ABSTRACT

Designed for use in basic electronics programs, this curriculum guide is comprised of 15 units of instruction. Unit titles are Review of the Nature of Matter and the P-N Junction, Rectifiers, Filters, Special Semiconductor Diodes, Bipolar-Junction Diodes, Bipolar Transistor Circuits, Transistor Amplifiers, Operational Amplifiers, Logic Devices, Logic Systems, Special Semiconductor Devices, Oscillators, Transmitters, Receivers, and Tubes. Each instructional unit includes some or all of the basic components of a unit of instruction: performance objectives, suggested activities for the instructor, information sheets, transparency masters, job sheets, assignment sheets, answers to assignment sheets, tests, and answers to tests. Each unit is planned for more than one lesson or class period of instruction. (YLB)
BASIC ELECTRONICS II

by
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and
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Developed by the
Mid-America Vocational Curriculum Consortium, Inc.

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FOREWORD

The Mid-America Vocational Curriculum Consortium (MAVCC) was organized for the purpose of developing instructional material for the eleven member states. Priorities for developing MAVCC material are determined annually based on the needs as identified by all member states. One priority identified was basic electronics. This publication is a part of a project designed to provide the needed instructional material for basic electronics programs.

The success of this publication is due, in large part, to the capabilities of the personnel who worked with its development. The technical writers have numerous years of industry as well as teaching experience. Assisting them in their efforts were representatives of each of the member states who brought with them technical expertise and the experience related to the classroom and to the trade. To assure that the materials would parallel the industry environment and be accepted as a transportable basic teaching tool, organizations and industry representatives were involved in the developmental phases of the manual. Appreciation is extended to them for their valuable contributions.

This publication is designed to assist teachers in improving instruction. As these publications are used, it is hoped that the student performance will improve and that students will be better able to assume a role in their chosen occupation, basic electronics.

Instructional materials in this publication are written in terms of student performance using measurable objectives. This is an innovative approach to teaching that accents and augments the teaching/learning process. Criterion referenced evaluation instruments are provided for uniform measurement of student progress. In addition to evaluating recall information, teachers are encouraged to evaluate the other areas including process and product as indicated at the end of each instructional unit.

It is the sincere belief of the MAVCC personnel and all those members who served on the committee that this publication will allow the students to become better prepared and more effective members of the work force.

David Merrill,
Chairman
Board of Directors
Mid-America Vocational Curriculum Consortium
PREFACE

For many years those responsible for teaching basic electronics have felt a need for instructional materials to use in this area. A team of teachers, industry representatives, and trade and industrial education staff members accepted this challenge and have produced manuals which will meet the needs of many types of courses where students are expected to become proficient in the area of electronics. The MAVCC Basic Electronics II publication is designed to include the basic information needed to be able to attain that proficiency.

As with all efforts of this nature, feedback from the instructors selected to use these curriculum materials will greatly assist MAVCC in evaluating its effort and contribute significantly to plans for future material development.

Every effort has been made to make this publication basic, readable and by all means, usable. Three vital parts of instruction have been intentionally omitted from this publication: motivation, personalization, and localization. These areas are left to the individual instructors and the instructors should capitalize on them. Only then will this publication really become a vital part of the teaching-learning process.

Ann Benson
Executive Director.
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for the MAVCC Board of Directors:

David Merrill, Chairman, South Dakota
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ACKNOWLEDGMENTS

Appreciation is extended to those individuals who contributed their time and talents to the development of Basic Electronics II.

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Lincoln, Nebraska  
Robeline, Louisiana  
Clovis, New Mexico  
Kirksville, Missouri  
Nevada, Missouri  
Sioux Falls, South Dakota  
Dickinson, Texas  
Tecumseh, Oklahoma  
Wichita, Kansas  
Fort Collins, Colorado  
Lake Havasu, Arizona  
Harrison, Arkansas  
Albuquerque, New Mexico

Thanks are extended to Richard Tinnell, Teacher Educator from Oklahoma State University and David Merrill, State Supervisor of Technical and Industrial Education, South Dakota, for their assistance and input into the development of this publication.

Special thanks are extended to Mel Winegarten, of the Electrician's Joint Apprenticeship and Training Committee, Tulsa, Oklahoma for his contributions to the development of this book.

Gratitude is expressed to Bill Reeves, Dan Fulkerson, and Kathy Dolan for editing; to Wendy Rodebaugh, Teddi Cox, Terry Stanley, Rose Primeaux, and Beth Renwick for typing; and to Gloria Koch for phototypesetting.

Appreciation is extended to Vance Story, Bill Dunn, Robert Randall, Lin Thurston, Nancy Hilley, Kim Hale, Edith Mekis, and Carrie Williams for the illustrations and drawings used in this publication.
Instructional Units

The Basic Electronics II curriculum includes 15 units. Each instructional unit includes some or all of the basic components of a unit of instruction: performance objectives, suggested activities for teachers and students, information sheets, assignment sheets, visual aids, tests, and answers to the test. Units are planned for more than one lesson or class period of instruction.

Careful study of each instructional unit by the teacher will help to determine:

A. The amount of material that can be covered in each class period
B. The skills which must be demonstrated
   1. Supplies needed
   2. Equipment needed
   3. Amount of practice needed
   4. Amount of class time needed for demonstrations
C. Supplementary materials such as pamphlets or filmstrips that must be ordered
D. Resource people who must be contacted

Objectives

Each unit of instruction is based on performance objectives. These objectives state the goals of the course, thus providing a sense of direction and accomplishment for the student.

Performance objectives are stated in two forms: unit objectives, stating the subject matter to be covered in a unit of instruction; and specific objectives, stating the student performance necessary to reach the unit objective.

Since the objectives of the unit provide direction for the teaching-learning process, it is important for the teacher and students to have a common understanding of the intent of the objectives. A limited number of performance terms have been used in the objectives for this curriculum to assist in promoting the effectiveness of the communication among all individuals using the materials.

Following is a list of performance terms and their synonyms which may have been used in this material:

<table>
<thead>
<tr>
<th>Name</th>
<th>Identify</th>
<th>Describe</th>
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<td>Identify</td>
<td>Describe</td>
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<tr>
<td>Label</td>
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<td>Discuss in writing</td>
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<tr>
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<td>Choose</td>
<td>Interpret</td>
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<td>Repeat</td>
<td>Locate</td>
<td>Tell how</td>
</tr>
<tr>
<td>Give</td>
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<td>Tell what</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Explain</td>
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</tbody>
</table>
Order
Arrange
Sequence
List in order
Classify
Divide
Isolate
Sort

Distinguish
Discriminate

Construct
Draw
Make
Build
Design
Formulate
Reproduce
Transcribe
Reduce
Increase
Figure

Demonstrate
Show your work
Show procedure
Perform an experiment
Perform the steps
Operate
Remove
Replace
Turn off/on
(Dis) assemble
(Dis) connect

Additional Terms Used
Evaluate
Complete
Analyze
Calculate
Estimate
Plan
Observe
Compare
Determine
Perform

Prepare
Make
Read
Tell
Teach
Converse
Lead
State
Write

Reading of the objectives by the student should be followed by a class discussion to answer any questions concerning performance requirements for each instructional unit.

Teachers should feel free to add objectives which will fit the material to the needs of the students and community. When teachers add objectives, they should remember to supply the needed information, assignment and/or job sheets, and criterion tests.

Suggested Activities for the Instructor:

Each unit of instruction has a suggested activities sheet outlining steps to follow in accomplishing specific objectives. Duties of instructors will vary according to the particular unit; however, for best use of the material they should include the following: provide students with objective sheet, information sheet, assignment sheets, and job sheets; preview filmstrips, make transparencies, and arrange for resource materials and people; discuss unit and specific objectives and information sheet; give test. Teachers are encouraged to use any additional instructional activities and teaching methods to aid students in accomplishing the objectives.

Information Sheets

Information sheets provide content essential for meeting the cognitive (knowledge) objectives in the unit. The teacher will find that the information sheets serve as an excellent guide for presenting the background knowledge necessary to develop the skill specified in the unit objective.

Students should read the information sheets before the information is discussed in class. Students may take additional notes on the information sheets.
Transparency Masters

Transparency masters provide information in a special way. The students may see as well as hear the material being presented, thus reinforcing the learning process. Transparencies may present new information or they may reinforce information presented in the information sheets. They are particularly effective when identification is necessary.

Transparencies should be made and placed in the notebook where they will be immediately available for use. Transparencies direct the class's attention to the topic of discussion. They should be left on the screen only when topics shown are under discussion.

Job Sheets

Job sheets are an important segment of each unit. The instructor should be able to and in most situations should demonstrate the skills outlined in the job sheets. Procedures outlined in the job sheets give direction to the skill being taught and allow both student and teacher to check student progress toward the accomplishment of the skill. Job sheets provide a ready outline for students to follow if they have missed a demonstration. Job sheets also furnish potential employers with a picture of the skills being taught and the performances which might reasonably be expected from a person who has had this training.

Assignment Sheets

Assignment sheets give direction to study and furnish practice for paper and pencil activities to develop the knowledge which are necessary prerequisites to skill development. These may be given to the student for completion in class or used for homework assignments. Answer sheets are provided which may be used by the student and/or teacher for checking student progress.

Test and Evaluation

Paper-pencil and performance tests have been constructed to measure student achievement of each objective listed in the unit of instruction. Individual test items may be pulled out and used as a short test to determine student achievement of a particular objective. This kind of testing may be used as a daily quiz and will help the teacher spot difficulties being encountered by students in their efforts to accomplish the unit objective. Test items for objectives added by the teacher should be constructed and added to the test.

Test Answers

Test answers are provided for each unit. These may be used by the teacher and/or student for checking student achievement of the objectives.
BASIC ELECTRONICS II

INSTRUCTIONAL/TASK ANALYSIS

JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)

RELATED INFORMATION: What the Worker Should Know (Cognitive)

UNIT I: REVIEW OF THE NATURE OF MATTER AND THE P-N JUNCTION

1. Terms
2. Components of an atomic model
3. Types of bonding
4. Semiconductor crystal structures
5. Majority and minority carriers
6. Components of a P-N junction
7. P-N junction polarity
8. P-N junction characteristic curves
9. Draw schematic symbols
10. Perform static test on semiconductor diodes
11. Plot characteristic curves

UNIT II: RECTIFIERS

1. Terms
2. Input and output waveforms
3. Formulas for average and DC output voltage
4. Conventional full-wave rectifiers and full-wave bridge rectifiers
5. Formulas for average and peak DC output voltage
6. DC output voltage of a multiplier circuit
7. Calculate average DC voltage
8. Draw current flow in a specified rectifier
JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)

9. Construct and test a half-wave rectifier circuit
10. Construct and test a full-wave bridge rectifier circuit
11. Construct and test a voltage doubler circuit

RELATED INFORMATION: What the Worker Should Know (Cognitive)

UNIT III: FILTERS

1. Terms
2. Purposes of filters
3. Voltage waveshapes
4. Basic filter types
5. Basic filter configurations
6. Ripple factor
7. Calculate ripple factor and percent regulation
8. Construct and test a capacitor filter circuit
9. Construct and test a Pi-section filter circuit

UNIT IV: SPECIAL SEMICONDUCTOR DIODES

1. Terms
2. Schematic symbols
3. Components of a zener diode
4. Applications of zener diodes
5. Components of tunnel diodes
6. Applications of tunnel diodes
7. Bias voltage and barrier capacitance in varactor diodes
8. Applications of varactor diodes
9. Instantaneous forward current in light-emitting diodes
10. Applications of light-emitting diodes
JOB TRAINING: What the Worker Should Be Able to Do (Psychomotor)

7. Label a transistor circuit
8. Test transistors

RELATED INFORMATION: What the Worker Should Know (Cognitive)

UNIT V: TRANSISTORS

1. Terms
2. Basics of PNP and NPN transistors
3. Major uses of transistors
4. Voltage drop for germanium and silicon transistors
5. Biasing arrangements for PNP and NPN transistors
6. Typical types of transistors

UNIT VI: BIPOLAR-JUNCTION TRANSISTOR CIRCUITS

1. Terms
2. Basic types of transistor circuits
3. Circuit current gain
4. Gain characteristics
5. Signal voltage phase reversal
6. Applications of transistor circuits
7. Impedances for basic transistor circuits
8. Compute stage gain in decibels
9. Construct and test a common-emitter circuit
10. Construct and test a common-base circuit
11. Construct and test a common-collector circuit
12. Plot a transistor output characteristic curve
UNIT VII: TRANSISTOR AMPLIFIERS

1. Terms
2. Voltage divider bias circuit
3. Leakage current
4. Classes of amplifiers
5. Class B push-pull amplifiers
6. Darlington-pair circuits
7. Common-emitter Class A amplifier circuits
8. Types of coupling
9. Stage gains in overall amplifier gain
10. Load-line
11. Multistage-amplifier circuits
12. Test a single-ended amplifier
13. Test a push-pull amplifier
14. Test a two stage amplifier
15. Test a Darlington-pair amplifier

UNIT VIII: OPERATIONAL AMPLIFIERS

1. Terms
2. Categories of integrated circuits
3. Characteristics of inverting and noninverting operational amplifiers
4. DC summing inverting and differential amplifiers
5. Calculate closed-loop gain
6. Calculate output voltage
7. Construct and test an inverting amplifier
8. Construct and test a noninverting amplifier
9. Construct and test a DC summing inverting amplifier
10. Construct and test a differential amplifier
UNIT IX

1. Terms
2. Schematic symbols
3. Truth tables

4. Construct and test an IC "AND" gate circuit
5. Construct and test an IC "OR" gate circuit
6. Construct and test an IC "NAND" gate circuit
7. Construct and test an IC "Exclusive-OR" gate circuit
8. Construct and test a diode "AND" gate circuit
9. Construct and test a diode-transistor "NOR" gate circuit

UNIT X: LOGIC SYSTEMS

1. Terms
2. Binary numbers
3. Truth table for half-adder
4. Multivibrators
5. Convert decimals to BCD
6. Add binary numbers
7. Construct and test a four-bit shift register

UNIT XI: SPECIAL SEMICONDUCTOR DEVICES

1. Terms
2. SCR characteristic curves
3. Triacs
4. Diac applications
5. Thermistor types
6. UJT characteristic curves
7. JFET characteristic curves
JOB TRAINING: What the Worker Should Be Able to Do
(Psychomotor)

RELATED INFORMATION: What the Worker Should Know (Cognitive)

8. Types of MOFETs
9. Types of IGFETs
10. Construct and test silicon-controlled rectifier circuits
11. Construct and test a unijunction transistor relaxation oscillator
12. Construct and test a field-effect transistor amplifier
13. Construct and test a thermistor-control circuit

UNIT XII: OSCILLATORS

1. Terms
2. Oscillator schematic diagrams
3. Construct and test a Hartley oscillator

UNIT XIII: TRANSMITTERS

1. Terms
2. CW transmitter stages
3. AM broadcast transmitter stages
4. FM broadcast transmitter stages
5. Television transmitting system stages
6. Characteristics of antennas
7. Calculate wavelength and antenna length

UNIT XIV: RECEIVERS

1. Terms
2. AM receiver stages
3. FM receiver stages
4. Frequency ranges
5. FCC responsibilities

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JOB TRAINING: What the Worker Should Be Able to Do
(Psychomotor)

RELATED INFORMATION: What the Worker Should Know
(Cognitive)

6. RF amplifier stages
7. Output frequencies
8. IF amplifier stages
9. Limiter stage
10. FM detection circuits

11. Locate and identify the major stages of AM/FM receivers

UNIT XV: ELECTRON TUBES

1. Terms
2. Schematic symbols
3. Pin numbers
4. Vacuum tube characteristic curves

5. Construct and test a vacuum tube diode circuit
REVIEW OF THE NATURE OF MATTER
AND THE P-N JUNCTION
UNIT I

UNIT OBJECTIVE

After completion of this unit the student should be able to match terms and definitions associated with matter and the P-N junction, describe the forward and reverse characteristics of a P-N junction diode, construct and test a semiconductor diode circuit and plot the diode characteristic curves. This knowledge will be evidenced by correctly performing the procedures outlined in the job sheet and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to the nature of matter and the P-N junction with their correct definitions.
2. Label the nucleus, protons, neutrons, electrons, and the valence shell of an atomic model.
3. Match types of bonding with their materials.
4. Identify semiconductor crystal structures.
5. State the majority and minority carriers and their electrical polarity in N-type and P-type semiconductors.
6. Complete a list of four methods and techniques used to manufacture a P-N junction.
7. Sketch a P-N junction and label the P material, the N material, the depletion region, and the barrier potential showing voltage ranges for the silicon and germanium diodes.
8. Label the proper polarity for a reverse-biased P-N junction and a forward-biased P-N junction.
9. Draw the schematic symbol for a diode, label the cathode, the anode and show the electrical polarity of each terminal to forward bias the device.
10. Identify, from the P-N junction diode characteristic curves, the forward-bias region, the reverse-bias region, the majority carriers, and the minority carriers.
11. Demonstrate the ability to:
   a. Perform a static test on semiconductor diodes.
   b. Test a semiconductor diode and plot the characteristic curves.
REVIEW OF THE NATURE OF MATTER
AND THE P-N JUNCTION
UNIT I

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.
II. Provide student with information and job sheets.
III. Make transparencies.
IV. Discuss unit and specific objectives.
V. Discuss information sheets.
VI. Demonstrate and discuss the procedures outlined in the job sheets.
VII. Give test.

INSTRUCTIONAL MATERIALS

I. Included in this unit:
   A. Objective sheet
   B. Information sheet
   C. Transparency masters
      1. TM 1--Atomic Model
      2. TM 2--Semiconductor Crystal Structures
      3. TM 3--P-N Junction
      4. TM 4--Forward and Reverse Bias
      5. TM 5--P-N Junction Diode Characteristic Curves
   D. Job sheets
      1. Job Sheet #1--Perform a Static Test of Semiconductor Diodes
      2. Job Sheet #2--Test a Semiconductor Diode and Plot the Characteristic Curves
   F. Test
   G. Answers to test

REVIEW OF THE NATURE OF MATTER
AND THE P-N JUNCTION
UNIT 1

INFORMATION SHEET

I. Terms and definitions
   A. Atom--The smallest particle of an element containing electrons, protons, and neutrons
   B. Nucleus--The core of the atom which contains two major particles, protons and neutrons
   C. Proton--An elementary atomic particle within the nucleus with a positive electrical charge
   D. Electron--An elementary atomic particle in orbit around the nucleus with a negative electrical charge
   E. Neutron--An elementary atomic particle within the nucleus with no electrical charge
   F. Shell--One of the orbital or energy levels of the electrons about the nucleus
   G. Valence number--The number of electrons in the outermost orbital shell (valence shell) of an atom
   H. Covalent bonding--Two or more atoms sharing electrons in their outer shell to form a stable molecule
   I. Intrinsic material--A pure crystal of a material
   J. Extrinsic material--An intrinsic material to which an impurity has been added
   K. Insulator--A material with very few or no free electrons in the valence shell
      (NOTE: This normally includes Valence Groups I to III.)
   L. Conductor--A material that has 1 or 2 electrons in the valence shell that are not tightly bound to the nuclei
      (NOTE: This normally includes Valence Groups II to VIII.)
   M. Semiconductor--A material in which the valence shell is partially filled with electrons which can be removed, when some form of energy is applied to the material
      (NOTE: This normally includes Valence Group IV.)
   N. Doping--The process of adding impurities to an intrinsic material
INFORMATION SHEET

Q. P-N junction--The region where N-type and P-type semiconductor material join together

P. Bias--External electric potential (voltage) applied to a P-N junction

Q. Diode--A two-terminal device consisting of a P-N junction which allows majority carriers to flow in one direction

R. Bonding--The holding together of atoms to form a molecule

S. Majority carriers--Electrons in N-type material and holes in P-type material

T. Minority carriers--Electrons in P-type material and holes in N-type material

U. Holes--The absence of electrons in a covalent bond

V. Peak inverse voltage (PIV or PRV)--The maximum reverse-bias voltage which can be applied to a P-N junction without damage to the junction

W. Depletion region--The junction area that has no free charges

II. Atomic model (Transparency 1)

A. Nucleus

B. Proton

C. Neutron

D. Electron

E. Valence shell

III. Types of bonding and their materials

A. Covalent--Insulators and semiconductors

B. Ionic--Gases

C. Metallic--Conductors

IV. Semiconductor crystal structures (Transparency 2)

A. Intrinsic--Pure semiconductor crystal

B. Extrinsic--N-type semiconductor crystal

1. Impurity

2. Free electron
INFORMATION SHEET

C. Extrinsic--P-type semiconductor crystal
   1. Impurity
   2. Hole

V. Majority and minority carriers and their electrical polarity
   A. N-type
      1. Majority carriers--Electrons, negative charge
      2. Minority carriers--Holes, positive charge
   B. P-type
      1. Majority carriers--Holes, positive charge
      2. Minority carriers--Electrons, negative charge

VI. P-N junction manufacturing methods and techniques
   A. Molten method or grown-junction technique
   B. Epitaxial-growth method
   C. Diffusion method
   D. Alloy method

VII. Depletion or barrier region of a P-N junction and the barrier potential (Transparency 3)
   A. Silicon diode barrier potential = 0.6 to 0.7 volts
   B. Germanium diode barrier potential = 0.2 to 0.3 volts

VIII. P-N junction bias (Transparency 4)
   A. Reverse bias--Positive battery terminal connected to N-type material
   B. Forward bias--Positive battery terminal connected to the P-type material

IX. Diode schematic symbols (Transparency 5)
   A. Anode + P-section
   B. Cathode - N-section
   C. Symbol—

   (NOTE: The arrow points to the N-type material.)
INFORMATION SHEET

X. P-N junction diode characteristic curves (Transparency 5)

A. Forward-bias region
B. Reverse-bias region
C. Majority carriers
D. Minority carriers
E. Breakdown

(NOTE: Breakdown occurs when PIV is exceeded.)
Atomic Model (Silicon)
Semiconductor Crystal Structures

Pure Silicon Crystal
Intrinsic

N-Type Silicon Crystal
Extrinsic

P-Type Germanium
Crystal
Extrinsic

Free Electron
Impurity
Impurity
Hole
P-N Junction

 Barrier Potential
Silicon 0.6 to 0.7 Volt
Germanium 0.2 to 0.3 Volt

Depletion Region

P-N Junction
Showing Barrier Potential
And
Depletion Region
Forward and Reverse Bias

Reverse Biased P-N Junction

Forward Biased P-N Junction

(Note—Barrier potential increases and depletion region widens as reverse bias is increased.)
P-N Junction Diode Characteristic Curves

Reverse Bias Region

Voltage

Minority Carriers

Current (mA)

Forward Bias Region

Voltage

Majority Carriers

Schematic Symbol

Anode +

Cathode -

Breakdown

PIV

(ma) Current

30
REVIEW OF THE NATURE OF MATTER
AND THE P-N JUNCTION
UNIT I

JOB SHEET #1–PERFORM A STATIC TEST OF
SEMICONDUCTOR DIODES

I. Tools and equipment
   A. 2 multimeters
   B. 3 different types of diodes from your instructor

II. Procedure
   A. Determine the polarity of your ohmmeter leads by connecting them to a voltmeter
   B. Mark the polarity of the ohmmeter leads
   C. Connect the positive lead of the ohmmeter to the anode of the diode and the negative lead of the ohmmeter to the cathode of the diode.
   D. Read and record the ohmmeter reading in the data table
      (NOTE: The ohmmeter should be on a $R \times 100$ scale to avoid possible damage to the diode.)
   E. Reverse the ohmmeter connection to the diode, read and record the ohmmeter reading
   F. Determine from the ohmmeter reading whether the diode is good or bad
      (NOTE: A good diode will have a low ohmic reading in the forward-biased direction and a high ohmic reading when reversed biased.)
   G. Repeat the above procedure for each of your diodes

DATA TABLE I - STATIC TEST

<table>
<thead>
<tr>
<th>DIODE</th>
<th>FORWARD RESISTANCE</th>
<th>REVERSE RESISTANCE</th>
<th>GOOD OR BAD</th>
</tr>
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<tbody>
<tr>
<td>$D_1$</td>
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<td>$D_2$</td>
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<td>$D_3$</td>
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<td>$D_4$</td>
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JOB SHEET #2 - TEST A SEMICONDUCTOR DIODE AND PLOT THE CHARACTERISTIC CURVES

I. Tools and equipment
   A. Variable DC power-supply (0-30 volts)
   B. 1-220 ohm, 5 Watt resistor
   C. 1-silicon diode (1N914 or equivalent) optional germanium diode
   D. 2-multimeters
   E. Graph paper

II. Procedure
   A. Connect the following circuit for a reverse-biased diode but do not apply power
      (NOTE: Connect the multimeters as voltmeters and observe the proper polarity.)
      ![Circuit Diagram]
   B. Apply power
   C. Read and record $V_D$ (voltage across the diode) and $V_R$ (voltage across the resistor) when the power supply is set at 0, 1, 2, 3, 4, 5, 10, 15, 20, and 25 volts
      (NOTE: The peak inverse voltage rating of the diode must be equal to or greater than 25 volts.)
   D. Turn the power supply off
   E. Reverse the diode connection in the circuit so it will be forward biased
   F. Read and record $V_D$ and $V_R$ for power supply settings of 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 2, 4, volts
G. Compute the current flowing in the circuit for each reading taken in steps B and E.

H. Draw a graph of the diode forward and reverse characteristic curve.
   (NOTE: The horizontal axis should be $V_D$ and the vertical axis should be $I_D$.)

I. Check your calculations and your graph with your instructor.
## JOB SHEET #2

### DATA TABLES

#### TABLE I - REVERSE BIAS

<table>
<thead>
<tr>
<th>$V_o$ Supply</th>
<th>0_V</th>
<th>1_V</th>
<th>2_V</th>
<th>3_V</th>
<th>4_V</th>
<th>5_V</th>
<th>10_V</th>
<th>15_V</th>
<th>20_V</th>
<th>25_V</th>
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<tr>
<td>$V_o$</td>
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</table>

#### TABLE II - FORWARD BIAS

<table>
<thead>
<tr>
<th>$V$ Supply</th>
<th>0.0</th>
<th>.1_V</th>
<th>.2_V</th>
<th>.3_V</th>
<th>.4_V</th>
<th>.5_V</th>
<th>.6_V</th>
<th>.7_V</th>
<th>.8_V</th>
<th>.9_V</th>
<th>1.0_V</th>
<th>2.0_V</th>
<th>4.0_V</th>
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<tr>
<td>$V_D$</td>
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<td>$V_R$</td>
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</tbody>
</table>
REVIEW OF THE NATURE OF MATTER AND THE P-N JUNCTION
UNIT I

NAME______________________________

TEST

1. Match the terms on the right with their correct definitions.

   a. Two or more atoms sharing electrons in their outer shell to form a stable molecule
   b. The smallest particle of an element containing electrons, protons, and neutrons
   c. The number of electrons in the outermost orbital shell of an atom
   d. The core of the atom which contains two major particles: protons and neutrons
   e. One of the orbital or energy levels of the electrons about the nucleus
   f. An elementary atomic particle within the nucleus with a positive electrical charge.
   g. An elementary atomic particle within the nucleus with no electrical charge
   h. An elementary atomic particle in orbit around the nucleus with a negative electrical charge
   i. An intrinsic material to which an impurity has been added
   j. A two-terminal device consisting of a P-N junction which allows majority carriers to flow in one direction
   k. External electric potential applied to a P-N junction
   l. The region where N-type and P-type semiconductor material join together
   m. The process of adding impurities to an intrinsic material
   n. A material in which the valence shell is partially filled with electrons which can be removed when some form of energy is applied to the material

   1. Atom
   2. Nucleus
   3. Proton
   4. Electron
   5. Neutron
   6. Shell
   7. Valence number
   8. Covalent bonding
   9. Insulator
   10. Intrinsic material
   11. Extrinsic material
   12. Diode
   13. Bias
   14. P-N junction
   15. Doping
   16. Conductor
   17. Semiconductor
   18. Bonding
   19. Majority carriers
   20. Minority carriers
   21. Holes
   22. Depletion region
   23. Peak inverse voltage
o. A material that has 1 or 2 electrons in the valence shell that are not tightly bound to the nuclei

p. A material with very few or no free electrons in the valence shell

q. A pure crystal of a material

r. The absence of electrons in a covalent bond

s. Electrons in P-type material and holes in N-type material

t. The holding together of atoms to form a molecule

u. Electrons in N-type material and holes in P-type material

v. The maximum reverse-bias voltage which can be applied to a P-N junction without damage to the junction

w. The junction area that has no free charges

2. Label the nucleus, protons, neutrons, electrons, and the valence shell of the atomic model given below.
3. Match types of bonding on the right with the materials to which they apply.

   a. Conductors
   b. Gases
   c. Insulators and semiconductors

4. Identify an intrinsic silicon crystal, an extrinsic N-type silicon crystal, and an extrinsic P-type germanium crystal.

   a._________  b._________  c._________

5. State the majority and minority carriers and their electrical polarity in N-type and P-type semiconductors.

   N-type
   a. Majority carriers are ________________________________
   b. Minority carriers are ________________________________

   P-type
   a. Majority carriers are ________________________________
   b. Minority carriers are ________________________________
6. Complete a list of four methods and techniques used to manufacture a P-N junction.
   a. Molten method or grown-junction technique
   b. Epitaxial-growth method
   c. ________________
   d. ________________

7. Sketch a P-N junction and label the P material, the N material, the depletion region, and the barrier potential showing voltage ranges for the silicon and germanium diodes.
8. Label the proper polarity for the reverse-biased P-N junction and the forward-biased P-N junction in the following illustrations.

