# DOCUMENT RESUME

ED 246 224 CE 039 209

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| TITLE | Electronic Principles IX, 7-13. Military Curriculum Materials for Vocational and Technical Education. |
| INSTITUTION | Air Force Training Command, Keesler AFB, Miss.; Ohio State Univ., Columbus. National Center for Research in Vocational Education. |
| SPONS AGENCY | Department of Education, Washington, DC. |
| PUB DATE | 75 |
| NOTE | 413p.; For related documents, see CE 039 201-210. |
| PUB TYPE | Guides - Classroom Use - Materials (For Learner) (051) -- Guides - Classroom Use - Guides (For Teachers) (052) |
| EDRS PRICE | MF01/PC17 Plus Postage. |
| DESCRIPTORS | Behavioral Objectives; *Communications; Course Content; Course Descriptions; *Electronic Equipment; *Electronics; Individualized Instruction; Learning Activities; Learning Modules; Pacing; Postsecondary Education; Programed Instructional Materials; Secondary Education; *Technical Education |
| IDENTIFIERS | Military Curriculum Project; *Troubleshooting |

ABSTRACT

This ninth of 10 blocks of student and teacher materials for a secondary/postsecondary level course in electronic principles comprises one of a number of military-developed curriculum packages selected for adaptation to vocational instruction and curriculum development in a civilian setting. Prerequisites are the previous blocks. This block on transmit and receive systems contains 11 modules covering 61 hours of instruction on heterodyning (4 hours), modulation (7), demodulation (5), transmission lines (7), antennas (8), AM systems (7), FM systems (5), single sideband systems (4), pulse modulation systems (4), troubleshooting techniques (4), and receiver troubleshooting (6). Printed instructor materials include a plan of instruction detailing the units of instruction, duration of the lessons, criterion objectives, and support materials needed. Student materials include a student text; 11 guidance packages containing objectives, assignments, review exercises, and answers for each module; three programmed texts; and a student handout. A digest of the modules in the block is provided for students who need only to review the material. Designed for self- or group-paced instruction, the material can be adapted for individualized instruction. Additional print and audiovisual materials are recommended but not provided. (YLB)

# MILITARY CURRICULUM MATERIALS

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

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

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- Operating information systems and services
- Conducting leadership development and training programs

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**Military Curriculum Materials**
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Program Information Office
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The Ohio State University
1960 Kenny Road, Columbus, Ohio 43210
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# Military Curriculum Materials for Vocational and Technical Education

## Information and Field Services Division

## The National Center for Research in Vocational Education

# Military Curriculum Materials Dissemination Is . . .

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

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

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

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

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

Project Staff:

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

Shirley A. Chase, Ph.D.
Project Director



# What Materials Are Available?

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

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

The 120 courses represent the following sixteen vocational subject areas:

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

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

# How Can These Materials Be Obtained?

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

## CURRICULUM COORDINATION CENTERS

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

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

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

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

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

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

# ELECTRONIC PRINCIPLES IX

## Table of Contents

# ELECTRONIC PRINCIPLES IX

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# ELECTRONIC PRINCIPLES IX

Classroom Course

**Developed by:**
United States Air Force

**Development and Review Dates**
November 7, 1975

**D.O.T. No.:**
003.081

**Occupational Area:**
Electronics

**Target Audiences:**
Grades 11-adult

**Print Pages:**
413

**Cost:**
$8.50

**Availability:**
Military Curriculum Project, The Center for Vocational Education, [illegible]0 Kenny Rd., Columbus, OH 43210

| Contents: | Type of Materials: Lesson Plans | Programmed Texts | Student Workbook: No. of pages | Handouts | Text Materials | Audio-Visuals | Instructional Design: Performance Objectives | Tests | Review Exercises | Additional Materials Required | Type of Instruction: Group Instruction | Individualized |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Block IX – *Transmit and Receive Systems* | | | | | | | | | | | | |
| Module 63 – Heterodyning | • | | 6 | | • | * | • | * | • | | • | • |
| Module 64 – Modulation | • | • | 11 | | • | * | • | * | • | | • | • |
| Module 65 – Demodulation | • | • | 16 | | • | * | • | * | • | | • | • |
| Module 66 – Transmission Lines | • | | 18 | | • | * | • | * | • | | • | • |
| Module 67 – Antennas | • | | 10 | | • | * | • | * | • | | • | • |
| Module 68 – AM Systems | • | | 19 | | • | * | • | * | • | | • | • |
| Module 69 – FM Systems | • | | 16 | | • | * | • | * | • | | • | • |
| Module 70 – Single Sideband Systems | • | | 20 | | • | * | • | * | • | | • | • |
| Module 71 – Pulse Modulation Systems | • | | 19 | | • | * | • | * | • | | • | • |
| Module 72 – Troubleshooting Techniques | • | • | 14 | • | • | * | • | * | • | | • | • |
| Module 73 – Receiver Troubleshooting | • | | 16 | | • | | • | * | • | * | • | • |

* Materials are recommended but not provided.

Course Description

This block is the ninth of a ten-block course providing training in electronic principles, use of basic test equipment, safety practices, circuit analysis, soldering, digital techniques, microwave principles and troubleshooting basic circuits. Prerequisites to this block are Blocks I through VIII covering DC circuits, AC circuits, RCL circuits, solid state principles, solid state power supplies and amplifiers, solid state wave generating and wave shaping circuits, digital techniques, and the principles and applications of electron tubes. Block IX—*Transmit and Receive Systems* contains eleven modules covering 61 hours of instruction over heterodyning, modulation, demodulation, transmission lines, antennas, AM and FM systems, sideband systems, and troubleshooting. The module topics and respective hours follow:

- Module 63 — **Heterodyning** (4 hours)
- Module 64 — **Modulation** (7 hours)
- Module 65 — **Demodulation** (5 hours)
- Module 66 — **Transmission Lines** (7 hours)
- Module 67 — **Antennas** (8 hours)
- Module 68 — **AM Systems** (7 hours)
- Module 69 — **FM Systems** (5 hours)
- Module 70 — **Single Sideband Systems** (4 hours)
- Module 71 — **Pulse Modulation Systems** (4 hours)
- Module 72 — **Troubleshooting Techniques** (4 hours)
- Module 73 — **Receiver Troubleshooting** (6 hours)

This block contains both teacher and student materials. Printed instructor materials include a plan of instruction detailing the units of instruction, duration of the lessons, criterion objectives, and support materials needed. Student materials consist of a student text used for all the modules; eleven guidance packages containing objectives, assignments, review exercises and answers for each module; three programmed texts on modulation, demodulation, and troubleshooting techniques and a student handout of a receiver schematic diagram. A digest of modules 63 through 73 for the students who have background in these topics and only need to review the major points of instruction is also included.

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

# PLAN OF INSTRUCTION
## (Technical Training)

ELECTRONIC PRINCIPLES

(Modular Self-Paced)

KEESLER TECHNICAL TRAINING CENTER

6 November 1975 - Effective 6 January 1976 with Class 760106

Volume 9

7-13

ATC Keesler 4-2148

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

PLAN OF INSTRUCTION 3AQR30020-1
6 November 1975

FOREWORD

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

2. COURSE DESIGN/DESCRIPTION. The instructional design for this course is Modular Scheduling and Self-Pacing; however, this POI can also be used for Group Pacing. The course trains both non-prior service airmen personnel and selected re-enlistees for subsequent entry into the equipment oriented phase of basic courses supporting 303XX, 304XX, 307XX, 309XX and 328XX AFSCs. Technical Training includes electronic principles, use of basic test equipment, safety practices, circuit analysis, soldering, digital techniques, microwave principles, and troubleshooting of basic circuits. Students assigned to any one course will receive training only in those modules needed to complement the training program in the equipment phase. Related training includes traffic safety, commander's calls/briefings and end of course appointments.

