point.

CONCLUSION: With an open emitter, I_C and I_B are zero, V_C is equal to the applied voltage (V_{CC}), and there is no sine wave signal at the collector.

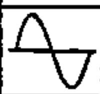
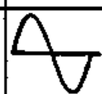
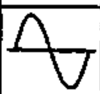
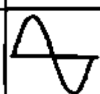
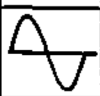
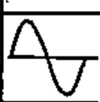
		1.	2.	3.	4.	5.	6.	7.
	Measurement Points	Normal Voltage, Current& Waveshape	Open Collector	Open Emitter	Open Biasing Arrangement	Open Output	Open Input	Shorted Transistor
	TP-2 to TP-3 (E_{IN})	ADJUST THE OUTPUT OF THE SIGNAL GENERATOR TO .05 VOLTS Pk-Pk ON THE OSCILLOSCOPE FOR EACH MALFUNCTION						
a.	TP-6 to TP-7 (I_B)	38 μa		0				
b.	TP-12 to TP-13 (I_C)	2 ma		0				
c.	TP-1 to TP-12 (E_{R_L})	8.5 V		0				
d.	TP-8 to TP-11 (V_C)	10.5 V		20 V				
e.	TP-7 to TP-9 (V_{EB})	.6 V		.85 V				
f.	TP-2 to TP-3 Input Waveshape							
g.	TP-7 to TP-4 Base Voltage Pk-Pk	.05 V Pk-Pk		.05 V Pk-Pk				
	TP-7 to TP-4 Base Waveshape							
h.	TP-8 to TP-11 Collector Voltage Pk-Pk	13 V Pk-Pk		0				
	TP-8 to TP-11 Collector Waveshape			——				
i.	TP-10 to TP-11 (E_{OUT}) Pk-Pk	13 V Pk-Pk		0				
	TP-10 to TP-11 (E_{OUT}) Waveshape			——				

Figure 10. Voltage, Current and Waveshapes with open emitter

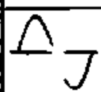
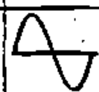
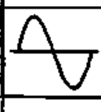
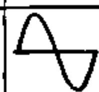
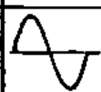
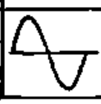
	Measurement Points	1. Normal Voltage, Current, Waveshape	2. Open Collector	3. Open Emitter	4. Open Biasing Arrangement	5. Open Output	6. Open Input	7. Shorted Transistor
	TP-2 to TP-3 (E_{IN})	ADJUST THE OUTPUT OF THE SIGNAL GENERATOR TO .05 VOLTS Pk-Pk ON THE OSCILLOSCOPE FOR EACH MALFUNCTION						
a.	TP-6 to TP-7 (I_B)	38 μa			0			
b.	TP-12 to TP-13 (I_C)	2 ma			0			
c.	TP-1 to TP-12 (E_{R_L})	8.5 V			0			
d.	TP-8 to TP-11 (V_C)	10.5 V			20 V			
e.	TP-7 to TP-9 (V_{EB})	.6 V			0			
f.	TP-2 to TP-3 Input Waveshape							
g.	TP-7 to TP-4 Base Voltage Pk-Pk	.05 V Pk-Pk			.05 V Pk-Pk			
	TP-7 to TP-4 Base Waveshape							
h.	TP-8 to TP-11 Collector Voltage Pk-Pk	13 V Pk-Pk			0			
	TP-8 to TP-11 Collector Waveshape				—			
i.	TP-10 to TP-11 (E_{OUT}) Pk-Pk	13 V Pk-Pk			0			
	TP-10 to TP-11 (E_{OUT}) Waveshape				—			

Figure 11. Voltage, Current and Waveshapes with open biasing arrangement

LABORATORY EXERCISE

EXERCISE 3 ANSWERS AND EXPLANATION (OPEN BIASING ARRANGEMENT)

See Figure 11 for voltage and current values, and waveforms.

1. There is no forward bias on the transistor when there is an open in the biasing arrangement. Without forward bias the transistor is cut off. At cut off, the resistance is very large so no current can flow from the emitter to either the base or the collector.

V_{EB} is zero because both the emitter and base are at ground potential.

2. V_C should be equal to V_{CC} (20 V). When the transistor is cut off the resistance is infinite, all of the voltage appears across the transistor.

3. The cut off transistor will not pass either AC or DC current. The sine wave signal is an AC current and so will not pass from the base to the collector and so cannot be seen at either the collector or output.

CONCLUSION: With an open biasing arrangement, there is zero I_C and I_B, V_C is equal to V_{CC}, and there is no signal observed at the output.

EXERCISE 4 ANSWERS AND EXPLANATION (OPEN OUTPUT)

See Figure 12 for voltage and current values, and waveforms.

1. No. Voltages and currents measured with an open output should be substantially the same as those measured without any malfunction. An open output has no effect on the DC current through the transistor nor on the voltage on the base or collector. Also, an open output has no effect on the sine wave signal until the signal reaches the open component.

2. There was a normal wave form at the collector.

3. There was no wave form at the output.

The only component between the collector and the output is the coupling capacitor so the trouble had to be that this capacitor was open.

CONCLUSION: With an open output, all voltages and currents are normal. The input and output from the transistor are normal. The output from the trainer is prevented from being observed due to an open coupling capacitor.

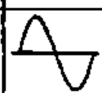
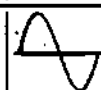
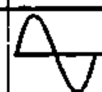
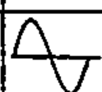
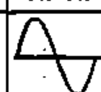
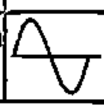
	Measurement Points	1. Normal Voltage, Current& Waveshape	2. Open Collector	3. Open Emitter	4. Open Biasing Arrangement	5. Open Output	6. Open Input	7. Shorted Transistor
	TP-2 to TP-3 (E_{IN})	ADJUST THE OUTPUT OF THE SIGNAL GENERATOR TO .05 VOLTS Pk-Pk ON THE OSCILLOSCOPE FOR EACH MALFUNCTION						
a.	TP-6 to TP-7 (I_B)	38 μa				40 ua		
b.	TP-12 to TP-13 (I_C)	2 ma				2 ma		
c.	TP-1 to TP-12 (E_{R_L})	8.5 V				8.5 V		
d.	TP-8 to TP-11 (V_C)	10.5 V				10.5 V		
e.	TP-7 to TP-9 (V_{EB})	.6 V				.6 V		
f.	TP-2 to TP-3 Input Waveshape							
g.	TP-7 to TP-4 Base Voltage Pk-Pk	.05 V Pk-Pk				.05 V Pk-Pk		
	TP-7 to TP-4 Base Waveshape							
h.	TP-8 to TP-11 Collector Voltage Pk-Pk	13 V Pk-Pk				13 V Pk-Pk		
	TP-8 to TP-11 Collector Waveshape							
i.	TP-10 to TP-11 (E_{OUT}) Pk-Pk	13 V Pk-Pk				0 V		
	TP-10 to TP-11 (E_{OUT}) Waveshape					—		

Figure 12. Voltage, Current and Waveshapes with an open output.

526

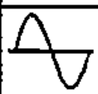
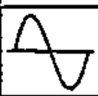
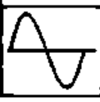
	Measurement Points	1. Normal Voltage Current Waveshape	2. Open Collector	Open Emitter	4. Open Biasing Arrange-ment	5. Open Output	Open Input	7. Shorted Tran-sistor
	TP-2 to TP-3 (E_{IN})	ADJUST THE OUTPUT OF THE SIGNAL GENERATOR TO .05 VOLTS Pk-Pk ON THE OSCILLOSCOPE FOR EACH MALFUNCTION						
a.	TP-6 to TP-7 (I_B)	38 μa					40 ua	
b.	TP-12 to TP-13 (I_C)	2 ma					2 ma	
c.	TP-1 to TP-12 (E_{R_L})	8.5 V					8.5 V	
d.	TP-8 to TP-11 (V_C)	10.5 V					10.5 V	
e.	TP-7 to TP-9 (V_{EB})	.6 V					.6 V	
f.	TP-2 to TP-3 Input Waveshape							
g.	TP-7 to TP-4 Base Voltage Pk-Pk	.05 V Pk-Pk					0	
	TP-7 to TP-4 Base Waveshape							
h.	TP-8 to TP-11 Collector Voltage Pk-Pk	13 V Pk-Pk					0	
	TP-8 to TP-11 Collector Waveshape							
i.	TP-10 to TP-11 (E_{OUT}) Pk-Pk	13 V Pk-Pk					0	
	TP-10 to TP-11 (E_{OUT}) Waveshape							

Figure 13. Voltage, Current and Waveshapes with an open input

536

EXERCISE 5 ANSWERS AND EXPLANATION (OPEN INPUT)

See Figure 13 for voltage and current values, and waveforms.

1. The waveform progresses through the amplifier from input, through the coupling capacitor to the base of the transistor then to the collector, coupling capacitor and output. If the waveform does not appear at any TP along this path it will not appear beyondthat TP. When it does not appear at TP-7 it will not appear at TP-8 or TP-10 and the trouble will be located between the input and TP-7.

2. DC current and voltage paths are intact and the components that the DC passes through are functioning properly. The waveform rides on this DC reference and has only a small effect on the DC currents and voltages.

3. With normal DC current and voltage, the trouble must be in the waveform signal path. When the waveform does not appear at any test points the trouble must be at the input. The only component that the waveform passes through between the input (TP-2) and TP-7 is the input coupling capacitor so this component must be open.

CONCLUSION: With an open input coupling capacitor, all DC currents and voltages are close to normal. The sinewave signal does not appear on the base, collector, or the output.

EXERCISE 6 ANSWERS AND EXPLANATION (SHORTED TRANSISTOR)

See Figure 14 (next page) for voltage and current values, and waveforms.

1. The transistor normally provides resistance to the flow of current. When the transistor is shorted there is no resistance so there is an increase in current flow.

2. Normally, a DC current path is from ground through the emitter resistor, through the transistor, and through the load resistor. This is a voltage divider network so part of the voltage is dropped across each component. When the transistor is shorted, the voltage is dropped only across the two resistors. As the emitter resistor is only about 1% as large as the load resistor, most of the voltage will be dropped across the load resistor, so E_{RL} will be almost as large as V_{CC}.

3. The output waveform is developed by the variation in the resistance of the transistor which normally allows more current to flow on the positive alternation (more forward bias) and less current to flow on the negative alternation. With Q_1 shorted maximum current flows at all times and is not effected by changes in bias. Therefore the output of the transistor is DC current which does not pass the coupling capacitor to the output.

CONCLUSION: With a shorted transistor, I_C increases, V_C decreases to almost zero, and there is no output from the circuit.