- **Reverse Biased P-N Junction**
  - Reverse Current
  - High Resistance

- **Forward Biased P-N Junction**
  - Forward Current
  - Low Resistance

9. Draw the schematic symbol for a diode, label the cathode, the anode and show the electrical polarity to forward bias the device.
10. Identify, from the following P-N junction diode characteristic curves, the forward-bias region, the reverse-bias region, the majority carriers, and the minority carriers.

![Diode Characteristic Curves Diagram]

a. ____________________________  c. ____________________________

b. ____________________________  d. ____________________________

11. Demonstrate the ability to:

a. Perform a static check of semiconductor diodes.

b. Test a semiconductor diode and plot the characteristic curves.

(NOTE: If these activities have not been accomplished prior to test, ask your instructor when they should be completed.)
REVIEW OF THE NATURE OF MATTER
AND THE P-N JUNCTION

UNIT I

ANSWERS TO TEST

1. a. 8 i. 11 q. 10
   b. 1 j. 12 r. 21
   c. 7 k. 13 s. 20
   d. 2 l. 14 t. 18
   e. 6 m. 15 u. 19
   f. 3 n. 17 v. 23
   g. 5 o. 16 w. 22
   h. 4 p. 9

2. a. Valence shell
    b. Neutron
    c. Electron
    d. Proton
    e. Nucleus

3. a. 3
    b. 2
    c. 1

4. a. Intrinsic silicon crystal
    b. Extrinsic N-type silicon crystal
    c. Extrinsic P-type germanium crystal

5. N-type
   a. Electrons, negative charge
   b. Holes, positive charge
   P-type
   a. Holes, positive charge
   b. Electrons, negative charge

6. c. Diffusion method
    d. Alloy method
BARRIER POTENTIAL
SILICON 0.6 TO 0.7 VOLT
GERMANIUM 0.2 TO 0.3 VOLT

DEPLETION REGION

Reverse Biased P-N Junction
- High Resistance

Forward Biased P-N Junction
- Low Resistance

Lieve Curreni
High Resistance

Reverse Current
9. Anode + Cathode –

10. a. Majority Carriers
    b. Reverse-bias region
    c. Forward-bias region
    d. Minority carriers

11. Performance skills evaluated to the satisfaction of the instructor
UNIT OBJECTIVE

After completion of this unit, the student should be able to state the formula which relates peak input voltage to average DC output voltage, identify conventional half-wave and full-wave rectifier circuits, and construct and test a half-wave rectifier, a full-wave rectifier, and a voltage multiplier circuit. This knowledge will be evidenced by correctly performing the procedures outlined in the assignment and job sheets and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to rectifiers with their correct definitions.
2. Sketch the input and output waveforms for a basic half-wave rectifier circuit.
3. State the formulas for the average and peak DC output voltage of a half-wave rectifier.
4. Identify a conventional full-wave rectifier and a full-wave bridge rectifier.
5. Select true statements concerning the advantages of a full-wave over a half-wave rectifier.
6. State the formulas for the average and peak DC output voltage of a full-wave rectifier.
7. Determine the DC output voltage of a multiplier circuit.
8. Calculate average DC voltage for half-wave rectifier and full-wave rectifier circuits.
9. Indicate the direction of current flow in a full-wave bridge rectifier and a conventional full-wave rectifier.
10. Demonstrate the ability to:
    a. Construct and test a half-wave rectifier circuit.
    b. Construct and test a full-wave bridge rectifier circuit.
    c. Construct and test a voltage doubler circuit.
RECTIFIERS
UNIT II

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.
II. Provide student with information, assignment, and job sheets.
III. Make transparencies.
IV. Discuss unit and specific objectives.
V. Discuss information and assignment sheets.
VI. Demonstrate and discuss the procedures outlined in the job sheets.
VII. Give test.

INSTRUCTIONAL MATERIALS

I. Included in this unit:

A. Objective sheet
B. Information sheet
C. Transparency masters
   1. TM 1-Half-Wave Rectifier Circuits
   2. TM 2-Conventional Full-Wave Rectifier
   3. TM 3-Bridge Rectifier
   4. TM 4-Voltage Doubler Circuit
D. Assignment sheets
   1. Assignment Sheet #1-Calculate Average DC Voltage for Half-Wave and Full-Wave Rectifier Circuits
   2. Assignment Sheet #2-Indicate the Direction of Current Flow in a Full-Wave Bridge Rectifier and a Conventional Full-Wave Rectifier
E. Answer to assignment sheets
F. Job sheets
   1. Job Sheet #1-Construct and Test a Half-Wave Rectifier Circuit
   2. Job Sheet #2-Construct and Test a Full-Wave Bridge Rectifier Circuit
3. Job Sheet #3--Construct and Test a Voltage Doubler Circuit

G. Test

H. Answers to test

I. Terms and definitions

A. Rectifier circuit--A circuit that converts AC voltages to pulsating DC voltages

B. Half-wave rectifier--A circuit that converts AC voltage to pulsating DC voltage and allows DC current to flow only through the load during one-half of each AC input cycle

C. Full-wave rectifier--A circuit that converts AC voltage to pulsating DC voltage and allows current to flow in the same direction through the load for both halves of the input AC voltage cycle

D. Transformer--A device which is used to either step up (increase) or step down (decrease) the AC voltage in a rectifier circuit

E. Bridge rectifier--A type of rectifier circuit that requires four diodes in order to make a full-wave rectifier

F. Voltage doubler--A rectifier circuit that is used to increase (double) the DC output voltage without using a step up transformer

II. Input and output waveforms for a basic half-wave rectifier circuit (Transparency 1)

A. Input voltage--

B. Output voltage--  OR

III. Formulas for the average and peak DC output voltage of a half-wave rectifier

A. \( V_{dc} = 0.318 \, V_{pk} \)

B. \( V_{pk} = 1.414 \, V_{rms} \)

IV. Full-wave rectifiers (Transparencies 2 and 3)

A. Conventional

B. Full-wave bridge
INFORMATION SHEET

V. Advantages of a full-wave over a half-wave rectifier
   A. More efficient
   B. Less ripple effect
   C. Wider variety of applications

VI. Formulas for the average and peak DC output voltage of a full-wave rectifier
   A. \( V_{dc} = 0.636 \times V_{peak} \)
   B. \( V_{pk} = 1.414 \times V_{rms} \)

VII. Steps in determining the DC voltage of a multiplier circuit
   A. Determine the voltage input (Transparency 4)
   B. Multiply the peak input voltage times the number of rectifiers

Example:

\[
\text{120V AC Input} \times 2 \text{ (rectifiers)} = 240V \text{ DC output}
\]

(NOTE: This is an example of a voltage doubler used in a specialized multiplier circuit.)
Half-Wave Rectifier Circuits

- Input Voltage
- Load Resistor
- Output Voltage

[Diagram of half-wave rectifier circuit with diode, load resistor, and input/output voltages]
Conventional Full-Wave Rectifier

(Note: If diodes D1 and D2 were reversed, the output voltage would be reversed.)
Bridge Rectifier

(Note: If each of the diodes were reversed the output would be reversed.)
Voltage Doubler Circuit

Diagram:

- Ac Line
- Filament Transformer
- Diodes D1 and D2
- Capacitors C1 and C2
- Vout

Symbols:
- Ac in
ASSIGNMENT SHEET #1--CALCULATE AVERAGE DC VOLTAGE FOR HALF-WAVE RECTIFIER AND FULL-WAVE RECTIFIER CIRCUITS

1. Calculate the average DC voltage for the following circuit.

\[ V_{dc} = \]

2. Calculate the average DC voltage for the following circuit.

\[ V_{dc} = \]

3. Calculate the transformer's secondary rms voltage.

\[ V_{rms} = \]
4. Calculate the average DC voltage for the following circuit.
ASSIGNMENT SHEET #2—INDICATE THE DIRECTION OF CURRENT FLOW IN A FULL-WAVE BRIDGE RECTIFIER AND A CONVENTIONAL FULL-WAVE RECTIFIER

1. Trace and label the paths of the current flow through the bridge rectifier circuit and the load for one complete input cycle and label the voltage polarity at points A and B.

2. Trace and label the paths of the current flow through a conventional full-wave rectifier circuit for one complete input cycle.
Assignment Sheet #1

1. $V_{L(\text{peak})} = 1.414 \text{ Vrms}$  
   $V_{L(\text{peak})} = (1.414)(30) = 42.4\text{ V}$  
   $V_{dc} = 0.318 \times V_{L(\text{peak})}$  
   $V_{dc} = (0.318)(42.4) = 13.5\text{ V}$  

2. $V_{L(\text{peak})} = (1.414)(400) = 565\text{ V}$  
   $V_{dc} = (0.318)(565) = 180\text{ V}$

3. $V_{L(\text{peak})} = \frac{54}{0.318} = 170\text{ V}$
   $V_{\text{rms}} = \frac{170}{1.414} = 120\text{ V}$

4. $V_{\text{peak}} = 1.414 \times 120 = 170\text{ V}$  
   $V_{dc} = (0.636)(170) = 108\text{ V}$

Assignment Sheet #2

1. 

First half-cycle
2. First half-cycle

Second half-cycle

DC Output

R

D1

D2

D3

D4

DC Output

R

First half-cycle

Second half-cycle
I. Tools and equipment
   A. Low power filament transformer (120V Primary)
   B. Silicon diode, 1N914 or equivalent
   C. 2-6800 Ohm, 1/2 Watt resistors
   D. Multimeter
   E. Oscilloscope
   F. Graph paper

II. Procedure
   (CAUTION: Dangerous voltage levels are present during this procedure. Check with your instructor regarding safety procedures.)
   A. Connect the multimeter (set for AC) to secondary of the filament transformer
   B. Plug the filament transformer into the line voltage and measure the secondary voltage at points A and B
   C. Turn off the power
   D. Connect the following circuit to the secondary of the filament transformer

![Circuit Diagram]
JOB SHEET #1

E. Turn the power on

F. Measure the voltage between points A and B and record this below as the AC input voltage

G. Measure and record the DC output voltage with the multimeter

H. Observe and make a scale drawing below of the AC input voltage (A to B) and the DC output voltage (C to B)

I. Calculate the average DC output voltage and compare it to the measured DC output voltage

J. Check your calculations and your drawing with your instructor

DATA:

Measured voltage A to B \( V_{\text{rms}} \)

Measured voltage B to C \( V_{\text{rms}} \)

Calculated output voltage \( V_{\text{dc}} \)
I. Tools and equipment
   A. Auto transformer (0-130V)
   B. Power transformer (110-220V CT)
      (NOTE: You may use a low power filament transformer. See Job Sheet #1.)
   C. Four silicon diodes IN914 or equivalent
   D. 1-10k, 1W resistor
   E. Multimeter
   F. Oscilloscope
   G. Graph paper

II. Procedure
   (CAUTION: Dangerous voltage levels are present during this procedure. Avoid shock hazards.)
   A. Construct the circuit shown below but do not connect power at this time

   ![Circuit Diagram]

   B. Have your instructor check your circuit
   C. Connect the multimeter across the secondary of the power transformer
   D. Connect the auto transformer to the AC line and adjust for a reading of 10V on the multimeter
**JOB SHEET #2**

E. Read and record the DC voltage across the 10K load resistor

F. Connect an oscilloscope across the filament transformer secondary and observe and sketch the waveform

G. Connect an oscilloscope across the 10K load resistor and observe and sketch the waveform

H. Calculate the average DC output voltage and compare with the measured DC output voltage

I. Check your calculations and your sketch with your instructor

**DATA:**

Measured voltage A to B \( V_{\text{rms}} \)

Measured voltage B to C \( V_{\text{dc}} \)

Calculated output voltage \( V_{\text{dc}} \)
RECTIFIERS
UNIT II

JOB SHEET #1.-CONSTRUCT AND TEST A VOLTAGE DOUBLER CIRCUIT

I. Tools and equipment
   A. Low power filament transformer (120V Primary)
   B. 2 silicon diodes, 1N914 or equivalent
   C. 2-20 μF capacitors, 450v
   D. Multimeter
   E. Oscilloscope

II. Procedure
   (CAUTION: Dangerous voltage levels are present during this procedure. Avoid
   shock hazards.)
   A. Connect the following circuit but do not connect the filament transformer
to the AC line.

   B. Have your instructor check your wiring, then plug in the filament
   transformer

   C. Measure and record the voltage across C1, C2, the output, and the secondary
   winding of the filament transformer

   D. Using an oscilloscope, observe and measure the input and output voltages
   of the rectifier circuit and sketch the waveforms

   E. Check your findings with your instructor
DATA:

\[ V_{c1} = \underline{\quad} \]

\[ V_{c2} = \underline{\quad} \]

\[ V_{\text{secondary}} = \underline{\quad} \]
1. Match the terms on the right with their correct definitions.

   a. A type of rectifier circuit that requires four diodes in order to make a full-wave rectifier circuit.
   b. A circuit that converts AC voltages to pulsating DC voltages.
   c. A rectifier circuit that is used to increase the DC output voltage without using a set-up transformer.
   d. A circuit that converts AC voltage to pulsating DC voltage and allows DC current to flow only through the load during one-half of each AC input cycle.
   e. A device which is used to either step up or step down the AC voltage in a rectifier circuit.
   f. A circuit that converts AC voltage to pulsating DC voltage and allows current to flow in the same direction through the load for both halves of the input AC voltage cycle.

2. Sketch the input and output waveform symbols for the basic half-wave rectifier circuit shown below.

   ![Half-wave Rectifier Diagram]

   - Input Voltage
   - Output Voltage

---

3. Sketch the input and output waveform symbols for the basic full-wave rectifier circuit shown below.

   ![Full-wave Rectifier Diagram]

   - Input Voltage
   - Output Voltage

---

4. Sketch the input and output waveform symbols for the basic bridge rectifier circuit shown below.

   ![Bridge Rectifier Diagram]

   - Input Voltage
   - Output Voltage

---

5. Sketch the input and output waveform symbols for the basic voltage doubler circuit shown below.

   ![Voltage Doubler Diagram]

   - Input Voltage
   - Output Voltage
3. State the formula for the average and peak DC output voltage of a half-wave rectifier.
   a. 
   b. 

4. Identify the conventional full-wave rectifier and the full-wave bridge rectifier in the following illustrations.

   a. 
   b. 

   ![Diagram of half-wave rectifier and bridge rectifier]
5. Select true statements concerning the advantages of a full-wave over a half-wave rectifier by placing an "X" in the appropriate blanks.

   a. Less efficient  [X]
   b. Less ripple effect  [X]
   c. Wider variety of applications  [X]

6. State the formulas for the average and peak DC output voltage of a full-wave rectifier.

   a.  
   b.  

7. Determine the DC output voltage of the multiplier circuit given below.

   ![Multiplier Circuit Diagram]

   \[ V_{out} = \] 

8. Calculate average DC voltage for half-wave rectifier and full-wave rectifier circuits.

9. Indicate the direction of current flow in a full-wave bridge rectifier and a conventional full-wave rectifier.

10. Demonstrate the ability to:
    a. Construct and test a half-wave rectifier circuit.
    b. Construct and test a full-wave bridge rectifier circuit.
    c. Construct and test a voltage doubler circuit.

    (NOTE: If these activities have not been accomplished prior to the test, ask your instructor when they should be completed.)
RECTIFIERS
UNIT II

ANSWERS TO TEST

1. a. 5  d. 2
   b. 1  e. 4
   c. 6  f. 3

2.

\[ + \]
\[ - \]
\[ \text{Input Voltage} \]
\[ + \]
\[ - \]
\[ \text{Output Voltage} \]

3. a. \( V_{dc} = 0.318 \text{ Vpk} \)
   b. \( V_{pk} = 1.414 \text{ Vrms} \)

4. a. Conventional full-wave rectifier
   b. Full-wave bridge-rectifier

5. b, c

6. a. \( V_{dc} = 0.636 \text{ Vpeak} \)
   b. \( V_{pk} = 1.414 \text{ Vrms} \)

7. \( V_{out} = (140)(5) = 700 \)

8. Evaluated to the satisfaction of the instructor

9. Evaluated to the satisfaction of the instructor

10. Performance skills evaluated to the satisfaction of the instructor
UNIT OBJECTIVES

After completion of this unit, the student should be able to identify the three most common filter configurations and calculate the ripple factor of a filtered power supply. This knowledge will be evidenced by correctly performing the procedures outlined in the assignment and job sheets and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to filters with their correct definitions.
2. Select a statement describing the purpose of filters.
3. Sketch the voltage waveshapes at the output of the transformer, rectifier, and filter for a half-wave power supply.
4. Distinguish between the basic filter types.
5. Identify the three basic filter configurations.
6. State the function of and the formula for ripple factor.
7. Calculate ripple factors and percent regulation.
8. Demonstrate the ability to:
   a. Construct and test a capacitor filter circuit.
   b. Construct and test a Pi-section filter circuit.
FILTERS
UNIT III

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.

II. Provide student with information, assignment, and job sheets.

III. Make transparency.

IV. Discuss unit and specific objectives.

V. Discuss information and assignment sheets.

VI. Demonstrate and discuss the procedures outlined in the job sheets.

VII. Give test.

INSTRUCTIONAL MATERIALS

I. Included in this unit:

A. Objective sheet

B. Information sheet

C. Transparency Master 1--Basic Filter Configurations

D. Assignment Sheet #1--Calculate Ripple Factors and Percent Regulation

E. Answers to assignment sheet

F. Job sheets
   1. Job Sheet #1--Construct and Test a Capacitor Filter Circuit
   2. Job Sheet #2--Construct and Test a Pi-Section Filter Circuit

G. Test

H. Answers to test

I. Terms and definitions
A. Ripple--Variations in the DC voltage
B. Filter--A device used to eliminate or minimize ripple
C. Bleeder resistor--A resistor placed in parallel with a capacitor in order to provide a discharge path for the capacitor when the power supply is turned off
D. Power supply voltage regulation--The ability of a power supply to maintain a constant output voltage under varying loads
E. Percent regulation--Comparison of the no-load voltage to the full-load voltage expressed as a percentage of the full-load voltage
\[
(\text{NOTE: } \% \text{ Reg } = \frac{V_{\text{out no-load}} - V_{\text{out full-load}}}{V_{\text{out full-load}}} \times 100)
\]
F. DC power supply--A basic electronic system generally consisting of a transformer, a rectifier, and a filter to convert AC voltage to DC voltage

II. Purpose of filters--Filters help to provide a smooth, nonfluctuating DC output voltage from a rectifier circuit

III. Output waveshapes for a half-wave power supply
A. Transformer output--
B. Rectifier output--
C. Filter output--

(Note: See Transparency 1 for location of output waveshapes A, B, and C.)

IV. Basic filter types
A. Capacitor filter
   1. Simplest filter
   2. Most economical
   3. Used where load does not require an extremely smooth DC voltage
INFORMATION SHEET

B. Pi-section filter
   1. Requires two capacitors and an inductor
      (NOTE: The inductor is sometimes replaced by a resistor.)
   2. Used when a smooth voltage with relatively low current is required
   3. Also called capacitance-input filter

C. L-section filter
   1. Used for high current applications
   2. Requires an inductor or "choke" in series with a capacitor

V. Basic filter configurations (Transparency 1)
   A. Capacitor filter
   B. Pi-section filter
   C. Two L-section filter (choke input)

VI. Function of and the formula for ripple factor
   A. Expresses the effectiveness of filtering
   B. \[ r = \frac{\text{rms value of ripple output}}{\text{DC output voltage}} \]
Basic Filter Configurations

Capacitor Filter
(NOTE - Capacitor must be removed to observe rectifier output waveform.)

Pl-Section Filter

Two L-Section Filter
(NOTE - $R_S$ in series with diode limits initial surge of current due to capacitor and is called a surge resistor.)
1. A power supply has DC output voltage of 30 volts and a ripple of 10 Vrms. The ripple factor is ________________

2. A power supply has DC output voltage of 15 volts and a ripple of .050 volts rms. The ripple factor is ________________

3. Which one of the above power supplies has the most effective filtering and why?

4. A power supply has an output voltage at no-load of $24V_{DC}$ and an output voltage of $22V_{DC}$ at full-load. The percent regulation is ________________
FILTERS
UNIT III

ANSWERS TO ASSIGNMENT SHEET #1

1. $r = 0.33'$
2. $r = 0.0033$
3. #2, smaller ripple factor
4. 8.3%
FILTERS
UNIT III

JOB SHEET #1--CONSTRUCT AND TEST A CAPACITOR FILTER CIRCUIT

I. Tools and equipment
   A. Low power filament transformer (120V primary)
   B. 4-silicon diodes 1N914 or equivalent
   C. 1-10K, 1/2 watt resistor, 1-1K, 1/2 watt resistor, 2-20 μf capacitor, 25 WVdc or greater
   D. Multimeter
   E. Oscilloscope
   F. Graph paper

II. Procedure

   (CAUTION: Dangerous voltage levels are present during this procedure. Avoid shock hazards.)

   A. Construct the circuit shown below but do not connect power at this time

   (NOTE: Do not connect the capacitor at point A & B at this time.)

   B. Have your instructor check your circuit

   C. Connect the multimeter across the secondary of the filament transformer and record the voltage

   D. Read and record the DC voltage across the load resistor
JOB SHEET #1

E. Connect an oscilloscope across the load resistor, observe and sketch the waveform.

F. Turn off the power.

G. Connect the 20 µf capacitor at points A and B.

H. Turn the power on.

I. Repeat steps D through F.

J. Replace the 10K load resistor with the 1K load resistor and repeat steps D through I.

K. Compare the wave shapes and DC voltage levels of the filter and a 10K load resistor with the filter and a 1K load resistor.

L. Using the output voltage measured with the 10K load resistor as no-load voltage and the output voltage measured with the 1K resistor as full-load, compute percent voltage regulation on the table below.

<table>
<thead>
<tr>
<th>DATA</th>
<th>V_{sec.}</th>
<th>V_{10K}</th>
<th>V_{1K}</th>
<th>% Reg</th>
</tr>
</thead>
<tbody>
<tr>
<td>No filter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With filter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

M. Check your calculations and sketches with your instructor.
I. Tools and equipment
   A. Low power filament transformer (120V primary)
   B. 4-silicon diodes 1N914 or equivalent
   C. 1-10K, 1/2-watt resistor
   D. 1-1K, 1/2 watt resistor
   E. 2-20 μF capacitors 25WVdc or greater
   F. Multimeter
   G. Oscilloscope
   H. Graph paper
   I. 1-270 ohm resistor

II. Procedure
   A. Connect the circuit shown below but do not apply power at this time
      (NOTE: Do not connect the Pi-section filter network at point A and B at this time.)

   B. Have your instructor check your circuit

   C. Connect the multimeter across the secondary of the filament transformer
D. Read and record the DC voltage across the load resistor
E. Connect an oscilloscope across the load resistor, observe and sketch the wave form
F. Turn off the power
G. Connect the Pi-section at points A and B
H. Turn on the power
J. Repeat steps D through F
J. Replace the 10K load resistor with a 1K load resistor and repeat steps D through I
K. Compare the wave shapes and DC voltage levels of the Pi-section filter and the 10K load resistor with the Pi-section filter and the 1K resistor
M. Using the output voltage measured with the 10K load resistor as no-load voltage and the output voltage measured with the 1K resistor as full-load, compute percent voltage regulation on the table below

<table>
<thead>
<tr>
<th>DATA</th>
<th>V&lt;sub&gt;10K&lt;/sub&gt;</th>
<th>V&lt;sub&gt;1K&lt;/sub&gt;</th>
<th>% Reg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-filter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With filter</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

N. Check your calculations and your sketches with your instructor
1. Match the terms on the right with their correct definitions.

   a. A basic electronic system generally consisting of a transformer, a rectifier, and a filter to convert AC voltage to DC voltage
   b. Variations in the DC voltage
   c. Comparison of the no-load voltage to the full-load voltage expressed as a percentage of the full-load voltage
   d. A device used to eliminate or minimize ripple
   e. The ability of a power supply to maintain a constant output voltage under varying loads
   f. A resistor placed in parallel with a capacitor in order to provide a discharge path for the capacitor when the power supply is turned off

2. Select the statement which describes the purpose of a filter by placing an "X" in the appropriate blank.

   a. To convert AC voltage to DC voltage
   b. To provide automatic voltage regulation for a power supply
   c. Help to provide a smooth, nonfluctuating DC output voltage from a rectifier circuit
   d. To step up the DC power supply/output voltage

3. Sketch the voltage waveform at the output of the transformer, rectifier, and filter for the half-wave power supply illustrated below.

   ![Voltage Waveform](image)
4. Distinguish between the basic filter types by placing a "C" next to descriptions of capacitor filters, a "P" next to descriptions of Pi-section filters, and an "L" next to descriptions of L-section filters.

- a. Requires two capacitors and an inductor
- b. Used for high current applications
- c. Most economical
- d. Also called capacitance-input filter
- e. Used when a smooth voltage with relatively low current is required
- f. Simplest filter
- g. Used where load does not require an extremely smooth DC voltage
- h. Requires an inductor or "choke" in series with a capacitor
5. Identify the three basic filter configurations shown below.

a. ________ Filter

b. ________ Filter

c. ________ Filter
6. State the function of and the formula for ripple factor.
   a. 
   b. 

7. Calculate ripple factors and percent regulation.

8. Demonstrate the ability to:
   a. Construct and test a capacitor filter circuit.
   b. Construct and test a Pi-section filter circuit.

   (NOTE: If these activities have not been accomplished prior to the test, ask your instructor when they should be completed.)
### FILTERS
#### UNIT III

### ANSWERS TO TEST

1. a. 4  
   b. 3  
   c. 2  
   d. 1  
   e. 6  
   f. 5

2. c

3. a. Transformer output
   ![Transformer output waveform]
   
   b. Rectifier output
   ![Rectifier output waveform]
   
   c. Filter output
   ![Filter output waveform]

4. a. P  
   b. L  
   c. C  
   d. P  
   e. P  
   f. C  
   g. C  
   h. L

5. a. Capacitor filter
   b. Two L-section filter
   c. Pi-section filter

6. a. Expresses the effectiveness of filtering
   
   b. \( r = \text{rms value of ripple output} \) 
   \[ \frac{\text{DC output voltage}}{\text{DC output voltage}} \]

7. Evaluated to the satisfaction of the instructor

8. Performance skills evaluated to the satisfaction of the instructor
SPECIAL SEMICONDUCTOR DIODES
UNIT IV

UNIT OBJECTIVE

After completion of this unit, the student should be able to list applications of special semiconductor diodes, construct the volt-amp characteristic curves for a zener diode, and construct and test a zener diode voltage regulator. This knowledge will be evidenced by correctly performing the procedures outlined in the job sheets and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to special semiconductor diodes with their correct definitions.
2. Select the schematic symbol for a zener diode.
3. Identify the operating point, the zener voltage, the forward-bias region, the zener current, and the reverse-bias region of a zener diode.
4. List the alternate names for zener diodes.
5. Select applications of zener diodes.
6. Select the schematic symbol for a tunnel diode.
7. Identify the negative resistance region, peak point, valley point, and the forward point of a tunnel diode.
8. Select applications of tunnel diodes.
9. Select the schematic symbol for a varactor diode.
10. Complete statements concerning bias voltage and barrier capacitance in varactor diodes.
11. List alternate names for varactor diodes.
12. Select applications of varactor diodes.
13. Select the schematic symbol for a light-emitting diode.
15. Select applications of light-emitting diodes.
16. Select the schematic symbol for a photo diode.

17. Complete statements concerning light-input intensity versus current in photo diodes.

18. List three applications of the photo diode.

19. Demonstrate the ability to:
   a. Construct a volt/ampere characteristic curve for a zener diode.
   b. Construct and test a zener diode voltage regulator.
SPECIAL SEMICONDUCTOR DIODES
UNIT IV

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.
II. Provide student with information and job sheets.
III. Make transparencies.
IV. Discuss unit and specific objectives.
V. Discuss information sheet.
VI. Demonstrate and discuss the procedures outlined in the job sheets.
VII. Show various types of transistors.
VIII. Give test.