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

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

FOR THE COMMANDER

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

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

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## PLAN OF INSTRUCTION/LESSON PLAN PART I

| NAME OF INSTRUCTOR | COURSE TITLE |
|---|---|
| | Electronic Principles |

| BLOCK NUMBER | BLOCK TITLE |
|---|---|
| IX | Transmit and Receive Systems |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 1. Heterodyning (Module 63) | 4 (3/1) |

a. Given a list of statements, select the one that describes heterodyning. CTS: 10a Meas: W

b. Given a list of statements concerning heterodyning, match each with the terms: Nonlinearity; Mixing; Filtering. CTS: 10a Meas: W

(1) Nonlinearity.

(a) Definition of nonlinearity.

(b) Schematic illustration of nonlinear impedance with volts-current chart and explanation.

(2) Requirements for heterodyning

(a) Number of AC voltages.

(b) Signal frequencies.

(c) Illustration of generator, nonlinear impedance, and resulting waveforms.

(3) Filtering

(a) Need for filtering.

(b) Illustration of filter circuit with explanation of operation.

(4) Mixing.

(a) Application in receiver.

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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

COURSE CONTENT

(b) Difference between mixer and converter.

(c) Requirements for conversion.

(d) Illustration of transistor receiver converter.

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-63, Heterodyning
KEP-ST-IX, Transmit and Receive Systems
KEP-110
KEP-ST/Digest IX, Digests (Modules 63-73)

Audio Visual Aids
TVK-30-652, Heterodyning

Training Methods
Discussion (3 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr)

Instructional Guidance
Assign specific objectives to be completed during CTT time in KEP-GP-63. Some students have a poor understanding of the principles of "heterodyning." The instructor may be able to assist the student by showing how an RF signal containing a carrier, an upper sideband frequency and a lower sideband frequency can be heterodyned. Heterodyning this complex signal with another RF signal produces three new frequencies. These three new frequencies still have the same frequency separation as did the original complex signal. This analysis can be used to illustrate how complex RF signals are converted to different RF frequencies without changing the intelligence. A simple vector analysis is also very useful if the carrier is used as a reference and the sidebands are rotated in "opposite" directions with reference to the carrier.

## PLAN OF INSTRUCTION/LESSON PLAN PART I

| NAME OF INSTRUCTOR | COURSE TITLE |
|---|---|
| | Electronic Principles |

| BLOCK NUMBER | BLOCK TITLE |
|---|---|
| IX | Transmit and Receive Systems |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 2. Modulation (Module 64) | 7 (5/2) |

a. Given a list of statements about modulation, select the one which describes amplitude; frequency; phase; pulse; single sideband. CTS: 10a Meas: W

(1) Define and state characteristics of

(a) amplitude modulation (AM).

(b) frequency modulation (FM).

(c) phase modulation (FM).

(d) pulse modulation (P-M).

(e) single sideband modulation (SSBM).

b. Given a list of statements about modulation, identify the one which describes the intelligence signal; the carrier wave; the sidebands. CTS: 4b, 10a Meas: W

(1) Define and illustrate characteristics of

(a) intelligence signals.

(b) carrier waves.

(c) sidebands.

c. Given a formula and an oscilloscope representation of a modulated carrier waveform showing E maximum and E minimum, compute the percent of amplitude modulation. CTS: 10a Meas: W

(1) Percent of modulation.

**SUPERVISOR APPROVAL OF LESSON PLAN (PART II)**

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

**COURSE CONTENT**

(a) Illustrate composite waveform with minimum and maximum values.

(2) Identify formula and explain use.

(3) Show 100% over and under modulation.

d. Given a list of statements about frequency modulation, match one with reactance tube modulator; one with varactor modulator. CTS: 5b(6), 10a Meas: W

(1) State characteristics, display circuit and rector relationships of

(a) reactance tube modulator.

(b) varactor modulator.

e. Given a list of statements about frequency modulation, select one that describes frequency deviation; modulating signal; rate of frequency change. CTS: 10a Meas: W

(1) Frequency deviation.

(a) Define.

(b) Illustrate effect on carrier frequency.

(2) Modulating signal.

(a) Define.

(b) Show relationship to carrier frequency.

(3) Rate of frequency change.

(a) Define.

(b) Relate to the modulating signal.

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-64, Modulation
KEP-ST-IX
KEP-110
KEP-PT-64

Audio Visual Aids
TVK 30-559, Amplitude Modulation
TVK 30-607, Transistor FM Oscillator
TVK 30-606, Reactance Tube Modulator
TVK 30-821, General Concepts of Modulation
TVK 30-902, Pulse Modulation

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

COURSE CONTENT

Training Methods
Discussion (5 hrs) and/or Programmed Self Instruction
CTT Assignments (2 hrs)

Instructional Guidance
Assign specific objectives to be completed during CTT time in KEP-GP-64. Weak students should have an additional assignment in KEP-PT-64. Sidebands are sometimes difficult to understand from the standpoint of how they are developed and the fact that they represent the actual intelligence. It may be necessary to show that sidebands are new frequencies which are created as a result of heterodyning the carrier frequency with the intelligence signal. If necessary, review the heterodyning process. In FM, students confuse the concept of frequency deviation with rate of frequency change. Students must be shown how the amplitude of the intelligence controls the amount of frequency deviation. The simple varactor modulator circuit can be used to illustrate and strengthen the concept of frequency deviation. Pulse modulation must be explained in greater detail. As an example, explain how a typical radar system using a pulse forming network develops a pulse which is then used to excite an oscillator. Point out that the oscillator generates an output frequency only during the pulse width time duration.

# PLAN OF INSTRUCTION/LESSON PLAN PART I

| NAME OF INSTRUCTOR | COURSE TITLE |
|---|---|
| | Electronic Principles |

| BLOCK NUMBER | BLOCK TITLE |
|---|---|
| IX | Transmit and Receive Systems |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 3. Demodulation (Module 65) | 5 (4/1) |

a. Given a list of statements about demodulation, select the one that describes AM; single sideband; pulse; phase; FM. CTS: 4b, 10a Meas: W

(1) Define and state demodulation characteristics of

(a) AM.

(b) single sideband

(c) pulse.

(d) phase.

(e) FM.

b. Given schematic diagrams of AM demodulators, match each with the diode detector; the grid leak detector; the plate detector; the infinite-impedance detector. CTS: 10a Meas: W

c. Given a list of statements, match each with the schematic of the Foster-Seeley discriminator; the ratio detector; the quadrature detector. CTS: 10a Meas: W

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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

COURSE CONTENT

## SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-65, Demodulation
KEP-ST-IX
KEP-110
KEP-PT-65, Demodulation

Audio Visual Aids
TVK 30-560, Detection
TVK 30-822, Principles of Detection

Training Methods
Discussion (4 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr)

Instructional Guidance
Assign specific objectives to be completed during CTT time in KEP-GP-65. Students have problems understanding how phase shift is obtained across the transformer secondary in the output to the FM discriminators. In the discussion the development of the vectors should be taken slowly. The difference between the various types of demodulation circuits used to demodulate the various types of modulation should be pointed out and discussed with the student. Insure that students know the difference between a Foster-Seeley discriminator and a ratio detector.

# PLAN OF INSTRUCTION/LESSON PLAN PART I

| NAME OF INSTRUCTOR | COURSE TITLE |
|---|---|
| | Electronic Principles |

| BLOCK NUMBER | BLOCK TITLE |
|---|---|
| IX | Transmit and Receive Systems |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 4. Transmission Lines (Module 66) | 7 (5/2) |

a. Given a list of statements about transmission line, match each with a diagram of an open two wire; a twisted pair; a twin lead; a flexible coaxial cable; a rigid coaxial cable. CTS: 9d Meas: W

(1) Transmission line losses.

(2) Types of transmission lines.

(a) Construction.

(b) Frequency limitations.

(c) Losses.

b. Given a list of statements about transmission lines, select the one which describes the physical length; the electrical length; the characteristic impedance; the cutoff frequency. CTS: 9d Meas:W

(1) Transmission Line Characteristics

(a) Series inductance.

(b) Shunt capacitance.