LABORATORY EXERCISE

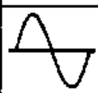
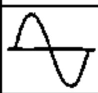
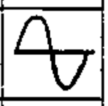
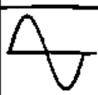
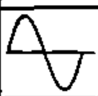
	Measurement Points	1. Normal Voltage, Current & Waveshape	2. Open Collector	3. Open Emitter	4. Open Biasing Arrangement	5. Open Output	6. Open Input	7. Shorted Transistor
	TP-2 to TP-3 (E_{IN})	ADJUST THE OUTPUT OF THE SIGNAL GENERATOR TO .05 VOLTS Pk-Pk ON THE OSCILLOSCOPE FOR EACH MALFUNCTION						
a.	TP-6 to TP-7 (I_B)	38 µa						40 ua
b.	TP-12 to TP-13 (I_C)	2 ma						4.6 ma
c.	TP-1 to TP-12 (E_{R_L})	8.5 V						19.5 V
d.	TP-8 to TP-11 (V_C)	10.5 V						0.2 V
e.	TP-7 to TP-9 (V_{EB})	.6 V						.6 V
f.	TP-2 to TP-3 Input Waveshape							
g.	TP-7 to TP-4 Base Voltage Pk-Pk	.05 V Pk-Pk						.05 V Pk-Pk
	TP-7 to TP-4 Base Waveshape							
h.	TP-8 to TP-11 Collector Voltage Pk-Pk	13 V Pk-Pk						0
	TP-8 to TP-11 Collector Waveshape							
i.	TP-10 to TP-11 (E_{OUT}) Pk-Pk	13 V Pk-Pk						0
	TP-10 to TP-11 (E_{OUT}) Waveshape							

Figure 14. Voltage, Current and Waveshapes with the transistor shorted

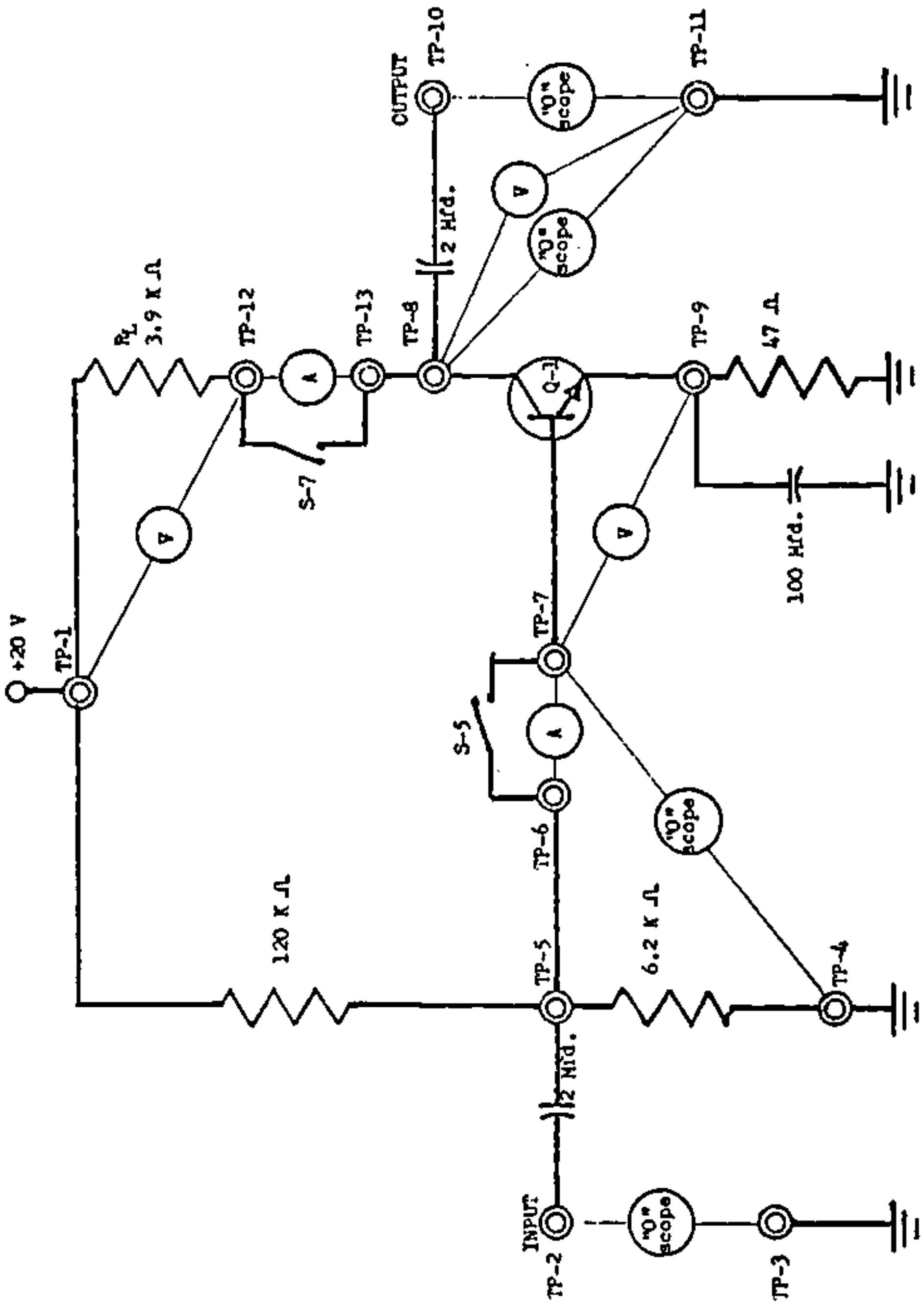


Figure 15. Transistor voltage amplifier test equipment connections

530

LABORATORY EXERCISE

	Measurement Points	1. Normal Voltage, Current Waveshape	2. Open Collector	3. Open Emitter	4. Open Biasing Arrangement	5. Open Output	6. Open Input	7. Shorted Transistor
	TP-2 to TP-3 (E_{IN})	ADJUST THE OUTPUT OF THE SIGNAL GENERATOR TO .05 VOLTS Pk-Pk ON THE OSCILLOSCOPE FOR EACH MALFUNCTION						
a.	TP-6 to TP-7 (I_B)							
b.	TP-12 to TP-13 (I_C)							
c.	TP-1 to TP-12 (E_{R_L})							
d.	TP-8 to TP-11 (V_O)							
e.	TP-7 to TP-9 (V_{EB})							
f.	TP-2 to TP-3 Input Waveshape							
g.	TP-7 to TP-4 Base Voltage Pk-Pk							
	TP-7 to TP-4 Base Waveshape							
h.	TP-8 to TP-11 Collector Voltage Pk-Pk							
	TP-8 to TP-11 Collector Waveshape							
i.	TP-10 to TP-11 (E_{OUT}) Pk-Pk							
	TP-10 to TP-11 (E_{OUT}) Waveshape							

Figure 16. Transistor Voltage Amplifier Trouble Shooting Summary Chart

531

PREPARE THE MAN

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-33

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

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SELECTED SOLID STATE DEVICES

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Basic and Applied Electronics Department
Keesler Air Force Base, Mississippi

Guidance Package 3AQR30020
KEP-GP-33
1 August 1974

ELECTRONIC PRINCIPLES

Module 33

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

Supersedes KEP-GP-33 dated 1 November 1973, stock on hand will be used.

SELECTED SOLID STATE DEVICES

1. SCOPE: This module will instruct you in the construction and basic operation of the Unijunction Transistor, the Junction Field Effect Transistor, the Metal Oxide Semiconductor Field Effect Transistor, the Tunnel Diode, the Varactor Diode, and the Silicon Controlled Rectifier. It will further instruct you on the application and physical characteristics of integrated circuits.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. From a list of statements, select the statement(s) that describe(s) the high and low conduction conditions of the Unijunction Transistor.

b. From a list of statements, select the statement(s) that describe(s) the conduction conditions of a Junction Field Effect Transistor.

c. Given a schematic diagram of a Junction Field Effect Transistor amplifier in the common source configuration, determine the effect input voltage changes have on drain current.

d. Given a list of statements, select the statement(s) that describe(s) conduction in enhancement and depletion Metal Oxide Semiconductor Field Effect Transistor.

e. Given a list of statements, select the statement(s) that describe(s) junction operation of a tunnel diode in terms of

(1) doping.

(2) tunneling.

f. Given a characteristic curve for a tunnel diode and a list of statements, select the statement(s) that correlate(s) its operation to areas and points on the curve.

g. Given a list of statements, select the statement(s) that describe(s) the effect of a changing bias voltage on the capacitance of a varactor diode.

h. From a list of statements, select the statement(s) that describe(s) the operation of a Silicon Controlled Rectifier in terms of

(1) breakover voltage.

(2) high conduction.

(3) holding current.

i. Given a list of statements, select the statement(s) that describe(s) the effect of gate to cathode potential on breakover voltage of a Silicon Controlled Rectifier.

j. Given a list of statements, select the statement(s) that describe(s) the operation of a Zener Diode in terms of

OVERVIEW

(1) doping

(2) voltage regulation

k. Given a list of statements, select the one which describes applications of integrated circuits.

l. Given a list of statements, select the one which describes the physical characteristics of integrated circuits.

AT THIS POINT, YOU MAY TAKE THE MODULE SELF-CHECK. IF YOU DECIDE NOT TO TAKE THE MODULE SELF-CHECK, TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

SELECTED SOLID STATE DEVICES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest

Adjunct Guide with Student Text

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

DIGEST

SELECTED SOLID STATE DEVICES

The Unijunction Transistor

The unijunction transistor (UJT) has two conduction conditions and operates similar to a switch. Figure 1 shows the basic construction and schematic symbols for the UJT.

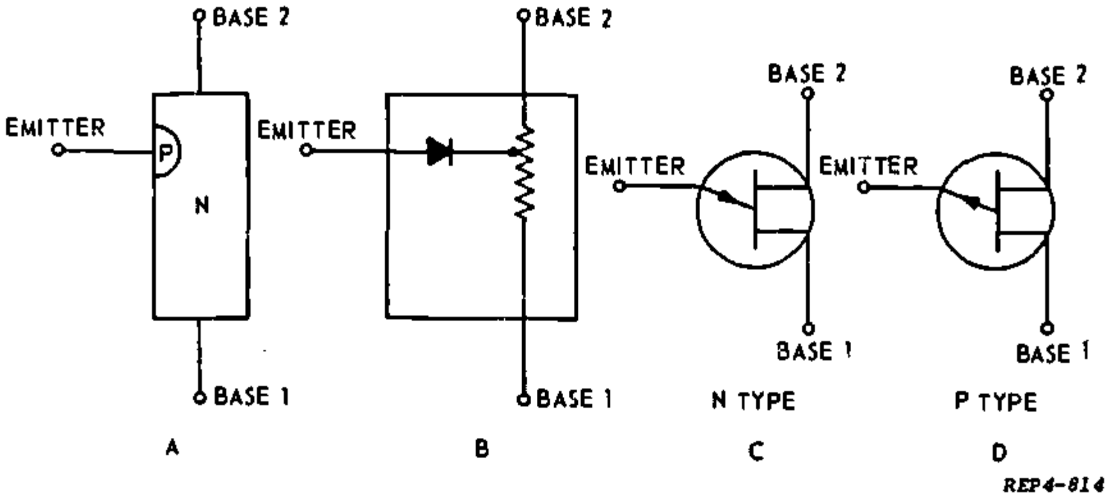


Figure 1. Unijunction Transistor

When the material between base 1 (B1) and base 2 (B2) is N type material, the emitter (E) will be P material. The opposite is true for the P type UJT.