INSTRUCTIONAL MATERIALS

I. Include in this unit:
   A. Objective sheet
   B. Information sheet
   C. Transparency masters
      1. TM 1--Zener Diode Characteristics and Schematic Symbol
      2. TM 2--Tunnel Diode Characteristics and Schematic Symbol
   D. Job sheets
      1. Job Sheet #1--Construct a Volt/Ampere Characteristic Curve for a Zener Diode
      2. Job Sheet #2--Construct and Test a Zener Diode Voltage Regulator
   E. Test
   F. Answers to test

I. Terms and definitions

A. Zener diode--A silicon diode that is designed to operate at a specific reverse-breakdown voltage

B. Tunnel diode--A diode that has a negative resistance characteristic and can be used as amplifiers, an oscillator, and an extremely fast switching device

C. Varactor diode--A diode which serves as a voltage-sensitive capacitor

D. Light-emitting diode (LED)--A diode specially doped to emit light when forward biased

E. Photo diode--A diode made from photo-sensitive material, the device's resistance decreases with increased light

F. Hot-carrier diode--A special diode which uses a metal-to-semiconductor junction and is used for high-frequency rectification

II. Zener diode's schematic symbol (Transparency 1)

III. Zener diode's volt/ampere characteristic curve (Transparency 1)

A. Operating point

B. Zener voltage

C. Zener current

D. Forward-bias region

E. Reverse-bias region

IV. Alternate names for zener diodes

A. Reference diode

B. Breakdown diode

V. Zener diode applications

A. Voltage regulator

B. Reference element
INFORMATION SHEET

VI. Schematic symbol for a tunnel diode (Transparency 2)

VII. Tunnel diode's volt/ampere characteristic curve (Transparency 2)
A. Negative resistance region
B. Peak point
C. Valley point
D. Forward point

VIII. Applications of tunnel diodes
A. Amplifiers
B. Oscillators
C. Switches
D. Multivibrators

IX. Schematic symbol for a varactor diode

X. Bias voltage and barrier capacitance in varactor diodes
A. The larger the reverse bias, the smaller the barrier capacitance
B. The larger the forward bias, the larger the barrier capacitance

XI. Alternate names for varactor diodes
A. Varicaps
B. Voltacaps

XII. Applications of varactor diodes
A. Automatic frequency controls
B. Variable RC and LC filters
XIII. Schematic symbol for a light-emitting diode (LED):

XIV. Instantaneous-forward current versus light output in light-emitting diodes
   A. Light output increases with forward current
   B. There is no light output when LED is reverse biased

XV. Applications of light-emitting diodes
   A. Electroluminescent displays
   B. Logic-level indicators

XVI. Schematic symbol for a photo diode:

XVII. Light-input intensity versus current in photo diodes
   A. An increase in input-light intensity increases diode current
   B. For a given light-input intensity the diode current is approximately constant for increased reverse-bias voltage

XVIII. Applications of the photo diode
   A. Light-detection systems
   B. High speed card and tape readers
   C. Production line counting of objects which interrupt a light beam
Zener Diode Characteristics and Schematic Symbol

For a Zener diode, the characteristics are as follows:

1. **Forward Current Region**: When the diode is forward biased, the current increases linearly with the voltage until the Zener voltage ($E_Z$) is reached.
2. **Zener Voltage ($E_Z$)**: This is the voltage at which the diode begins to conduct heavily due to the presence of a reverse bias.
3. **Zener Current ($I_Z$)**: The current at which the voltage is $E_Z$.
4. **Forward Bias Region**: The region where the diode operates in the forward direction.
5. **Reverse Bias Region**: The region where the diode operates in the reverse direction.

The operational point is determined by the specific voltage and current requirements of the circuit in which the diode is used.
Tunnel Diode Characteristics and Schematic Symbol

![Schematic Symbols]

- **Anode**
- **Cathode**

Forward Current

- **Peak-Point Current** \( I_P \)
- **Peak-Point Voltage** \( V_P \)
- **Valley-Point Current** \( I_V \)
- **Valley-Point Voltage** \( V_V \)
- **Forward-Point Voltage** \( V_{FP} \)

**Note:**

- Negative Resistance Region Exists Between Points B and C
I. Tools and equipment
   A. Power supply (0-15V)
   B. Voltmeter
   C. Milliammeter
   D. 1-1K ohm resistor, 1/2 watt
   E. 1-N4739 zener diode or equivalent
   F. Graph paper

II. Procedure
   A. Set the power supply for 0 volts output
   B. Connect the following circuit
      (NOTE: The zener diode is forward biased.)

<table>
<thead>
<tr>
<th>MA</th>
<th>+</th>
<th>0 - 15v</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-</td>
<td></td>
</tr>
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<td></td>
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</tr>
</tbody>
</table>

   C. Adjust the power supply for 1 volt output
   D. Read and record the voltage across the zener diode and the current flowing through the zener diode
   E. Repeat steps C and D in one volt increments as specified in data table
   F. Return the power supply to zero volts, then reverse the connections of the zener diode
      (NOTE: The zener is now reverse biased.)
G. Set the power supply for 1 volt

H. Read and record the voltage across the zener diode and the current through the diode

I. Repeat step H while increasing the voltage in one volt steps to 15 Volts

J. Graph the forward and reverse characteristics (current versus voltage) for the zener diode from the values just measured

K. Check your calculations and your graph with your instructor

**DATA:**

<table>
<thead>
<tr>
<th>FORWARD BIAS</th>
<th>REVERSE BIAS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VOLTAGE (VOLTS)</strong></td>
<td><strong>CURRENT (MA)</strong></td>
</tr>
<tr>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SPECIAL SEMICONDUCTOR DIODES
UNIT IV

JOB SHEET #2—CONSTRUCT AND TEST A
ZENER DIODE VOLTAGE REGULATOR

I. Tools and equipment
   A. Power supply (0-15V)
   B. 2-DC voltmeters
   C. 1-DC milliammeter
   D. 1-1K ohm resistor, 1/2 watt
   E. 1-10K ohm resistor, 1/2 watt
   F. 1-1N4739 zener diode or equivalent
   G. Graph paper

II. Procedure
   A. Connect the circuit shown below
   B. Adjust the power supply from zero to 15 volts in steps of 1 volt
   C. For each value of power supply voltage read and record the voltage across
      the 10K ohm load resistor and circuit current
   D. Graph power supply voltage versus load voltage for each data point
   E. Check your calculations and your graph with your instructor
1. Match the terms on the right with their correct definitions.
   
   a. A silicon diode that is designed to operate at a specific reverse-breakdown voltage
   
   b. A diode that has a negative resistance characteristic and can be used as amplifiers, an oscillator, and an extremely fast switching device
   
   c. A diode which serves as a voltage-sensitive capacitor
   
   d. A diode specially doped to emit light when forward biased
   
   e. A diode made from photosensitive material; the device's resistance decreases with increased light
   
   f. A special diode which uses a metal-to-semiconductor junction and is used for high-frequency rectification

2. Select the schematic symbol for a zener diode from the symbols given below by circling the letter next to it.

   a. ![Symbol A]
   b. ![Symbol B]
   c. ![Symbol C]
   d. ![Symbol D]
3. Identify the operating point, the zener voltage, the forward-bias region, the zener current, and the reverse-bias region of a zener diode from the zener volt/ampere characteristics given below.

4. List the alternate names for zener diodes.
   a. _________________________________
   b. _________________________________

5. Select the zener diode applications by placing an "X" in the appropriate blanks.
   _____ a. Voltage regulator
   _____ b. Amplifier
   _____ c. Reference element
   _____ d. Switch
6. Select the schematic symbol for a tunnel diode from the symbols given below by circling the letter next to it.

![Schematic symbols](image)

a. ![Diagram a](image)  
b. ![Diagram b](image)  
c. ![Diagram c](image)  
d. ![Diagram d](image)

7. Identify the negative resistance region, peak point, valley point, and the forward point for a tunnel diode from the volt/ampere characteristics given below.

![Voltage/Current Characteristics](image)

a.  
b.  
c.  
d.  

101
8. Select applications of tunnel diodes by placing an "X" in the appropriate blanks.

   _____ a. Logic level indicators
   _____ b. Amplifiers
   _____ c. Oscillators
   _____ d. Voltage regulators
   _____ e. Switches
   _____ f. Multivibrators

9. Select the schematic symbol for a varactor diode from the symbols given below by circling the letter next to it.

   a. 
   b. 
   c. 
   d. 

10. Complete statements concerning bias voltage and barrier capacitance in varactor diodes by underlining the correct words in the sentences below.

   a. The (larger) (smaller) the reverse bias, the (smaller) (larger) the barrier capacitance
   b. The (larger) (smaller) the forward bias, the (larger) (smaller) the barrier capacitance

11. List alternate names for varactor diodes.

   a. __________________________
   b. __________________________

12. Select applications of varactor diodes by placing an "X" in the appropriate blanks.

   _____ a. Switches
   _____ b. Voltage regulators
   _____ c. Automatic frequency controls
   _____ d. Variable RC and LC filters
13. Select the schematic symbol for a light-emitting diode from the symbols given below by circling the letter next to it.

a. 

b. 

c. 

d. 

14. Complete statements concerning instantaneous-forward current versus light output in light-emitting diodes by underlining the correct words in the sentences below.

a. Light output (increases) (decreases) with forward current

b. There is no light output when LED is (forward) (reverse) biased

15. Select applications of light-emitting diodes by placing an "X" in the appropriate blanks.

___ a. Electroluminescent displays

___ b. Multivibrators

___ c. Logic-level indicators

___ d. Oscillators

___ e. Voltage regulators

16. Select the schematic symbol for a photo diode from the symbols given below by circling the letter next to it.

a. 

b. 

c. 

d. 
17. Complete statements concerning light-input intensity versus current-in photo diodes by underlining the correct words in the sentences below.
   a. An increase in input-light intensity (increases) (decreases) diode current
   b. For a given light-input intensity the diode current is (approximately) (exactly) constant for increased reverse-bias voltage

18. List three photo diode applications.
   a. 
   b. 
   c. 

19. Demonstrate the ability to:
   a. Construct a volt/ampere characteristic curve for a zener diode.
   b. Construct and test a zener diode voltage regulator.

   (NOTE: If these activities have not been accomplished prior to the test, ask your instructor when they should be completed.)
1. a. 3  
   b. 1  
   c. 2

2. c

3. FORWARD CURRENT
   Forward Bias Region
   Zener Voltage
   Operating Point
   Zener Current
   Reverse Bias Region

4. a. Reference diode  
   b. Breakdown diode

5. a, c

6. d

7. a. Peak point  
   b. Negative resistance region  
   c. Valley point  
   d. Forward point

8. b, c, e, f

9. d

10. a. The larger the reverse bias, the smaller the barrier capacitance  
    b. The larger the forward bias, the larger the barrier capacitance

11. a. Varicaps  
    b. Voltacaps
14. a. Light output increases with forward current  
   b. There is no light output when LED is reverse biased

15. a, c

16. d

17. a. An increase in input-light intensity increases diode current  
   b. For a given light-input intensity the diode current is approximately constant for increased reverse-bias voltage

18. a. Light-detection systems  
   b. High speed card and tape readers  
   c. Production line counting of objects which interrupt a light beam

19. Performance skills evaluated to the satisfaction of the instructor
UNIT OBJECTIVE

After completion of this unit, the student should be able to identify the standard symbols and correct biasing arrangements for NPN and PNP transistors and draw and label the current flow in NPN and PNP transistor circuits. The student should also be able to test transistors. This knowledge will be evidenced by correctly performing the procedures outlined on the assignment and job sheets and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to bipolar-junction transistors with their correct definitions.
2. Match transistor terms with their standard abbreviations.
3. Identify the basic elements in PNP and NPN transistor block diagrams and schematics.
4. Select the major uses of transistors.
5. State the base to emitter forward voltage drop for germanium and silicon transistors.
6. Identify the correct biasing arrangements for PNP and NPN transistors.
7. Draw the electron flow in NPN and PNP transistor circuits.
8. Distinguish between the typical types of transistors.
9. Label a transistor circuit.
10. Demonstrate the ability to test transistors.
BIPOLAR JUNCTION TRANSISTORS
UNIT V

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.

II. Provide student with information, assignment, and job sheets.

III. Make transparencies.

IV. Discuss unit and specific objectives.

V. Discuss information and assignment sheets.

VI. Demonstrate and discuss the procedures outlined in the job sheet.

VII. Show various types of transistors.

VIII. Give test.

INSTRUCTIONAL MATERIALS

I. Included in this unit:

A. Objective sheet

B. Information sheet

C. Transparency masters

1. TM 1—Transistor Block Diagrams and Schematic Symbols

2. TM 2—Correctly Biased Transistors

3. TM 3—Electron Flow in NPN and PNP Transistor Circuits

4. TM 4—Typical Transistor Types

D. Assignment sheet #1—Label a Transistor Circuit

E. Answers to assignment sheet

F. Job Sheet #1—Test Transistors

G. Test

H. Answers to test
II. References:


BIPOLAR JUNCTION TRANSISTORS
UNIT V

INFORMATION SHEET

I. Terms and definitions

A. Bipolar junction transistor (BJT)--A three-terminal semiconductor current-controlled device that is normally used as a control switch or as a signal or power amplifier

B. Emitter--The section that supplies majority carriers

C. Collector--The section that collects majority carriers

D. Base--The section used to control the flow of majority carriers (current) from emitter to collector

E. PNP transistor--One of the two major categories of bipolar transistors consisting of P-type material for the emitter, N-type material for the base, and P-type material for the collector

F. NPN transistor--One of the two major categories of bipolar transistors consisting of N-type material for the emitter, P-type material for the base, and N-type material for the collector

G. Bias--The voltages required to make the semiconductor devices (such as diodes and transistors) operate correctly

H. Bipolar--Two types of carriers, holes, and electrons flowing in transistors (NOTE: The emitter-base junction must be forward biased while the base-collector junction must be reverse biased.)

II. Transistor terms and standard abbreviations

A. Transistor-base lead--B

B. Transistor-emitter lead--E

C. Transistor-collector lead--C

D. Base current--I_B

E. Emitter current--I_E

F. Collector current--I_C
III. Basic elements in transistor block diagrams and schematics (Transparency 1)

A. PNP transistors
   1. Block diagram
      a. Emitter
      b. Base
      c. Collector
   2. Schematic
      a. Emitter
      b. Base
      c. Collector
      (NOTE: The emitter arrow is pointing toward the N-type material and toward the base.)

B. NPN transistors
   1. Block diagram
      a. Emitter
      b. Base
      c. Collector
   2. Schematic
      a. Emitter
      b. Base
      c. Collector
      (NOTE: The emitter arrow is pointing toward the N-type material and away from the base, which is P-type material.)

IV. Major uses of transistors

A. Amplification
B. Switching
V. Forward voltage drop for transistors
   A. Germanium (Ge)--0.2 to 0.3 volts
   B. Silicon (Si)--0.6 to 0.7 volts

VI. Biasing arrangements for PNP and NPN transistors (Transparency 2)
   A. Emitter--Base has forward bias
   B. Base--Collector has reverse bias

   (NOTE: The difference in the PNP and NPN biasing arrangements is that polarity is reversed.)

VII. Electron flow in NPN and PNP transistor circuits (Transparency 3)
   A. PNP--Electrons flow from emitter to collector through external circuit
   B. NPN--Electrons flow from collector to emitter through external circuit

VIII. Typical transistor types (Transparency 4)
   A. Small signal--Relatively small and handles small currents
   B. Power--Relatively large and handles large currents
Transistor Block Diagrams and Schematics

PNP Transistor

(NOTE: In both PNP and NPN transistors, the arrow on the emitter lead points toward the N-type material.)
Correctly Biased Transistors

Common Base

PNP Transistor Bias

Common Emitter

NPN Transistor Bias
Electron Flow in NPN and PNP Transistor Circuits

**NPN Circuit**

\[ I_E = I_B + I_C \]

**PNP Circuit**

\[ I_E = I_B + I_C \]
Typical Transistor Types

Small Signal Transistors

Power Transistors

(Note: There may be other base diagrams)
Directions: On the transistor circuit below, label or draw the following:

a. Category of transistor
   1. NPN
   2. PNP

b. Leads
   1. Emitter
   2. Base
   3. Collector

c. Draw in the correct battery-bias supplies

d. Electron circuit flow
   1. $I_E$
   2. $I_B$
   3. $I_C$
TRANSISTORS
UNIT V

ANSWERS TO ASSIGNMENT SHEET #1

a. NPN

b. 

c. 

\( I_C \)

\( I_B \)

\( I_E \)
TRANSISTORS UNIT V

JOB SHEET #1--TEST TRANSISTORS

I. Tools and equipment
   A. Assortment of transistors (both signal and power types)
   B. Ohmmeter
   C. Transistor tester (if available)

II. Procedure
   A. Carefully examine the assortment of transistors and note the differences in size, shape, and lead arrangements
   B. Choose two signal transistors and one power transistor
   C. Determine which ohmmeter lead is positive and which is negative
      (NOTE: Either get this from the manufacturer's instruction book or by measuring the voltage with a voltmeter.)
   D. Identify the emitter, base, and collector leads
   E. Place the ohmmeter on R x 100 range
      (NOTE: This is necessary because there may be too much voltage if the ohmmeter is placed in a high range.)
   F. Determine the forward-biased emitter base junction
      1. Place the positive ohmmeter lead on the emitter lead and the negative ohmmeter lead on the base lead
      2. Note the resistance reading
      3. Place the negative ohmmeter lead on the emitter and the positive ohmmeter lead on the base
      4. Note the resistance reading
      5. Compare the two resistance readings
      6. Repeat steps 1 through 5 for the collector-base junction
      7. From above reading, determine whether the transistor is good or bad
      8. If the transistor tested was good, state whether it is PNP or NPN
      9. If the transistor tested was bad, state where it was open or shorted
JOB SHEET #1

G. If your lab has a transistor tester, following the instructions given in operations manual, check the transistor.

H. Check your findings with your instructor.

DATA CHART

EMITTER-BASE JUNCTION

- $R_{EB}$
- $R_{BE}$

COLLECTOR-BASE JUNCTION

- $R_{CB}$
- $R_{BC}$

TYPE OF TRANSISTOR
1. Match the terms on the right with their correct definitions.

   a. The section that collects majority carriers
   b. The voltages required to make the semiconductor devices operate correctly
   c. The section used to control the flow of majority carriers from emitter to collector
   d. The section that supplies majority carriers
   e. One of the two major categories of bipolar transistors consisting of P-type material for the emitter, N-type material for the base, and P-type material for the collector
   f. A three-terminal semiconductor current-controlled device that is normally used as a control switch or as a signal or power amplifier
   g. One of the two major categories of bipolar transistors consisting of N-type material for the emitter, P-type material for the base, and N-type material for the collector
   h. Two types of carriers, holes, and electrons flowing in transistors

2. Match transistor terms with their standard abbreviations.

   a. I_B
   b. C
   c. E
   d. I_E
   e. B
   f. I_C
3. Identify the basic elements in PNP and NPN transistor block diagrams and schematics.

PNP Transistor

A

NPN Transistor

If

Schematic

Block Diagram
4. Select the major uses of transistors by placing an "X" in the appropriate blank.
   a. Amplification
   b. Oscillation
   c. Switching
   d. Transforming
   e. Energy storage

5. State the base to emitter forward voltage drop for germanium and silicon transistors.
   a. Germanium ______ to ______ volts
   b. Silicon ______ to ______ volts

6. Identify the correct biasing arrangements for PNP and NPN transistors by drawing the battery connections in the circuit schematics below.
   a. PNP
   
   ![PNP Circuit Diagram]

   b. NPN
   
   ![NPN Circuit Diagram]
7. Draw the correct election flow in NPN and PNP transistor circuits.

\[ \text{NPN Circuit} \]
\[ \text{PNP Circuit} \]

8. Distinguish between small signal and power transistors by placing an "X" next to the signal transistors.

\[ \text{a.} \quad \text{b.} \quad \text{c.} \quad \text{d.} \quad \text{e.} \quad \text{f.} \]
9. Label a transistor circuit.

10. Demonstrate the ability to test transistors.

    (NOTE: If these activities have not been accomplished prior to the test, ask your instructor when they should be completed.)
BIPOLAR JUNCTION TRANSISTORS
UNIT V

ANSWERS TO TEST

1. a. 3   e. 6
    b. 7   f. 1
    c. 4   g. 5
    d. 2   h. 8

2. a. 4
    b. 3
    c. 2
    d. 5
    e. 1
    f. 6

3. a. Emitter   e. Collector (C)   i. Base
    b. Collector  f. Base (B)   j. Emitter (E)
    c. Base      g. Emitter     k. Collector (C)
    d. Emitter (E) h. Collector   l. Base (B)

4. a, c

5. a. 0.2 to 0.3 volts
    b. 0.6 to 0.7 volts

6. a. PNP

   b. NPN
7. a. PNP

b. NPN

8. b, c, e

9. Evaluated to the satisfaction of the instructor
UNIT OBJECTIVES

After completion of this unit, the student should be able to identify transistor circuits, state the relative values of current, voltage, and power gain in decibels, and list the most common applications for basic transistor circuit types. The student should also be able to construct and test each of the basic transistor circuit types and demonstrate the ability to plot the output characteristic curves for a common-emitter transistor circuit. This knowledge will be evidenced by correctly completing the procedures outlined in the assignment and job sheets and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to bipolar-junction transistor circuits with their correct definitions.
2. Identify the basic types of transistor circuits.
3. Match transistor circuits with terms or values associated with circuit current gain.
4. Complete a table showing the gain characteristics of basic transistor types.
5. State which types of transistor circuits give signal voltage phase reversal.
6. Match transistor circuits with their common applications.
7. Complete a table showing the relative magnitudes of the input and output impedances for basic transistor circuits.
8. Compute voltage, current, and power stage gain in decibels.
9. Demonstrate the ability to:
   a. Construct and test a common-emitter circuit.
   b. Construct and test a common-base circuit.
   c. Construct and test a common-collector circuit.
   d. Plot a transistor output characteristic curve.
SUGGESTED ACTIVITIES

I. Provide student with objective sheet.

II. Provide student with information, assignment, and job sheets.

III. Make transparencies.

IV. Discuss unit and specific objectives.

V. Discuss information and assignment sheets.

VI. Demonstrate and discuss the procedures outlined in the job sheets.

VII. Show various types of transistors.

VIII. Give test.

INSTRUCTIONAL MATERIALS

I. Included in this unit:
   A. Objective sheet
   B. Information sheet
   C. Transparency masters
      1. TM 1-Circuit Schematic Diagrams
      2. TM 2-Gain Characteristics of Basic Transistor Types
      3. TM 3-Impedance Characteristics
   D. Assignment Sheet #1-Compute Voltage, Current, and Power Stage Gain in Decibels
   E. Answers to assignment sheet
   F. Job sheets
      1. Job Sheet #1-Construct and Test a Common-Emitter Circuit
      2. Job Sheet #2-Construct and Test a Common-Base Circuit
3. Job Sheet #3—Construct and Test a Common-Collector Circuit

4. Job Sheet #4—Plot a Transistor Output Characteristic Curve

BIPOLAR-JUNCTION TRANSISTOR CIRCUITS
UNIT VI

INFORMATION SHEET

I. Terms and definitions

A. Gain--Ratio of the output quantity to input quantity, often abbreviated as "A"

B. Voltage gain ($A_v$)--Output voltage divided by input voltage

C. Current gain ($A_i$)--Output current divided by input current

D. Power gain ($A_p$)--Output power divided by input power

E. Input impedance--The impedance of a circuit as viewed from its input terminals

F. Output impedance--The impedance of a circuit as viewed from the output terminals

G. db (decibel)--A ratio of an output level to an input level

II. Basic types of transistor circuits (Transparency 1)

A. Common emitter

B. Common base

C. Common collector

(NOTE: For PNP transistor, reverse-bias polarity of battery terminals.)

III. Transistor circuit current gain ($A_i$)

A. Common emitter

1. $h_{fe}$

2. Beta or $\beta$

3. Much greater than 1; typical current gain value = 50

B. Common base

1. $h_{fb}$

2. Alpha or $\alpha$

3. Current gain less than 1; typically 0.95 to 0.99
INFORMATION SHEET

C. Common collector
   1. Current gain is greater than 1
   2. Called emitter follower

IV. Gain characteristics of the basic transistor types (Transparency 2)

A. Common emitter
   1. $A_v =$ high (300)
   2. $A_i = h_{fe} = \beta =$ high (50)
   3. $A_p =$ very high (15,000)

B. Common base
   1. $A_v =$ high (500)
   2. $A_i = h_{fb} = \beta =$ low (0.97)
   3. $A_p =$ medium (485)

C. Common collector
   1. $A_v =$ low (less than 1)
   2. $A_i =$ high (50)
   3. $A_p =$ low (48)

V. Signal voltage phase reversal

A. CE - yes
B. CB - no
C. CC - no

VI. Transistor circuits and their common applications

A. CE - Small signal amplification
B. CB - High frequency power amplification (current regulation)
C. CC - Voltage follower (impedance matching)
VII. Impedance Characteristics (Transparency 3)

A. CE
   1. Input impedance - Medium (1,000 ohms)
   2. Output impedance - Medium (50,000 ohms)

B. CB
   1. Input impedance - Low (60 ohms)
   2. Output impedance - High (1 Meg ohm)

C. CC
   1. Input impedance - High (400,000 ohms)
   2. Output impedance - Low (100 ohms)
Circuit Schematic Diagrams

CE (Common Emitter)

CB (Common Base)

CC (Common Collector)

For PNP Transistors Reverse The Polarity of Battery Terminals.
## Gain Characteristics of Basic Transistor Types

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Common Emitter</th>
<th>Common Base</th>
<th>Common Collector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Gain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$A_V = \frac{V_{Out}}{V_{In}}$</td>
<td>High (300)</td>
<td>High (500)</td>
<td>Low Less Than One</td>
</tr>
<tr>
<td>Current Gain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$A_I = \frac{I_{Out}}{I_{In}}$</td>
<td>High (50)</td>
<td>Less Than One (0.97)</td>
<td>High (50)</td>
</tr>
<tr>
<td>Power Gain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$A_P = \frac{P_{Out}}{P_{In}}$</td>
<td>Very High (15,000)</td>
<td>Medium (400)</td>
<td>Low (30)</td>
</tr>
</tbody>
</table>
## Impedance Characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Common Emitter</th>
<th>Common Base</th>
<th>Common Collector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input, Impedance</td>
<td>Medium (1,000)</td>
<td>Low (60)</td>
<td>High (400,000)</td>
</tr>
<tr>
<td>Output Impedance</td>
<td>Medium (50,000)</td>
<td>High (1 M)</td>
<td>Low (100)</td>
</tr>
</tbody>
</table>
BIPOLAR-JUNCTION TRANSISTOR CIRCUITS
UNIT VI

ASSIGNMENT SHEET #1-COMPUTE VOLTAGE, CURRENT, AND POWER STAGE GAIN IN DECIBELS

Directions: Using the formulas given below, convert the gain values to their equivalent db value.

I. Formulas
   A. Voltage gain-20 log \( A_v \) = gain in db
   B. Current gain-20 log \( A_i \) = gain in db
   C. Power gain-10 log \( A_p \) = gain in db

   Example: If voltage gain is 100, then the gain in db would be 20 times the log of 100 which is equal to 20 x 2 or a db gain of 40

II. Problems
   A. Voltage gain
      1. \( A_v = 100 \) \hspace{1cm} db gain =
      2. \( A_v = 75 \) \hspace{1cm} db gain =
   B. Current gain
      1. \( A_i = 1 \) \hspace{1cm} db gain =
      2. \( A_i = .96 \) \hspace{1cm} db gain =
   C. Power gain
      1. \( A_p = 25 \) \hspace{1cm} db gain =
      2. \( A_p = 2 \) \hspace{1cm} db gain =
BIPOLAR-JUNCTION TRANSISTOR CIRCUITS
UNIT VI

ANSWERS TO ASSIGNMENT SHEET #1

A.  1.  40 db
    2.  37.5 db

B.  1.  0 db
    2.  -0.35 db

C.  1.  13.98 db
    2.  3.01 db
BIPOLAR-JUNCTION TRANSISTOR CIRCUITS
UNIT VI

JOB SHEET #1--CONSTRUCT AND TEST A COMMON-EMITTER CIRCUIT

I. Tools and equipment
   A. 1 NPN transistor (2N1304 transistor)
   B. Microammeter and 2 milliammeters (or 3 multimeters-zero to 50mA range)
   C. VTVM
   D. Oscilloscope
   E. Audio signal generator
   F. 1-1M resistor. 1-47K resistor. 1-1K resistor, 1-10K and 1-1K potentiometer
      (use 1/2 watt resistor)
      (NOTE: Resistor values may vary for your particular transistor)
   G. 1-10 μF capacitor
   H. Power supply 0-20VDC

II. Procedure
   A. Do not turn on power supply at this time
   B. Connect the circuit as shown below

![Circuit Diagram]

(NOTE: If you do not have a microammeter for IB insert a 100 ohm resistor
in series and use your VTVM to read the voltage drop. Then, compute the
current from the VTVM reading and the value of the resistor.)
JOB SHEET #1

C. Have your instructor approve your circuit wiring.

D. Set the potentiometers to zero ohms between points A and W.

E. Set the power supply for 20V DC.

F. Adjust the collector potentiometer $R_3$ until $V_{ce}$ is 6.0 volts.

G. Adjust the base resistor $R_2$ until the base current, $I_B$, is 20 microamperes.

H. Recheck $V_{ce}$ to see that it has remained at 6.0 volts.
   (NOTE: It may be necessary to readjust $R_3$ to maintain $V_{ce} = 6$ volts and $I_a = 20 \mu A$.)