(2) Wavelength.

c. From a list of statements concerning transmission lines, match each with the following terms: Traveling wave; Incident wave; Reflected wave; Nonresonant line; Resonant line; Standing wave; Standing wave ratio; Voltage node; Voltage loop; Current note; Current loop. CTS: 9d Meas: W

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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

COURSE CONTENT

(1) Types of Terminations

(a) Open.

(b) Short.

(c) Capacitive.

(d) Inductive.

(e) Resistance less than $Z_O$.

(f) Resistance greater than $Z_O$.

(2) Phase relationship of incident and reflected waves.

(3) Result of incident and reflected waves.

d. Given a group of terms concerning transmission lines, match each with the illustrations of delta matching; stub matching; matching transformer.
CTS: 9d Meas: W

(1) Uses of

(a) nonresonant transmission lines.

(b) resonant transmission lines.

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-66, Transmission Lines
KEP-ST-IX
KEP-110

Audio Visual Aids
TVK 30-659, Transmission Lines
TVK 30-660A, Transmission Lines (Resonant Lines)
TVK 30-660B, Transmission Lines (Resonant Sections)

Training Methods
Discussion (5 hrs) and/or Programmed Self Instruction
CTT Assignments (2 hrs)

Instructional Guidance
Assign specific objectives to be completed during CTT time in KEP-GP-66. Students have some difficulty distinguishing among traveling waves, incident waves and reflected waves on a transmission line. Since all of these waves are characterized by movement on the transmission line, Audio Visual Aids should help broaden the student's understanding. The nonresonant transmission line is frequently misunderstood by the students. Students must know that this type transmission line is characterized as having no reflected waves and no standing waves.

# PLAN OF INSTRUCTION/LESSON PLAN PART I

| NAME OF INSTRUCTOR | COURSE TITLE |
|---|---|
| | Electronic Principles |

| BLOCK NUMBER | BLOCK TITLE |
|---|---|
| IX | Transmit and Receive Systems |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 5. Antennas (Module 67) | 8 (6/2) |

a. From a list of statements describing antenna polarization, select the one that describes circular polarization; horizontal polarization/ vertical polarization. CTS: 9e Meas: W

(1) Antenna Function.

(2) Electromagnetic Waves.

(a) E field.

(b) H field.

(c) Induction field.

(d) Radiation field.

b. From a list of statements on antenna wavelengths, select the one that describes the half wave; the quarter wave. CTS: 9e Meas: W

(1) Antenna length.

(a) Input resistive

(b) Input inductive

(c) Input capacitive

c. From a list of statements about the elements of a directional antenna, select the one that describes the function of the driven element; the reflector; the directors. CTS: 9e Meas: W

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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

**COURSE CONTENT**

(1) Element spacing and phase.

d. Given a list of statements concerning antenna arrays, match each with the following terms: Broadside array; End-fire array; Cardioid array; Collinear array. CTS: 9e Meas: W

(1) Antenna Elements.

(a) Spacing.

(b) Phase.

(c) Number of elements.

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

a. Measurement test

b. Test critique

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-67, Antennas
KEP-ST-IX
KEP-110

Audio Visual Aids
TVK 30-661, Antennas
VTF-5401A, Antenna Propagation
VTF-5401B, Antenna Directivity
VTF-5401C, Antenna Bandwidth

Training Methods
Discussion (6 hrs) and/or Programmed Self Instruction
CTT Assignments (2 hrs)

Instructional Guidance
Assign specific objectives to be completed during CTT time in KEP-GP-67. TVK-30-661 provides an excellent overview to the study of antennas. It effectively explains the theories of emission and propagation, and practical antenna design briefly and systematically. The three color films by the RCAF are outstanding teaching aids, particularly the films on propagation and directivity, which virtually cover all objectives. They show all fields and ratidation patterns in full color on a black background, with a clear narration in plan language. Inform students that Part 1 of the measurement test covers modules 63 through 67.

**PLAN OF INSTRUCTION/LESSON PLAN PART I**

| NAME OF INSTRUCTOR | COURSE TITLE |
|---|---|
| | Electronic Principles |

| BLOCK NUMBER | BLOCK TITLE |
|---|---|
| IX | Transmit and Receive Systems |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 7. AM Systems (Module 68) | 7 (5/2) |

a. Given a list of statements of transmitter characteristics, select the statement that describes frequency stabilization. CTS: 10b Meas: W

(1) An oscillator as a transmitter.

(a) Instability caused by a small load resistance placed in parallel.

(b) Instability caused by Direct Modulation.

(2) Basic transmitter with

(a) modulation in the power amplifier.

(b) isolation between the load and the oscillator.

b. Given a list of statements of the following receiver characteristics, select the statement which describes sensitivity; selectivity. CTS: 4b, 10b Meas: W

(1) Receiver functions.

(a) Reception.

(b) Detection.

(c) Amplification.

(d) Reproduction.

c. From a list of statements, select the statements that identify the causes of second harmonic distortion; bandpass distortion; cochannel interference. CTS: 10b Meas: W

**SUPERVISOR APPROVAL OF LESSON PLAN (PART II)**

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

**COURSE CONTENT**

d. Given a labeled block diagram and a list of statements that describe each block of an AM transmitter, match each block with the proper statement . CTS: 10b Meas: W

e. Given a labeled block diagram and a list of statements that describe each block of a single conversion AM receiver, match each block with the proper statement. CTS: 10b Meas: W

(1) Heterodyning action.

(2) Image frequency.

(a) Importance of IF frequency.

(b) Importance in BW of RF amplifier.

(3) Selectivity

(a) Tracking.

(b) BW of IF amplifiers.

f. Given a schematic diagram of an AM transmitter, trace the RF and intelligence signal flow from origin to output; the direct current paths through each stage in a closed loop. CTS: 10b Meas: W

g. Given a schematic diagram of a super heterodyne AM receiver, trace the signal flow from origin to output; the direct current path through each state in a closed loop. CTS: 10b Meas: W

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-68, AM Systems
KEP-ST-IX
KEP-110

Audio Visual Aids
TVK 30-609, Introduction to Receivers

Training Methods
Discussion (5 hrs) and/or Programmed Self Instruction
CTT Assignments (2 hrs)

Instructional Guidance
Make specific objective assignments to be completed during CTT time in KEP-GP-68. Students have considerable difficulty understanding the causes of second har[illegible] distortion, bandpass distortion and cochannel interference. Students should [illegible] encouraged to spend extra time in studying the block diagrams of the AM tran[illegible] mitter and receiver. They must know the function of each stage in order to understand fully the characteristics of AM systems.

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# PLAN OF INSTRUCTION/LESSON PLAN PART I

| NAME OF INSTRUCTOR | COURSE TITLE |
|---|---|
| | Electronic Principles |

| BLOCK NUMBER | BLOCK TITLE |
|---|---|
| IX | Transmit and Receive Systems |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 8. FM Systems (Module 69) | 5 (4/1) |

a. Given a labeled block diagram and a list of statements that describe each block of an FM transmitter, match each block with the proper statement. CTS: 10b Meas: W

(1) Modulation

(a) Amplitude of modulating signal.

(b) Frequency of modulating signal.

(2) Frequency multipliers.

b. Given a labeled block diagram and a list of statements that describe each block of an FM receiver, match each block with the proper statement. CTS: 10b Meas: W

(1) Noise free reception.

(a) Limiter.

(b) FM demodulators.

c. Given a schematic diagram of an FM transmitter, trace the RF and Intelligence signal flow from origin to output; the direct current paths through each stage in a closed loop. CTS: 10b Meas: W

d. Given a schematic diagram of an FM receiver, trace the signal flow from origin to output; the direct current path through each stage in a closed loop. CTS: 10b Meas: W

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

**COURSE CONTENT**

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-CP-69, FM Systems
KEP-ST-IX
KEP-110

Audio Visual Aids
TVK 30-659, Frequency Modulation

Training Methods
Discussion (4 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr)

Instructional Guidance
Assign specific objectives to be covered during CTT time in KEP-GP-69. Students have difficulty with the signal path and the direct current path in the FM receiver schematic diagram. Increased emphasis should be placed on tracing the DC current paths through the emitter - base junction of each stage. It should also be pointed out that the DC current path terminates at Vcc.