The point where the emitter region is attached to the basic material forms a PN junction. When the PN junction is forward biased, the UJT is in its high conduction or ON state. When the PN junction is reverse biased, the UJT is in its low conduction or OFF state.

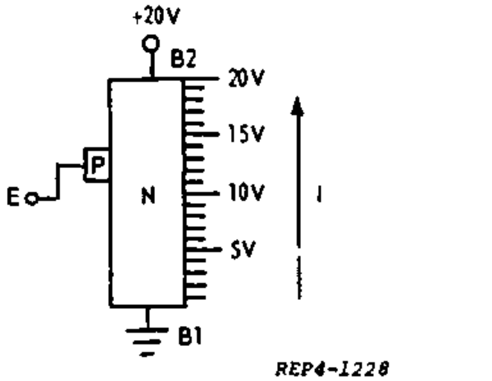


Figure 2. Pictorial Diagram of UJT Showing Low Conduction (OFF) Condition

First consider a voltage applied between B1 and B2 as illustrated in figure 2.

The applied voltage will be distributed evenly across the N material. The emitter to B1 junction will be reverse biased because the voltage gradient at the point where the emitter material is attached to the N material is at approximately +13 V. The emitter current at this time will be zero and the UJT will be its low conduction condition. This condition is illustrated as the peak voltage point (B) on figure 3.

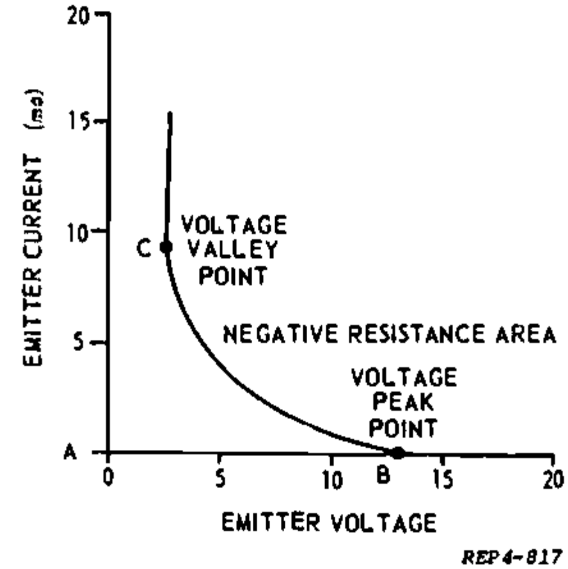


Figure 3. UJT Characteristic Curve

Figure 4 illustrates the high conduction (ON) condition of the UJT.

The 15 volts applied to the emitter will forward bias the emitter base 1 junction and a high emitter current will flow. The result of this high concentration of carrier movement in the area between the E and B1 causes the resistivity of the material to decrease and the voltage gradient across the bulk N material to be redistributed, as shown. The emitter current through R1 will drop the emitter voltage from 15 V to a value determined by the size of R1. Referring to figure 3, the UJT is now operating at point C on the curve.

The area between points B and C on the curve is referred to as the negative resistance (-R) area because emitter current increases for a decrease in emitter voltage. The time for the UJT to change from its low conduction to its high conduction condition is extremely short, in the order of nanoseconds (10^{-9}). The UJT is utilized in instances where fast switching is required.

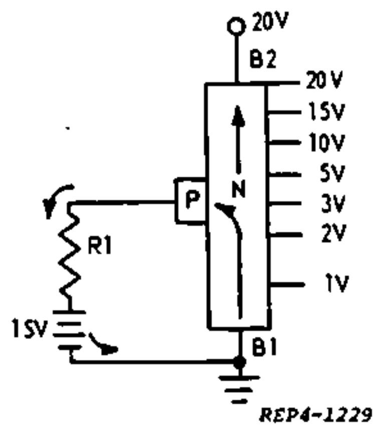


Figure 4. Pictorial Diagram of UJT Showing High Conduction (ON) Condition

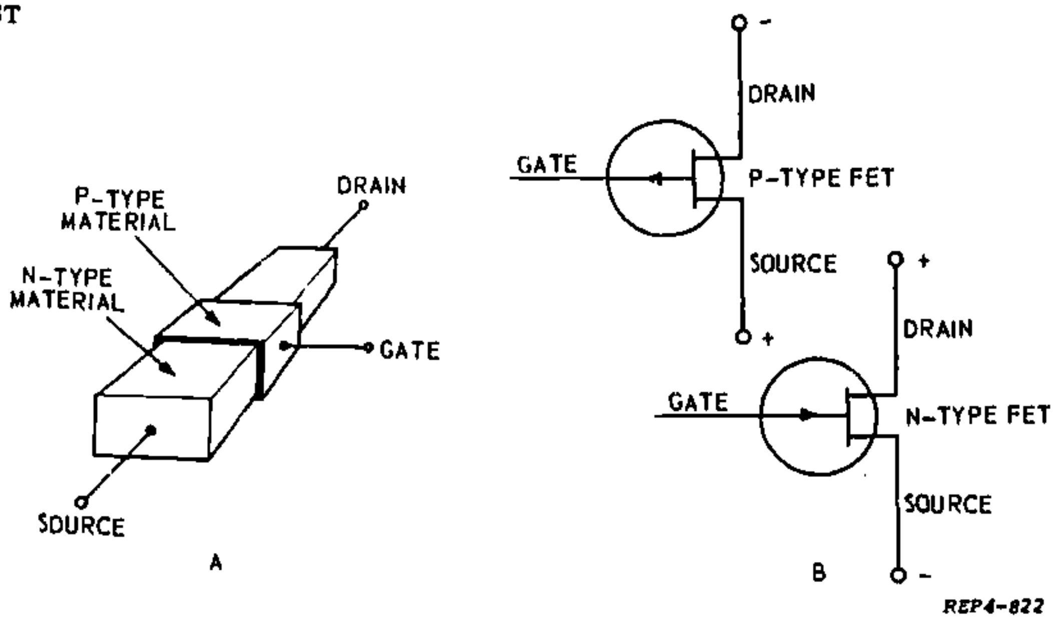


Figure 5. Pictorial Diagram and Schematic Symbols for JFETS

The Junction Field Effect Transistor (JFET)

The Junction Field Effect Transistor (JFET) is available in N and P types. Figure 5A illustrates the basic construction of an N type JFET and figure 5B shows the schematic symbol for N and P JFETS.

Connecting a voltage between the source and drain as illustrated in figure 6 will result in drain current (I_D) and a voltage gradient across the bulk N material. The voltage gradient between points A and B results in a reverse biased PN junction between the gate and the bulk N material and produces a cone-shaped depletion region between the P type gate material and the bulk N material. The depletion region projects completely around the bulk material and is cone-shaped, therefore, the size of the depletion region controls the area in the vicinity of the gate called the channel, through which I_D can flow. In other words, controlling the size of the depletion region controls I_D. Increasing the drain to source voltage (V_{DS}) will increase I_D and the size of the depletion region until the depletion region becomes so large that it restricts further increases in I_D. At this point, the device is saturated. This point is referred to as channel pinch-off and further increases in V_{DS} will not result in increases in I_D.

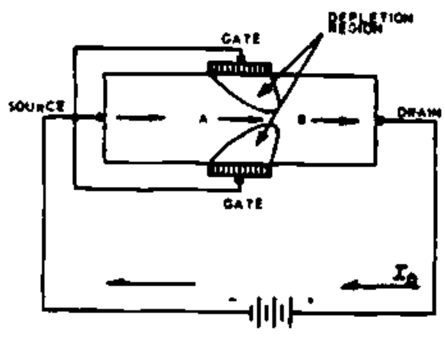


Figure 6. Conduction in an N Type JFET

The effect of V_{DS} changes is illustrated pictorially and graphically in figure 7. V_B is the point where the breakdown voltage of the PN junction is reached.