I. Read and record $I_c$ when $V_{ce} = 6.0$ v and $I_B = 20 \mu A$.

J. Using your VTVM read and record the base-emitter DC voltage.

K. Increase the base resistor, $R_2$, until $I_B$ is 40 microamperes.

L. Recheck $V_{ce} = 6.0$ volts, adjust $R_3$ as needed.

M. Read and record $I_c$ when $V_{ce} = 6.0$ v and $I_B = 40 \mu A$.

N. Connect the signal generator across the 47K input resistor, and set the output frequency to 1 KHz.

O. Turn the signal generator on and adjust the input signal, $e_{in}$, across the input resistor $R_1$ to 10 mV rms value.

P. Use the oscilloscope to view this waveshape and make a sketch of the waveshape showing frequency and amplitude.

Q. Move the oscilloscope to observe the output voltage across the 1K ohm output resistor.

R. Make a sketch of the output waveform, showing amplitude and frequency.

S. Compute and record the output voltage, $e_o$, in rms.

T. Compute the output current, $i_{out}$, by dividing the output voltage, $e_o$, by the load resistance, 1K.

U. Measure the rms voltage across the 1 M ohm series resistor.

V. Compute and record the input current $i_{in}$.

W. Calculate the current gain by dividing $i_{out}$ by $i_{in}$, and express your answer in db.

X. Have your instructor check your calculations.
# Data Table

## DC measurements

<table>
<thead>
<tr>
<th>V_{CE}</th>
<th>I_E</th>
<th>I_B</th>
<th>I_C</th>
<th>V_{BE}</th>
</tr>
</thead>
<tbody>
<tr>
<td>6v</td>
<td></td>
<td>20μA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>40μA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## AC measurements

<table>
<thead>
<tr>
<th>V_{in}</th>
<th>P-P</th>
<th>rms</th>
</tr>
</thead>
<tbody>
<tr>
<td>\text{i}_{in}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>\text{calculated}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V_{out}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>\text{i}_{out}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>\text{A dB= Cal.}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>\text{A}_{i dB cal.}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>\text{A}_{p dB cal.}</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
JOB SHEET #2--CONSTRUCT AND TEST A COMMON-BASE CIRCUIT

I. Tools and equipment
A. 1-PNP transistor (2N1305 or equivalent)
B. Variable power supply (0-20V DC)
C. Oscilloscope
D. Audio signal generator
E. VTVM
F. Microammeter (or multimeter)
G. 2-milliammeters (or multimeter)
H. Resistor 1-1K, 1-47K, 1-1M (use 1/2 watt resistor)
I. One capacitor - 10μF
J. Potentiometers - 50 ohm, 1W & 750 ohm, 1W

II. Procedure
A. Do not turn on power supply at this time
B. Connect the circuit as shown below
C. Have your instructor check your circuit wiring

D. Adjust potentiometer $R_2$ until the resistance between point A and point W reads zero ohms

E. Turn on power supply and set for 20 volts

F. Adjust potentiometer $R_3$ until $V_{CB}$ reads 5.8 Volts

G. Adjust potentiometer $R_2$ until the collector current reads 25 mA

H. Read and record $I_C$, $I_B$, and $I_E$

I. Adjust potentiometer $R_2$ to obtain a 20 microamp increase in $I_B$

J. Measure and record $I_C$, $I_B$, and $I_E$

K. Measure $V_{EB}$ with the VTVM

L. State whether your transistor is germanium or silicon

M. Connect the signal generator across to 47K input resistor

N. Set the signal generator for 1 KHz

O. Adjust the signal generator until the voltage across the 47K input resistor reads 10mV rms

P. Using the oscilloscope, observe the waveshape of the voltage $e_{in}$ across the 47K input resistor

Q. Sketch the waveshape of $e_{in}$ showing frequency and amplitude

R. Measure the rms voltage across the 1M resistor and compute the rms input current, $i_{in}$

S. Using the oscilloscope, observe the waveshape of the voltage $e_o$ across the 1K load resistor

T. Sketch the waveshape of $e_o$ showing amplitude and frequency

U. Calculate the rms value of $e_o$

V. Calculate the rms value of the output current, $i_o$

W. Calculate the voltage gain of the circuit

X. Express the voltage gain of the circuit in db

Y. Have your instructor check your calculations

(NOTE: Remember to convert peak-to-peak voltage readings from scope to rms value)
## Data Table

### DC measurements

<table>
<thead>
<tr>
<th>VCE</th>
<th>I_C</th>
<th>I_B</th>
<th>I_E</th>
<th>Δ I_C/Δ I_B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1 (step H)</td>
<td>25μA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 2 (step J)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### AC measurements

<table>
<thead>
<tr>
<th>e_in</th>
<th>V_in</th>
<th>i_in</th>
<th>e_o (Vix)</th>
<th>i_o</th>
<th>A_v</th>
<th>A_v dB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

P-P | RMS

[146]
BIPOLAR-JUNCTION TRANSISTOR CIRCUITS
UNIT VI

JOB SHEET #3—CONSTRUCT AND TEST A COMMON-COLLECTOR CIRCUIT

I. Tools and equipment
   A. Variable power supply (0-20V)
   B. 1-PNP transistor (2N1305 or equivalent)
   C. Oscilloscope
   D. Signal generator
   E. VTVM
   F. 1 - 10μf capacitor
   G. Resistors - 1 47K, 1-1K, 1-1M (use 1/2 watt resistor)
   H. Microammeter (multimeter)
   I. Two milliammeters (multimeters)
   J. Potentiometers - 1-10K, 1-1K (use 1 watt potentiometer)

II. Procedure
   A. Do not turn on power supply at this time
   B. Connect circuit as shown below
JOB SHEET #3

C. Have your instructor approve your circuit wiring

D. Set potentiometer $R_2$ to zero ohms between points A and W

E. Set the power supply to 20 volts

F. Adjust potentiometer $R_2$ until $I_B$ reads 20 $\mu$A

G. Adjust potentiometer $R_3$ until $V_{ce}$ as measured by the VTVM reads 6 volts

H. Measure and record $I_E$, $I_B$, and $I_C$

I. Adjust potentiometer $R_2$ until $I_B$ reads 40 $\mu$A

J. Measure and record $I_E$, $I_B$, $I_C$

K. Measure $V_{BE}$ with the VTVM and determine if the transistor is germanium or silicon

L. Connect the signal generator across the input resistor (47K)

M. Connect the VTVM across the 47K resistor and adjust the signal generator at 1 KHz until the VTVM reads 10mV, rms

N. Read the rms voltage across the 1 meg ohm resistor

O. Calculate the input current

P. Sketch the waveshape of the input voltage showing both amplitude and frequency, as displayed on the oscilloscope

Q. Sketch the observed output waveshape across the 1K load resistor and calculate the rms output voltage

R. Calculate the rms value of the output current, $I_D$

S. Calculate the circuit's power gain and express the value in db

T. Have your instructor check your calculations
## Data Table

### DC measurements

<table>
<thead>
<tr>
<th>V_{CE}</th>
<th>I_C</th>
<th>I_B</th>
<th>I_E</th>
<th>\frac{\Delta I_C}{\Delta I_B}</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0V</td>
<td>20\mu A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.0V</td>
<td>40\mu A</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### AC measurements

<table>
<thead>
<tr>
<th></th>
<th>P-P</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>I_{in}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_{out}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V_{ik}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_{out}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V_{1m}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_{in}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A_i</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A_{i dB}</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
BIPOLAR-JUNCTION TRANSISTOR CIRCUITS
UNIT VI

JOB SHEET #4--PLOT A TRANSISTOR OUTPUT CHARACTERISTIC CURVE

I. Tools and equipment
   A. 1-NPN transistor (2N1304 transistor)
   B. 1-microammeter and 2-milliameters (or three multimeters)
   C. VTVM
   D. 2-power supplies (0-20V DC)
   E. Graph paper

II. Procedure
   A. Do not turn on power supply at this time
   B. Connect the circuit as shown below
      \[ \text{\includegraphics[width=0.8\textwidth]{circuit_diagram.png}} \]
      
      C. Set the $V_{BB}$ power supply until $I_B$ reads 20 $\mu$A
      D. Record this value
      E. Adjust the $V_{CC}$ power supply for voltages from 0 to 15 volts and record the value of $I_C$ for each voltage reading
      (NOTE: It will be necessary to use small voltage clamps for $V_{CC}$ between 0 and 5 volts. This will allow more measurements for $I_C$ at the points where $I_C$ rises rapidly.)
      F. Set $V_{CC}$ back to 0 volts
      G. Readjust $V_{BB}$ for $I_B$ equal to 40 $\mu$A
      H. Record this value
I. Readjust \( V_{CC} \) from 0 to 15 volts, recording the value of \( I_C \) at each value of \( V_{CC} \).

J. Set \( V_{CC} \) equal to 0 volts.

K. Readjust \( V_{BB} \) for \( I_B \) equal to 60 \( \mu \)A.

L. Record this value.

M. Readjust \( V_{CC} \) from 0 to 15 volts, recording the values of \( I_C \) at each value of \( V_{CC} \).

N. Ask your instructor how many settings of \( I_B \) you should use.

O. Plot a graph showing the relationship between \( I_B \), \( I_C \), and \( V_{CC} \).

(NOTE: The following is a sample of what your graph should look like.)
### DATA TABLE

<table>
<thead>
<tr>
<th>$V_{CC}$</th>
<th>0.2</th>
<th>0.4</th>
<th>0.6</th>
<th>0.8</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
<th>2.5</th>
<th>3.0</th>
<th>5.0</th>
<th>7.5</th>
<th>10.0</th>
<th>15.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_C$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tbody>
</table>

$I_B=20 \mu A$

<table>
<thead>
<tr>
<th>$V_{CC}$</th>
<th>0.2</th>
<th>0.4</th>
<th>0.6</th>
<th>0.8</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
<th>2.5</th>
<th>3.0</th>
<th>5.0</th>
<th>7.5</th>
<th>10.0</th>
<th>15.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_C$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

$I_B=40 \mu A$

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<th>0.6</th>
<th>0.8</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
<th>2.5</th>
<th>3.0</th>
<th>5.0</th>
<th>7.5</th>
<th>10.0</th>
<th>15.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_C$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$I_B=60 \mu A$

<table>
<thead>
<tr>
<th>$V_{CC}$</th>
<th>0.2</th>
<th>0.4</th>
<th>0.6</th>
<th>0.8</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
<th>2.5</th>
<th>3.0</th>
<th>5.0</th>
<th>7.5</th>
<th>10.0</th>
<th>15.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_C$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
BIPOLAR-JUNCTION TRANSISTOR-CIRCUITS
UNIT VI

NAME ____________________________

TEST

1. Match the terms on the right with their correct definitions.

   a. The impedance of a circuit as viewed from its input terminals
   b. Output voltage divided by input voltage
   c. Output power divided by input power
   d. The impedance of a circuit as viewed from the output terminals
   e. Output current divided by input current
   f. Ratio of the output quantity to input quantity, often abbreviated as "A"
   g. A ratio of an output level to an input level

2. Identify the basic types of transistor circuits.

   a. ____________________________
   b. ____________________________
   c. ____________________________

3. Match the transistor circuits on the right with the terms or values for circuit current gain.

   a. \( h_{fe} \)
   b. \( h_{fb} \)
   c. Much greater than 1; typical current gain value = 50
   d. Beta or \( \beta \)
   e. Alpha or \( \alpha \)
   f. Called emitter follower
   g. Current gain less than 1; typically 0.95 to 0.99

1. Gain
2. Power gain
3. Current gain
4. Voltage gain
5. Input impedance
6. Output impedance
7. \( \text{db} \)
4. Complete the following table to show the relative magnitudes of current, voltage, and power gain for basic transistor circuits.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Common Emitter</th>
<th>Common Base</th>
<th>Common Collector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Gain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( A_V = \frac{V_{Out}}{V_{In}} )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current Gain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( A_I = \frac{I_{Out}}{I_{In}} )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Gain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( A_P = \frac{P_{Out}}{P_{In}} )</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. State which transistor circuit types give phase reversal by indicating yes or no by each.
   a. CE ______
   b. CB ______
   c. CC ______

6. Match the transistor circuits on the right with their common applications.
   ______ a. Small signal amplification 1. CC
   ______ b. High frequency power amplification 2. CE
   ______ c. Voltage follower 3. CB

7. Complete the following table to show the relative magnitudes of input and output impedances for basic transistor circuits.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Common Emitter</th>
<th>Common Base</th>
<th>Common Collector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Impedance</td>
<td></td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Output Impedance</td>
<td>Medium</td>
<td></td>
<td>Low</td>
</tr>
</tbody>
</table>
8. Compute voltage, current, and power gain in decibels.

9. Demonstrate the ability to:
   a. Construct and test a common-emitter circuit.
   b. Construct and test a common-base circuit.
   c. Construct and test a common-collector circuit.
   d. Plot a transistor output characteristic curve.

   (NOTE: If these activities have not been accomplished prior to the test, ask your instructor when they should be completed.)
BIPOLAR JUNCTION TRANSISTOR CIRCUITS
UNIT VI

ANSWER TO TEST

1. a. 5 e. 3
   b. 4 f. 1
   c. 2 g. 7
   d. 6

2. a. Common emitter
     b. Common base
     c. Common collector

3. a. 2 e. 1
    b. 3 f. 3
    c. 2 g. 1
    d. 2

4. | Characteristics | Common Emitter | Common Base | Common Collector |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Gain</td>
<td>High (300)</td>
<td>High (500)</td>
<td>Low Less Than One</td>
</tr>
<tr>
<td>A_V = V_out/V_in</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current Gain</td>
<td>High (50)</td>
<td>Less Than One (0.97)</td>
<td>High (50)</td>
</tr>
<tr>
<td>A_I = I_out/I_in</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Gain</td>
<td>Very High (15,000)</td>
<td>Medium (400)</td>
<td>Low (30)</td>
</tr>
<tr>
<td>A_P = P_out/P_in</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. a. Yes
    b. No
    c. No

6. a. 2
    b. 3
    c. 1

7. | Characteristics | Common Emitter | Common Base | Common Collector |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Impedance</td>
<td>Medium (1,000)</td>
<td>Low (60)</td>
<td>High (400,000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Impedance</td>
<td>Medium (50,000)</td>
<td>High (1 M)</td>
<td>Low (100)</td>
</tr>
</tbody>
</table>

8. Evaluated to the satisfaction of the instructor

9. Performance skills evaluated to the satisfaction of the instructor
TRANSISTOR AMPLIFIERS
UNIT VII

UNIT OBJECTIVE

After completion of this unit, the student should be able to match terms associated with single-stage and multi-stage amplifiers, construct a load line, calculate overall amplifier gain in db, list the various coupling techniques, and construct and test various types of amplifier circuits. This knowledge will be evidenced by correctly performing the procedures outlined in the assignment and job sheets and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to transistor amplifiers with their correct definitions.
2. Identify a voltage divider bias circuit.
3. Select true statements concerning leakage current.
4. Complete a table showing the classes of amplifiers, applications, and performance characteristics.
5. Select statements describing the characteristics of a Class B push-pull amplifier.
6. Select statements describing the characteristics of a Darlington-pair circuit.
7. Locate the Q point, saturation point, and cutoff point in a common emitter Class A amplifier circuit.
8. Complete a list showing the characteristics of different types of coupling.
9. Distinguish between ratio stage gains and dB stage gains in overall amplifier gain.
10. Select true statements concerning frequency considerations.
12. Calculate the overall gain of multistage-amplifier circuits.
13. Demonstrate the ability to:
   a. Test a single-ended amplifier.
   b. Test a push-pull amplifier.
   c. Test a two stage direct coupled amplifier.
   d. Test a basic Darlington-pair amplifier.
TRANSISTOR AMPLIFIERS
UNIT VII

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.

II. Provide student with information, assignment, and job sheets.

III. Make transparencies.

IV. Discuss unit and specific objectives.

V. Discuss information and assignment sheets.

VI. Demonstrate and discuss the procedures outlined in the job sheets.

VII. Give test.

INSTRUCTIONAL MATERIALS

I. Included in this unit:

A. Objective sheet

B. Information sheet

C. Transparency masters

1. TM 1--Voltage Divider Bias Circuit

2. TM 2--Amplifier Characteristics by Class of Operation

3. TM 3--Class B Push-Pull Amplifier

4. TM 4--Darlington Pair

5. TM 5--Transistor Load Line

6. TM 6--Coupling Methods

7. TM 7--Frequency Compensation Networks

D. Assignment sheets

1. Assignment Sheet #1--Construct a Load Line for a Common-Emitter Amplifier Circuit

2. Assignment Sheet #2--Calculate the Overall Gain of Multistage-Amplifier Circuits
E. Answer to assignment sheets

F. Job sheets
   1. Job Sheet #1--Test a Single-Ended Amplifier
   2. Job Sheet #2--Test a Push-Pull Amplifier
   3. Job Sheet #3--Test a Two Stage Direct Coupled Amplifier
   4. Job Sheet #4--Test a Basic Darlington Pair Amplifier

G. Test

H. Answers to test

I. Terms and definitions
   A. Single-ended amplifier--An amplifier in which only one transistor is used in the amplifier stage
   B. Class A circuit--An amplifier biased so that the collector current flows during the entire input-signal cycle
   C. Class B circuit--An amplifier biased so that the collector current flows during half of the input-signal cycle
   D. Class C circuit--An amplifier biased so that the collector current flows for less than half of the input-signal cycle
   E. Push-pull amplifier--An amplifier which uses two transistors connected so that each transistor contributes current to the output signal on alternate half cycles of the input signal
   F. Darlington pair--An amplifier circuit in which two transistors are directly coupled in such a way as to provide impedance matching wide-band frequency response and high current gain
   G. Coupling--The methods used to connect the output of one stage of amplification to the input of another amplifier stage
   H. Leakage current--The current that flows through a reverse-bias transistor junction
   I. Efficiency--The ratio of AC power delivered to the load to the DC power taken from the power supply
   J. Crossover distortion--Distortion of the output of push-pull amplifier due to non-linear characteristics of the transistors

II. Voltage divider bias circuit (Transparency 1)
   A. Divides source voltage across a network of resistors
   B. Permits use of a selected portion of source voltage

III. Leakage current
   A. Types
      1. Common-base leakage current ($I_{CBO}$)--With no emitter current
      2. Common-emitter leakage current ($I_{CEO}$)--With no base current
INFORMATION SHEET

B. Problems

1. Ambient temperature rise increases leakage current

2. Leakage current rise increases junction temperature

3. Conditions given in parts 1 and 2 can cause thermal runaway which may result in the destruction of the transistor

C. Stabilizing resistor (Re in a common-emitter circuit)--Reduces the amount of voltage available at the input, which reduces the input-bias current and provides more stable operating conditions

IV. Classes of amplifiers, applications, and performance characteristics (Transparency 2)

<table>
<thead>
<tr>
<th>Class</th>
<th>Application</th>
<th>Distortion</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Audio-type amplifiers</td>
<td>Least</td>
<td>Least</td>
</tr>
<tr>
<td>B</td>
<td>Push-pull audio power amplifiers</td>
<td>Approximately same as Class A when operated in a push-pull configuration</td>
<td>Medium</td>
</tr>
<tr>
<td>C</td>
<td>High frequency applications and oscillators</td>
<td>Highest</td>
<td>Highest</td>
</tr>
</tbody>
</table>

(NOTE: Class B amplifiers conduct only during one half of the input signal cycle, when operated in a single-ended configuration giving medium distortion.)

V. Class B push-pull amplifier (Transparency 3)

A. Requires two transistors

B. Reduces distortion (even and odd harmonic)

C. Increases load impedance

D. Increases output power

E. Each transistor conducts during one-half of the input cycle

F. Requires proper bias to eliminate crossover distortion

VI. Darlington-pair circuit (Transparency 4)

A. Direct coupled type of circuit

B. Used for impedance matching or in place of an impedance matching transformer
INFORMATION SHEET

C. Wide band frequency response
D. Voltage gain is less than one
E. High current gain

VII. Class A operation load line (Transparency 5)

A. Characteristic curves
   1. $I_C$
   2. $V_{CE}$
   3. $I_B$
B. Saturation $I_{CMAK} = \frac{V_{CC}}{R_L}$
C. Cut off. $I_C = 0; V_{CE} = V_{CC}$
D. Operating point or Q point for Class A amplifier

VIII. Characteristics of different types of coupling

A. Resistance-capacitance (RC) coupling (Transparency 6)
   1. Broad frequency response
   2. Economical
   3. Small physical size
   4. Provides dc isolation
   5. Limits low frequency response

B. Impedance coupling (Transparency 6)
   1. Amplifier output is larger at high frequencies than at low frequencies
   2. Used when a narrow band of frequencies or a single frequency is to be amplified

C. Transformer coupling (Transparency 6)
   1. Used in power stages
   2. Used for impedance matching
   3. More costly than RC coupling
   4. Requires more space and is heavier
   5. Excellent dc isolation between stages
INFORMATION SHEET

D. Direct coupling
   1. Used for very low frequency or dc
   2. Used to couple only a few stages because of noise and signal amplification
   3. Widely used for a Darlington-pair amplifier

IX. Overall amplifier gain
   A. Ratio stage gains—Multiply
   B. dB stage gains—Add
      Example: (calculation - Av):

      \[
      A_1 = 5, A_2 = 10, A_3 = 6; \quad (A_1) (A_2) (A_3) = A_V \quad \text{Total} = 300
      \]

      \[
      \text{dB} - A_1 = 13.98\text{dB}, A_2 = 20\text{dB}, A_3 = 15.56\text{dB}
      \]
      \[
      \text{or } A_V\text{db} = 20 \log 300 \quad 49.54\text{dB}
      \]
      \[
      A_1 + A_2 + A_3 = A_V\text{dB Total} = 49.54\text{dB}
      \]

X. Frequency considerations
   A. Low frequency response of an amplifier is limited by circuit series capacitance or shunt inductance
   B. High frequency response of an amplifier is limited by circuit shunting capacitance or series inductance
   C. Frequency compensation networks (Transparency 7)
      1. High frequency compensation
      2. Low frequency compensation
Voltage Divider Bias Circuit
Amplifier Characteristics by Class of Operation

Class A Operation

Class B Operation

Class C Operation
Class B Push-Pull Amplifier
Darlington Pair
Transistor Load Line
(Class A Operation)

Procedure
A. Locate maximum current point
   \[ V_{CC} = \frac{I_{max}}{RL} \]
B. Locate maximum voltage point
   \[ V_{CE} = V_{CC} \]
C. Connect these two points with a straight line
D. Locate operating point, Q point, by the intersection of the IB line with the load line
E. Saturation point
F. Cut off point
Coupling Methods

RC Coupling

Impedance Coupling

Transformer Coupling

Direct Coupling
Frequency Compensation Networks

High Frequency Compensation

Low Frequency Compensation
TRANSISTOR AMPLIFIERS
UNIT VII

ASSIGNMENT SHEET #1–CONSTRUCT A LOAD LINE FOR A COMMON-EMITTER AMPLIFIER CIRCUIT

Direction: Construct a load-line for the transistor circuit shown below and locate the following points:

A. Q point (operating point)
B. Saturation point
C. Cutoff point

[Diagram of transistor circuit]

- $I_B = 80\mu A$
- $I_B = 60\mu A$
- $I_B = 40\mu A$
- $I_B = 20\mu A$
- $I_B = 10\mu A$
- $I_B = 0$

$I_C$ (ma) vs. $V_{CE}$ (volts)
ASSIGNMENT SHEET #2 - CALCULATE THE OVERALL GAIN OF MULTISTAGE-AMPLIFIER CIRCUITS

Directions: Given the amplifier block diagrams below, calculate the overall gain and express in dB.

A.

\[ A_{V1} = 7 \quad A_{V2} = 9 \]

B.

\[ A_{V1} = 10 \quad A_{V2} = 4 \quad A_{V3} = 2T \]

C.

\[ A_{P1} = 0.9 \quad A_{P2} = 100 \]
TRANSISTOR AMPLIFIERS
UNIT VII

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #1

\[
\frac{V_{CC}}{R_L} = \frac{20}{2.2K} = 9\text{mA}
\]

\[I_B = 80\mu\text{A}\]
\[I_B = 60\mu\text{A}\]
\[I_B = 40\mu\text{A}\]
\[I_B = 20\mu\text{A}\]
\[I_B = 10\mu\text{A}\]
\[I_B = 0\]

\[\begin{align*}
V_{CE} &= V_{CC} \\
V_{CE} &= -130\text{pA} \\
V_{CE} &= 60\text{pA} \\
V_{CE} &= 40\text{pA} \\
V_{CE} &= 20\text{pA} \\
V_{CE} &= 0
\end{align*}\]

\[I_B = \frac{10V}{500K} = 20\mu\text{A}\]

A. \(Q_{pt}\) = \[I_B = 20\mu\text{A}\]
B. Saturation point
C. Cut off point
Assignment Sheet #2

1. $A_v \text{ total} = 35.99 \text{db}$

   $A_{v1}(7) \times A_{v2}(9) = 63$

   $A_v \text{dB} = 20 \log 63$

2. $A_{v1} = 10 \quad A_{v2} = 4 \quad A_v = 21$

   $A_v \text{ Total} = 10 \times 4 \times 21 = 840$

   $A_v \text{ Total dB} = 20 \log 840 = 58.49$

3. $A_{p1} = 0.9 \quad A_{p2} = 100 \quad = 90$

   $A_{p1} \text{ dB} = -.46 \quad A_{p2} = 20 \text{db} \quad = 19.54$

   $A_v \text{ Total} = (0.9)(100) = 90$

   $A_v \text{ Total dB} = (10 \log .9) + 10 \log 100$

   $\quad \quad \quad \quad \quad \quad = 19.54$
TRANSISTOR AMPLIFIERS
UNIT VII

JOB SHEET #1—TEST A SINGLE-ENDED AMPLIFIER

I. Tools and equipment

A. 1-2N2222 transistor
B. 1-47k resistor
C. 1-1k resistor
D. Microammeter and 1 milliammeter (or two multimeters)
E. 1-22k resistor
F. 1-220k resistor
G. 1-1.5k resistor
H. 1-4.7k resistor
I. DC power supply (0-25V)
J. Soldering iron or soldering gun
   (NOTE: All resistors are + watt.)
K. 1-1k potentiometer
L. 1-10V potentiometer

II. Procedure

A. Wire the circuit shown below
JOB SHEET #1

B. Adjust potentiometer $R_2$ so that the voltage between points $Q$ and $P$ is zero.

C. Plug in soldering iron or gun.

D. After instructor approves wiring, turn on the power; then adjust $R_3$ for 18 volts between points $Q$ and $R$.

E. Adjust $R_2$ to 50 microamps of base current, $I_B$.

   (NOTE: It may be necessary to readjust $R_3$ for 18 volts.)

F. Record the value of collector current, $I_C$.

G. Hold hot-soldering gun or iron near the transistor case for three seconds.

H. Record the maximum value of the collector current.

I. Remove iron and wait until the collector current is approximately the same value as that recorded in Step D.

J. Remove power and insert a 1.5k resistor ($R_e$) between the emitter and ground.

K. Apply power and readjust $R_2$ to 50 microamps base current.

   (NOTE: It may be necessary to readjust $R_3$ for 18 volts.)

L. Read and record the collector current.

M. Repeat steps G and I.

N. Remove power and replace 1.5k with a 4.7k resistor.

O. Repeat steps G and I.

P. Calculate the changes in collector current, $I_C$, for each of the three conditions as shown in the table below:

<table>
<thead>
<tr>
<th>$R_e$</th>
<th>$I_B$</th>
<th>$I_C$ (cool)</th>
<th>$I_C$ (hot)</th>
<th>$\Delta I_C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5k</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.7k</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Q. Turn off the power supplies and rewire circuit as shown below

R. After instructor has checked the wiring, turn on the power supply and set it for an output of 15 volts

S. Read and record $I_B$ and $I_C$

T. Hold the soldering gun or iron close to the transistor and heat it for 3 seconds

U. Read and record the maximum value of $I_C$

V. Remove power and leave one end of the 220k-ohm resistor connected to the base

W. Remove the other end from the power supply and connect it to the collector of the transistor

X. Apply power and read and record $I_B$ and $I_C$

Y. Hold the soldering gun close to the transistor and heat it for 3 seconds

Z. Read and record the maximum value of $I_C$

AA. Compute the change observed in $I_C$ in these two circuits and record in the table below

<table>
<thead>
<tr>
<th>Voltage Divider across $V_{CC}$</th>
<th>$I_B$</th>
<th>$I_C$ (cool)</th>
<th>$I_C$ (hot)</th>
<th>$\Delta I_C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collector Feedback</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BB. Check completed tables with your instructor
JOB SHEET #2—TEST A PUSH-PULL AMPLIFIER

I. Tools and equipment
A. 2 power transistors (T13027 or equivalent)
B. Input transformer (500 ohm primary - 200 ohm center tapped secondary)
C. Output transformer (100 ohm CT - 4 ohm)
D. 1-15k resistor, 1/2 watt
E. 1-470 ohm resistor, 1/2 watt
F. 1-4 ohm resistor, 2 W
G. 1-0.47 ohm resistor, 2 W
H. AF signal generator
I. Oscilloscope
J. Graph paper
K. 0.01 μfd capacitor
L. Power supply
M. Multimeter

II. Procedure
A. Wire the circuit shown in the following schematic with power off.
JOB SHEET #2

B. Have instructor approve wiring; then turn on the power supply and adjust for 15 volts

C. Measure and record the base-emitter bias voltages $V_{BE}$ of Q1 and Q2

D. Compute the DC-emitter currents using Ohm's Law by measuring the voltage drops across the 0.47 ohm resistors

E. Connect the audio generator to the input transformer and set the output of the generator to 1000 Hz

F. Connect the oscilloscope across the 4-ohm load on the secondary of the output transformer and adjust the signal generator for maximum undistorted output as read on the oscilloscope and sketch the waveshape

G. Connect the oscilloscope across the input and make a scale drawing of the scope display

H. Connect the oscilloscope across the base-emitter junction of Q1 and sketch the waveshape

I. Repeat for Q2

J. Check calculations and drawings with your instructor

Data Table

<table>
<thead>
<tr>
<th>Q1</th>
<th>V_{BE}</th>
<th>I_E</th>
<th>V_{OUT} P-P</th>
<th>V_{IN} P-P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$V_{OUT}$

$V_{IN}$

OUTPUT WAVESHAPE

INPUT WAVESHAPE
TRANSISTOR AMPLIFIERS
UNIT VII

JOB SHEET #3—TEST A TWO STAGE DIRECT COUPLED AMPLIFIER

I. Tools and equipment
   A. 2-2N1304 transistors or equivalent
   B. 2-10 μF capacitors (20V)
   C. 2-100 μF capacitors (20V)
   D. 1-47k resistor (1/2 watt)
   E. 3-6.8k resistors, 1/2W
   F. 2-4.7k resistors, 1/2W
   G. 1-3.3k resistor, 1/2W
   H. 2-510 ohm resistors, 1/2W
   I. Variable DC power supply (0-20V)
   J. Oscilloscope
   K. Signal generator
   L. Graph paper
   M. D.C. voltmeter

II. Procedure
   A. Connect the following circuit with power off
      (NOTE: A voltage divider is used between the two stages to provide the
      necessary bias for the second stage.)