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# PLAN OF INSTRUCTION/LESSON PLAN PART I

| NAME OF INSTRUCTOR | COURSE TITLE |
|---|---|
| | Electronic Principles |

| BLOCK NUMBER | BLOCK TITLE |
|---|---|
| IX | Transmit and Receive Systems |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 9. Single Sideband Systems (Module 70) | 4 (3/1) |

a. Given a labeled block diagram and a list of statements that describe each block of a single sideband transmitter, match each block with the proper statement. CTS: 10b Meas: W

(1) Power efficiency

(a) Elimination of the carrier in a balanced modulator.

(b) Elimination of one set of sidebands in a filter.

b. Given a labeled block diagram and a list of statements that describe each block of a single sideband receiver, match each block with the proper statement. CTS: 10b Meas: W

(1) Reinsertion of the carrier.

(2) Narrow Bandwidth.

c. Given a schematic diagram of a single sideband transmitter, trace the RF and intelligence signal flow from origin to output; the direct current path through each stage in a closed loop. CTS: 10b Meas: W

d. Given a schematic diagram of a single sideband receiver, trace the signal flow from origin to output; the direct current path through each stage in a closed loop. CTS: 10b Meas: W

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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

**COURSE CONTENT**

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-70, Single Sideband Systems
KEP-ST-IX
KEP-110

Audio Visual Aids
TVK 30-611, Introduction to Single Sideband

Training Methods
Discussion (3 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr)

Instructional Guidance
Assign specific objectives to be covered during CTT time in KEP-GP-60. The largest area of difficulty is in DC paths and AC signal path tracing. Most errors in this area are due to simple mistakes while the student is tracing the path.

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# PLAN OF INSTRUCTION/LESSON PLAN PART I

| NAME OF INSTRUCTOR | COURSE TITLE |
|---|---|
| | Electronic Principles |

| BLOCK NUMBER | BLOCK TITLE |
|---|---|
| IX | Transmit and Receive Systems |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 10. Pulse Modulation Systems (Module 71) | 4 (3/1) |

a. Given a labeled block diagram and a list of statements that describe each block of a pulse transmitter, match each block with the proper statement. CTS: 10b Meas: W

(1) Uses of pulse modulator

(a) Time division multiplexing.

(b) Radar.

b. Given a labeled block diagram and a list of statements that describe each block of a pulse receiver, match each block with the proper statement. CTS: 10b Meas: W

c. Given a schematic diagram of a pulse modulation transmitter, trace the RF and Intelligence signal flow from origin to output; the direct current path through each stage in a closed loop. CTS: 5g(1), 10b Meas: W

d. Given a schematic diagram of a pulse modulation receiver, trace the signal flow from origin to output; the direct current path through each stage in a closed loop. CTS: 10b Meas: W

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

COURSE CONTENT

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-71, Pulse Modulation Systems
KEP-ST-IX
KEP-110

Audio Visual Aids
TVK 30-952, Pulse Amplitude Modulation

Training Methods
Discussion (3 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr) -

Instructional Guidance
Assign specific objectives to be covered during CTT time in KEP-GP-71. Since the P-M transmitter has many unique characteristics when compared to typical AM or FM transmitters, students have considerable difficulty tracing signal flow and the DC current paths. Provide additional instruction and assistance with the block diagram analysis until the student sufficiently understands the principles of a P-M transmitter. Quite often students if not cautioned, come to the conclusion that the AM receivers and P-M receivers are the same. While the principles are identical, the P-M receiver requires circuits that provide a much wider bandwidth. The circuit diagram shown in the text as a typical P-M receiver will not function in this regard because the audio circuits do not provide sufficient bandwidth.

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# PLAN OF INSTRUCTION/LESSON PLAN PART I

| NAME OF INSTRUCTOR | COURSE TITLE |
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| | Electronic Principles |

| BLOCK NUMBER | BLOCK TITLE |
|---|---|
| IX | Transmit and Receive Systems' |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 11. Troubleshooting Techniques (Module 72) | 4 (3/1) |

a. Given a list of statements, select one that describes the layout of a receiver schematic diagram. CTS: 10b Meas: W

(1) Schematic diagram analysis.

(a) Definition.

(b) Component arrangement.

(c) Circuit division.

1 RF

2 IF

3 AF

4 Power supply

b. Given a list of troubleshooting steps, arrange them in a logical sequence. CTS: 10c Meas: W

(1) Troubleshooting procedures.

(a) Definitions.

(b) Procedures.

1 Operational check.

2 Half split method

3 Stage by stage.

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

COURSE CONTENT

4 Component isolation.

5 Visual check.

(2) Adjustment and Alignment

(a) When to adjust.

(b) How to adjust.

c. Given a transistor receiver schematic diagram, indicate the frequencies used at each point where a signal generator would be connected to align a receiver. CTS: 10a, 10b Meas: W

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-72, Troubleshooting Techniques
KEP-HO-IX-1, AM Receiver Schematic and Block Diagram
KEP-ST-IX
KEP-110
KEP-PT-72, Troubleshooting Techniques

Audio Visual Aids
TVK 30-610, Troubleshooting Procedures

Training Methods
Discussion (3 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr)

Instructional Guidance
Assign specific objectives to be covered during CTT time in KEP-GP-72 and/or KEP-PT-72. Students are often unable to indicate the frequencies that should be injected at each point a signal generator would be used to align a receiver. The students should be encouraged to note all injection frequencies on their schematic diagram. This will also help in troubleshooting the receiver.

Jl

## PLAN OF INSTRUCTION/LESSON PLAN PART I

| NAME OF INSTRUCTOR | COURSE TITLE |
|---|---|
| | Electronic Principles |

| BLOCK NUMBER | BLOCK TITLE |
|---|---|
| IX | Transmit and Receive Systems |

| 1 COURSE CONTENT | 2 DURATION (Hours) |
|---|---|
| 12. Receiver Troubleshooting (Module 73) | 6<br>(5/1) |

a. Given a transistor radio receiver, schematic diagram, multimeter, oscilloscope, and signal generator, determine the faulty component four out of five times. CTS: 10c Meas: PC

(1) Preliminary instructions on equipment.

(a) Oscilloscope.

(b) Multimeter.

(c) RF Signal Generator.

(d) Radio Receiver Trainer

(2) Procedure A, measure normal voltages at all test jacks.

(3) Procedure B, locate trouble #1.

(4) Procedure C, locate trouble #2.

(5) Procedure D, locate trouble #3.

(6) Procedure E, locate trouble #4.

(7) Procedure F, locate trouble #5.

(8) Procedure G, locate trouble #6.

(9) Procedure H, locate trouble #7.

(10) Procedure I, locate trouble #8.

(11) Procedure J, locate trouble #9.

(12) Progress Check.

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

COURSE CONTENT

13. Related Training (identified in course chart) 1

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

a. Measurement test.

b. Test critique.

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-73, Receiver Troubleshooting
KEP-SH-IX-1
KEP-ST-IX
KEP-110

Training Equipment
Transistor Radio Receiver Trainer 5975 (1)
Oscilloscope (1)
RF Signal Generator 4867 (1)
Multimeter (1)

Training Methods
Performance (5 hrs)
CTT Assignment (1 hr)

Multiple Instructor Requirements
Supervision (2)

Instructional Guidance
Students who have not had considerable prior experience in electronics should not attempt to take the progress check until they have completed the laboratory exercise. If too high a level signal is injected it may produce an output even if the portion of the receiver being tested is defective. When injecting a signal at the input to the frequency converter, an output can be obtained by using either an RF or an IF signal. If an RF signal is used, the operation of both the amplifier and oscillator functions of the frequency converter are checked. If, however, an IF frequency is injected, only the operation of the amplifier function of the frequency converter is checked. The students should be cautioned in this regard. Due to errors in the frequency areas on the equipment used in this module, it may be necessary to tune the signal generator slightly off the desired frequency to obtain an output. Furnish any required assistance for the laboratory project.