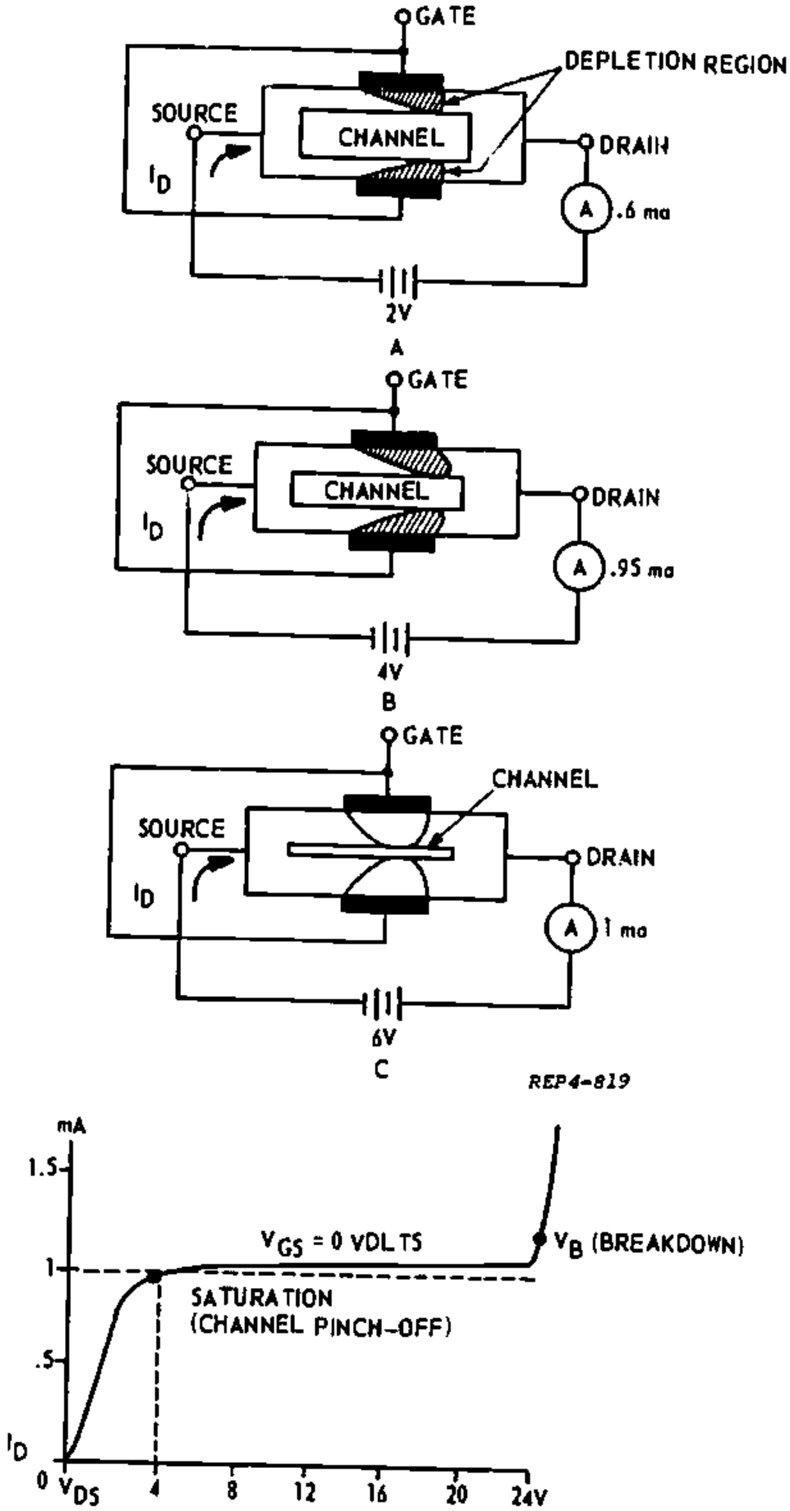


Figure 7. Effect of V_{DS} on I_D REP4-820

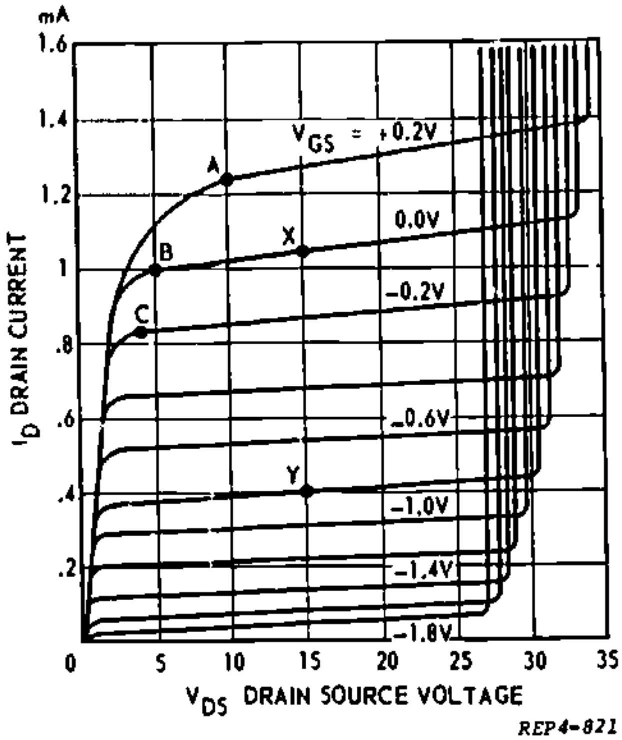


Figure 8. N-Type JFET Characteristic Curves

The size of the depletion region controls drain current. Figure 8 graphically illustrates the control that a voltage applied between the gate and source leads (V_{GS}) has on I_D. Note the similarity to the characteristic curves for a transistor.

The significant difference is that with the transistor, the base current (I_B) controls conduction; whereas in the JFET, the gate to source voltage controls the conduction. In other words, the JFET is a voltage-controlled device. Small changes in V_{GS} result in large changes in I_D.

The JFET can be used in three basic configurations, as with the transistor. They are the common source, common gate and common drain. Figure 9 illustrates a common source amplifier.

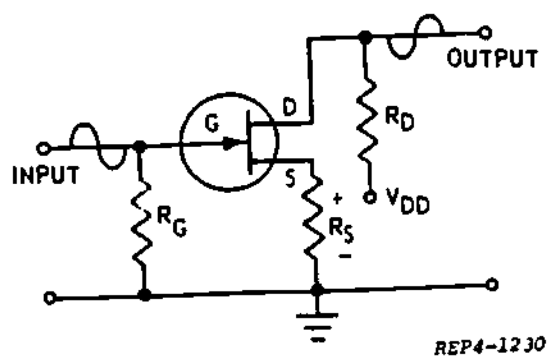


Figure 9. JFET Common Source Amplifier

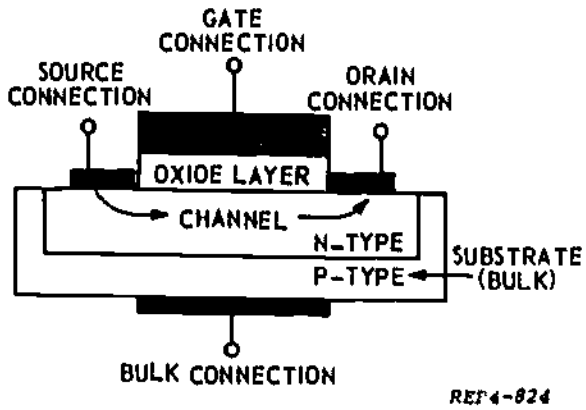


Figure 10. Cutaway View of MOSFET N Channel

Note that no biasing voltage is required. On the positive alternation, the reverse bias gate-to-source junction is decreased, decreasing the depletion region and increasing the channel size and drain current (I_D). This results in an increased voltage across the load resistor and a decreased output voltage (V_{DS}). The negative alternation increases the reverse bias, increases the depletion retion. and decreases I_D and E_{RL}, increasing the output (V_{DS}). The output voltage waveshape is larger than the input waveshape, thus amplification. Positive or negative biasing voltages (V_{GS}) can be used with a JFET to move the operating (Q) point.

The Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

The construction of an "N" Channel Metal Oxide Semiconductor Field Effect Transistor (MOSFET) is illustrated in figure 10. The "P" channel MOSFET uses an N type substrate.

MOSFETS can be constructed in the enhancement and depletion types. In the depletion MOSFET, the channel is heavily doped which results in high drain current for small drain-to-source voltages. The enhancement type MOSFET is lightly doped and I_D is small. Figure 11 and 12 illustrate the effect of V_{DS} and V_{GS} on the channel and I_D for N channel enhancement and depletion MOSFETS. Because the enhancement type MOSFET is lightly doped, the depletion region is large, thus restricting the channel and resulting in low drain current. The voltage gradient produced by V_{DS} modifies the channel width and a positive gate to

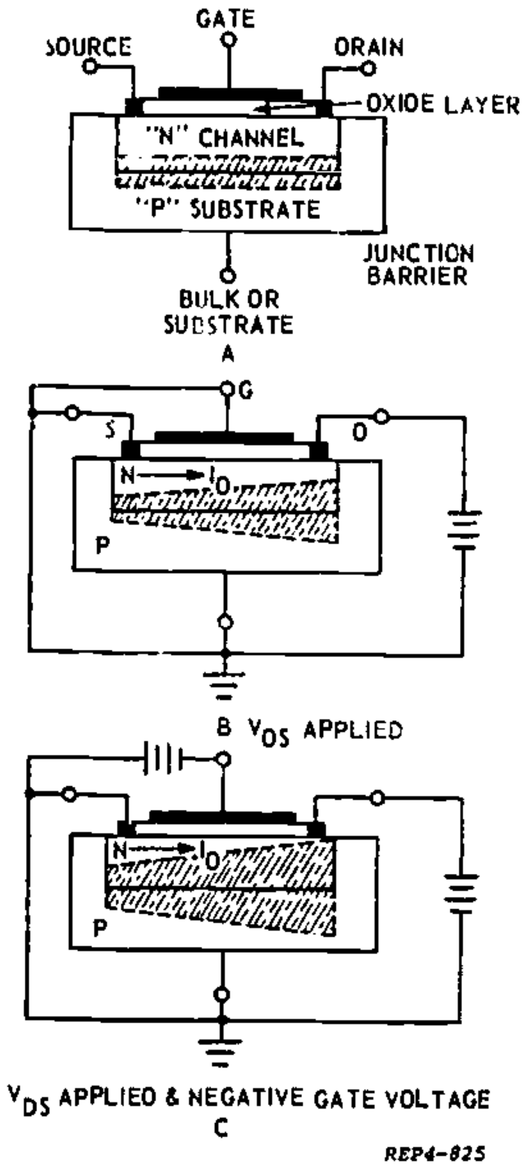


Figure 11. N-Channel Depletion Type MOSFET

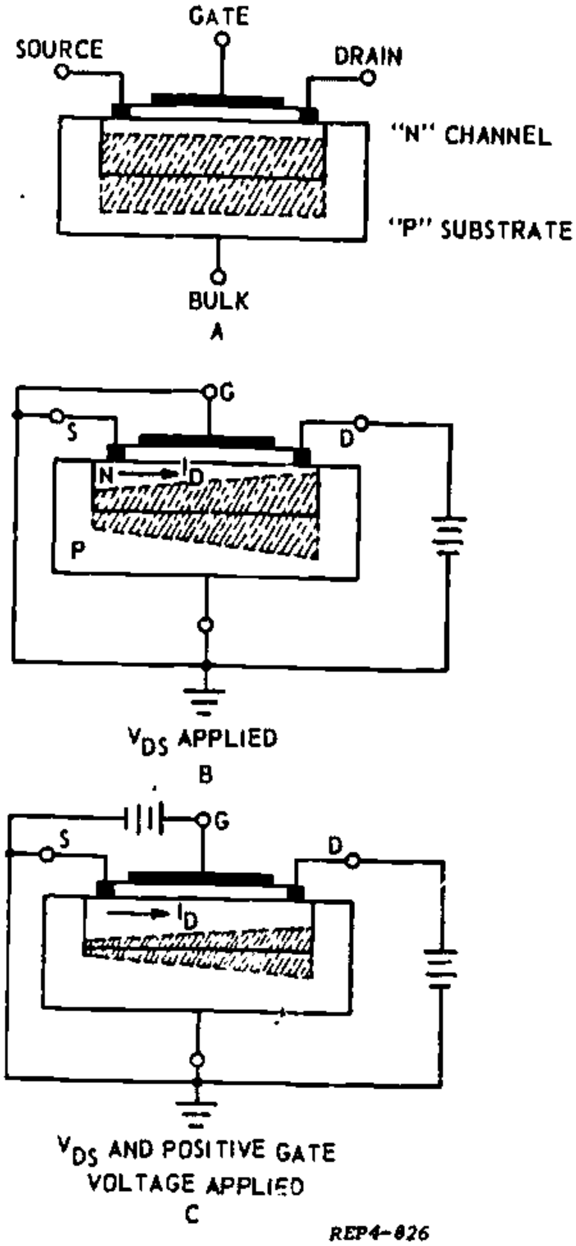


Figure 12. N-Channel Enhancement Type MOSFET

source voltage increases or enhances the channel. I_D increases with increases in the positive V_{GS} voltage.