![Circuit Diagram]
B. Connect the oscilloscope across the 4.7k output resistor

C. Connect the signal generator to the input terminals and adjust the frequency for 1000Hz; leave the voltage level at zero

D. Adjust the power supply for 15 volts and measure and record the voltages with respect to ground on the emitter, base, and collector of the two transistors

E. Adjust the signal generator until an undistorted waveshape appears on the oscilloscope

(NOTE: All voltage measurements should be referenced to ground.)

F. Measure and record the peak-to-peak output voltage using the oscilloscope and sketch the waveshape

G. Measure and record the peak-to-peak input voltage at the base of the second transistor

H. Measure and record the peak-to-peak output voltage at the collector of the first stage

I. Measure and record the peak-to-peak input voltage at the base of the first stage

J. Determine the voltage gain of the first stage and convert the voltage gain to a dB gain

K. Determine the voltage gain of the second stage and convert the voltage gain to dB gain

L. Determine the overall voltage gain and convert the voltage gain to dB gain

M. Connect the oscilloscope on the input (base) to the first stage and adjust the signal generator for the maximum undistorted signal at 10KHz.

(Note: The input signal voltage must be maintained at a constant level.)

N. Measure and sketch the voltage across the output resistor

O. Adjust the signal generator for the following frequencies and record the input and output voltage for each frequency: 10,000, 8000, 6000, 4000, 2000, 1000, 800, 600, 400, and 200 Hz.

P. Plot a graph of the output voltage versus the frequency; the frequency should be plotted on the horizontal axis and the voltage on the vertical axis

Q. Check calculations and sketches with your instructor
## Data Table

<table>
<thead>
<tr>
<th>VBE</th>
<th>VCE</th>
<th>VEN</th>
<th>V_OUT P-P</th>
<th>V_IN P-P</th>
<th>V_OUT P-P</th>
<th>V_IN P-P</th>
<th>AV</th>
<th>AVdB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Q2</td>
<td></td>
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</tr>
</tbody>
</table>

\[ A_{V_{\text{TOTAL}}} = \frac{A_{V}}{10} \text{ dB} \]

<table>
<thead>
<tr>
<th>10KHz</th>
<th>8KHz</th>
<th>6KHz</th>
<th>4KHz</th>
<th>2KHz</th>
<th>1KHz</th>
<th>800Hz</th>
<th>600Hz</th>
<th>400Hz</th>
<th>200Hz</th>
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</thead>
<tbody>
<tr>
<td>V_IN P-P</td>
<td></td>
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<tr>
<td>V_IN P-P</td>
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</tbody>
</table>
TRANSISTOR AMPLIFIERS
UNIT VII

JOB SHEET #4-TEST A BASIC DARLINGTON-PAIR AMPLIFIER

I. Tools and equipment
   A. 2-PNP transistors (2N3638 or equivalent)
   B. 1-10 µF capacitor (25V)
   C. 1-3 M resistor, 1/2W
   D. 1-1 k resistor, 1W
   E. Oscilloscope
   F. Signal generator
   G. Power supply (0-40V; DC)

II. Procedure
   A. Wire the following circuit with power off

   ![Circuit Diagram]

   B. Connect the oscilloscope to the output of the signal generator and the signal generator to the circuit input
   C. Set the generator for 1000 Hertz and adjust until 4 volts peak-to-peak is on the oscilloscope screen
   D. Place the generator leads to the Darlington circuit input leads, and leave the oscilloscope still connected to the generator output
   E. Move the oscilloscope leads from the input to the output and measure the output voltage (peak-to-peak)
F. Compute the overall voltage gain in dB

G. Check your calculations with your instructor

<table>
<thead>
<tr>
<th>$V_{IN \ P-P}$</th>
<th>$V_{OUT \ P-P}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$A_{VdB}$</td>
</tr>
</tbody>
</table>

$A_{VdB} =$
1. Match the terms on the right with their correct definitions.

   a. The current that flows through a reverse-bias transistor junction
   b. An amplifier which uses two transistors connected so that each transistor contributes current to the output signal on alternate half cycles of the input signal.
   c. An amplifier biased so that the collector current flows for less than half of the input-signal cycle
   d. An amplifier in which only one transistor is used in the amplifier stage.
   e. The methods used to connect the output of one stage of amplification to the input of another amplifier stage.
   f. The ratio of AC power delivered to the load to the DC power taken from the power supply.
   g. An amplifier biased so that the collector current flows during the entire input-signal cycle.
   h. An amplifier biased so that the collector current flows during half of the input-signal cycle.
   i. An amplifier circuit in which two transistors are directly coupled in such a way as to provide impedance matching wide-band frequency response and high current gain.
   j. Distortion of the output of the push-pull amplifier due to non-linear characteristics of the transistors.

   1. Leakage current
   2. Single-ended amplifier
   3. Class A circuit
   4. Darlington pair
   5. Push-pull amplifier
   6. Coupling
   7. Class B circuit
   8. Class C circuit
   9. Efficiency
   10. Crossover distortion
2. Identify the voltage divider bias circuit by placing an "X" under the appropriate circuit.

a. MCC

b. Series Cap.

Compensation Network
3. Select true statements concerning sources of leakage current and problems associated with it by placing an "X" in the appropriate blanks.

   a. \( I_{CBO} \) is a type of leakage with no emitter current  
   b. \( I_{CEO} \) is a type of leakage with no base current  
   c. Ambient temperature rise increases leakage current  
   d. Leakage current rise increases junction temperature  
   e. Conditions given in parts c and d above can cause thermal runaway which may result in the destruction of the transistor  
   f. The stabilizing resistor increases the amount of voltage available at the input, which reduces the input-bias current and provides more stable operating conditions

4. Complete the following table showing the classes of amplifiers, applications, and performance characteristics.

<table>
<thead>
<tr>
<th>Class</th>
<th>Application</th>
<th>Distortion</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Audio-type amplifiers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Push-pull audio power amplifiers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>High frequency applications and oscillators</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Select true statements describing the characteristics of a Class B push-pull amplifier by placing an "X" in the appropriate blanks.

   a. Requires only one transistor  
   b. Requires two transistors  
   c. Reduces distortion  
   d. Decreases output power  
   e. Each transistor conducts during one-half the input cycle  
   f. Requires proper bias to eliminate crossover distortion
6. Select true statements describing the characteristics of a Darlington pair circuit by placing an "X" in the appropriate blanks.

- a. Capacitance coupled between stages
- b. Direct coupled type of circuit
- c. Narrow band frequency response
- d. Voltage gain is less than one
- e. High current gain

7. Locate the Q point, saturation point, and cutoff point in a common-emitter Class A amplifier circuit by correctly labeling the diagram that follows.

8. Complete a list showing the characteristics of different types of coupling by placing the correct information in the blanks below each of the following headings.

a. Resistance-capacitance coupling
   1) ________________
   2) Economical
   3) Small physical size
   4) Provides dc isolation
   5) Limits low frequency response

b. Impedance coupling
   1) ________________
   2) Used when a narrow band of frequencies or a single frequency is to be amplified
d. Test a basic Darlington-pair amplifier

(NOTE: If these activities have not been accomplished prior to the test, ask your instructor when they should be completed.)
c. Transformer coupling
   1) Used in power stages
   2) Used for impedance matching
   3) More costly than RC coupling
   4) Requires more space and is heavier
   5) ______________________

d. Direct coupling
   1) Used for very low frequency or dc
   2) Used to couple only a few stages because of noise and signal amplification
   3) ______________________

9. Distinguish between ratio stage gains and dB stage gains in overall amplifier gain by placing an "R" next to material that applies to ratio gains and "dB" beside material that applies to dB gain.

   _____ a. Multiply
   _____ b. Add:

10. Select true statements concerning frequency considerations by placing an "X" in the appropriate blanks.

   _____ a. Low frequency response of an amplifier is limited by circuit series capacitance or shunt inductance
   _____ b. High frequency response of an amplifier is limited by circuit series capacitance or series inductance
   _____ c. Frequency compensation networks include
       1) High frequency compensation
       2) Low frequency compensation


12. Calculate the overall gain of multistage-amplifier circuits.

13. Demonstrate the ability to:
   a. Test a single-ended amplifier
   b. Test a push-pull amplifier
   c. Test a two stage direct coupled amplifier
d. Test a basic Darlington-pair amplifier

(NOTE: If these activities have not been accomplished prior to the test, ask your instructor when they should be completed.)
TRANSISTOR AMPLIFIERS
UNIT VII

ANSWERS TO TEST

1. a. 1
   b. 5
   c. 8
   d. 2
   e. 6
   f. 9
   g. 3
   h. 7
   i. 4
   j. 10

2. a

3. a, b, c, d, e

4. | Class | Application                        | Distortion  | Efficiency |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Audio-type amplifiers</td>
<td>Least</td>
<td>Least</td>
</tr>
<tr>
<td>B</td>
<td>Push-pull audio power amplifiers</td>
<td>Approximately same as Class A when operated in a push-pull configuration</td>
<td>Medium</td>
</tr>
<tr>
<td>C</td>
<td>High frequency applications and oscillators</td>
<td>Highest</td>
<td>Highest</td>
</tr>
</tbody>
</table>

5. b, c, e, f

6. b, d, e

7. a. Saturation point
     b. Q point
     c. Cutoff point

8. a. 1) Broad frequency response
     b. 1) Amplifier output is larger at high frequencies than at low frequencies
     c. 5) Excellent dc isolation between stages
     d. 3) Widely used for a Darlington-pair amplifier

9. a. R
    b. dB

10. a, c

11. Evaluated to the satisfaction of the instructor
12. Evaluated to the satisfaction of the instructor
13. Performance skills evaluated to the satisfaction of the instructor
OPERATIONAL AMPLIFIERS
UNIT VIII

UNIT OBJECTIVE

After completion of this unit, the student should be able to identify the categories and subdivisions of integrated circuits, list advantages and disadvantages of integrated circuits, calculate gain for various types of operational amplifiers, and construct and test various types of operational amplifier circuits. This knowledge will be evidenced by correctly performing the procedures outlined in the assignment and job sheets and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to operational amplifiers with their correct definitions.
2. Complete a diagram to show the categories and subdivisions of integrated circuits.
3. Distinguish between the advantages and disadvantages of integrated circuits.
4. Match inverting and noninverting operational amplifiers with their characteristics and $A_v$ formulas.
5. Match DC summing inverting and differential amplifiers with their characteristics and $V_{out}$ formulas.
6. Calculate the closed-loop gain for an inverting and a noninverting amplifier.
7. Calculate the output voltage of a DC summing inverting amplifier.
8. Demonstrate the ability to:
   a. Construct and test an inverting amplifier.
   b. Construct and test a noninverting amplifier.
   c. Construct and test a DC summing inverting amplifier.
   d. Construct and test a differential amplifier.
OPERATIONAL AMPLIFIERS
UNIT VIII

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.
II. Provide student with information, assignment, and job sheets.
III. Make transparencies.
IV. Discuss unit and specific objectives.
V. Discuss information and assignment sheets.
VI. Demonstrate and discuss the procedures outlined in the job sheets.
VII. Give test.

INSTRUCTIONAL MATERIALS

I. Included in this unit:
   A. Objective sheet
   B. Information sheet
   C. Transparency masters
      1. TM 1--Categories of Integrated Circuits
      2. TM 2--Monolithic Integrated Circuit
      3. TM 3--Hybrid Thick Film Circuit
      4. TM 4--Inverting and Noninverting Amplifiers
      5. TM 5--DC Summing Inverting Amplifier
      6. TM 6--Differential DC Amplifier
   D. Assignment sheets
      1. Assignment Sheet #1--Calculate the Closed-Loop Gain for an Inverting and a Noninverting Amplifier
      2. Assignment Sheet #2--Calculate the Output Voltage of a DC Summing Inverting Amplifier
   E. Answers to assignment sheets
F. Job sheets
   1. Job Sheet #1--Construct and Test an Inverting Amplifier
   2. Job Sheet #2--Construct and Test a Noninverting Amplifier
   3. Job Sheet #3--Construct and Test a DC Summing Inverting Amplifier
   4. Job Sheet #4--Construct and Test a Differential Amplifier

G. Test

H. Answers to test

II. References
I. Terms and definitions

A. Integrated circuit (IC)--A complete electronic circuit that is fabricated on a single chip of silicon

B. Operational amplifier (OP-AMP)--A solid-state integrated circuit amplifier that uses external feedback to control its gain

C. Linear IC--A classification of integrated circuits used for analog amplification purposes

D. Digital IC--A classification of integrated circuits used for switching purposes

E. Monolithic device--A complete circuit including active and passive devices and all interconnections fabricated upon a single piece of silicon crystal material

F. Hybrid device--A device which is made by mounting separate components (resistors, transistors, and other devices) onto a substrate of insulating material such as glass or ceramic

G. Open-loop operation--An application of an operational amplifier circuit that uses no external feedback

H. Closed-loop operation--An application of an operational amplifier circuit that uses external feedback

II. Categories and subdivisions of integrated circuits (Transparency 1)

A. Monolithic--One method of IC fabrication (Transparency 2)
   1. Bipolar--Diode and transistors
   2. Unipolar--MOSFET and JFET device

B. HYBRID--One method of IC fabrication
   1. Thick film--Components are approximately 100 times thicker than thin film (Transparency 3)
   2. Thin film--Components are a few angstroms thick (Angstrom unit, $A^0 = 10^{-8} \text{ cm}$)
III. Advantages and disadvantages of integrated circuits

A. Advantages
   1. Small size
   2. Low cost
   3. High reliability

B. Disadvantages
   1. Limited to low voltage applications
   2. Limited to low power applications
   3. Limited component selection

IV. Characteristics and $A_v$ formulas for inverting and noninverting operational amplifiers

A. Inverting amplifier (Transparency 4)
   1. Output is $180^\circ$ out of phase with the input
   2. $A_v = -\frac{R_2}{R_1}$

B. Noninverting amplifier (Transparency 4)
   1. Input is in phase with the output
   2. $A_v = \frac{R_1 + R_2}{R_1}$

V. Characteristics and $V_{out}$ formulas for DC summing inverting amplifier and differential amplifiers

A. DC summing inverting amplifiers (Transparency 5)
   1. Output is the sum of the input voltages with a $180^\circ$ phase shift
   2. $V_{out} = R_4 \left( \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \right)$
B. Differential amplifiers (Transparency 6).

1. Output is a function of the difference between the two input signals

2. \( V_{out} = \frac{R_2}{R_1} (V_2 - V_1); \) \( R_1 = R_3, \) \( R_2 = R_4 \)
Categories of Integrated Circuits

Integrated Circuits

Monolithic

- Bipolar
- Unipolar

Hybrid Circuits

- Thin Film
- Thick Film
Monolithic Integrated Circuit

Top View (oxide omitted)

Gold Metallic Connections

Silicon Oxide

Cross Section

P-Type Substrate

Schematic
Hybrid Thick Film Circuit

- Package Body
- Diode
- Capacitor
- Gold Wire
- Film Resistor
- Lead
- Substrate
- Conducting Trace
Inverting and Noninverting Amplifiers

Inverting DC Amplifier

Noninverting DC Amplifier

\[ V_D = A_V \cdot V_I \]

\[ A_V = \frac{R_2}{R_1} \]

\[ V_O = V_i \cdot A_V \]

\[ A_V = \frac{R_1 + R_2}{R_1} \]
DC Summing Inverting Amplifier

$$V_{out} = -R_4 \left( \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \right)$$
Differential DC Amplifier

\[ A_v = \frac{R_2}{R_1} \]
\[ R_4 = R_2 \quad R_1 = R_3 \]
\[ V_{out} = \frac{R_2}{R_1} (V_2 - V_1) \]
ASSIGNMENT SHEET #1--CALCULATE THE CLOSED-LOOP GAIN FOR AN INVERTING AND A NONINVERTING AMPLIFIER

A. Inverting amplifier
   1. For the schematic shown below, calculate the closed-loop gain given $R_1 = 10K$ and $R_2 = 100K$
   2. Calculate $V_o$ for part 1 above given $V_{in} = +5$ volts.

![Inverting amplifier schematic](image1)

B. Noninverting amplifier
   1. For the schematic shown below, calculate the closed-loop gain given $R_1 = 5K$ and $R_2 = 10K$
   2. Calculate $V_{in}$ for part 1 above given $V_o = +10$ volts.

![Noninverting amplifier schematic](image2)
ASSIGNMENT SHEET #2 - CALCULATE THE OUTPUT VOLTAGE OF A DC SUMMING INVERTING AMPLIFIER

A. For the schematic shown below, $R_1 = 10\,\text{K}$, $R_2 = 5\,\text{K}$, $R_3 = 10\,\text{K}$, $R_4 = 10\,\text{K}$

Calculate $V_o$

B. Repeat part A above if $R_4$ is $100\,\text{K}$
OPERATIONAL AMPLIFIERS
UNIT VIII

ANSWERS TO ASSIGNMENT SHEETS

Assignment Sheet #1
A. Inverting amplifier
   1. \[ A_v = -\frac{R_2}{R_1} = -\frac{100K}{10K} = -10 \]
   2. \[ A_v = \frac{V_o}{V_{in}} \]
      \[ V_o = (A_v)(V_{in}) = (-10)(5) = -50 \text{ Volts.} \]

B. Noninverting amplifier
   1. \[ A_v = \frac{R_1 + R_2}{R_1} = \frac{10K}{5K} = 1 + \frac{2}{3} = 1 + 2 = 3 \]
   2. \[ A_v = \frac{V_o}{V_{in}} \]
      \[ V_{in} = \frac{V_o}{A_v} = \frac{10}{3} = 3.33 \text{ Volts} \]

Assignment Sheet #2
A. \[ V_o = \left[ \frac{(V_1)}{R_1} \frac{R_4}{R_4} + \frac{(V_2)}{R_2} \frac{R_4}{R_4} + \frac{(V_3)}{R_3} \frac{R_4}{R_4} \right] \]
   \[ V_o = \left[ \frac{(5)}{10K} \frac{10K}{10K} + \frac{(2)}{5K} \frac{10K}{5K} + \frac{(1)}{10K} \frac{10K}{10K} \right] \]
   \[ V_o = (5 + 4 + 1) = -10 \text{ Volts.} \]

B. \[ V_o = \left[ \frac{(5)}{10K} \frac{100K}{10K} + \frac{(2)}{5K} \frac{100K}{5K} + \frac{(1)}{10K} \frac{100K}{10K} \right] \]
   \[ = -(50 + 40 + 10) \]
   \[ = -100 \text{ Volts} \]
JOB SHEET #1--CONSTRUCT AND TEST AN INVERTING AMPLIFIER

I. Tools and equipment
   A. OP AMP type LM741 or equivalent
   B. 470K resistor 1/4 watt
   C. 47K resistor 1/4 watt
   D. 2.2K resistor 1/4 watt
   E. ± 15 volt DC power supply or dual tracking DC supply
   F. Variable DC power supply
   G. Proto-board or equipment to connect an integrated circuit
   H. Multimeter

II. Procedure
   A. Connect the following circuit
      (NOTE: Review the data sheet for pin connection for the operational amplifier.)

   B. Calculate the voltage gain
   C. Calculate the output voltage across the 2.2K ohm load resistor
   D. Apply a 1 volt DC to the input resistor R1
   E. Turn on the power supply (15V) to the operational amplifier
      (NOTE: Most operational amplifiers require a power supply that has a + and a minus voltage with reference to a common point [ground].)
JOB SHEET #1

F. Measure and record the output voltage and the input voltage
   (NOTE: Be sure to observe the polarity of the output voltage as compared to
   the input voltage.)

G. Using the measured values calculate the voltage gain; \( A_v = \frac{V_{out}}{V_{in}} \)

H. Compare the measured gain value (step G) with the calculated gain value
   (step B)

I. Check your calculations with your instructor

Data Table

<table>
<thead>
<tr>
<th>( A_v ) Calculated</th>
<th>Vout Calculated</th>
<th>Vin Measured</th>
<th>Vout Measured</th>
<th>( A_v ) Measured</th>
<th>% Diff</th>
</tr>
</thead>
<tbody>
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</table>
JOB SHEET #2—CONSTRUCT AND TEST A NONINVERTING AMPLIFIER

I. Tools and equipment
   A. OP AMP type LM741 or equivalent
   B. 470K resistor 1/4 watt
   C. 47K resistor 1/4 watt
   D. 2.2K resistor 1/4 watt
   E. ± 15 volt DC power supply or dual tracking DC supply
   F. Variable DC power supply
   G. Proto-board or equipment to connect an integrated circuit
   H. Multimeter

II. Procedure
   A. Connect the following circuit for a noninverting DC amplifier.
      (Caution: Do not turn on power at this time.)

      ![Circuit Diagram]

      R2=470K
      R1=47K
      V1=1V
      + Vcc
      15V
      2.2K

   B. Calculate the voltage gain
   C. Calculate the output voltage
   D. Apply 1 volt DC to the noninverting input (pin 3)
   E. Turn on the ± 15 volt power supply
   F. Measure and record the output voltage and the input voltage
      (NOTE: Observe the polarity of the output voltage as compared to the input voltage.)
JOB SHEET #2

G. Using the measured values calculate the voltage gain, \( A_v = \frac{V_{out}}{V_{in}} \)

H. Compare the measured gain value (step G) with calculated gain value (step B)

I. Check your calculations with your instructor

Data Table

<table>
<thead>
<tr>
<th>( A_v ) Calculated</th>
<th>Vout Calculated</th>
<th>Vin Measured</th>
<th>Vout Measured</th>
<th>( A_v ) Measured</th>
<th>% Diff</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
I. Tools and equipment
   A. OP AMP type LM741 or equivalent
   B. 470K resistor 1/4 watt
   C. 3-47K resistors 1/4 watt
   D. 2.2K resistor 1/4 watt
   E. ± 15 V DC power supply or equivalent
   F. Variable DC power supply
   G. Proto-board or equipment to connect an integrated circuit
   H. Multimeter

II. Procedure
   A. Connect the following circuit for a DC summing inverting amplifier
      (CAUTION: Do not turn on the power at this time.)

   B. Calculate the output voltage
   C. Apply 0.5V to input V₁, 0.2V to input V₂, 0.3 V to input V₃
      (NOTE: It may be necessary to build a voltage divider to achieve these input voltages.)
   D. Turn on the ± 15 volt power supply.
E. Measure and record the output voltage and the input voltage
   (NOTE: Observe the polarity of the output voltage as compared to the input voltage.)

F. Compare the output voltage measured to the output voltage calculated

G. Compute the output voltage if $R_1 = R_2 = R_3 = 470\,\Omega$ ohm resistance

H. Compute the output voltage if $R_1 = 4.7\,\Omega$ ohm, $R_2 = 3.3\,\Omega$ ohm, and $R_3 = 6.8\,\Omega$ ohm

I. Check your calculations with your instructor

Data Table

<table>
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<tr>
<th>Vout Calculated</th>
<th>Vin Measured</th>
<th>Vout Measured</th>
<th>% Diff</th>
<th>Vout 470K Calculated</th>
<th>Vout 4.7K Calculated</th>
</tr>
</thead>
</table>
JOB SHEET #4--CONSTRUCT AND TEST A DIFFERENTIAL AMPLIFIER

I. Tools and equipment
A. OP AMP type LM741 or equivalent
B. 2-470K resistors
C. 2-47K resistors
D. 1-2.2K resistor
E. \pm 15 volt power supply or dual tracking
F. 2-DC power supplies (variable)
G. Proto-board or equipment to connect an integrated circuit

II. Procedure
A. Connect the following circuit for a differential DC amplifier
   (CAUTION: Do not apply power at this time.)

   \[ \begin{align*}
   R_1 &= 47k \\
   R_2 &= 470k \\
   V_1 &= +1.0 \text{ Volt} \\
   V_2 &= +1.5 \text{ Volt} \\
   \end{align*} \]

   \[ \begin{align*}
   R_3 &= 47k \\
   R_4 &= 470k \\
   \end{align*} \]

B. Calculate the output voltage, \( V_{\text{out}} \)
C. Apply 1.0 volts at \( V_1 \) and 1.5 volts at \( V_2 \)
   (NOTE: You may use two separate power supplies to obtain these inputs.)
D. Turn on the \( \pm 15 \) volt power supply
E. Measure and record the output voltage and the input voltages
F. Compare the output voltage measured to the output voltage calculated
JOB SHEET #4

G. Adjust $V_2$ to 1 volt and measure the output voltage
   (NOTE: The output voltage should be very small.)

H. Calculate the common mode gain by the following formula:
   $$A_C = \frac{V_{out}}{V_1} - \frac{V_{out}}{V_2}$$
   (NOTE: Use values from part G for the above calculation.)

I. Calculate the difference mode gain by the following formula:
   $$A_D = \frac{V_{out}}{V_2 - V_1}$$
   (NOTE: Use values from part E for the above calculation.)

J. Check your calculations with your instructor

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<th>Data Table</th>
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<tr>
<td>$V_{out}$ Measured</td>
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<tr>
<td>V1 = 1.0V V2 = 1.5V</td>
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OPERATIONAL AMPLIFIERS
UNIT VIII

NAME _____________________________

TEST

1. Match terms on the right with their correct definitions.

   a. A complete electronic circuit this is fabricated on a single chip of silicon
   1. Linear IC

   b. A solid-state. integrated circuit amplifier that uses external feedback to control its gain
   2. Monolithic device

   c. A classification of integrated circuits used for analog amplification purposes
   3. Hybrid device

   d. A classification of integrated circuits used for switching purposes
   4. Integrated circuit

   e. A complete circuit including active and passive devices and all interconnections fabricated upon a single piece of silicon crystal material
   5. Closed-loop operation

   f. A device which is made by mounting separate components onto a substrate of insulating material such as glass or ceramic
   6. Operational amplifier

   g. An application of an operational amplifier circuit that uses no external feedback
   7. Digital IC

   h. An application of an operational amplifier circuit that uses external feedback
   8. Open-loop operation

2. Complete the following diagram to show the categories and subdivisions of integrated circuits.

   Integrated Circuits
   
   a. _____________________________
   b. _____________________________
   c. _____________________________
   d. _____________________________
   e. _____________________________
   f. _____________________________
3. Distinguish between the advantages and disadvantages of integrated circuits by placing an "A" beside advantages and a "D" beside disadvantages.

   a. Small size
   b. Limited to low voltage applications
   c. Low cost
   d. Limited to low-power applications
   e. High reliability
   f. Limited component selection

4. Match inverting and noninverting operational amplifiers with their characteristics and Av formulas.

   a. Output is 180° out of phase with the input
   b. Input is in phase with the output
   c. \[ Av = \frac{-R_2}{R_1} \]
   d. \[ Av = \frac{R_1 + R_2}{R_1} \]

5. Match DC summing inverting and differential amplifiers with their characteristics and Vout formulas.

   a. Output is the sum of the input voltages with a 180° phase shift
   b. Output is a function of the difference between the two input signals
   c. \[ V_{out} = -R_4 \left( \frac{V_1 + V_2 + V_3}{R_1 + R_2 + R_3} \right) \]
   d. \[ V_{out} = \frac{R_2}{R_1} \left( V_1 - V_2 \right) \]

6. Calculate the closed-loop gain for an inverting and a noninverting amplifier.

7. Calculate the output voltage of a DC summing inverting amplifier.
8. Demonstrate the ability to:
   a. Construct and test an inverting amplifier.
   b. Construct and test a noninverting amplifier.
   c. Construct and test a DC summing inverting amplifier.
   d. Construct and test a differential amplifier.