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ATC ST 3AQR3X020-X
Prepared by Keesler TTC
KEP-ST-IX

Technical Training

# Electronic Principles (Modular Self-Paced)

## Volume IX

## TRANSMIT AND RECEIVE SYSTEMS

1 July 1975

AIR TRAINING COMMAND

7-13

Designed For ATC Course Use

ATC Keesler 6.4187

*DO NOT USE ON THE JOB*

# TRANSMIT AND RECEIVE SYSTEMS

## VOLUME IX

This student text is the prime source of information for achieving the objectives of this course. This training publication is designed for training purposes only and should not be used as a basis for job performance in the field.

CONTENTS



**Supersedes ST, KEP-ST-IX, 1 Jul 74.**

Chapter 1

# HETERODYNING

1-1. In this chapter we will discuss heterodyne principles. HETERODYNE is "the process of combining or beating two signal frequencies in a nonlinear device, with the result that frequencies equal to the sum and difference of the combining frequencies are produced." The heterodyne principle can be applied when explaining the operation of the following circuits:

1. Mixing

2. Frequency conversion

3. Amplitude modulation

4. Amplitude Detection

Mixing and conversion circuits are explained in this chapter, amplitude modulation and detector circuits will be explained in later chapters.

1-2. The definition of heterodyne employs the use of a nonlinear device to obtain new frequencies. The new frequencies (sum and difference frequencies) are the new beat signals obtained through heterodyning.

1-3. Nonlinear Device.

1-4. For our purpose here the nonlinear device is any electronic device where the resulting current through the device is not proportional to the applied voltage. We call these devices nonlinear impedances or impedances with nonlinearity. Examples of nonlinear impedances are electron tubes and transistors.

1-5. Figure 1-1A illustrates a circuit that contains a nonlinear impedance (Z) and figure 1-1B shows its voltage-current curve.

1-6. When the applied voltage is varied, ammeter readings which correspond with the various voltages can be recorded. For example, assume that 50 V yields .4 mA (point a), 100 V produces 1 mA (point b), and 150 V causes 2.2 mA (point c). Current through the nonlinear impedance does not vary proportionally to the voltage. The chart is NOT a straight line. Therefore, Z is a nonlinear impedance. That is, the impedance does not remain constant when the voltage changes. Various combinations of voltage and current for this particular nonlinear impedance may be obtained by use of this voltage-current curve.

1-7. If the device were a diode tube in figure 1-1A, we could say we were changing the DC resistance ($R_p$) of the diode as we change the applied voltage. The resulting nonlinearity in figure 1-1B, shows a response which is not directly proportional or inversely proportional to a given variable (voltage).

1-8. Heterodyning.

1-9. Certain conditions must be met in a circuit if heterodyning is to occur. The conditions are:

1. There must be at least two AC voltages, each voltage must be changing at a different frequency.

2. The two different signal frequencies must be applied to a nonlinear device.

1-10. Figure 1-2A illustrates a basic circuit where heterodyning can occur. The two generators G1 and G2 furnish the two different signal voltages, each at a different frequency. The diode tube V1 is the nonlinear impedance. The nonlinear device will cause one of the signals applied to its plate to dominate the amplitude of the other. The resistor RL will develop the output voltages.

1-11. The waveforms in figure 1-2B, detail a and b, illustrate the amplitude and frequency of the generators drawn with respect to time. These two waveforms will be in phase at times and at various degrees

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out-of-phase at other times. You can see this by closely observing the two waveforms (11 Hz and 10 Hz) at different instants of time. The result of this phase relationship is the waveform in detail c. The detail c waveform represents the plate voltage variations of V1. Recall the diode tube conducts only when the plate is positive with respect to the cathode. Thus, V1 (figure 1-2A) conducts only on the positive amplitudes of the waveform in detail c (figure 1-2B), V1 conducts through $R_L$ and the waveform in detail d will be developed across $R_L$. The voltage waveform across $R_L$ shows that the $R_p$ of V1 was decreased when the plate voltage, detail c, was at maximum amplitude and increased when the plate voltage was minimum. Look again at the response curve in figure 1-1B and see that the change in $R_p$ (Z) of V1 was nonlinear.

1-12. The complex waveform developed across the linear impedance $R_L$ (figure 1-2B) detail d has a DC level, and new beat signals of the nonlinear impedance V1 (figure 1-2A). These new beat signals are the new frequencies other than the two original frequencies of G1 and G2 (11 Hz and 10 Hz). The new frequencies are:

1. Harmonics of G1 and G2 signals.

2. The sum frequency of G1 and G2 signals (21 Hz).

3. The difference frequency of G1 and G2 signals (1 Hz).

The sum and difference frequencies occur because the phase angles of the two original signals (11 Hz and 10 Hz) are constantly changing at the plate of V1. The harmonics of the two sinewave generator signals (11 Hz and 10 Hz) occur because of the amplitude distortion to their signals.

1-13. In most practical heterodyne circuits the harmonic frequencies are of no use. For this reason we will make no further mention of them. Practical use is made of either the sum frequency or difference frequency, which are the new frequencies produced by the heterodyne principle.

1-14. Filtering.

1-15. The circuit in figure 1-2A has a resistor to develop the output. The output has several frequencies in its makeup. If we wished to select one of the new frequencies (sum or difference) and reject all others we would need an output frequency selection device, thus, filtering is required.

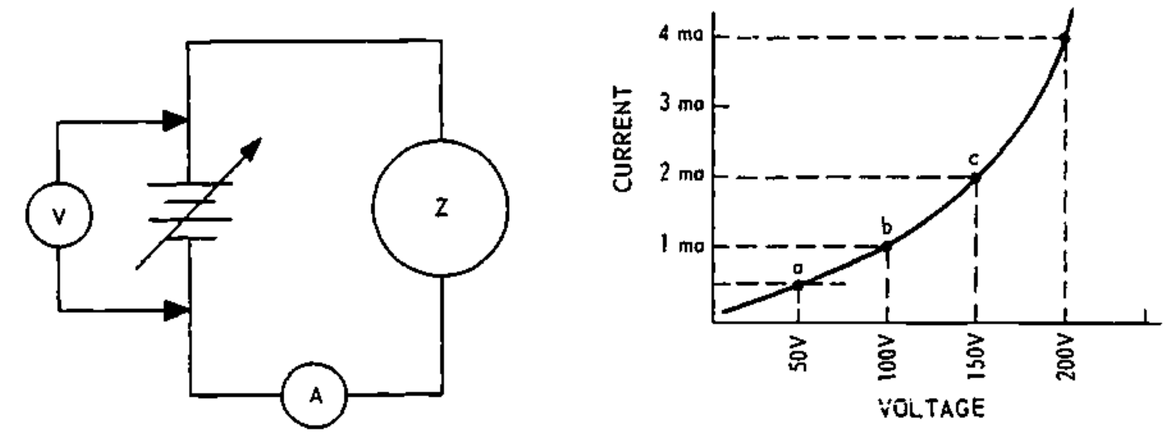
1-16. The circuit in figure 1-3 has a filter to replace the load resistor of figure 1-2A. The filter components are C1 and L1. The filter components make up a tank circuit. The tank circuit is tuned to select one of the new frequencies that was the result of the heterodyne process. The tank circuit will offer a high reactance to the frequency at which it is tuned and a low reactance to all others. If the reactance is high a maximum voltage is developed across the tank circuit. Signals not falling within the bandpass of the tank circuit are not developed; therefore, they are FILTERED to ground.

1-17. Mixing.

1-18. Heterodyne principles are used in superheterodyne receivers to convert the received RF signal to a lower frequency RF signal. The lower RF signal is called the receiver's intermediate frequency (IF). The IF signal is selected by the output frequency of the filter, and coupled to a fixed tuned circuit, where the IF signal will be amplified. This process improves overall receiver selectivity.