In the depletion MOSFET which is heavily doped, the depletion region is small, making the channel large and resulting in high drain current. The voltage gradient produced by V_{DS} modifies the channel and the negative gate to source voltage decreases, or depletes the channel width. I_D decreases with increases in the negative V_{GS} voltage.

Figure 13 shows the schematic symbols for MOSFETS.

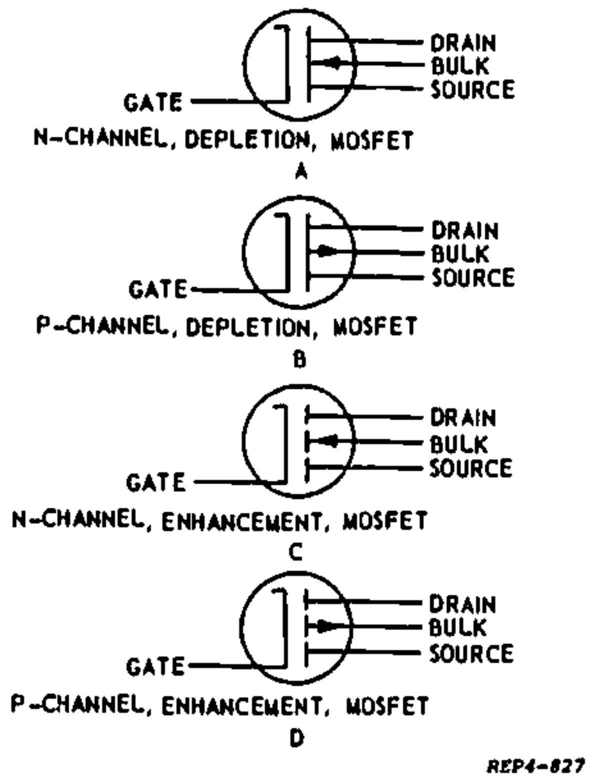


Figure 13. MOSFET Symbols

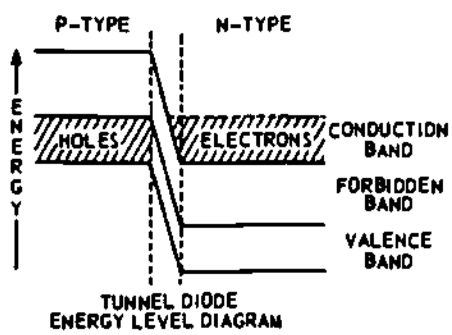


Figure 14. Energy Level Diagram of an Unbiased Tunnel Diode

The Tunnel Diode

A Tunnel Diode is an extremely heavily doped PN junction diode. Figure 14 shows the energy level diagram of an unbiased tunn^l diode.

The ionization at the junction caused by junction recombination results in the displacement of the energy bands, so that the conduction band electrons in the N material are at the same energy level as the valence band holes in the P material. The depletion region is extremely thin.

Applying a small forward bias results in the movement of electrons from the conduction band of the N material directly into the valence band of the P material. Holes in the valence

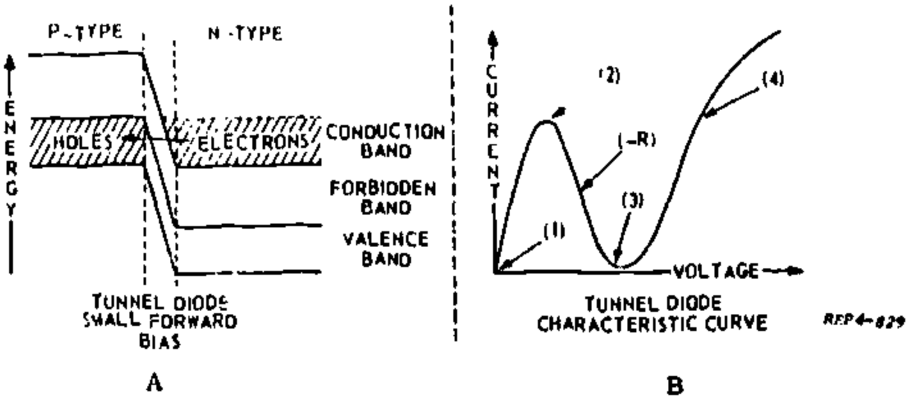


Figure 15. Energy Level Diagram and Characteristic Curve for a Tunnel Diode

band of the P material move directly into the conduction band of the N material. This is a very unconventional movement in that the carriers p. s through, or tunnel under, the forbidden band as they move across the PN junction. Figure 15A depicts this movement and figure 15B graphically illustrates the voltage/current relationship for the tunnel diode. The current that flows between points 1 and 3 on the graph occurs because of this tunneling.

Increasing forward bias changes the relationship between the energy levels of the N and P materials. The N material increases in energy and the P material decreases. The area on the characteristic curve between points 2 and 3 is where the electrons in the N material become opposite in energy to the forbidden band of the P material and the holes in the P material become opposite the forbidden band of the N material. This action is illustrated in figure 16.

This increase in forward bias will result in decreased conduction until the majority carriers are all aligned with the forbidden band and current flow is minimum (point 3 on the curve). Between points 2 and 3 on the curve, the tunnel diode exhibits a negative resistance characteristic (-R). As forward bias is further increased, the electrons in the N material pass into the conduction band of the P material and the holes in the P material pass into the valence band of the N material. This is conventional conduction and it is illustrated in figure 17. The area between points 3 and 4 on the characteristic curve represents conventional conduction.

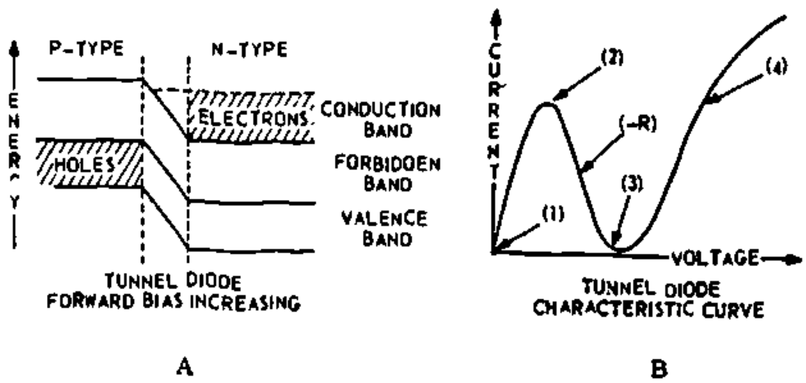


Figure 16. Energy Level Diagram and Characteristic Curve for a Tunnel Diode

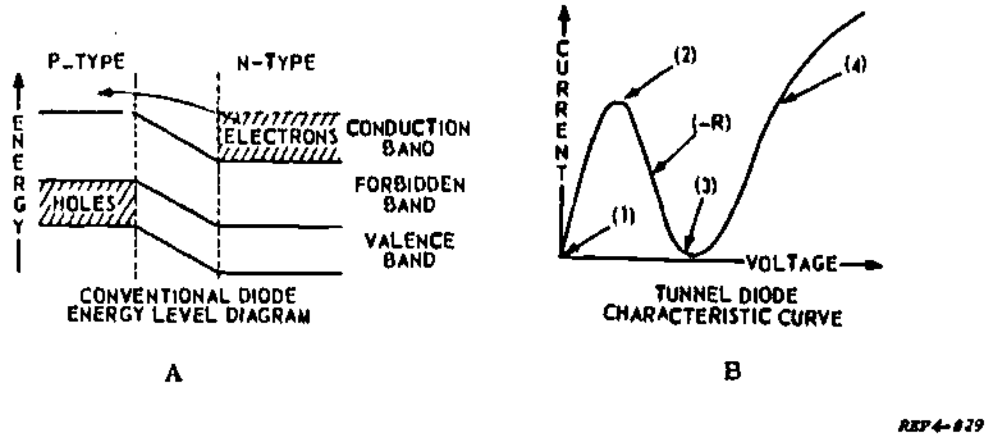


Figure 17. Tunnel Diode Energy Level Diagram and Characteristic Curve

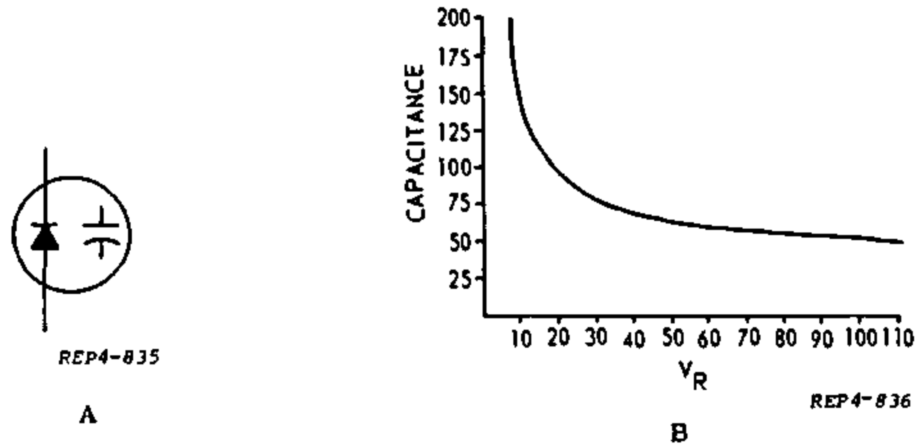


Figure 18. Varactor Diode Schematic Symbol and Characteristic Curve

The Varactor Diode

A capacitor is described as two conductors separated by a dielectric. A reverse biased PN junction diode exhibits the properties of a capacitor. The N and P materials become the conductors separated by the depletion region (the dielectric). Varying the reverse bias changes the width of the depletion region, thus changing the capacitance of the diode. A diode designed to be used as a variable capacitor is called a VARACTOR. From the formula for capacitance:

$$C = K\frac{A}{D}$$

the effect of changing the reverse bias on capacitance can be determined. Increasing reverse bias increases the depletion region (increased distance, D) resulting in a decreased capacitance. Decreasing reverse bias increases capacitance. Figure 18 shows the schematic symbol (A) and characteristic curve (B) for a varactor diode.