   (NOTE: If these activities have not been accomplished prior to the test, ask your instructor when they should be completed.)
OPERATIONAL AMPLIFIERS
UNIT VIII

ANSWERS TO TEST

1. a. 4  e. 2
    b. 6  f. 3
    c. 1  g. 8
    d. 7  h. 5

2. a. Monolithic  d. Hybrid circuits
    b. Bipolar  e. Thick film
    c. Unipolar  f. Thin film


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

5. a. 1  b. 2  c. 1  d. 2

6. Evaluated to the satisfaction of the instructor

7. Evaluated to the satisfaction of the instructor

8. Performance skills evaluated to the satisfaction of the instructor
After completion of this unit, the student should be able to identify the schematic symbols for logic devices, complete truth tables for the most common logic devices, and construct and test various IC and discrete logic gate circuits. This knowledge will be evidenced by correctly performing the procedures outlined in the job sheets and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to logic devices with their correct definitions.
2. Identify the schematic symbols for AND gates, OR gates, NAND gates, NOR gates, Exclusive-OR gates, and NOT gates.
3. Complete truth tables for the most common logic devices.
4. Demonstrate the ability to:
   a. Construct and test an IC "AND" gate circuit.
   b. Construct and test an IC "OR" gate circuit.
   c. Construct and test an IC "NAND" gate circuit.
   d. Construct and test an IC "Exclusive-OR" gate circuit.
   e. Construct and test a diode "AND" gate circuit.
   f. Construct and test a diode-transistor "NOR" gate circuit.
LOGIC DEVICES
UNIT IX

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.
II. Provide student with information and job sheets.
III. Make transparencies.
IV. Discuss unit and specific objectives.
V. Discuss information sheet.
VI. Demonstrate and discuss the procedures outlined in the job sheets.
VII. Give test.

INSTRUCTIONAL MATERIALS

I. Included in this unit
   A. Objective sheet
   B. Information sheet
   C. Transparency masters
      1. TM 1--AND and OR Gate Symbols and Truth Tables
      2. TM 2--NAND and NOR Gate Symbols and Truth Tables
      3. TM 3--INVERTERS and EXCLUSIVE-OR Gate Symbols and Truth Tables
   D. Job sheets
      1. Job Sheet #1--Construct and Test an IC "AND" Gate Circuit
      2. Job Sheet #2--Construct and Test an IC "OR" Gate Circuit
      3. Job Sheet #3--Construct and Test an IC "NAND" Gate Circuit
      4. Job Sheet #4--Construct and Test an IC "Exclusive-OR" Gate Circuit
      5. Job Sheet #5--Construct and Test a Diode "AND" Gate Circuit
      6. Job Sheet #6--Construct and Test a Diode-Transistor "NOR" Gate Circuit
II. References


LOGIC DEVICES
UNIT IX

INFORMATION SHEET

I. Terms and definitions

A. Digital circuits--Circuits that produce discontinuous signals at the output terminals

B. Truth table--Summarizes the various combinations of input and corresponding output signals for logic gates

C. High logic level--Usually considered a high voltage for positive logic and symbolized by a "1"

D. Low logic level--Usually considered a low voltage for positive logic and symbolized by a "0"

E. AND gate--Gives a logic output (1) only if all inputs are logic (1)

F. OR Gate--Gives a high level output (1) when any one or more inputs are high (1)

G. Inverter--Changes the output logic level to the opposite logic level of the input; also called a NOT

H. NAND gate--An AND gate followed by an inverter; also called a NOT-AND gate

I. NOR gate--An OR gate followed by an inverter; also called a NOT-OR gate

J. TTL (Transistor-transistor logic)--A means of fabricating an extremely fast operating gate by using a multiemmitter transistor

K. MSI (medium-scale integration)--A digital device which contains from 12 to 100 individual basic logic gates

L. LSI (large-scale integration)--A digital device that contains 100 or more individual logic gates

M. Exclusive-OR gate--Gives a high level output when one and only one input is at a high level

N. DTL (diode transistor logic)--A means of fabricating an operating logic gate using diodes and transistors
INFORMATION SHEET

II. Schematic symbols

A. AND gate (Transparency 1)
   1. Symbol
      \[ A \quad B \quad C \quad Y \]
   2. Output \( Y = ABC \)
      (NOTE: \( ABC \) refers to \( A \) and \( B \) and \( C \))

B. OR gate (Transparency 1)
   1. Symbol
      \[ A \quad B \quad C \quad Y \]
   2. Output \( Y = A + B + C \)
      (NOTE: \( A + B + C \) refers to \( A \) or \( B \) or \( C \))

C. NOT gate (inverter) (Transparency 3)
   1. Symbol
      \[ A \quad \bar{A} \quad Y \]
   2. Output \( Y = \bar{A} \)
      (NOTE: \( \bar{A} \) refers to \( A \) inverted)

D. NAND gate (Transparency 2)
   1. Symbol
      \[ A \quad B \quad C \quad Y \]
   2. Output \( Y = \overline{ABC} \)

E. NOR gate (Transparency 2)
   1. Symbol
      \[ A \quad B \quad C \quad Y \]
   2. Output \( Y = \overline{A + B + C} \)
INFORMATION SHEET

F. Exclusive-OR gate (Transparency 3)
   1. Symbol:
      \[ A \quad B \quad Y \]
   2. Output \( Y = \overline{AB} + A\overline{B} \)

III. Truth tables
   A. AND gate (Transparency 1)

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   B. OR gate (Transparency 1)

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   C. NOT gate (Transparency 3)

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### INFORMATION SHEET

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#### E. NOR gate (Transparency 2)

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#### F. Exclusive-OR gate (Transparency 3)

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AND and OR Gate Symbols and Truth Tables

### AND Gate

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### OR Gate

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NAND and NOR Gate Symbols and Truth Tables

**NAND Gate**

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\[ \overline{ABC} = Y \]

**NOR Gate**

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\[ \overline{A+B+C} = Y \]
Inverters and Exclusive-OR
Gate Symbols and Truth Tables

NOT Gate

\[ \neg A = Y \]

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Exclusive-OR

\[ Y = \neg AB + AB \]

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Exclusive-OR Table
JOB SHEET #1--CONSTRUCT AND TEST AN IC "AND" GATE CIRCUIT

I. Tools and equipment
   A. SN7411 triple 3-input positive-AND gates
   B. 3 SPDT switches
   C. DC power supply (+5 Volt)
   D. Multimeter
   E. Proto-board or equipment system for connecting ICs
   F. LED and a 470 ohm resistor (optional)

II. Procedure
   A. Wire the following logic AND gate circuit
      (NOTE: This device, 7411, contains three AND gates on one chip, but only one of the gates will be tested.)

   B. Check with your multimeter to be sure switches are as shown in the above diagram.
      (NOTE: The switches may be replaced by simply connecting the inputs to +5 volts or ground.)

   C. Connect the multimeter to the output of the gate
      (NOTE: A visual output indication may be made by placing an LED and a series resistor [approximately 470 ohms] from the output to ground. The diodes cathode must be connected to ground.)
D. Complete the following truth table by switching the three input switches into all possible combinations and recording whether the output is a "1" (high voltage) or a "0" (low voltage)

<table>
<thead>
<tr>
<th>SW-1 Input A</th>
<th>SW-2 Input B</th>
<th>SW-3 Input C</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
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<tr>
<td>1</td>
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</tbody>
</table>

E. Compare the output results with the truth table given on TM 1

F. Check your results with your instructor
LOGIC DEVICES
UNIT IX

JOB SHEET #2–CONSTRUCT AND TEST AN IC "OR" GATE CIRCUIT

I. Tools and equipment
   A. SN7432 Quadruple 2-input positive-OR gates
   B. 2-SPDT switches
   C. DC power supply
   D. Multimeter
   E. Proto-board or equipment system for connecting ICs
   F. LED and a 470 ohm resistor (optional)

II. Procedure
   A. Wire the following logic OR gate circuit

   (NOTE: This device, 7432, contains four OR gates on one chip but only
   one of the gates will be tested.)

   ![OR Gate Circuit Diagram]

   B. Check with your multimeter to be sure switches are as shown in the above
      diagram.

   C. Connect the multimeter (DC volts) to the output of the gate

      (NOTE: A visual output indication may be made by placing an LED and a
      series resistor [approximately 470 ohms] from the output to ground. The
      diodes cathode must be connected to ground.)
JOB SHEET #2

D. Complete the following truth table by switching the two input switches into all possible combinations and record whether the output is a "1" (high voltage) or a "0" (low voltage)

<table>
<thead>
<tr>
<th>SW-1 Input A</th>
<th>SW-2 Input B</th>
<th>Y Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

E. Compare the output results with the truth table given on TM 1

F. Check your results with your instructor
LOGIC DEVICES
UNIT IX

JOB SHEET #3--CONSTRUCT AND TEST AN IC "NAND" GATE CIRCUIT

I. Tools and equipment
A. SN7400 Quadruple 2-input Positive-NAND gates
B. 2 SPDT switches
C. DC power supply
D. Multimeter
E. Proto-board or equipment system for connecting ICs
F. LED and a 470 ohm resistor (optional)

II. Procedure
A. Wire the following logic NAND gate circuit
   (NOTE: Only one of the four gates on the chip will be tested. This device, SN7400, contains four NAND gates on one chip but only one of the gates will be tested.)

```
VCC +5V
A
B
1 14
3Y
7400 NAND GATE

Y OUTPUT
Y = AB
```

B. Check with your multimeter to be sure switches are as shown in the above diagram

C. Connect the multimeter to the output of the gate
   (NOTE: A visual output indication may be made by placing an LED and a series resistor (approximately 470 ohms) from the output to ground. The diodes cathode must be connected to ground.)
D. Complete the following truth table by switching the two input switches into all possible combinations and recording whether the output is a "1" (high voltage) or a "0" (low voltage)

<table>
<thead>
<tr>
<th>SW-1 Input A</th>
<th>SW-2 Input B</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

E. Compare the output results with the truth table given on TM 2

F. Check your results with your instructor
JOB SHEET #4-CONSTRUCT AND TEST AN IC "EXCLUSIVE-OR" GATE CIRCUIT

I. Tools and equipment
A. SN7485 Quadruple 2-input Exclusive-OR gate
B. 2-SPDT switches
C. DC power supply
D. Multimeter
E. Proto-board or equipment system for connecting ICs
F. LED and a 470 ohm resistor (optional)

II. Procedure
A. Wire the following logic exclusive OR gate circuit
   (NOTE: This device, SN7485, contains four Exclusive-OR gates on one chip, but only one of the gates will be tested.)

B. Check with your multimeter to be sure switches are as shown in the above diagram.

C. Connect the multimeter to the output of the gate
   (NOTE: A visual output indication may be made by placing an LED and a series resistor [approximately 470 ohms] from the output to ground. The diodes cathode must be connected to ground.)
D. Complete the following truth table by switching the two inputs into all possible combinations and recording whether the output is a "1" (high voltage) or a "0" (low voltage).

<table>
<thead>
<tr>
<th>SW-1 Input A</th>
<th>SW-2 Input B</th>
<th>Y Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

E. Compare the output results with the truth table given on TM 3.
JOB SHEET #5--CONSTRUCT AND TEST A DIODE "AND" GATE CIRCUIT

I. Tools and equipment
A. 3-silicon diodes (any available type)
B. 3-SPDT switches
C. 1-1000 ohm Resistor 1/4-watt
D. DC power supply (+5 Volts)
E. Multimeter

II. Procedure
A. Wire the following AND gate circuit

B. Check your multimeter to be sure the switches are shown as the above schematic
   (NOTE: Check to see that the polarity of the diodes are as shown.)

C. Connect the multimeter to the output of the gate
   (NOTE: A visual output indication may be made by placing an LED and a series resistor [approximately 470 ohms] from the output to ground. The diodes cathode must be connected to ground.)
D. Complete the following truth table by switching the three switches into all possible combinations and recording whether the output is a "1" (high voltage) or a "0" (low voltage).

<table>
<thead>
<tr>
<th>SW-1</th>
<th>SW-2</th>
<th>SW-3</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

E. Check your results with your instructor.
JOB SHEET #6--CONSTRUCT AND TEST A DIODE-TRANSISTOR "NOR" GATE CIRCUIT

I. Tools and equipment
   A. 1-NPN Transistor (2N3568 or equivalent)
   B. 2-silicon diodes (any available type)
   C. 3-1000 ohm resistors, 1/2 W
   D. 1-10K ohm resistor, 1/2 W
   E. 2-SPDT Switches
   F. Multimeter
   G. DC power supply

II. Procedure
   A. Wire the following NOR gate

   ![NOR gate diagram]

   B. Check to be sure both switches are in the position shown in the schematic.

   C. Set the multimeter to the correct DC voltage scale and connect it across the transistor output.

   D. Note the reading on the multimeter with both inputs "0".

   E. Change SW1 to the upper position that connects to +5V; this is the "1" position of SW1.

   F. Note the multimeter reading.
G. Change SW2 to the "1" position and note the multimeter reading.

H. Change SW1 to the "0" position and note the output.

I. Change SW2 to the "0" position and note the output.

J. Complete the following truth table as indicated by the multimeter output, high or low (assume 3.5V or above is logic one and 0.4 or below is logic zero).

<table>
<thead>
<tr>
<th>Sw-1</th>
<th>Sw-2</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

K. Check your results with your instructor.
LOGIC DEVICES  
UNIT IX  

NAME 

TEST  

1. Match terms on the right with their correct definitions.  

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>Gives a high level output when any one or more inputs are high.</td>
</tr>
<tr>
<td>b.</td>
<td>An AND gate followed by an inverter; also called a NOT-AND gate.</td>
</tr>
<tr>
<td>c.</td>
<td>Circuits that produce discontinuous signals at the output terminals.</td>
</tr>
<tr>
<td>d.</td>
<td>A digital device that contains 100 or more individual logic gates.</td>
</tr>
<tr>
<td>e.</td>
<td>A means of fabricating an extremely fast operating gate by using a multimeter transistor.</td>
</tr>
<tr>
<td>f.</td>
<td>An OR gate followed by an inverter; also called a NOT-OR gate.</td>
</tr>
<tr>
<td>g.</td>
<td>Summarizes the various combinations of input and corresponding output signals for logic gates.</td>
</tr>
<tr>
<td>h.</td>
<td>Usually considered a high voltage for positive logic and symbolized by a &quot;1&quot;.</td>
</tr>
<tr>
<td>i.</td>
<td>Gives a logic output only if all inputs are logic.</td>
</tr>
<tr>
<td>j.</td>
<td>A digital device which contains from 12 to 100 individual basic logic gates.</td>
</tr>
<tr>
<td>k.</td>
<td>Gives a high level output when one and only one input is at a high level.</td>
</tr>
<tr>
<td>l.</td>
<td>A means of fabricating an operating logic gate using diodes and transistors.</td>
</tr>
<tr>
<td>m.</td>
<td>Changes the output logic level to the opposite logic level of the input; also called a NOT.</td>
</tr>
<tr>
<td>n.</td>
<td>Usually considered a low voltage for positive logic and symbolized by a &quot;0&quot;.</td>
</tr>
</tbody>
</table>
2. Identify the schematic symbols for AND gates, OR gates, NAND gates, NOR gates, Exclusive-OR gates, and NOT gates in the illustrations that follow.

a. _______ Gate

b. _______ Gate

c. _______ Gate
d. _______ Gate

e. _______ Gate

3. Complete truth tables for the most common logic devices listed below.

a. AND gate:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
b. OR gate --

\[
\begin{array}{cccc}
A & B & C & Y \\
0 & 0 & 0 & 0 \\
0 & 0 & 1 & 1 \\
0 & 1 & 0 & 1 \\
0 & 1 & 1 & 1 \\
1 & 0 & 0 & 0 \\
1 & 0 & 1 & 1 \\
1 & 1 & 0 & 1 \\
1 & 1 & 1 & 1 \\
\end{array}
\]

c. NOT gate --

\[
\begin{array}{cc}
A & Y \\
0 & 1 \\
1 & 0 \\
\end{array}
\]

d. NAND gate --

\[
\begin{array}{cccc}
A & B & C & Y \\
0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 1 & 0 & 0 \\
0 & 1 & 1 & 0 \\
1 & 0 & 0 & 0 \\
1 & 0 & 1 & 1 \\
1 & 1 & 0 & 1 \\
1 & 1 & 1 & 1 \\
\end{array}
\]

e. NOR gate --

\[
\begin{array}{cccc}
A & B & C & Y \\
0 & 0 & 0 & 0 \\
0 & 0 & 1 & 1 \\
0 & 1 & 0 & 1 \\
0 & 1 & 1 & 1 \\
1 & 0 & 0 & 1 \\
1 & 0 & 1 & 1 \\
1 & 1 & 0 & 1 \\
1 & 1 & 1 & 1 \\
\end{array}
\]

f. Exclusive-OR gate --

\[
\begin{array}{cc}
A & B & Y \\
0 & 0 & 0 \\
0 & 1 & 1 \\
1 & 0 & 1 \\
1 & 1 & 0 \\
\end{array}
\]

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4. Demonstrate the ability to:
   a. Construct and test an IC "AND"-gate circuit.
   b. Construct and test an IC "OR" gate circuit.
   c. Construct and test an IC "NAND" gate circuit.
   d. Construct and test an IC "Exclusive-OR" gate circuit.
   e. Construct and test a diode "AND" gate circuit.
   f. Construct and test a diode-transistor "NOR" gate circuit.

   (NOTE: If these activities have not been accomplished prior to the test, ask your instructor when they should be completed.)
1. a. 4  f. 9  k. 13
b. 8  g. 2  l. 14
c. 1  h. 6  m. 5
d. 12  i. 3  n. 7
e. 10  j. 11

2. a. NAND Gate  d. AND Gate
   b. OR Gate  e. Exclusive-OR Gate
   c. NOR Gate  f. NOT Gate

3. a. AND gate
     | A | B | C | Y |
     | 0 | 0 | 0 | 0 |
     | 0 | 0 | 1 | 0 |
     | 0 | 1 | 0 | 0 |
     | 0 | 1 | 1 | 0 |
     | 1 | 0 | 0 | 0 |
     | 1 | 0 | 1 | 0 |
     | 1 | 1 | 0 | 0 |
     | 1 | 1 | 1 | 1 |

   b. OR gate
     | A | B | C | Y |
     | 0 | 0 | 0 | 0 |
     | 0 | 0 | 1 | 1 |
     | 0 | 1 | 0 | 1 |
     | 0 | 1 | 1 | 1 |
     | 1 | 0 | 0 | 1 |
     | 1 | 0 | 1 | 1 |
     | 1 | 1 | 0 | 1 |
     | 1 | 1 | 1 | 1 |

   c. NOT gate
     | A | Y |
     | 0 | 1 |
     | 1 | 0 |

   d. NAND gate
     | A | B | C | Y |
     | 0 | 0 | 0 | 1 |
     | 0 | 0 | 1 | 0 |
     | 0 | 1 | 0 | 0 |
     | 0 | 1 | 1 | 0 |
     | 1 | 0 | 0 | 1 |
     | 1 | 0 | 1 | 0 |
     | 1 | 1 | 0 | 1 |
     | 1 | 1 | 1 | 0 |

   e. NOR gate
     | A | B | Y |
     | 0 | 0 | 0 |
     | 0 | 1 | 0 |
     | 1 | 0 | 1 |
     | 1 | 1 | 1 |

   f. Exclusive-OR gate
     | A | B | Y |
     | 0 | 0 | 0 |
     | 0 | 1 | 1 |
     | 1 | 0 | 1 |
     | 1 | 1 | 0 |

4. Performance skills evaluated to the satisfaction of the instructor
LOGIC SYSTEMS
UNIT X

UNIT OBJECTIVE

After completion of this unit, the student should be able to write the binary equivalent of decimal numbers, add numbers expressed in binary digits, and complete a truth table for a half-adder. The student should also be able to identify multivibrators, and construct and test a four-bit shift register. This knowledge will be evidenced by correctly performing the procedures outlined in the assignment and job sheets and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to logic systems with their correct definitions.
2. Convert a sequence of binary numbers to decimal numbers.
3. Add binary numbers.
4. Complete a truth table for a half-adder.
5. Identify multivibrators given their input and output signal waveforms.
6. Convert decimal numbers to their equivalent BCD.
7. Add numbers expressed in binary digits.
8. Demonstrate the ability to construct and test a four-bit shift register.
LOGIC SYSTEMS
UNIT X

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.

II. Provide student with information, assignment, and job sheets.

III. Make transparencies.

IV. Discuss unit and specific objectives.

V. Discuss information and assignment sheets.

VI. Demonstrate and discuss the procedures outlined in the job sheet.

VII. Give test.

INSTRUCTIONAL MATERIALS

I. Included in this unit:

A. Objective sheet

B. Information sheet

C. Transparency masters
   1. TM 1--Binary to Decimal Conversions
   2. TM 2--Binary Addition
   3. TM 3--Half-Adder Logic
   4. TM 4--Multivibrators
   5. TM 5--Binary Coded Decimals

D. Assignment Sheet #1--Add Numbers Expressed in Binary Digits

E. Answers to assignment sheet

F. Job Sheet #1--Construct and Test a Four-Bit Shift Register

G. Test

H. Answers to test
II. References:


LOGIC SYSTEMS
UNIT X

INFORMATION SHEET

I. Terms and definitions

A. Binary number system--Lowest useful number system which has digits 0 and 1 only

B. Bit--A single binary digit, 0 or 1

C. Byte--8 bits

D. Half-adder--A combination of AND gates, OR gates, and INVERTERS used to perform binary addition of two single digit numbers

E. Full-adder--A combination of two half-adders which requires the three inputs of A, B, and the previous carry

F. Flip-flop (bistable multivibrator)--A circuit that is stable in two states (0 or 1) and is used as a memory element in digital circuits

G. One-shot (monostable multivibrator)--A circuit that is stable in only one state and is used in timing and pulse-shaping circuits

H. Free-running (astable multivibrator)--Provides a fixed-frequency square wave often referred to as a clock

I. Binary coded decimal (BCD)--A digital code where a four bit binary character is used to represent each one digit decimal character

J. Discrete devices--Individual components such as transistors and diodes (a single device)

II. Binary to Decimal Conversions (Transparency 1)

\[2^3 2^2 2^1 2^0\]

A. Number places, i.e., 1 0 1 1

B. Number conversions--Binary to decimal

III. Binary addition (Transparency 2)

A. Add unit digits
INFORMATION SHEET

B. Carry from right to left

Example: To find the sum of 1 0 1
                    + 0 0 1, proceed as follows:

1. Add unit digits starting from right column

\[
\begin{array}{c}
  1 \\
+ 1 \\
\hline
  10 \quad \text{(NOTE: This number has a carry which must be added to the next column of digits to the left.)}
\end{array}
\]

2. Add second column from right

\[
\begin{array}{c}
  1 \quad \text{(carry from first column)} \\
  0 \\
+ 0 \\
\hline
  1 \quad \text{(NOTE: No carry on this addition.)}
\end{array}
\]

3. Add third column from right

\[
\begin{array}{c}
  0 \quad \text{(No carry from second column)} \\
  1 \\
+ 0 \\
\hline
  1 
\end{array}
\]

4. Total all columns and the sum of 1 0 1

\[
\begin{array}{c}
  1 \\
+ 0 1 \\
\hline
  1 1 0 
\end{array}
\]

IV. Truth table for a half-adder (Transparency 3)

A. Has a sum and a carry output
B. Used for adding two single digit numbers

\text{(NOTE: A carry occurs only when the inputs are both equal to 1.)}

V. Multivibrators and their input and output signal waveforms (Transparency 4)

A. Flip-flop--Bistable multivibrator
B. One-shot--Monostable multivibrator
C. Free-running--Astable multivibrator
VI. Binary Coded Decimal (BCD) numbers (Transparency 5)
   A. BCD system--Coding structure
   B. Conversion from decimal to BCD
Binary to Decimal Conversions

A. \[ 1011 = \sum_{i=0}^{3} 2^i \cdot a_i \]
\[ = (1 \cdot 8) + (0 \cdot 4) + (1 \cdot 2) + (1 \cdot 1) = 8 + 0 + 2 + 1 = 11 \]

B. \[ 111 = \sum_{i=0}^{2} 2^i \cdot a_i \]
\[ = (1 \cdot 4) + (1 \cdot 2) + (1 \cdot 1) = 4 + 2 + 1 = 7 \]

C. \[ 11011 = \sum_{i=0}^{4} 2^i \cdot a_i \]
\[ = (1 \cdot 16) + (1 \cdot 8) + (0 \cdot 4) + (1 \cdot 2) + (1 \cdot 1) = 16 + 8 + 0 + 2 + 1 = 27 \]
Binary Addition

Rules For Binary Addition:

- \(0 + 0 = 0\)
- \(0 + 1 = 1\)
- \(1 + 0 = 1\)
- \(1 + 1 = 10\)

A. \(01\) + \(10\) = \(11\)

\[
\begin{array}{c}
\text{Binary} \\
01 \\
+ 10 \\
\hline
11
\end{array}
\]

B. \(11\) + \(3\) = \(11\)

\[
\begin{array}{c}
\text{Digital:} \\
(1) \\
+ (2) \\
\hline
3
\end{array}
\]

\[
\begin{array}{c}
\text{B:} \\
01 \\
\hline
10:0 \\
\hline
10:10 \\
\hline
4
\end{array}
\]

(Check: \(1 + 1 = 0 + \text{a carry 1}\))

C. \(1101\) + \(111\) = \(10100\)

\[
\begin{array}{c}
\text{Binary:} \\
1101 \\
+ 111 \\
\hline
10100
\end{array}
\]

D. \(10110\) + \(7\) = \(100000\)

\[
\begin{array}{c}
\text{Binary:} \\
10110 \\
+ 7 \\
\hline
100000
\end{array}
\]

\[
\begin{array}{c}
\text{Digital:} \\
13 \\
+ 7 \\
\hline
20
\end{array}
\]

\[
\begin{array}{c}
\text{D:} \\
\hline
101010 \\
\hline
100000
\end{array}
\]

\[
\begin{array}{c}
\text{10:10} \\
\hline
32:10
\end{array}
\]
Half-Adder Logic

Truth Table

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Multivibrators

Multivibrators may be made from either discrete devices or integrated circuits.
## Binary Coded Decimals

### BCD States

<table>
<thead>
<tr>
<th>Binary</th>
<th>Decimal</th>
<th>Binary</th>
<th>Decimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>0</td>
<td>1010</td>
<td>10</td>
</tr>
<tr>
<td>0001</td>
<td>1</td>
<td>1011</td>
<td>11</td>
</tr>
<tr>
<td>0010</td>
<td>2</td>
<td>1100</td>
<td>12</td>
</tr>
<tr>
<td>0011</td>
<td>3</td>
<td>1101</td>
<td>13</td>
</tr>
<tr>
<td>0100</td>
<td>4</td>
<td>1110</td>
<td>14</td>
</tr>
<tr>
<td>0101</td>
<td>5</td>
<td>1111</td>
<td>15</td>
</tr>
<tr>
<td>0110</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0111</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1001</td>
<td>9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Four bits represent each decimal digit.

- Decimal BCD code: 0111 0100
- Decimal BCD code: 0011 0110
- Decimal BCD code: 1001 1001
- Decimal BCD code: 0011 1000 0100

\[ 263 \]
A. The binary equivalent for the decimal number 20 is 10100. The binary equivalent for the decimal number 17 is 10001. Add the two binary equivalent numbers and check by converting your answer in binary back to a decimal number.

B. Add the following binary numbers:

\[
\begin{array}{c}
100011 \\
+110101 \\
+101011 \\
\end{array}
\]

Sum:

What is the decimal equivalent of your answer? 

C. Convert the decimal number 375 to equivalent BCD code.

264
LOGIC SYSTEMS
UNIT X

ANSWERS TO ASSIGNMENT SHEET

A.  

<p>| | | | |</p>
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<thead>
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B.  

<p>| | | | |</p>
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C.  

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</tbody>
</table>

263
JOB SHEET #1—CONSTRUCT AND TEST A FOUR-BIT SHIFT REGISTER

I. Tools and equipment

A. 2-SN7473 Dual J-K Flip-flops
B. DC power supply (+5 volts)
C. 4-LEDs
D. 4.7 ohm resistors
E. Proto-board or equivalent system for connecting ICs
F. Function generator or means of producing a square wave pulse with a single step capability
G. 1-SN7404 HEX inverter

(NOTE: This experiment will use four flip-flops (J-K Flip-flops) to transfer the contents of the first flip-flop (register) into a second flip-flop (register) and so on, one bit at a time. This type of circuit is called a shift register.)

<table>
<thead>
<tr>
<th>'73</th>
<th>J73</th>
<th>L73</th>
</tr>
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<tbody>
<tr>
<td>FUNCTION TABLE</td>
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<table>
<thead>
<tr>
<th>INPUTS</th>
<th>OUTPUTS</th>
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<tbody>
<tr>
<td>CLEAR</td>
<td>CLOCK</td>
</tr>
<tr>
<td>L</td>
<td>X</td>
</tr>
<tr>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>

266
II. Procedure

A. Connect the following circuit

(NOTE: If data books are available, study the logic diagrams for the 7473 and the 7404 logic chips.)

```
Input
VCC + 5v
```

```
7473
Most sig. bit.
```

```
7473
Less sig. bit.
```

```
7404
```

Shift pulse (clock)
you should be able to single step the clock pulse

```
X3
```

Output indicators place an LED and resistor on each of the flip-flops
X output (X3, X2, X1, X0)

(NOTE: The outputs of all flip-flops should be "0" before you start. If not, momentarily ground the clear pin (2 or 6) for the output which is high. You may want to try shifting additional numbers through the four bit binary shift register.