1-19. To convert the received energy to the IF signal requires the received signal be mixed with a locally generated signal. The locally generated signal is furnished by the receivers local oscillator circuit.

1-20. Circuits used to convert the received signal to the receivers IF signal are called mixer or converter circuits. The only difference between a mixer circuit and a converter circuit is the number of electron tubes or transistors involved to perform the operation. Two tubes or transistors are used in a mixer section, while one tube or transistor is used in a converter circuit. In a

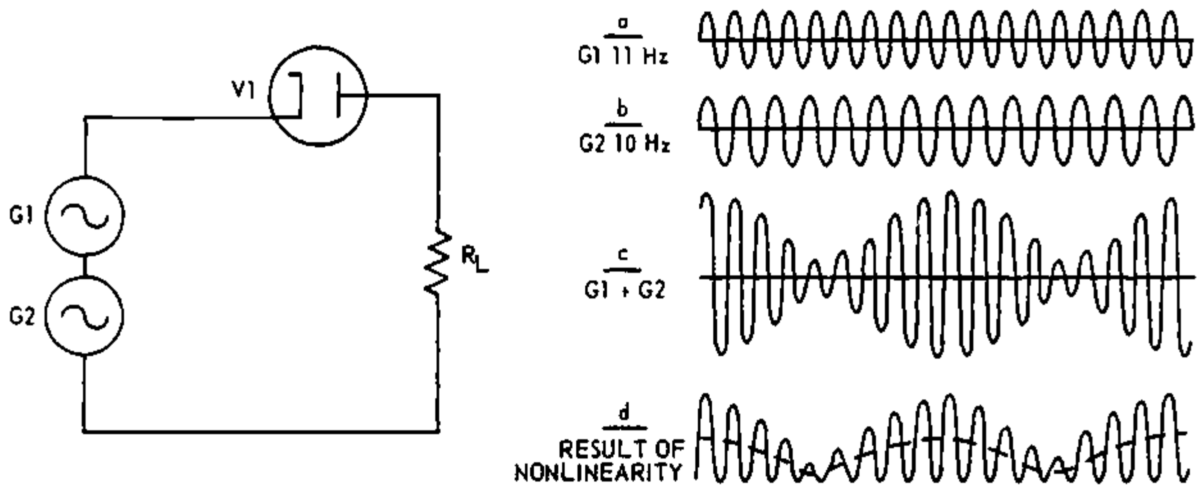



A. Nonlinear Impedance Circuit

B. (Z Changes are Nonlinear)

Figure 1-1. Nonlinear Impedance Characteristics

REP4-1702




A.

B.

REP4-1703

Figure 1-2. Two Sinewave Generators and a Nonlinear Impedance with Resulting Waveforms mixer circuit an electron tube or transistor is used for the local oscillator circuit. When one electron tube or transistor is used, the device must perform both functions (mixer and local oscillator). However, mixer and converter circuits perform the same functions in the receiver. That is conversion of the received signal to the receivers IF signal.

1-21. Before conversion of the received signal to the IF signal can occur we must have the following:

1. Two different signal frequencies. One signal frequency must be of sufficient amplitude to dominate the amplitude of the other.

2. A nonlinear device where mixing of the two signals can take place.

3. An output frequency selection device so the new conversion frequency can be selected, and all other signals can be filtered from the output.

1-22. Figure 1-4 is the frequency conversion section of a superheterodyne receiver. This circuit is a transistor converter. The circuit will be used to show how the received RF signal of a receiver is converted to the receiver's IF frequency.

1-23. Q1 is biased to operate nonlinearly. Assume that we adjust the receiver tuning dial to receive a radio transmitting station signal operating on an assigned frequency of 1060 kHz. This signal will be selected and amplified by a previous RF amplifier stage, and is developed across the frequency selection tank C1 and L1. The signal (1060 kHz) is then coupled to the base of Q1. The local oscillators frequency determining tank L3 and C4 is tuned to operate on a frequency of 1515 kHz. Because the tuning dial of the receiver is gang-tuned to C1 and C4, the local oscillator frequency tank circuit and the received frequency tank circuit will change simultaneously as the dial is adjusted. The local oscillators output frequency 1515 kHz) is coupled through C3 and developed across emitter resistor R2. The 1060 kHz received signal at the base of Q1 is of a much lower amplitude than the 1515 kHz signal which was locally generated by the local oscillator. When the 1060 kHz signal at the base of Q1 is mixed with the local oscillator (1515 kHz) in the nonlinear transistor Q1, heterodyning action takes place which causes two new RF signals to appear at TP2 along with the two original signals used. The four signals appearing at TP2 will be:

1. 1060 kHz, the original received signal frequency.

2. 1515 kHz, the local oscillator frequency.

3. 2575 kHz, a new frequency, the sum of the two signals.

4. 455 kHz, the difference frequency of the two signals.

The output frequency tank, L5 and C6 (figure 1-4) is tuned to select the receivers IF signal (455 kHz).

1-24. Conversion.

1-25. "The process of combining two RF signals to produce a new and different RF signal is called frequency conversion. Thus the result of heterodyning is frequency conversion. If one of the RF signals is modulated or contains more than one frequency, the conversion will change all of those frequencies proportionally and the modulation will not be altered".

1-26. The difference frequency will always be 455 kHz for this particular receiver. Notice the receiver tuning dial will change C1 and C4 as the dial is rotated. Because the tuning dial changes the capacitance in both circuits, the receiver input tank frequency will change, as will the local oscillator frequency. The local oscillator frequency will always be above the received signal by 455 kHz. Thus, the received signal will always be converted to 455 kHz, the IF frequency.

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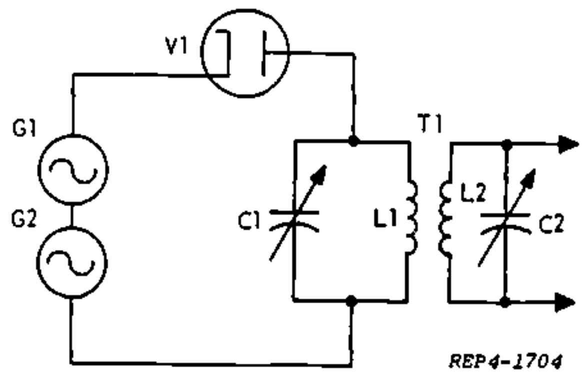