The Silicon Controlled Rectifier (SCR)

A Silicon Controlled Rectifier (SCR) is a 4 layer, 3 junction device. Figure 19 is the pictorial diagram and schematic symbol for the SCR. Conduction in the SCR can be achieved by the application of an anode to cathode voltage and by applying a gate-to-cathode voltage. After conduction is achieved, the anode-to-cathode voltage and the gate-to-cathode voltages lose control of conduction. Figure 20A illustrates how high conduction is achieved by the application of an anode to cathode voltage and figure 20B is the characteristic curve.

Section 1 (S_1) of the SCR is more heavily doped than section 2 (S_2). Junctions J_1 and J_3 are forward biased and J_2 is reverse biased. As the arm of the potentiometer (R_1) is moved up (more positive), the anode to cathode voltage is increased. The only conduction is the reverse current across J_2. When the anode-to-cathode voltage reaches the breakover voltage (see curve) junction, J_2 goes into reverse breakdown momentarily. This results in the injection of a high concentration of electron carriers from section S_1 to S_2. These electrons, once in S_2, act as minority carriers (electrons in P material) and move easily across the junction (J_2). Once they arrive in S_3, they again become majority carriers and move easily across J_1. The result is high conduction and a large voltage drop across R_L. This immediately reduces the anode-to-cathode voltage and brings junction, J_2, out of reverse breakdown. The SCR remains in high conduction because of the continued injection of electron carriers from S_1 to S_2. If the current is allowed to drop below "holding current" (see chart), then carrier

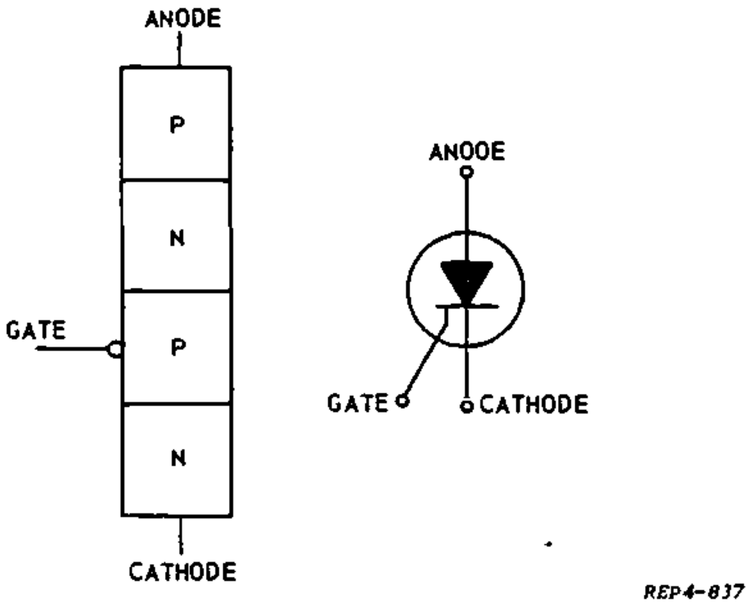


Figure 19. Silicon Controlled Rectifier (SCR) Structure and Schematic Symbol

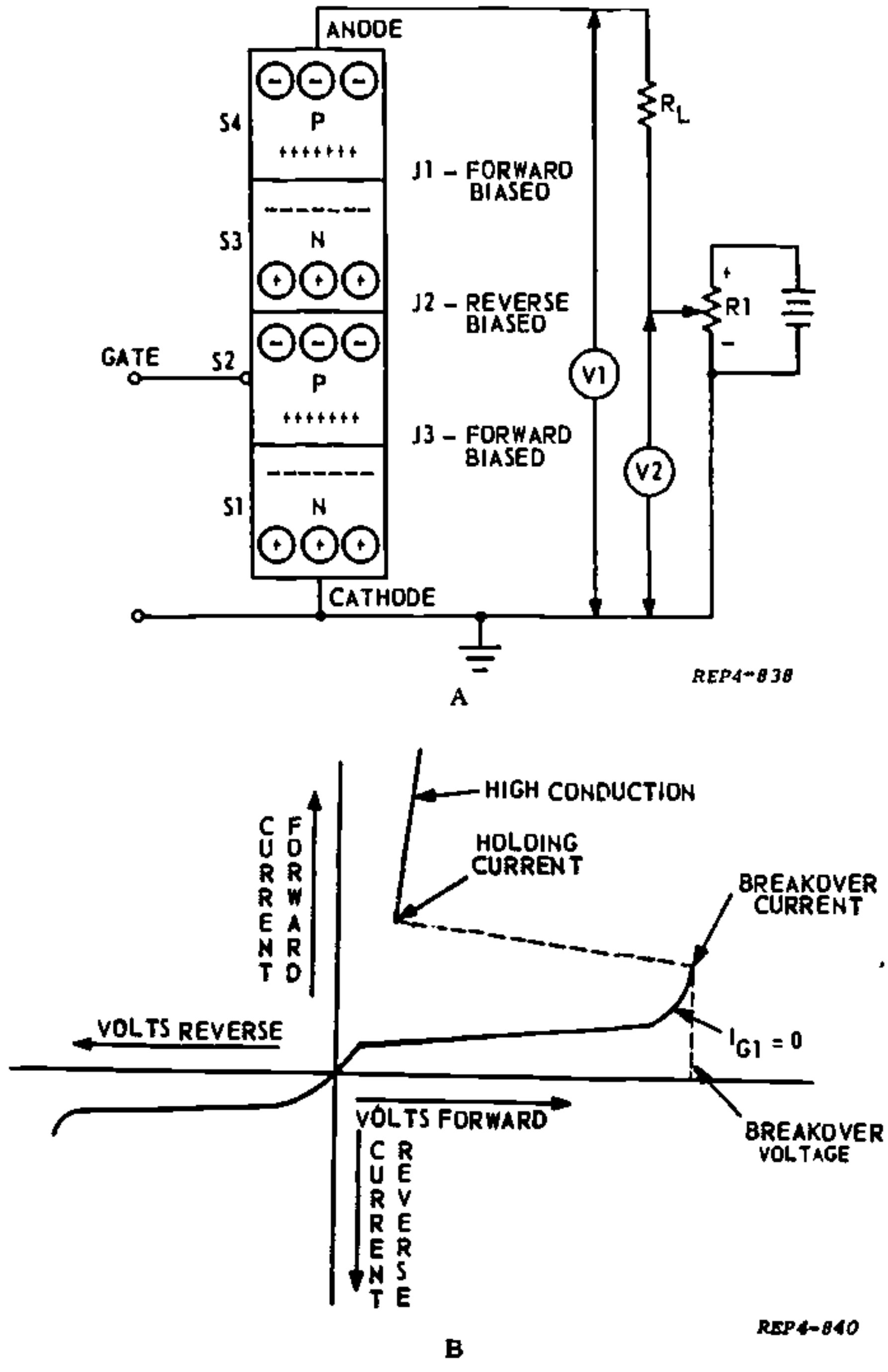


Figure 20. Biasing and Characteristic Curve for an SCR

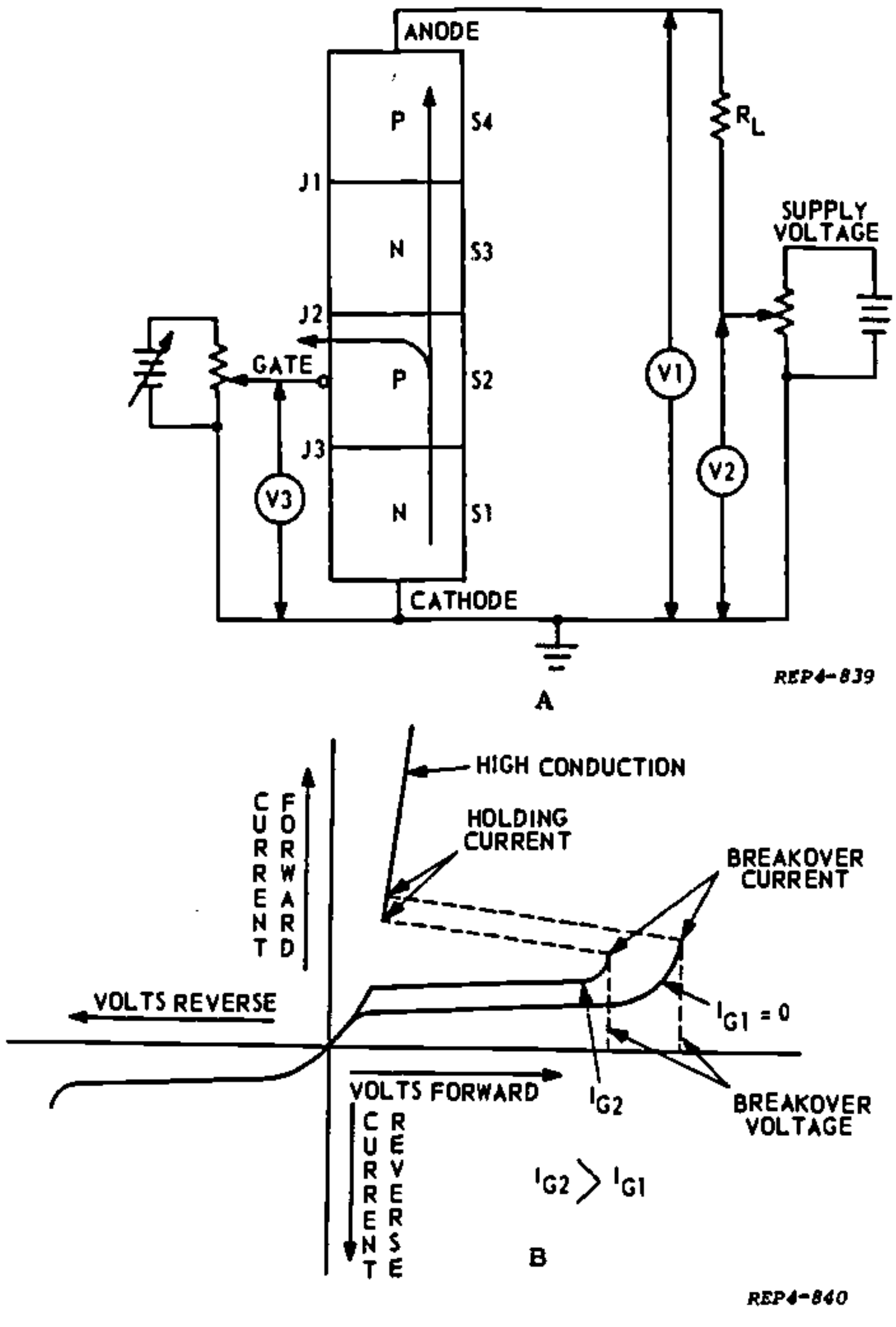


Figure 21. Schematic Diagram and Characteristic Curve for a Gated SCR

injection into S_2 will not be sufficient to maintain high conduction. Notice that the anode-to-cathode voltage remains relatively constant for large changes in current. Refer to figure 21A and 21B to determine the effect of a gate-to-cathode voltage on conduction in an SCR.