The binary number 1 0 1 1 will be shifted through the shift register one bit at a time starting with the least significant bit (the far right bit) and moving from right to left.)

B. Place a logic level "1" on the input terminal by connecting the input terminal to + Vcc (5v)
JOB SHEET #1

C. Push the shift pulse switch or clock pulse switch one time.

D. Record the outputs of each flip-flop: X₃, X₂, X₁, X₀
   (NOTE: The LED should light for "1" and be off for a "0").

E. The next bit to be entered is also a "1" (1 0 1 1) so push the shift pulse switch one time.

F. Record the outputs of each flip-flop.

G. Place a "0" on the input terminal by changing the input from +5 volts to ground.

H. Push the shift pulse switch.

I. Record the outputs of each flip-flop.

J. Place a "1" on the input terminal by changing the input from ground to +5v (Vcc).

K. Push the shift pulse switch.

L. Record the outputs of each flip-flop.

M. Check your results with your instructor.
LOGIC SYSTEMS
UNIT X

NAME 

TEST

1. Match terms on the right to their correct definitions.

   a. 8 bits
   b. A combination of two half-adders which requires the three inputs of A, B, and the previous carry
   c. A circuit that is stable in only one state and is used in timing and pulse-shaping circuits
   d. A digital code where a four bit binary character is used to represent each one digit decimal character
   e. Lowest useful number system which has digits 0 and 1 only
   f. A combination of AND gates, OR gates, and INVERTERS used to perform binary addition of two single digit numbers
   g. A single binary digit, 0 or 1
   h. Provides a fixed-frequency square wave often referred to as a clock
   i. A circuit that is stable in two states and is used as a memory element in digital circuits
   j. Individual components such as transistors and diodes

2. Convert the following sequence of binary numbers to decimal numbers.

   a. 01   f. 110
   b. 10   g. 111
   c. 11   h. 1000
   d. 100  i. 1001
   e. 101  j. 1010
3. Add the following binary numbers.

\[
\begin{align*}
100011 \\
110101 \\
101011
\end{align*}
\]

4. Complete the following truth table for a half-adder.

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

5. Identify multivibrators from their input and output signal waveforms.

![Waveforms](image)
6. Convert the following decimal numbers to their equivalent BCD codes.
   a. 3972
   b. 2874
   c. 8197

7. Add numbers expressed in binary digits.

8. Demonstrate the ability to construct and test a four-bit shift register.
   (NOTE: If these activities have not been accomplished prior to the test, ask your
   instructor when they should be completed.)
LOGIC SYSTEMS
UNIT X

ANSWERS TO TEST

1. a. 3   f. 4
   b. 5   g. 2
   c. 7   h. 8
   d. 9   i. 6
   e. 1   j. 10

2. a. 1   f. 6
   b. 2   g. 7
   c. 3   h. 8
   d. 4   i. 9
   e. 5   j. 10

3. 100011   35
   110101   53
   101011   43
   1000011   131

4. | Input | Output |
<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>0</td>
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</table>

5. a. Free-running or astable
     b. Flip-flop or bistable
     c. One-shot or monostable

6. a. 0011 1001 0111 0010
     b. 0010 1000 0111 0100
     c. 1000 0001 1001 0111

7. Evaluated to the satisfaction of the instructor

8. Performance skills evaluated to the satisfaction of the instructor
UNIT OBJECTIVE

After completion of this unit, the student should be able to identify the schematic symbols and output characteristic curves for various special semiconductor devices, state the applications for various special semiconductor devices, and construct and test various special semiconductor device circuits. This knowledge will be evidenced by correctly performing the procedures outlined in the job sheets and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to special semiconductor devices with their correct definitions.
2. Identify the schematic symbol for an SCR.
3. Sketch the output characteristic curves of an SCR.
4. Select true statements concerning other characteristics of an SCR.
5. Identify the schematic symbol for a Triac.
6. Sketch the output characteristic curves of a Triac.
7. Identify the schematic symbol for a Diac.
8. Select true statements concerning Diac applications.
9. Distinguish between the schematic symbols for two types of thermistors.
10. Select true statements concerning thermistor applications.
11. Identify the schematic symbol for a UJT.
12. Sketch the output characteristic curves of a UJT.
13. Select true statements concerning UJT applications.
14. Identify the schematic symbol for a PUT.
15. Distinguish between the advantages of a PUT over a UJT.
16. Identify the schematic symbol for a JFET.
17. Sketch the output characteristic curves of a JFET.
18. Distinguish between the schematic symbols for the two types of MOSFETs.
19. Select true statements concerning the characteristics of IGFETs or MOSFETs.

20. Demonstrate the ability to:
   a. Construct and test a silicon controlled rectifier circuit.
   b. Construct and test a unijunction transistor relaxation oscillator.
   c. Construct and test a field effect transistor amplifier.
   d. Construct and test a thermistor controlled circuit.
SPECIAL SEMICONDUCTOR DEVICES
UNIT XI

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.
II. Provide student with information and job sheets.
III. Make transparencies.
IV. Discuss unit and specific objectives.
V. Discuss information sheet.
VI. Demonstrate and discuss the procedures outlined in the job sheets.
VII. Give test.

INSTRUCTIONAL MATERIALS

I. Included in this unit:
   A. Objective sheet
   B. Information sheet
   C. Transparency masters
      1. TM 1--Silicon Controlled Rectifier
      2. TM 2--Triac
      3. TM 3--Unijunction Transistor
      4. TM 4--Junction Field Effect Transistor
      5. TM 5--Insulated Gate Field Effect Transistors
   D. Job sheets
      1. Job Sheet #1--Construct and Test a Silicon Controlled Rectifier Circuit
      2. Job Sheet #2--Construct and Test a Unijunction Transistor Relaxation Oscillator
      3. Job Sheet #3--Construct and Test a Field Effect Transistor Amplifier
      4. Job Sheet #4--Construct and Test a Thermistor Control Circuit
   E. Test
   F. Answers to test
I. Terms and definitions

A. Thyristors—A family of multilayered semiconductor devices which are used primarily for switching current

B. SCR (Silicon Controlled Rectifier)—A three-terminal device similar to an ordinary rectifier except its rectifying characteristics can be controlled; a member of the thyristor family

C. Triac—A three-terminal device which is a member of the thyristor family and is generally applied as an AC switching device

D. Diac—A bidirectional trigger diode

E. Thermistor—A temperature-sensitive resistor

F. UJT (Unijunction Transistor)—A specialized type of junction transistor which is normally used as a switching device

G. FET (Field Effect Transistor)—A specialized type of transistor which is voltage controlled and has very high input impedance

H. PUT (Programmable Unijunction Transistor)—A specialized semiconductor device used for switching purposes; it has a trigger voltage that is programmable

II. SCR schematic symbol (Transparency 1)

III. Output characteristic curves of an SCR (Transparency 1)

A. Gate current

B. Forward breakover voltage

C. Holding current

D. Normal rectifier characteristic

IV. Other characteristics of an SCR

A. Small gate current required to turn on device when P-N junction is forward biased

B. Remains on until anode to cathode current is reduced below minimum holding current.
INFORMATION SHEET

V. Triac schematic symbol (Transparency 2)

VI. Output characteristic curves of a Triac (Transparency 2)
A. Forward condition
B. Reverse condition
C. Forward breakover
D. Reverse breakover
E. AC switch characteristic

VII. Diac schematic symbol

VIII. Diac applications
A. Used to trigger Triacs
B. Provides protection against overvoltages

IX. Thermistor schematic symbols
A. Directly heated
B. Indirectly heated

X. Thermistor applications
A. Used when a negative temperature coefficient is required
B. Detects changes in the temperature of the surroundings
C. Detects changes in current flow by indirect heating of the device
XI. UJT schematic symbol (Transparency 3)

XII. Output characteristic curves of a UJT (Transparency 3)
   A. Resistance from base-1 to emitter is high at low-emitter voltages
   B. When emitter voltage reaches the forward-bias level, the base-1 resistance drops quite suddenly between base-1 and emitter

XIII. UJT applications
   A. Wave-shaping generators
   B. Pulse-forming circuits

XIV. PUT schematic symbol

XV. Advantages of a PUT over a UJT (or transistor switch)
   A. Higher breakdown voltage
   B. Low voltage operation capability
   C. Programmable trigger voltage
   D. Low cost and small size

XVI. JFET schematic symbols (Transparency 4)

XVII. Output characteristic curves of a JFET
   A. Reverse-bias junction (gate to source) controls output
   B. Normally "on" device conducts when voltage is applied between the drain and the source
   C. High input impedance because of the reverse-biased junction
XVIII. MOSFET schematic symbols

A. Enhancement mode--

![Enhancement mode schematic](image)

P - Channel

B. Depletion mode--

![Depletion mode schematic](image)

P - Channel

XIX. Characteristics of IGFETs or MOSFETs

A. Gate insulated from source and drain

B. High input impedance because of the insulation layer

C. Enhancement type is normally "off" and has no deposited channel region

D. Depletion type is normally "on" and has a deposited channel region
Silicon Controlled Rectifier

![Schematic Symbol]

Normal Rectifier Characteristic

Holding Current

Forward Breakover Voltage

Output Characteristic Curves
Triac

Schematic Symbol

Output Characteristic Curves
Unijunction Transistor

Output Characteristic Curve
Junction Field Effect Transistor

JFET

N-Channel Junction Field Effect Transistor

JFET Construction

N-Channel Junction Field Effect Transistor

![Diagram of JFET](image)

<table>
<thead>
<tr>
<th>$V_{GS}$</th>
<th>$I_D$</th>
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<tbody>
<tr>
<td>0 V</td>
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</tr>
<tr>
<td>0.2 V</td>
<td></td>
</tr>
<tr>
<td>0.4 V</td>
<td></td>
</tr>
<tr>
<td>0.6 V</td>
<td></td>
</tr>
<tr>
<td>0.8 V</td>
<td></td>
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</table>

$V_{DS}$
Insulated Gate Field Effect Transistor (IGFET) or Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

**Enhancement Mode (Type N-Channel)**

**Depletion Mode (Type N-Channel)**

Arrow always points toward the N-type material.

MOSFET Construction – Depletion-Type
I. **Tools and equipment**
   
   A. GE C106B SCR or equivalent
   
   B. 6-volt power supply (300 mA)
   
   C. #328 incandescent lamp and holder or equipment
   
   D. 1-10k potentiometer
   
   E. 1-220 ohm resistor
   
   F. 1-560 ohm resistor

II. **Procedure**
   
   A. Connect the circuit as shown below
      
      (CAUTION: Do not turn on the power supply at this time.)
   
      ![Circuit Diagram]
   
   B. Adjust the 10k potentiometer for maximum resistance
   
   C. Turn on power supply
   
   D. Connect your voltmeter between the gate and cathode leads of the SCR
   
   E. Slowly decrease the resistance of the 10k potentiometer until the lamp lights; then read and record the gate voltage
   
   F. Disconnect the gate lead and observe
   
   G. Replace the gate lead
   
   H. Return the potentiometer to its maximum resistance position
JOB-SHEET #1

I. Place a jumper between the anode and cathode of the SCR, then remove the jumper and observe that the lamp goes out.

J. Repeat Steps D through H, and compare the results obtained the second time with those obtained the first time.

K. Turn off the power supply, then turn it on again, and observe the lamps.

L. Check your results with your instructor.
SOFTWARE SEMICONDUCTOR DEVICES
UNIT XI

JOB SHEET #2 - CONSTRUCT AND TEST A UNIJUNCTION TRANSISTOR RELAXATION OSCILLATOR

I. Equipment and material needed
   A. GE 2N2646 UJT or equivalent
   B. Power supply (12 volts)
   C. 10k potentiometer
   D. 100 ohm resistor
   E. 470 ohm resistor
   F. 33 ohm resistor
   G. 0.1μF capacitor
   H. Multimeter
   I. Oscilloscope
   J. Graph paper
   K. Soldering iron or gun

II. Procedure
   A. With an ohmmeter, read and record the resistance between the two bases
   B. Connect the circuit shown below

   (CAUTION: Do not turn on the power supply at this time.)
C. Place the potentiometer in approximately the midrange position

D. Turn on the power supply

E. Connect the oscilloscope to observe the waveshape across the capacitor and sketch a scale drawing of this voltage waveshape

F. Connect the oscilloscope to observe the waveshape across the 33 ohm resistor and sketch a scale drawing of this voltage waveshape

(NOTE: If your oscilloscope has two channels or if you have an electronic switch, observe the waveshapes of Steps E and F simultaneously. If not, draw your two pictures so you can relate the time on the sketches to each other.)

G. From your sketches determine the frequency of oscillation, that is, the number of pulses per second that are being generated

H. Change the potentiometer setting and observe the voltage waveshapes to see if the frequency changes; determine whether frequency increases or decreases when the potentiometer resistance is increased

I. Connect the oscilloscope across the 33 ohm resistor and set the potentiometer approximately to midrange, then while observing the oscilloscope, hold a hot soldering gun near the UJT for three seconds and observe any change.

J. Check your results and sketches with your instructor

(NOTE: Record observation from step I.)

\[ f = \frac{1}{2\pi \sqrt{C R}} \]

(Note: Record observations from step I)
SPECIAL SEMICONDUCTOR DEVICES
UNIT XI

JOB SHEET #3--CONSTRUCT AND TEST A FIELD EFFECT TRANSISTOR AMPLIFIER

I. Tools and equipment
   A. 2N5555 JFET or equivalent
   B. 2-15 volt power supplies
   C. 1-100k resistor
   D. 1-1k resistor
   E. 1-100k potentiometer
   F. 1-1μF capacitor
   G. Signal generator
   H. Oscilloscope
   I. Multimeter
   J. Milliammeter
   K. Graph paper

II. Procedure
   A. Wire the following circuit

   (CAUTION: Do not turn on the power at this time.)
JOB SHEET #3

B. Turn on the drain power supply \( (V_{DD}) \) and observe the drain current on the milliammeter meter

C. Turn on the gate power supply \( (V_G) \) and observe any change in drain current

D. Adjust the potentiometer until the drain current is barely measurable, then record the voltage at Point A to ground

E. Recheck to see that both power supplies are set to 15 volts (with polarities as shown in the schematic)

F. Adjust the potentiometer until the drain current is at 4 mA, then record the voltage at Point A to ground

G. Adjust the potentiometer until the drain current is at 5 mA, then record the voltage at Point A to ground

H. Short out the milliammeter

I. While reading the drain to source voltage with a multimeter, adjust the potentiometer until the voltage equals +10 volts

J. Connect the signal generator through a 1 \( \mu \)F capacitor to Point B

K. Adjust the signal generator for a signal of 1 kHz, and an amplitude of 0.1 volt peak-to-peak

L. Connect the oscilloscope across the 1k load resistor

M. Record the amplitude of the signal voltage across the load resistor

N. Make a scale drawing of both input and output voltage waveshapes

O. Check your results and your drawing with your instructor
**JOB SHEET #3**

Data Table

<table>
<thead>
<tr>
<th>$I_D$</th>
<th>$V_{AN}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td></td>
</tr>
<tr>
<td>4mA</td>
<td></td>
</tr>
<tr>
<td>5mA</td>
<td></td>
</tr>
</tbody>
</table>

Diagram:

- $V_{IN}$
- $V_{OUT}$
- $t$
I. Equipment and materials needed
   A. Thermistor CA31J1 .3 inch disc thermister $R_o \ @ \ 25^\circ C. = 1000 \text{ ohms or equivalent}$
   B. DC milliammeter (center scale deflection)
   C. 1-4.7k ohm resistor, 1-1k ohm resistor
   D. 1-10k ohm potentiometer
   E. 1-1K resistor
   F. DC power supply
   G. Multimeter (optional)
   H. Soldering iron or some means to heat the thermistor

II. Procedure
   A. Connect the circuit shown below

   ![Circuit Diagram]

   B. Turn the power supply on and adjust to 10 volts then adjust the potentiometer until the meter gives a "0" indication
JOB SHEET #4

C. Measure and record the voltage across the thermistor; heat the thermistor with a soldering iron or light bulb and note any change of current through the millimeter; remove the heat source from the thermistor and note any change of current and voltage.

Optional

A. Measure the room temperature next to the thermistor before heating the thermistor and record the temperature, current, and the voltage drop across the thermistor.

B. Heat the thermistor until you obtain a change in current, then record the new current, the temperature, and the voltage across the thermistor.

C. Calculate the thermistor's resistance for both the cold and heated conditions.

(NOTE: You may need to review the basic electrical equations for a resistive bridge circuit.)

D. Measure and record the voltage across the thermistor.

E. Heat the thermistor with a soldering iron or light bulb and note any change of current through the millimeter.

F. Measure and record the voltage drop across the thermistor.

G. Remove the heat source from the thermistor and note any change of current and voltage.
SPECIAL SEMICONDUCTOR DEVICES
UNIT XI

NAME ________________________

TEST

1. Match the terms on the right with their correct definitions:

   a. A family of multilayered semiconductor devices which are used primarily for switching current

   b. A three-terminal device similar to an ordinary rectifier except its rectifying characteristics can be controlled; a member of the thyristor family

   c. A three-terminal device which is a member of the thyristor family and is generally applied as an AC switching device

   d. A bidirectional trigger diode

   e. A temperature-sensitive resistor

   f. A specialized type of junction transistor which is normally used as a switching device

   g. A specialized type of transistor which is voltage-controlled and has very high input impedance

   h. A specialized semiconductor device used for switching purposes; it has a trigger voltage that is programmable

   1. UJT
   2. Diac
   3. PUT
   4. Thyristors
   5. FET
   6. SCR
   7. Triac
   8. Thermistor

2. Identify the schematic symbol for an SCR by circling the correct letter.

   a. 
   b. 
   c. 

   A
   G
   K
   A
   G
   D
   S
3. Sketch the output characteristic curves of an SCR on the diagram that follows.

4. Select true statements concerning other characteristics of an SCR by placing an "X" in the appropriate blanks.
   a. Medium gate current
   b. Remains on until anode to cathode current is reduced below minimum holding current, $I_H$

5. Identify the schematic symbol for a Triac by circling the correct letter.
   a. 
   b. 
   c. 

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6. Sketch the output characteristic curves of a Triac on the diagram below.

7. Identify the schematic symbol for a Diac by circling the correct letter.
   a. 
   b. 
   c. 

8. Select true statements concerning Diac applications by placing an "X" in the appropriate blanks.
   a. Used to trigger Triacs
   b. Used only with extremely low voltages

9. Distinguish between the schematic symbols for directly and indirectly heated thermistors by placing an "X" beneath the schematic for the directly heated thermistor.
   a. 
   b. 

10. Select true statements concerning thermistor applications by placing an "X" in the appropriate blanks.

- a. Used when a positive temperature coefficient is required
- b. Detects changes in the temperature of the surroundings
- c. Detects changes in current flow by indirect heating of the device.

11. Identify the schematic symbol for a UJT by circling the correct letter.

a. 

b. 

c. 

12. Sketch the output characteristic curves of a UJT on the diagram that follows.

13. Select true statements concerning UJT applications by placing an "X" in the appropriate blanks.

- a. Wave-shaping generators
- b. Pulse-forming circuits
14. Identify the schematic symbol for a PUT by circling the correct letter.

- a. 
- b. 
- c. 

15. Distinguish between the advantages of a PUT over a UJT by placing an "x" beside the statements that indicate PUT advantages.

- a. Higher breakdown voltage
- b. Low voltage operation capability
- c. Programmable trigger voltage
- d. High cost but small size

16. Identify the schematic symbol for a JFET by circling the correct letter.

- a. 
- b. 
- c. 

17. Sketch the output characteristic curves of a JFET on the diagram that follows.
18. Distinguish between the schematic symbols for MOSFETs in the enhancement mode and MOSFETs in the depletion mode by circling the letter beneath the schematic for the MOSFET in the enhancement mode.

a. 

b. 

19. Select true statements concerning characteristics of IGFETs and MOSFETs by placing an "X" in the appropriate blanks.

a. Gate insulated from source and drain
b. High input impedance because of the insulation layer
c. Enhancement type is normally "on" and has no deposited channel region
d. Depletion type is normally "off" and has a deposited channel region

20. Demonstrate the ability to:

a. Construct and test a silicon controlled rectifier circuit.
b. Construct and test a unijunction transistor relaxation oscillator.
c. Construct and test a field effect transistor amplifier.
d. Construct and test a thermistor controlled circuit.

(Note: If these activities have not been accomplished prior to the test, ask your instructor when they should be completed.)
ANSWERS TO TEST

1. a. 4  e. 8  
b. 6  f. 1  
c. 7  g. 5  
d. 2  h. 3  

2. b  

3. 

4. b  

5. a  

6. 

7. a
8. a
9. b
10. b, c
11. c
12.

- V

- V

13. a, b
14. a
15. a, b, c
16. a
17.

18. b
19. a, b

20. Performance skills evaluated to the satisfaction of the instructor
After completion of this unit, the student should be able to identify the circuit schematic diagrams for various oscillator types and construct and test a Hartley oscillator. This knowledge will be evidenced by correctly performing the procedures outlined in the job sheet and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

1. Match terms related to oscillators with the correct definitions.
2. Identify the circuit schematic diagrams for a Hartley oscillator, a Colpitts oscillator, and a Clapp oscillator.
3. Identify the circuit schematic diagrams for a Pierce oscillator, a TBTC oscillator, and an RC oscillator.
4. Demonstrate the ability to construct and test a Hartley oscillator.
OSCILLATORS
UNIT XII

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.

II. Provide student with information and job sheets.

III. Make transparencies.

IV. Discuss unit and specific objectives.

V. Discuss information sheet.

VI. Demonstrate and discuss the procedures outlined in the job sheets.

VII. Give test.

INSTRUCTIONAL MATERIALS

I. Included in this unit:

A. Objective sheet
B. Information sheet
C. Transparency masters
   1. TM 1--Härtley, Colpitts, and Clapp Oscillators
   2. TM 2--Pierce, TBTC, and RC Oscillators
D. Job Sheet #1--Construct and Test a Hartley Oscillator
E. Test
F. Answers to test

II. References:


OSCILLATORS
UNIT XII

INFORMATION SHEET

I. Terms and definitions

A. Oscillator--An electronic device which converts energy from a DC supply source into AC energy at some specific frequency

B. Feedback--The coupling of energy from the output back to the input of a circuit

C. Resonant frequency ($F_0$ or $F_r$)--The frequency of oscillation of a tuned circuit

D. LC circuit--One of the classifications of oscillators in which the resonant frequency is determined by the inductor (L) and the capacitor (C) in the circuits

E. RC circuit--One of the classifications of oscillators in which the resonant frequency is determined by the resistance and capacitance in the circuit

F. Crystal circuit--One of the classifications of oscillators in which the resonant frequency is determined by a crystal

II. Oscillators (Transparency 1)

A. Hartley oscillator
   1. Common-base or common-emitter type amplifier
   2. Tapped inductor
   3. Capacitor feedback
   4. Used for frequencies up to 160 megahertz

B. Colpitts oscillator
   1. Tapped capacitors
   2. Resonant frequency determined by the value of the inductor, $L$, and the series connected value of the two capacitors, $C_1$ and $C_2$
   3. Capacitor feedback
INFORMATION SHEET

C. Clapp oscillator
   1. High degree of frequency stability in a variable-frequency oscillator
   2. Inductor replaced by a series resonant circuit
   3. Limited operating frequency range
   4. Capacitor feedback

III. Oscillators (Transparency 2)
   A. Pierce oscillator
      1. Uses a fixed-frequency crystal
      2. Very stable frequency response, often better than 0.01 percent of center frequency
      3. Capacitor feedback
   B. TBTC (Tuned Base Tuned Collector) oscillator
      1. Uses interelectrode capacitance for a feedback path
      2. \( C_F \) small capacitance to assure sufficient feedback at all times
      3. Capacitor feedback
   C. RC phase shift oscillator
      1. Usually audio-frequency oscillators
      2. Considerable power loss
      3. Inexpensive to build
      4. Capacitor feedback
Hartley, Colpitts and Clapp Oscillators

**Hartley Oscillator**

![Hartley Oscillator Circuit Diagram]

**Colpitts Oscillator**

![Colpitts Oscillator Circuit Diagram]

**Clapp Oscillator**

![Clapp Oscillator Circuit Diagram]
Pierce, TBTC and RC Oscillators

Crystal Equivalent Circuit

Pierce Oscillator

Tuned–Base–Tuned–Collector Oscillator (TBTC)

RC Phase Shift Oscillator
JOB SHEET #1--CONSTRUCT AND TEST A HARTLEY OSCILLATOR

I. Tools and equipment
   A. 2N3638 PNP transistor or equivalent
   B. 2mH RF transformer
   C. 1 - 0.1 \( \mu \)F variable capacitor
   D. 1 - 0.1 \( \mu \)F capacitor
   E. 1 - 0.5 \( \mu \)F capacitor
   F. 1 - 1K resistor
   G. 1 - 2K resistor
   H. 1 - 6.2K resistor
   I. Oscilloscope
   J. DC power supply (0-25V)
   K. Frequency counter (optional)

II. Procedure
   A. Wire the following circuit
      (CAUTION: Do not turn on power supply at this time.)

   B. Connect the oscilloscope to the output winding of the RF transformer
JOB SHEET #1

C. Turn on the power supply and observe the waveshape

D. Adjust the variable capacitor and observe the change in frequency

E. Measure the lowest frequency obtainable by adjusting the variable capacitor and the peak-to-peak voltage output.

F. Measure (using the oscilloscope) the highest frequency obtainable and the peak-to-peak output voltage.

G. With the oscillator operating at its highest frequency, place your finger on the transistor until you observe a change in frequency caused by the slight heating of the transistor.

H. Turn off the power supply and replace the transistor with another 2N3638 PNP transistor.

I. Turn on the power supply and notice the changes that occur in the output frequency or the output voltage level.

J. Check your findings with your instructor.
1. Match the terms on the right with their correct definitions.

   a. The frequency of oscillation of a tuned circuit
   b. An electronic device which converts energy from a DC supply source into AC energy at some specific frequency
   c. One of the classifications of oscillators in which the resonant frequency is determined by a crystal
   d. The coupling of energy from the output back to the input of a circuit
   e. One of the classifications of oscillators in which the resonant frequency is determined by the inductor and the capacitor in the circuit
   f. One of the classifications of oscillators in which the resonant frequency is determined by the resistance and capacitance in the circuit

2. Identify a Hartley oscillator, a Colpitts oscillator, and a Clapp oscillator from the schematics that follow.

   a. [Diagram of a circuit with labels L1, C1, R1, R2, C2, VCC, and Eo]
3. Identify a Pierce oscillator, a TBTC oscillator, and an RC oscillator from the schematics that follow.
b. 

4. Demonstrate the ability to construct and test a Hartley oscillator.

(NOTE: If this activity has not been accomplished prior to test, ask your instructor when it should be completed.)
ANSWERS TO TEST

1. a. 3  
b. 1  
c. 6  
d. 2  
e. 4  
f. 5

2. a. Hartley  
b. Colpitts  
c. Clapp

3. a. TBTC  
b. RC  
c. Pierce

4. Performance skills evaluated to the satisfaction of the instructor
UNIT OBJECTIVE

After completion of this unit, the student should be able to identify the various stages of CW, AM, FM, TV transmitters, and those found in a television transmitting system. The student should also be able to calculate wavelength and antenna length for various types of antennas. This knowledge will be evidenced by correctly performing the procedures outlined in the assignment sheet and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

1. Match terms related to transmitters with their correct definitions.
2. Identify the stages found in a CW transmitter.
3. Identify the stages found in an AM broadcast transmitter.
4. Identify the stages found in an FM broadcast transmitter.
5. Identify the stages found in a television transmitting system.
6. Select true statements concerning the characteristics of antennas.
7. Calculate wavelength and antenna length.
SUGGESTED ACTIVITIES

I. Provide student with objective sheet.
II. Provide student with information and assignment sheets.
III. Make transparencies.
IV. Discuss unit and specific objectives.
V. Discuss information and assignment sheet.
VI. Tour a transmitting facility if possible.
VII. Give test.