Figure 1-3. Heterodyne Circuit with a Filter

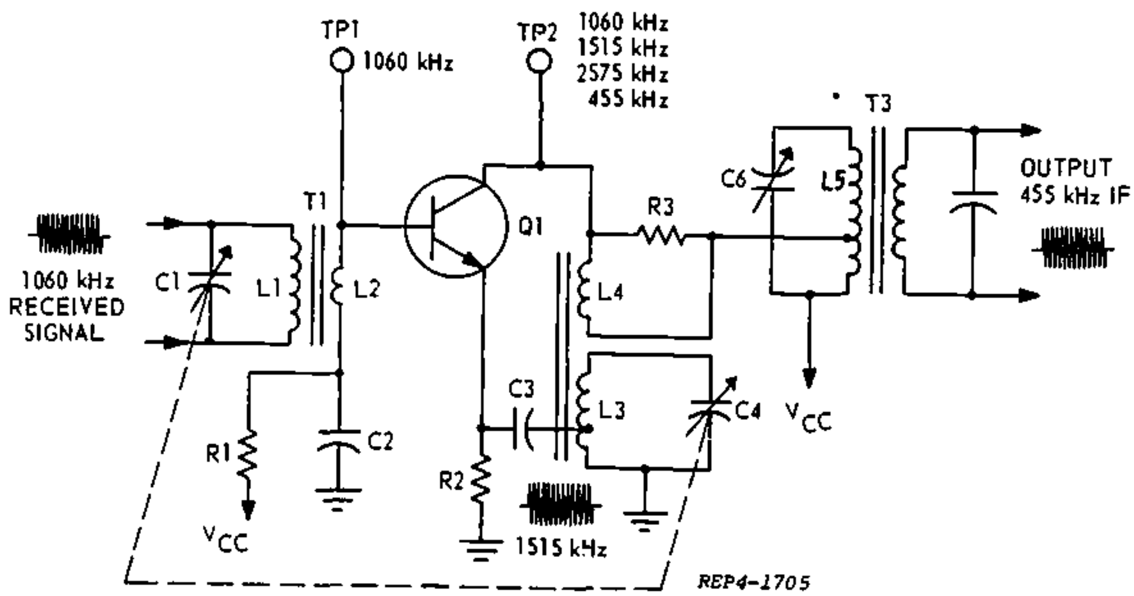


Figure 1-4. Heterodyne Receiver Frequency Converter Section

# Chapter 2

# MODULATION

## 2-1. Modulation.

2-2. A radio announcer speaks into a microphone, and his voice is heard on a radio receiver some distance away. In this chapter we will discuss how the announcer's voice was changed from sound energy into electrical energy, the electrical energy then was used to modify one or more characteristics of an RF waveform before being propagated into space. The process of modifying the RF waveform with this electrical energy is known as modulation.

## 2-3. Principles of Modulation.

2-4. The term MODULATION is defined as: "The process in which the amplitude, frequency, or phase of an RF carrier wave is varied with time in accordance with the waveform of the superimposed intelligence."

2-5. Figure 2-1 shows one cycle of an RF waveform with two of the characteristics which can be altered when the sine wave is subjected to the modulation process. The two characteristics are amplitude, and frequency. Another characteristic which may be altered is the phase. Figure 2-2 shows how the wave will appear after being modulated.

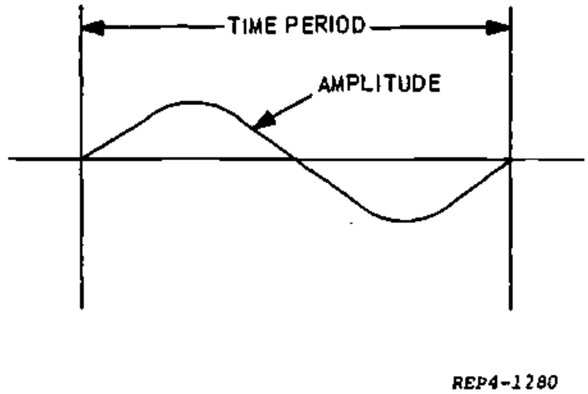


Figure 2-1. Characteristics of an RF Sine Wave

2-6. Figure 2-2A shows an amplitude change on each succeeding cycle of an RF wafevorm. Figure 2-2B shows a frequency change on each succeeding cycle. Figure 2-2C shows two RF waveforms of the same frequency, but out of phase. All of the waveforms in figure 2-2 are complex waves.

2-7. Based on the preceding discussion, the three basic types of modulation are:

1. Amplitude Modulation (AM).

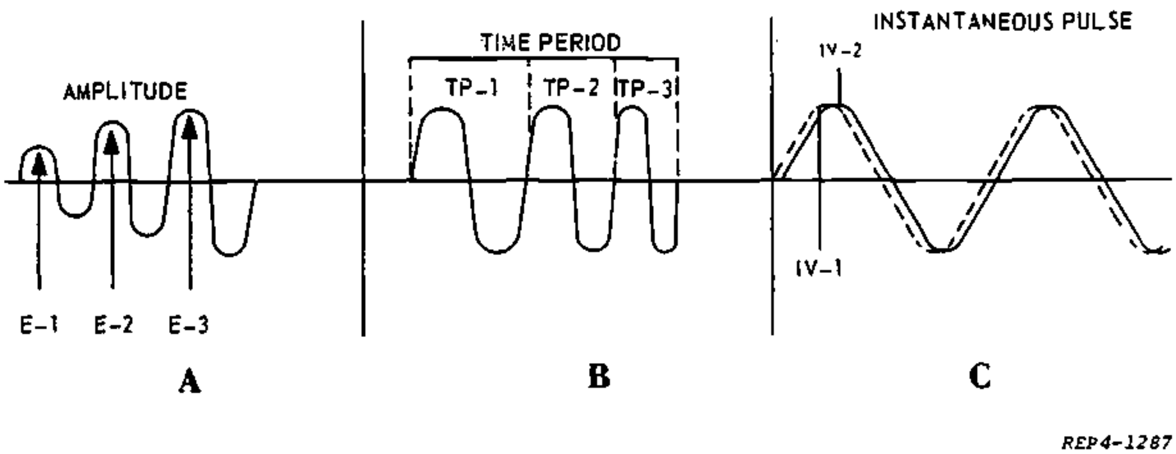


Figure 2-2. Variations in a Sine Wave's Characteristics

2. Frequency Modulation (FM).
3. Phase Modulation (PM).

2-8. Each type of modulation has certain advantages and disadvantages. The type of modulation used in a transmitter system is dependent upon the intended use of the system, the carrier frequency assigned, and the bandwidth available.

2-9. Lets define the terms that we will use in our discussion of modulation:

INTELLIGENCE SIGNAL: "Signal that conveys information." The intelligence signal can be a single tone (one frequency) or a complex waveform like the one shown in figure 2-3, that contain many frequencies.

SIDEBANDS: "Frequency bands on both sides of the carrier frequency which contain the frequencies produced by modulation."

CARRIER: "A wave having at least one characteristic which may be varied from a known reference value by modulation."

2-10. Amplitude Modulation.

2-11. Lets consider amplitude modulation and see how the amplitude characteristics of an RF carrier waveform are modified by the intelligence signal. Amplitude modulation implies that the amplitude of the carrier waveform is varied in accordance with the modulating frequency and voltage while the frequency of the carrier is maintained constant. When an amplitude-modulated waveform is viewed on an oscilloscope, its amplitude varies in accordance with the amplitude and frequency of the modulating signal. The frequency of the carrier waveform will not change throughout the modulating process.

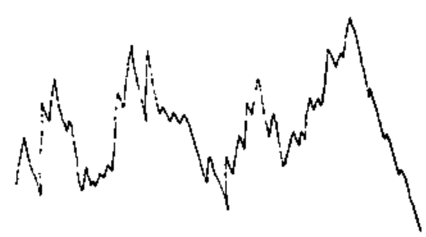

Figure 2-3. Waveshape of Complex Sounds

2-12. Modulating tone, unmodulated carrier waveform, and resulting amplitude-modulated wave, as viewed on an oscilloscope, is illustrated in figure 2-4.

2-13. Figure 2-4A illustrates a sinewave which will be used to modulate the carrier. Figure 2-4B illustrates the unmodulated RF carrier wave which has a constant amplitude and frequency. Figure 2-4C illustrates an amplitude modulated carrier.

2-14. During time interval T1 and T3, one cycle of the 1000 Hz modulating tone modulates the 1000 kHz carrier signal. Because the carrier frequency is one thousand times higher than the modulating tone, it undergoes one thousand more cycles per second than the modulating tone does. The resulting amplitude modulated carrier in figure 2-4C is changing in amplitude in accordance with the changing amplitude of the modulating tone.