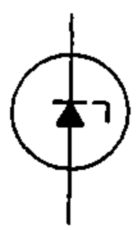
The application of a gate voltage will result in gate current and the injection of electron carriers from S_1 and S_2 with no anode-to-cathode voltage applied. The result is that a significantly smaller amount of anode-to-cathode voltage is required to achieve high conduction (see chart). The gate voltage, therefore, can be used to determine what breakover voltage is required to achieve high conduction. Again, the holding current determines when the SCR will drop out of high conduction.

The Zener Diode

A zener diode is a PN junction diode whose doping has been increased so that it can operate in the reverse breakdown, avalanche current area of the characteristic curve without causing structural breakdown. While operating in the avalanche current area, the zener diode will maintain a relatively constant voltage across it for a wide range of diode currents. Figure 22A and 22B show the schematic symbol and the characteristic curve for a zener diode. By controlling doping, a zener diode can be manufactured to provide a regulated voltage between approximately 3 to 20 volts. They are connected in series if a larger regulated voltage is required. Structural breakdown occurs when the maximum power dissipation rating is exceeded.

Integrated Circuits

Integrated circuits are divided into two categories, HYBRID and MONOLITHIC. In the monolithic integrated circuit, all elements (resistors, transistors, diodes, and capacitors are fabricated inseparably within a continuous piece of material called the SUBSTRATE. If the substrate is N material, then controlled amounts of P material will be doped into the substrate



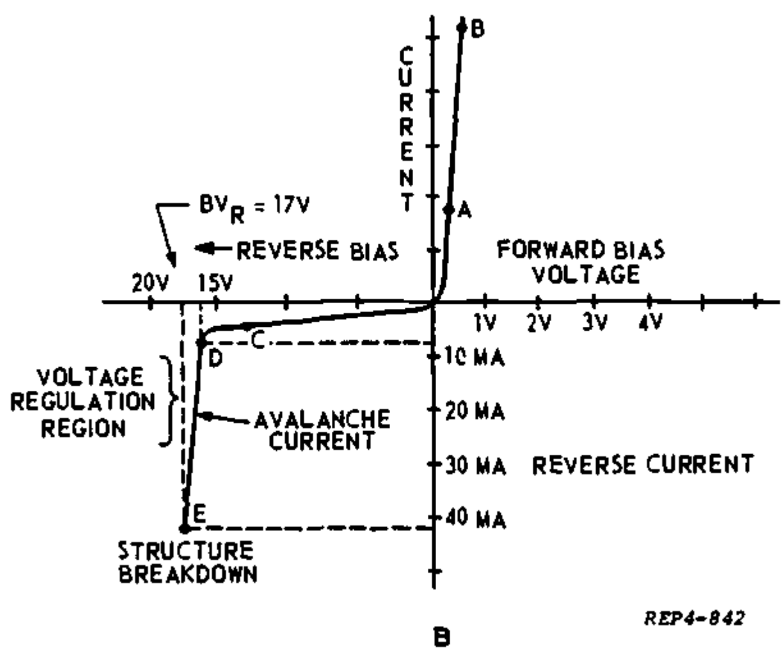


Figure 22. Schematic Symbol and Characteristic Curve for a Zener Diode

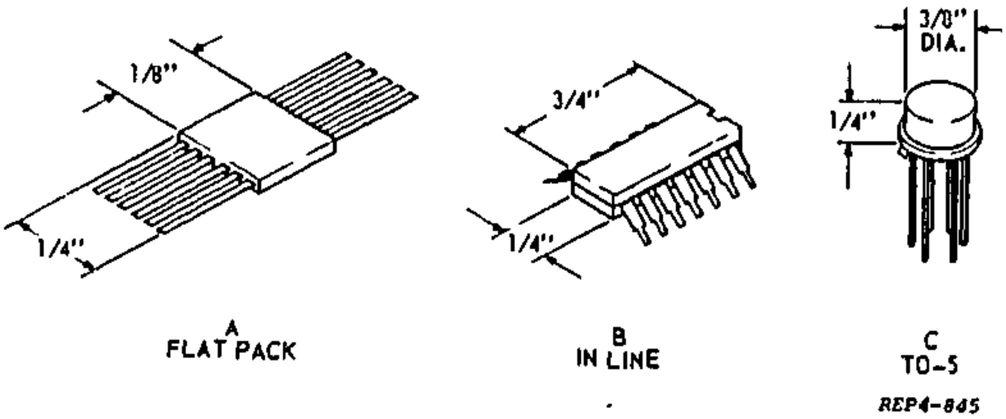


Figure 23. Package Styles for Integrated Circuits

to form the components. Metallic contacts are attached to these areas and leads are connected. An entire electronic circuit can be manufactured on a single piece of substrate 40 by 60 thousandths of an inch in size.

Hybrid integrated circuits have the passive components (resistors, capacitors) deposited on a substrate made of glass, ceramic, or some other insulating material. The active components (diodes, transistors) are then attached to the substrate. Figure 23 shows some typical examples of integrated circuit packages. One of these tiny packages may contain one or several circuits and often have several hundred components.

Integrated circuits are small in size and light in weight. They consume very little power and are highly reliable. This makes them ideally suited for use in airborne equipment, missile systems, computers, spacecraft, and portable equipment. Because of their construction they are not normally repaired. When a package fails, the entire package is replaced.

SELECTED SOLID STATE DEVICES

INSTRUCTIONS:

Study the referenced material as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the top of the next even numbered page following the questions.

If you experience any difficulty, contact your instructor.

Begin the program.

Since the invention of the transistor there has been a continuing effort to improve it. This improved technology has resulted in the development of solid state devices capable of performing practically any of the electrical functions demanded by today's society. This module will investigate the basic construction and operation of some of the more common devices. All new Air Force Systems employ some or all of these devices; therefore, it is extremely important to become familiar with them.

A. Turn to Student Text, Volume IV, and read paragraphs 4-1 through 4-11. Return to this page and answer the following questions.

1. A unijunction transistor (UJT) exhibits a (negative) (positive) resistance characteristic between the peak and valley voltage points.

2. The amount of time required for a UJT to change from its low conduction to its high conduction condition is (short) (long) when compared to a mechanical switch.

3. When the UJT is in its high conduction condition, the resistance between the emitter and base #1 is (low) (high).

4. When the UJT is in its low conduction condition the resistance between the emitter and base #1 is (low) (high).

5. The emitter-to-base #1 junction must be (forward) (reverse) biased to cause high conduction or the ON condition of the UJT.

6. What will be the conduction condition of the UJT if the emitter-to-base #1 junction were reverse biased? ______________________________

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

B. Turn to Student Text, Volume IV, and read paragraphs 4-12 through 4-30. Return to this page and answer the following questions.

1. The input impedance to a Junction Field Effect transistor (JFET) is (low) (high).

ADJUNCT GUIDE

ANSWERS TO A:

1. negative
2. short
3. low
4. high
5. forward
6. low conduction on OFF condition.

2. Increasing the positive voltage applied to the gate of a "N" type JFET would result in an (increase) (decrease) in drain current (I_D).

3. What effect would applying a more negative voltage to the gate lead of an N type JFET (figure 9) have on the drain to source voltage (V_{DS})?____________________.

4. The JFET is a (voltage) (current) controlled device.

5. Increasing the drain-to-source voltage applied to a JFET would cause a/an (increase) (decrease) in the channel width.

6. When a further increase in V_{DS} will not cause an increase in I_D, the JFET is saturated. The point that this condition occurs is referred to as ____________________.

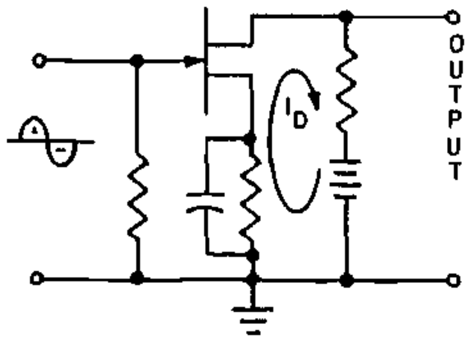
7. The value of gate-to-source (V_{GS}) that reduces the channel width of a JFET to a point where I_D ceases to flow is referred to as ________________ voltage.

8. The controlling element in a JFET is the __________________.

9. Increasing the negative voltage applied to the gate of a "P" type JFET would cause I_D to (increase) (decrease).

10. Refer to diagram on the next page:

On the positive alternation of the input signal the drain current will (increase) (decrease).



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11. Refer to diagram above:

The voltage waveshape at the output terminals will be (in) (180° out of) phase with the input.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

C. Turn to Student Text, Volume IV, and read paragraphs 4-31 through 4-38. Return to this page and answer the following questions:

1. The input impedance of a Metal Oxide Semi-conductor Field Effect Transistor (MOSFET) is (higher) (lower) than that for a JFET.

2. The type MOSFET that works on the principle that an increase in gate voltage results in an increase in drain current is a/an ____________________ type MOSFET.

3. The type MOSFET that works on the principle that an increase in gate voltage results in a decrease in drain current is a/an ____________________ type MOSFET.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

D. Turn to Student Text, Volume IV, and read paragraphs 4-39 through 4-49. Return to this page and answer the following questions.

1. The doping of a tunnel diode is (heavier) (lighter) than that of a conventional PN junction diode.

2. Compare the barrier height and width of a tunnel diode to that of a conventional PN junction diode.

Barrier height is ____________________.

Barrier width is ____________________.

ADJUNCT GUIDE

ANSWERS TO B:

1. high
2. increase
3. V_{DS} would increase
4. voltage
5. decrease
6. channel pinch-off
7. pinch off
8. gate
9. increase
10. increase
11. 180° out of

If you missed ANY questions, review the material before you continue.

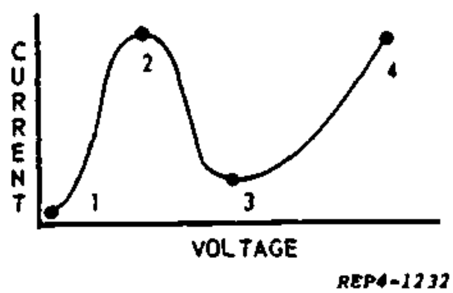
ANSWERS TO C:

1. higher
2. enhancement
3. depletion

If you missed ANY of the questions, review the material before you continue.