INSTRUCTIONAL MATERIALS

I. Objective sheet
   A. Objective sheet
   B. Information sheet
   C. Transparency masters
      1. TM 1--Continuous Wave Transmitter
      2. TM 2--AM Transmitter
      3. TM 3--FM Transmitter
      4. TM 4--Television Transmitting System
   D. Assignment Sheet #1--Calculate Wavelength and Antenna Length
   E. Answers to assignment sheet
   F. Test
   G. Answers to test
I. Terms and definitions

A. Transmitter—A device that converts messages into electrical signals which are sent on a wire or radiated through space from an antenna

B. Modulation—The process by which the message signal is used to vary some characteristic of a carrier signal, such as amplitude, frequency, or phase

C. AM (amplitude modulation)—The process by which the message signal is used to vary the amplitude of the carrier signal

D. FM (frequency modulation)—The process by which the message signal is used to vary the frequency of the carrier signal

E. CW (continuous wave) transmitter—The system for sending a message signal by turning the RF carrier on and off

F. Broadcast transmitter (FM or AM) —The system for sending a message signal by modulating the RF carrier

G. Television transmitter—A system which uses FM to transmit the audio message signal and AM to transmit the video message signal

H. Antenna—A device which radiates into space the power delivered to it from the transmitter

I. RF—Radio frequency

II. CW transmitter stages (Transparency 1)

A. RF oscillator

B. RF amplifier (buffer)

C. Power amplifier

III. AM broadcast transmitter stages (Transparency 2)

A. Audio amplifier

B. Modulating signal amplifier

C. RF oscillator

D. Power amplifier
INFORMATION SHEET

IV. FM broadcast transmitter stages (Transparency 3)
   A. Audio amplifier
   B. Crystal oscillator
   C. Modulator
   D. Frequency multipliers
   E. Power amplifier

V. Television transmitting system stages (Transparency 4)
   A. Sync generators
   B. Camera and camera circuits
   C. Video amplifier
   D. Line and control amplifier
   E. Modulator
   F. RF power amplifier
   G. FM transmitter

VI. Antennas
   A. Wavelength
      1. Greek symbol lambda \( \lambda \)
      2. \( \lambda = \frac{c}{f} \) where \( c \) is the velocity of light in m/sec and \( f \) is frequency in hertz; \( c = 3 \times 10^8 \) m/sec; therefore, \( \lambda = 3 \times 10^8 / f \)
      (NOTE: \( \lambda \) is in meters and \( f \) is the frequency in megahertz.)
   B. Hertz antenna (Figure 1)
      1. One-half wavelength long
      2. Also called a half-wave dipole antenna
INFORMATION SHEET

3. Does not need to be connected to an earth ground

C. Marconi antenna (Figure 2)

1. A grounded antenna

2. Length is "one-fourth wave" or any odd multiple of one-fourth wavelength

FIGURE 1

FIGURE 2
Continuous Wave Transmitter

Block Diagram
AM Transmitter

- Microphone
- Audio Amplifier
- Modulating Signal Amplifier
- Audio Signal
- Power Amplifier
- Buffer
- RF Oscillator
- RF Oscillations
- Antenna
- Modulated RF Wave

Sound Waves
FM Transmitter

Block Diagram

Crystal Oscillator → Modulator → Frequency Multipliers → Power Amplifier → Antenna
Television Transmitting System

Block Diagram

- Video Information
  - Camera & Camera Circuits
  - Video Amplifier
  - Line & Control Amplifier
  - Modulator
  - RF Power Amplifier
  - Antenna

- Sound
  - FM Transmitter
ASSIGNMENT SHEET #1--CALCULATE WAVELENGTH AND ANTENNA LENGTH

1. Calculate the wavelength (λ) for a signal.
   (NOTE: Frequency = 1 MHz.)
   \[ \lambda = \text{meters} \]

2. Calculate the length of a marconi and a hertz antenna.
   (NOTE: There will be resonance at this frequency.)
   a. Hertz antenna length = \text{meters}
   b. Marconi antenna length = \text{meters}
ANSWERS TO ASSIGNMENT SHEET

1. \( \lambda = \frac{300}{1} = 300 \) meters

2. a. Hertz = \( \frac{\lambda}{2} = \frac{300}{2} = 150 \) meters
   
   b. Marconi = \( \frac{\lambda}{4} = \frac{300}{4} = 75 \) meters
1. Match the terms on the right with their definitions.

a. A device that converts messages into electrical signals which are sent on a wire or radiated through space from an antenna

b. The process by which the message signal is used to vary some characteristic of a carrier signal, such as amplitude, frequency, or phase

c. The process by which the message signal is used to vary the frequency of the carrier signal

d. The process by which the message signal is used to vary the amplitude of the carrier signal

e. The system for sending a message signal by turning the RF carrier on and off

f. The system for sending a message signal by modulating the RF carrier

g. A system which uses FM to transmit the audio message signal and AM to transmit the video message signal

h. A device which radiates into space the power delivered to it from the transmitter

i. Radio frequency
2. Identify the stages found in the following CW transmitter.

3. Identify the stages found in the following AM broadcast transmitter.
4. Identify the stages found in the following FM transmitter.

Microphone

Antenna

a. __________________________
b. __________________________
c. __________________________
d. __________________________
e. __________________________

5. Identify the stages found in the following television transmitting system.

Video Information

Sound

Antenna

a. __________________________
b. __________________________
c. __________________________
d. __________________________
e. __________________________
f. __________________________
g. __________________________
6. Select true statements concerning the characteristics of antennas by placing an "X" in the appropriate blanks.

   a. The Greek symbol lambda equals c/f where c is the velocity of light in m/sec and f is frequency in hertz
   b. The hertz antenna is also called a full-wave dipole antenna
   c. The hertz antenna does not need to be connected to an earth ground
   d. The Marconi antenna is a grounded antenna
   e. The Marconi antenna is "one-fourth wave" or any odd multiple of one-fourth wavelength

7. Calculate wavelength and antenna length.

   (NOTE: If this activity has not been accomplished prior to the test, ask your instructor when it should be completed.)
TRANSMITTERS
UNIT XIII

ANSWERS TO TEST

1. a. 8 e. 3 i. 9
   b. 2 f. 5
   c. 6 g. 7
   d. 4 h. 1

2. a. RF oscillator
   b. RF amplifier
   c. Power amplifier

3. a. Audio amplifier
   b. Modulating signal amplifier
   c. RF oscillator
   d. Power amplifier

4. a. Audio amplifier
   b. Crystal oscillator
   c. Modulator
   d. Frequency multipliers
   e. Power amplifier

5. a. Sync generators
   b. Camera and camera circuits
   c. Video amplifier
   d. Line and control amplifier
   e. Modulator
   f. RF power amplifier
   g. FM transmitter

6. a, c, d, e

7. Evaluated to the satisfaction of the instructor
UNIT OBJECTIVE

After completion of this unit, the student should be able to locate and identify the major stages of AM and FM receivers. This knowledge will be evidenced by correctly performing the procedures outlined in the job sheet and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to receivers with the correct definitions.
2. Identify the stages in an AM superheterodyne receiver.
3. Identify the stages in an FM receiver.
4. Select the frequency ranges for AM and FM broadcast stations.
5. Select true statements concerning the responsibilities of the FCC.
6. Select true statements concerning the RF amplifier stage in AM and FM receivers.
7. State the output frequencies of the mixer stage given the frequency of the RF signal and the local oscillator frequency.
8. Select true statements concerning the IF amplifier stage of AM and FM receivers.
9. Select true statements concerning the AM detector stage.
10. Select true statements concerning the limiter stage in an FM receiver.
11. Select true statements concerning an FM detection circuit.
12. Demonstrate the ability to locate and identify the major stages of AM/FM receivers.
RECEIVERS
UNIT XIV

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.

II. Provide student with information and job sheets.

III. Make transparencies.

IV. Discuss unit and specific objectives.

V. Discuss information sheet.

VI. Demonstrate and discuss the procedures outlined in the job sheet.

VII. Give test.

INSTRUCTIONAL MATERIALS,

I. Included in this unit:

A. Objective sheet

B. Information sheet

C. Transparency masters

   1. TM 1--AM Superheterodyne Receiver Block Diagram

   2. TM 2--FM Receiver Block Diagram

D. Job Sheet #1--Locate and Identify the Major Stages of AM/FM Receivers

E. Test

F. Answers to test

II. References:


I. Terms and definitions

A. Receiver--Selects a particular signal that is present on an antenna, removes the carrier frequency, and amplifies the message signal enough to drive a load (speaker or headphones)

B. AM receiver--A receiver designed to receive an amplitude-modulated signal

C. FM (frequency modulated) receiver--A receiver designed to receive a frequency-modulated signal

D. Selectivity--The ability of a receiver to select one signal and reject all others

E. Sensitivity--The ability of a receiver to amplify a small signal

F. RF frequencies--Those frequencies designated as carrier frequencies for radio systems (3 kilohertz to 3,000,000 megahertz)

G. Local oscillator--Stage which produces an unmodulated variable RF signal

H. Mixer--Modulates or heterodynes the RF signal from the antenna (RF amplifier) with the local oscillator RF signal

I. IF (intermediate frequency)--The frequency that results from mixing an RF signal from the amplifier with the local oscillator RF signal; it is then amplified by the IF amplifier

J. Detector--Stage in a receiver that separates the IF frequency from the message signal

(Note: A detector is also called a demodulator.)

K. Audio amplifier--The amplifier designed to amplify the message portion of the signal

L. Limiter--Removes or clips the upper and lower amplitude portions of the signal waveshape which removes most of the noise in an FM receiver

M. Discriminator--Separates the IF from the message signal in an FM receiver

N. AVC/AGC (automatic volume/gain control)--Increases the gain of a receiver when the signal becomes weak and decreases the gain of the receiver when the signal becomes strong

O. AFC (automatic frequency control)--Assures a constant IF center frequency by keeping the local oscillator frequency separated from the RF amplifier signal by a fixed amount in FM receivers
INFORMATION SHEET

P. Converter-Stage which combines both local oscillator and mixer stages into one-stage

II. Stages in an AM superheterodyne receiver (Transparency 1)
   A. Antenna
   B. RF amplifier
   C. Mixer
   D. Local oscillator
   E. IF amplifier
   F. Detector
   G. Audio amplifier
   H. Speaker

III. Stages in an FM receiver (Transparency 2)
   A. Antenna
   B. RF amplifier
   C. Mixer
   D. Local oscillator
   E. Wide band IF amplifier
   F. Limiter
   G. Discriminator
   H. AF amplifier
   I. Speaker

IV. AM and FM broadcast station-frequency ranges
   A. AM-535 kilohertz to 1605 kilohertz
   B. FM-88 megahertz to 108 megahertz

V. FCC (Federal Communication Commission) responsibilities
   A. Licenses broadcast stations and station operators
   B. Assigns broadcast frequencies
   C. Regulates operation of broadcast stations
INFORMATION SHEET

VI. RF amplifier stage in AM and FM receivers
A. Selects one carrier frequency
B. Variable tuning
C. Operates over a wide frequency range
D. Lower gain than an amplifier designed for one specific frequency
F. May be omitted from inexpensive receivers

VII. Mixer output frequencies
A. RF frequency
B. Local oscillator frequency
C. Local oscillator frequency minus RF frequency
D. Local oscillator frequency plus RF frequency

Example: If RF = 760 kilohertz and the local oscillator signal is 1216 kilohertz, the output from the mixer will consist of four different frequencies: (1) 760 kilohertz, (2) 1216 kilohertz, (3) 1976 kilohertz, and (4) 456 kilohertz

VIII. IF amplifier stage in AM and FM receivers
A. Tuned to IF frequency kilohertz
B. Amplifies a narrow band of frequencies
C. Generally consists of two or three stages of amplification

IX. AM detector stage
A. Eliminates either the positive or the negative half of the carrier
B. Filters out the RF component leaving only the message waveform

X. Limiter stage in an FM receiver
A. Removes the amplitude modulation
B. Limits the signal to a constant amplitude
C. Removes most of the noise from the FM signal

XI. FM detection circuit
A. Known as a discriminator or ratio detector
B. Output is a function of frequency variation

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AM Superheterodyne Receiver
Block Diagram

Antenna
(540-1600KHz)
RF Amplifier
RF Signal
Local Oscillator
995 KHz
2055 kHz
Mixer
(455 kHz)
IF Amplifier
Detector
Audio Amplifier
(20·20000Hz - 20·20000Hz)
Speaker

(NOTE: When oscillator and mixer are combined into one stage the result is called a converter.)
FM Receiver Block Diagram

Antenna
(88-108 MHz)

RF Amplifier

Mixer

Wide Band IF Amplifier

(10.7 MHz)

Limiter

(10.7 MHz)

Discriminator

(20-20000 Hz)

AF Amplifier

(20-20000 Hz)

Speaker

Local Oscillator

(98.7-118.7 MHz)

Wide Band

IF, Amplifier

Discrim

inator

AF Amplifier

Hz

Hz
RECEIVERS
UNIT XIV

JOB SHEET #1--LOCATE AND IDENTIFY THE
MAJOR STAGES OF AM/FM RECEIVERS

I. Tools and equipment
   A. An available AM/FM receiver
   B. Schematic diagram for the receiver (Figure 1)
      (NOTE TO INSTRUCTOR: If the class is constructing a receiver kit, use
      the kit schematic and the kit for this job sheet.)

II. Procedure
   A. Locate the power supply section in your receiver schematic
   B. Determine the type of power supply used by the receiver, full-wave, half-wave, doubler, or some other type
   C. Locate the power amplifier (audio amplifier) section of the receiver
   D. Identify the detector section on your schematic
      (NOTE: The stage preceding the power amplifier is the detector.)
   E. Locate the IF amplifier of your receiver and determine how many stages of amplification there are in the IF section
   F. Locate the mixer and the local oscillator or the converter
   G. Locate the AVC/AGC section
   H. Locate the RF amplifier stage
      (NOTE: All receivers may not have an RF amplifier section.)
   I. Identify each of the above sections of the receiver that you found on the schematic by locating it in the receiver
      (CAUTION: DO NOT plug in the receiver.)
   J. Locate the antenna of your receiver
A Typical AM Receiver Schematic

For Transformerless Phase Inverter, substitute the schematic below at point A
1. Match the terms on the right with the correct definitions.

   a. Separates the IF from the message signal in an FM receiver
   1. Detector

   b. A receiver designed to receive a frequency-modulated signal
   2. AFC

   c. The ability of a receiver to amplify a small signal
   3. IF

   d. Stage in a receiver that separates the IF frequency from the message signal
   4. FM receiver

   e. The amplifier designed to amplify the message portion of the signal
   5. Mixer

   f. Removes or clips the upper and lower amplitude portions of the signal waveshape which removes most of the noise in an FM receiver
   6. AM receiver

   g. Assures a constant IF center frequency by keeping the local oscillator frequency separated from the RF amplifier signal by a fixed amount in FM receivers
   7. Limiter

   h. Stage which produces an unmodulated variable RF signal
   8. Discriminator

   i. Modulates or heterodynes the RF signal from the antenna with the local oscillator RF signal
   9. Selectivity

   j. The frequency that results from mixing an RF signal from the amplifier with the local oscillator RF signal; it is then amplified by the IF amplifier
   10. Audio amplifier

   k. Selects a particular signal that is present on an antenna, removes the carrier frequency, and amplifies the message signal enough to drive a load
   11. RF frequencies

   l. Stage which combines both local oscillator and mixer stages into one stage
   12. AVC/AGC

   m. Receiver

   n. Sensitivity

   o. Converter
m. The ability of a receiver to select one signal and reject all others

n. A receiver designed to receive an amplitude-modulated signal

o. Those frequencies designated as carrier frequencies for radio systems

p. Increases the gain of a receiver when the signal becomes weak and decreases the gain of the receiver when the signal becomes strong

2. Identify the stages in the AM superheterodyne receiver in the block diagram below.

a. b. c. d. e. f. g. h.
3. Identify the stages in the FM receiver in the block diagram below.

![Block Diagram](image)

- a.
- b.
- c.
- d.
- e.
- f.
- g.
- h.
- i.

4. Select the frequency ranges for AM and FM broadcast stations from the list given below by writing AM or FM in the appropriate blanks.

   - a. 20 hertz to 20 kilohertz.
   - b. 88 megahertz to 108 megahertz.
   - c. 30 megahertz to 300 megahertz.
   - d. 535 kilohertz to 1605 kilohertz.

5. Select true statements concerning the responsibilities of the FCC by placing an "X" in the appropriate blanks.

   - a. Licenses broadcast stations
   - b. Licenses station operators
   - c. Assigns broadcast frequencies
   - d. Regulates operation of broadcast stations
6. Select true statements concerning the RF amplifier stage in AM and FM receivers by placing an "X" in the appropriate blanks.

   a. Amplifies one frequency with very high gain
   b. Variable tuning
   c. Must be included in all receivers
   d. Selects one carrier frequency
   e. Operates over a wide frequency range

7. State the output frequencies of a mixer stage if the RF signal frequency is 930 kilohertz and the local oscillator frequency is 1386 kilohertz.

   a. _______ kilohertz
   b. _______ kilohertz
   c. _______ kilohertz
   d. _______ kilohertz

8. Select true statements concerning the IF amplifier stage in AM and FM receivers by placing an "X" in the appropriate blanks.

   a. Generally consists of two or three stages of amplification
   b. Single stage amplifier
   c. Tuned to IF frequency kilohertz
   d. Variable frequency tuning
   e. Amplifies a wide band of frequencies

9. Select true statements concerning the AM detector stage by placing an "X" in the appropriate blanks.

   a. Eliminates both the positive and negative half of the carrier
   b. Eliminates either the positive or the negative half of the carrier
   c. Filters out the RF component leaving only the message waveform
   d. Filters out both the RF component and the message waveform

10. Select true statements concerning the limiter stage in an FM receiver by placing an "X" in the appropriate blanks.

    a. Removes the amplitude modulation
    b. Separates audio signal from RF scanner signal
    c. Limits the signal to a constant amplitude
    d. Removes most of the noise from the FM signal
11. Select true statement concerning an FM detection circuit by placing an "X" in the appropriate blanks.

   - a. Known as a discriminator
   - b. Also called a ratio detector
   - c. Output is a function of frequency variation

12. Demonstrate the ability to locate and identify the major stages of AM/FM receivers.

   (NOTE: If this activity has not been accomplished prior to the test, ask your instructor when it should be completed.)
ANSWERS TO TEST

1. a. 8 i. 5
   b. 4 j. 3
   c. 15 k. 14
   d. 1 l. 16
   e. 10 m. 9
   f. 7 n. 6
   g. 2 o. 11
   h. 13 p. 12

2. a. Antenna
    b. RF amplifier
    c. Mixer
    d. Local oscillator
    e. IF amplifier
    f. Detector
    g. Audio amplifier
    h. Speaker

3. a. Antenna
    b. RF amplifier
    c. Mixer
    d. Local oscillator
    e. Wide band IF amplifier
    f. Limiter
    g. Discriminator
    h. AF amplifier
    i. Speaker

4. b. FM d. AM

5. a, b, c, d

6. b, d, e

7. Answer must show the following four frequencies; order makes no difference.
   a. 2316 kilohertz (sum)
   b. 466 kilohertz (difference)
   c. 930 kilohertz
   d. 1386 kilohertz (Local oscillator)

8. a, c

9. b, c

10. a, c, d

11. a, b, c

12. Performance skills evaluated to the satisfaction of the instructor
ELECTRON TUBES

UNIT XV

UNIT OBJECTIVE

After completion of this unit, the student should be able to identify schematic symbols for basic vacuum tubes and special tubes, identify typical characteristic curves for various electron tubes, and construct and test a vacuum tube diode circuit. This knowledge will be evidenced by correctly performing the procedures outlined in the job sheet and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student should be able to:

1. Match terms related to electron tubes with their correct definitions.
2. Identify the schematic symbols for diodes, triodes, pentodes, tetodes, beam-power tubes, and thyatrons.
3. Label the pin numbers given the bottom views of tubes.
4. Identify typical characteristic curves for diode, triode, and pentode vacuum tubes.
5. Demonstrate the ability to construct and test a vacuum tube diode rectifier.
E. Test

F. Answers to test

ELECTRON TUBES
UNIT XV

SUGGESTED ACTIVITIES

I. Provide student with objective sheet.
II. Provide student with information and job sheets.
III. Make transparencies.
IV. Discuss unit and specific objectives.
V. Discuss information sheet.
VI. Demonstrate and discuss the procedures outlined in the job sheet.
VII. Show various types of tubes.
VIII. Give test.

INSTRUCTIONAL MATERIALS

I. Included in this unit:
   A. Objective sheet
   B. Information sheet
   C. Transparency masters
      1. TM 1 - Schematic Symbols for Diodes
      2. TM 2 - Schematic Symbol for Triodes
      3. TM 3 - Schematic Symbol for Tetrodes
      4. TM 4 - Schematic Symbol for Pentodes
      5. TM 5 - Schematic Symbol for Beam-Power Tubes
      6. TM 6 - Schematic Symbol for Thyatrons
      7. TM 7 - Diode Characteristic Curve
      8. TM 8 - Triode Characteristic Curve
      9. TM 9 - Pentode Characteristic Curve
   D. Job Sheet #1 - Construct and Test a Vacuum Tube, Diode Rectifier
I. Terms and definitions

A. Electrodes--The basic internal parts of a vacuum tube, usually consisting of cathodes, grids, and plates

B. Cathode--The electrode which emits electrons
   (NOTE: The cathode is similar to an emitter.)

C. Grid--The electrode which controls electron flow

D. Plate--The electrode which attracts electrons

E. Pins--Conductors used to connect the tube's electrodes to external circuits

F. Diode (vacuum tube)--An electronic tube that has two electrodes, a cathode and a plate
   (NOTE: It serves the same function as a solid state diode.)

G. Filament--A directly-heated cathode

H. Heater--A small conducting wire which indirectly heats the cathode

I. Triode--A vacuum tube containing three electrodes: cathode, plate, and control grid

J. Control grid--The grid nearest the cathode in a vacuum tube which has the greatest control over electron flow

K. Inter-electrode capacitance--Capacitance between any two electrodes in a vacuum tube
   (NOTE: Plate to grid capacitance, $C_{pg}$; plate to cathode capacitance, $C_{pk}$; grid to cathode capacitance, $C_{gk}$.)

L. Tetrode--A tube with four electrodes: cathode, control grid, screen grid, and plate

M. Screen grid--A grid placed between the plate and the control grid in a tetrode which helps to reduce the effects of inter-electrode capacitance

N. Secondary emission--Impact emission of electrons from the plate caused by high speed collisions of cathode-emitted electrons with the plate

O. Pentode--A tube with five electrodes: cathode, control grid, screen grid, suppressor grid, and plate
INFORMATION SHEET

P. Suppressor grid--Grid placed between the plate and the screen grid in a pentode which reduces the effect of secondary emission

Q. Beam-power tube--A tube designed so that the electrons flow in concentrated beams from the cathode through the grids to the plate

R. Multunit tube--A tube in which the electrodes of two or more tube types are placed in the same envelope

S. Gas tube--An electron tube which has the electrodes enclosed in a gas-filled envelope

T. Vacuum tube--An electron tube which has the electrodes enclosed in an evacuated envelope

U. Thyatron--A gas-filled tube that uses a grid to initiate the ionizing process of the gas

V. Thermionic emission--The "boiling off" of electrons from the cathode by thermal excitation

W. Envelope--Enclosure, usually glass, around the electrode of a vacuum tube

II. Schematic symbols for tubes

A. Diode (Transparency 1)
B. Triode (Transparency 2)
C. Tetrode (Transparency 3)
D. Pentode (Transparency 4)
E. Beam power tube (Transparency 5)
F. Thyatron (Transparency 6)

III. Tube pin numbers

A. Seven pin tube
   Bottom View of Tube

B. Eight pin tube (octal)
   Bottom View of Tube
IV. Typical characteristic curves

A. Diode (Transparency 7)
B. Triode (Transparency 8)
C. Pentode (Transparency 9)
Schematic Symbols for Diodes

Directly Heated
- Plate
- Filament

Indirectly Heated
- Plate
- Cathode
- Heater
Schematic Symbol for Triodes

- Plate
- Control Grid
- Cathode
- Heater
Schematic Symbol for Tetrodes

- Plate
- Screen Grid
- Control Grid
- Cathode
- Heater
Schematic Symbol for Pentodes
Schematic Symbol for Beam Power Tubes
Schematic Symbol for Thyratrons

- Cathode
- Control Grid
- Heater
- Plate
- Designates Gas Filled Envelope

Thyratron
Diode Characteristic Curve

Plate Voltage

Plate Current
ln mA

Point of Saturation
Triode Characteristic Curve

$I_p$ (Milliamperes) vs. $E_p$ (Volts)

$E_g = 0$, $-2$, $-4$, $-6$, $-8$, $-10$, $-12$

Range:
- $0$ to $300$ Volts
- $0$ to $25$ Milliamperes
Pentode Characteristic Curve

$E_{G2} = 180 \text{ volts}$
$E_{G1} = 0$

$I_p \text{ Milliamperes}$

$E_p \text{ Volts}$

0 50 100 150 200 250 300
ELECTRON TUBES
UNIT XV

JOB SHEET #1--CONSTRUCT AND TEST A VACUUM TUBE DIODE RECTIFIER

I. Tools and equipment and materials
   A. Variable AC power supply (e.g. Variac)
   B. Multimeter
   C. Oscilloscope
   D. 6.3 Volt filament power supply
   E. Vacuum diode type 6AX5 or equivalent.
   F. Octal type socket
   G. Graph paper
   H. 1-10K resistor, 5W

II. Procedure
   A. Connect the circuit shown below
      (NOTE: Small numerals indicate pin numbers.)

      ![Circuit Diagram]

      (CAUTION: Do not turn on the power supply until your instructor has checked your wiring.)

   B. Turn on the filament power supply and let the tube warm up for approximately two minutes

   C. Adjust the AC power supply for 110 volts as indicated on the multimeter

   D. Connect the oscilloscope across the AC power supply and adjust the oscilloscope controls until approximately two cycles appear on the screen

   E. Make a sketch of the waveshape indicating the height of the waveshape shown on the oscilloscope

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JOB SHEET #1

F. Without adjusting the scope controls, move the leads across the resistor

G. Make a sketch of the waveshape indicating the height of the waveshape shown on the oscilloscope

H. Compare the two sketches made in parts F and H

I. Using the multimeter, measure the DC voltage output across the resistor
   (NOTE: Be sure to observe proper polarity.)

J. Check your results and sketches with your instructor

DATA TABLE

\[
\begin{array}{|c|c|}
\hline
\text{Vin (Volts)} & \text{V_{Rf} (Volts)} \\
\hline
\text{Time (m sec.)} & \text{Time (m sec.)} \\
\hline
\end{array}
\]

Measured DC Output Voltage
1. Match the terms on the right with the correct definitions.

   a. The basic internal parts of a vacuum tube, usually consisting of cathodes, grids, and plates
   b. The electrode which emits electrons
   c. The electrode which controls electron flow
   d. The electrode which attracts electrons
   e. Conductors used to connect the tube's electrodes to external circuits
   f. An electronic tube that has two electrodes, a cathode and a plate
   g. A directly-heated cathode
   h. A small conducting wire which indirectly heats the cathode
   i. A vacuum tube containing three electrodes: cathode, plate, and control grid
   j. The grid nearest the cathode in a vacuum tube which has the greatest control over electron flow
   k. Capacitance between any two electrodes in a vacuum tube
   l. A tube with four electrodes: cathode, control grid, screen grid, and plate
   m. A grid placed between the plate and the control grid in a tetrode which helps to reduce the effects of interelectrode capacitance
   n. Impact emission of electrons from the plate caused by high speed collisions of cathode-emitted electrons with the plate

1. Diode
2. Triode
3. Tetrode
4. Pentode
5. Thyatron
6. Electrodes
7. Grid
8. Plate
9. Interelectrode capacitance
10. Gas tube
11. Cathode
12. Pins
13. Filament
14. Heater
o. A tube with five electrodes: cathode, control grid, screen grid, suppressor grid, and plate

p. Grid placed between the plate and the screen grid in a pentode which reduces the effect of secondary emission

q. A tube designed so that the electrons flow in concentrated beams from the cathode through the grids to the plate

r. A tube in which the electrodes of two or more tube types are placed in the same envelope

s. An electron tube which has the electrodes enclosed in a gas-filled envelope

t. An electron tube which has the electrodes enclosed in an evacuated envelope

u. A gas-filled tube that uses a grid to initiate the ionizing process of the gas

v. The "boiling off" of electrons from the cathode by thermal excitation

w. Enclosure, usually glass, around the electrode of a vacuum tube

2. Identify the schematic symbols for diodes, triodes, pentodes, tetrodes, beam-power tubes, and thyratrons from the schematics that follow.
3. Label the pin numbers of the tubes shown below.

a. 

b. 

c. 

d. 

4. Identify typical characteristics curves for the diode, triode, and pentode vacuum tubes shown in the diagrams that follow.

![Graph of I_p vs E_P with values for different E_g]
5. Demonstrate the ability to construct and test a vacuum tube diode rectifier.

(NOTE: If this activity has not been accomplished prior to the test, ask your instructor when it should be completed.)
ELECTRON TUBES
UNIT XV

ANSWERS TO TEST

1. a. 6  g. 13  m. 20  s. 10
    b. 11  h. 14  n. 22  t. 17
    c. 7  i. 2  o. 4  u. 5
    d. 8  j. 23  p. 21  v. 18
    e. 12  k. 9  q. 19  w. 16
    f. 1  l. 3  r. 15

2. a. Pentode
    b. Diode
    c. Tetrode
    d. Triode
    e. Beam-power tube
    f. Thyatron

3. a. 
    b. 
    c. 
    d. 

4. a. Pentode
    b. Diode
    c. Triode

5. Performance skills evaluated to the satisfaction of the instructor