3. In a tunnel diode, tunnelling occurs when electrons from the conduction band of the N material pass through the depletion region directly into the valence band of the P material. (True) (False)

Refer to the following diagram for questions 4 through 7.



Tunnel Diode Characteristic Curve

4. The area between points 2 and 3 is where a tunnel diode exhibits a (negative) (positive) resistance characteristic.

5. At point 3, the placement of the energy bands of the P and N materials has the valence band of the P material aligned with the ________________ band of the N material.

6. The tunnel diode operates similarly to a conventional PN junction diode between points __________ and __________.

7. At point 2, the valence band of the P material is exactly aligned with the ______ band of the N material.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

E. Turn to Student Text, Volume IV, and read paragraphs 4-50 through 4-56. Return to this page and answer the following questions.

1. The varactor diode will act as a capacitor with forward or reverse bias applied. (True) (False)

2. The dielectric of the varactor diode used as a capacitor is the junction depletion region. (True) (False)

3. Increasing the reverse bias applied to a varactor diode will (increase) (decrease) its capacitance.

4. The varactor diode responds best as a variable capacitor for (high) (low) values of reverse bias.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

F. Turn to Student Text, Volume IV, and read paragraphs 57 through 65. Return to this page and answer the following questions.

Refer to the diagram on the next page for questions 1 and 2.

1. What is the doping relationship that exists between section #1 and section #2?

____

____.

ANSWERS TO D:

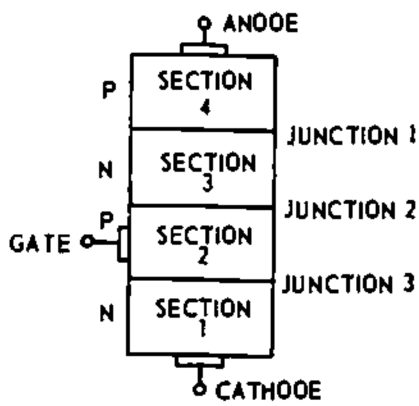
1. heavier
2. higher, narrower
3. true
4. negative
5. forbidden
6. 3 and 4
7. conduction

If you missed ANY questions, review the material before you continue.

ANSWERS TO E:

1. false
2. true
3. decrease
4. low

If you missed ANY questions review the material before you continue.



2. When the SCR is in its non-conducting or OFF state what will be the bias conditions of junctions 1, 2, and 3?

Junction 1 is ____________________

Junction 2 is ____________________

Junction 3 is ____________________

3. There are two methods of achieving high conduction in an SCR. They are:

1. ______________________________

2. ______________________________

4. The breakover voltage is the voltage required between the anode and cathode to turn the SCR ON or put it into its high conduction condition. (True) (False)

5. Applying a small positive voltage to the gate of an SCR will cause the breakover voltage required to obtain high conduction to (increase) (decrease).

6. The minimum current that can be realized in an SCR and still maintain high conduction is referred to as __________________________ current.

7. What effect does the gate-to-cathode voltage have on the operation of an SCR after it is in its high conduction condition? ____.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

G. Turn to Student Text, Volume IV, and read paragraphs 4-66 through 4-71. Return to this page and answer the following questions.

1. Operating the zener diode in the breakdown voltage/avalanche current area will cause structural breakdown. (True) (False).

2. The zener diode is designed to operate over a wide range of current values and maintain a relatively constant voltage across the diode. (True) (False)

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

ANSWERS TO F:

1. Section #1 is more heavily doped than section #2.
2. Junction #1 is forward biased.

   Junction #2 is reversed biased.

   Junction #3 is forward biased.
3. Exceeding the anode to cathode breakover voltage or applying a positive gate to cathode voltage.
4. true
5. decreased
6. holding current
7. no effect.

If you missed ANY questions, review the material before you continue.

ANSWERS TO G:

1. false
2. true

If you missed ANY questions, review the material before you continue.

H. Turn to Student Text, Volume IV, and read paragrpahs 4-72 through 4-81. Return to this page and answer the following questions.

1. Integrated circuits are small in size, height and weight and are highly reliable. Because of this they are readily adaptable to many circuit applications. List five of their most common uses:

a. ______________________________

b. ______________________________

c. ______________________________

d. ______________________________

e. ______________________________

2. A monolithic integrated circuit differs from a hybrid integrated circuit in that the monolithic circuit has all of its components, including the transistors, resistors, capacitors and diodes fabricated within a single piece of material and the hybrid circuit uses discrete components mounted on a substrate. (True) (False)

3. It is impossible to repair a monolithic integrated circuit (True) (False)

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

ANSWERS TO H:

1. a. missiles

   b. computers

   c. spacecraft

   d. portable equipment

   e. airborne equipment

2. true

3. true

If you missed ANY questions, review the material before you continue.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

SELECTED SOLID STATE DEVICES

QUESTIONS:

1. A unijunction transistor acts as a voltage controlled __________________________ .

2. Refer to figure 1. Under the condition shown, current through R_2 is (high) (low) and the emitter-base 1 junction is (forward) (reverse) biased.

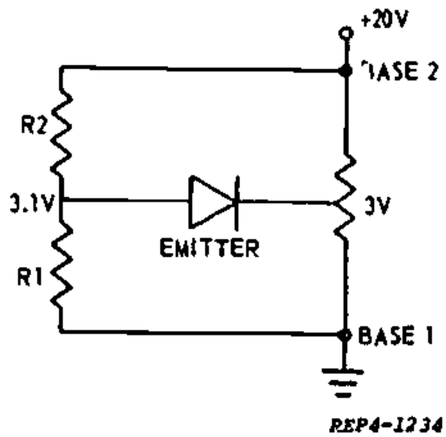


Figure 1

3. The negative resistance characteristic of a unijunction transistor determines its SWITCHING time. True___ False___

4. The input impedance of a JFET is (low) (high).

5. Select the correct statement about JFET's.

_____ a. The amount of drain current, under saturation conditions, depends mainly on drain-to-source (V_{DS}) voltage.

_____ b. In an N-channel JFET, the gate-to-source (V_{GS}) voltage is always positive.

_____ c. After PINCH-OFF, I_{DS} depends primarily on V_{GS}.

_____ d. Prior to PINCH-OFF, the depletion region decreases as V_{DS} increases.

MODULE SELF-CHECK

Refer to figure 2 for questions 6 and 7.

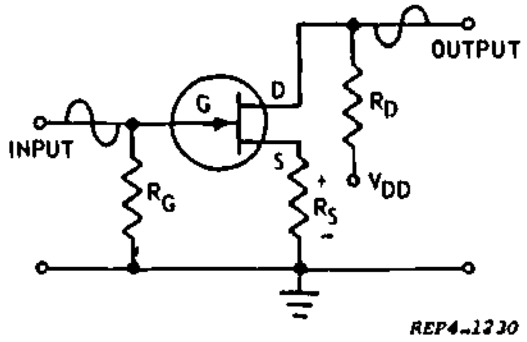


Figure 2

6. The configuration is:

_____a. common drain.

_____b. common source.

_____c. common gate.

7. As the input signal goes positive, drain current (decreases) (increases).

8. The MOSFET has a low input impedance and capacitance. True ___ False ___

9. With zero volts V_{GS} and 10 volts V_{DS} applied to both, drain current would be (greater) (less) in a depletion type MOSFET than in an enhancement type.

10. In a tunnel diode, the barrier width is extremely thin due to very heavy doping. True ___ False _____

11. When a tunnel diode is properly biased for tunneling, the conduction band of the N material is aligned with the ______________________ band of the P material.

Refer to figure 3 for questions 12 and 13.

12. TUNNELING occurs only between points

_____a. 1 and 2. _____c. 3 and 4.

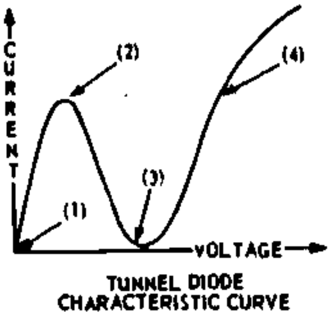
_____b. 2 and 3. _____d. 1 and 3.

13. The negative resistance area is between points

_____a. 2 and 3.

_____b. 1 and 2.

_____c. 3 and 4.



REP4-829

Figure 3

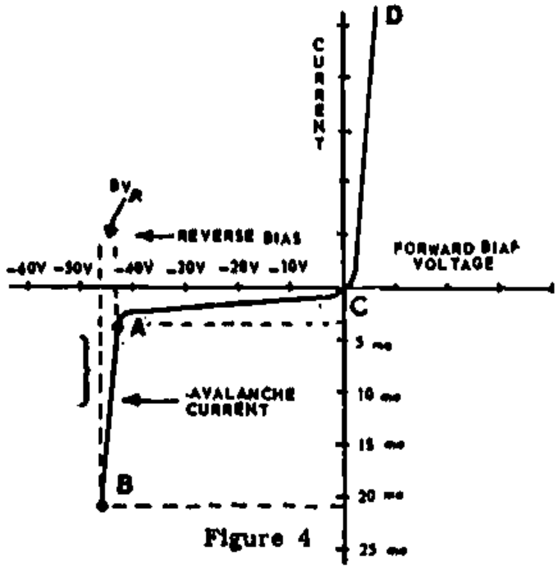


Figure 4

14. As the reverse bias applied to a varactor diode increases its capacitance ________.

15. A silicon controlled rectifier (SCR) is a __________ layer semiconductor with __________ junctions.

16. High conduction occurs in a SCR when forward __________ potential is reached or when the gate is __________ in respect to the cathode.

17. As long as HOLDING current flows in a SCR, its resistance will be (high) (low).

18. The forward breakover voltage of a SCR (increases) (decreases) as the gate to cathode voltage is made more positive.

19. The voltage at which a zener diode regulates depends on the amount of

_____a. forward bias _____c. reverse current

_____b. forward current _____d. doping.

20. Refer to figure 4. The voltage regulating region is between points

_____a. A and B

_____b. A and C.

_____c. C and D.

21. The small size and weight and high reliability of integrated circuits make them ideally suited for use in missile, spacecraft and portable equipment. True____ False____

22. An integrated circuit whose physical dimensions measure 1/4" x 1/8" could contain several dozen components. True___ False____

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

MODULE SELF-CHECK

ANSWERS TO MODULE SELF-CHECK:

1. switch
2. high, forward
3. True
4. high
5. c
6. b
7. increases
8. False
9. greater
10. True
11. valence
12. d
13. a
14. decreases
15. 4, 3
16. breakover, positive
17. low
18. decreases
19. d
20. a
21. True
22. True

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.