2-15. You should note as the modulating sinewave voltage in figure 2-4A, is increased positively (0° to 90°), the resulting modulated carrier in figure 2-4C is increasing. As the modulating sinewave voltage in figure 2-4A changes to its maximum negative value (90° to 270°), the modulated carrier in figure 2-4C decreases to its minimum value. As the amplitude of the

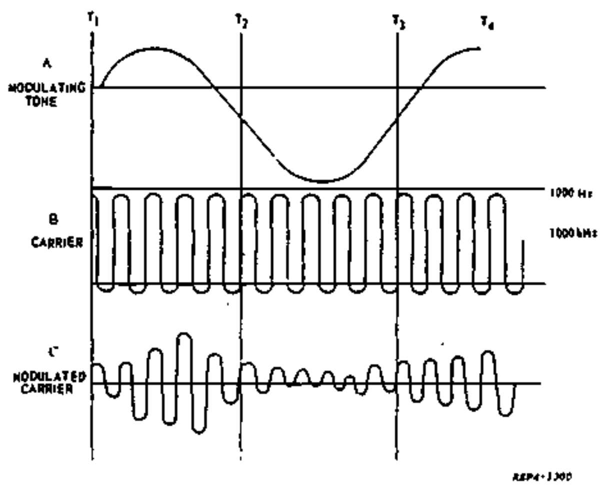


Figure 2-4. The AM Wave

modulating sinewave voltage in figure 2-4A starts to decrease toward a zero value (270° to 360°), the modulated carrier in figure 2-4C is increasing in amplitude.

## 2-16. Analysis of an AM Waveform.

2-17. An analysis of the modulated carrier waveform is shown in figure 2-5. This analysis shows that the modulated carrier (figure 2-5A) contains the carrier frequency (figure 2-5B) plus two new frequencies (figure 2-5D and figure 2-5E). The unmodulated carrier component illustrated in figure 2-5B has a frequency of 1000 kHz with a constant amplitude.

2-18. The upper frequency of 1001 kHz (figure 2-5D) is equal to the carrier frequency (figure 2-5B) plus the modulating frequency (figure 2-5C).

2-19. The lower frequency of 999 kHz (figure 2-5E) is equal to the carrier frequency (figure 2-5B) minus the modulating frequency. The amplitude of both new frequencies are equal. These characteristics of the carrier and the pair of new frequencies are illustrated in figure 2-5.

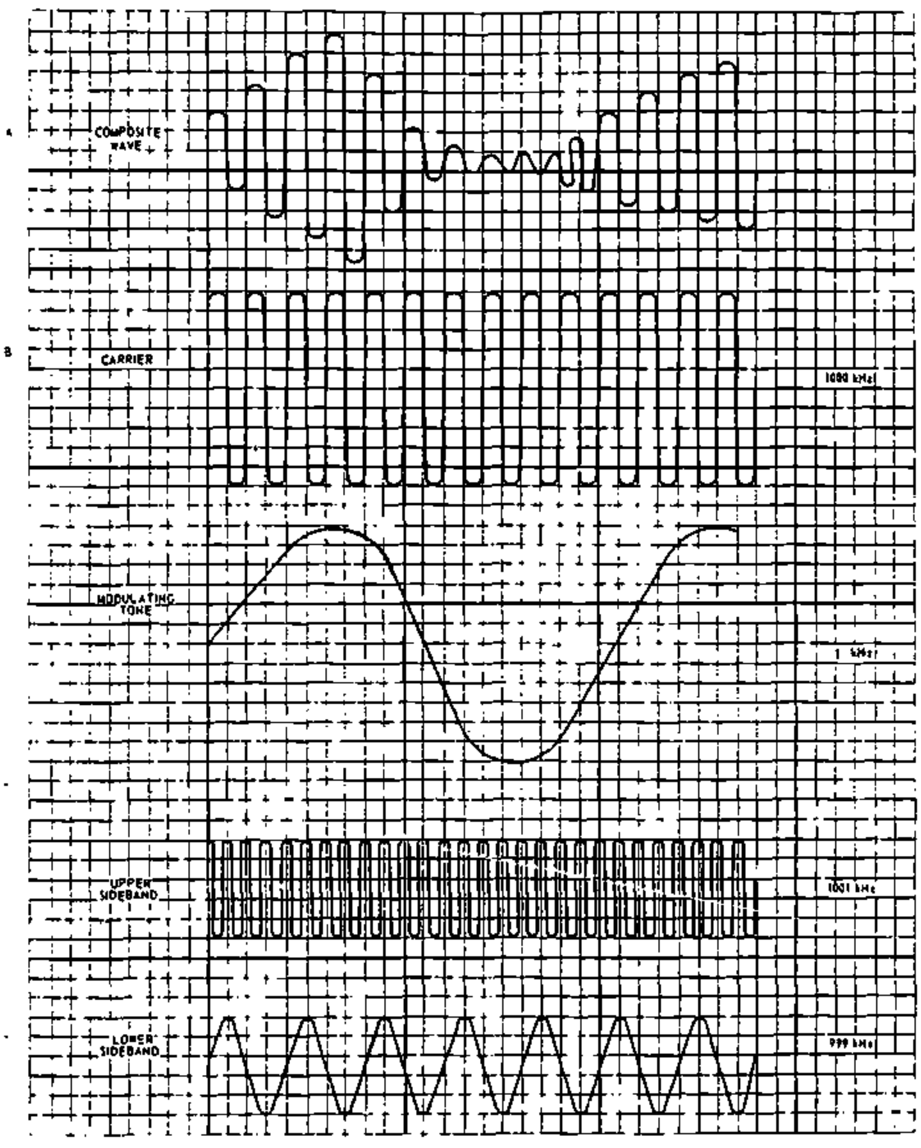


Figure 2-5. Components of an AM Wave

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2-20. The amplitude modulated carrier is the algebraic sum of the instantaneous amplitudes of the unmodulated carrier and the upper frequency and the lower frequency signals. These waveforms are drawn using a common scale with respect to time in figure 2-6. The modulated carrier then contains three distinct frequencies when modulated with a single tone, the unmodulated carrier wave, the upper frequency, and the lower frequency.

2-21. Figure 2-7 shows the space occupied in the radio frequency spectrum by the modulated wave (carrier plus upper and lower frequencies), and the original modulating frequency. You should see by studying figure 2-7 that the position of the modulating frequency is far below the carrier and the two new frequencies produced during the modulation process. This is important to remember because later, when we see a practical circuit using AM, we will find that the original modulating frequency will not be in the transmitted frequencies. The transmitted frequencies in this example would be 1000 kHz, 999 kHz, and 1001 kHz.

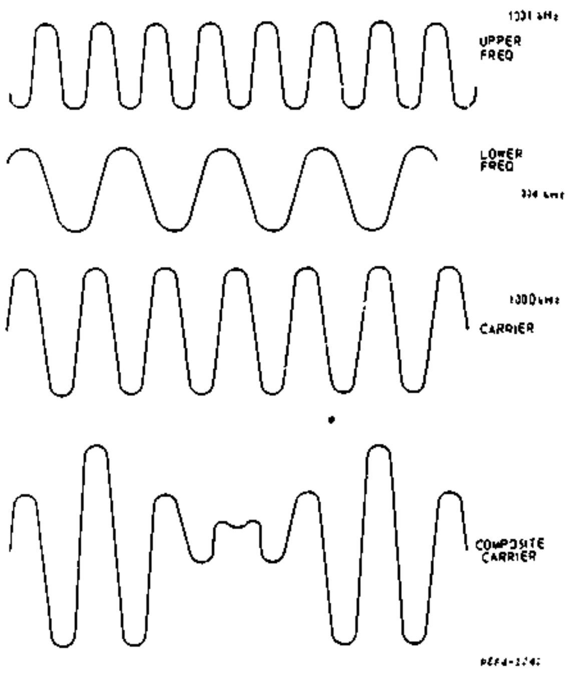


Figure 2-6. Algebraic Addition of Components in an AM Waveform

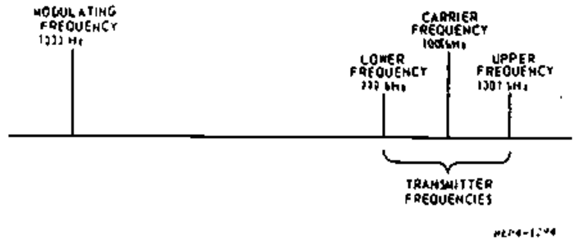


Figure 2-7. Spectrum Analysis of an AM Waveform

2-22. Sidebands.

2-23. We have been referring to the new frequencies produced during the modulation process as upper frequency and lower frequency.

2-24. In actual operation most waveforms used to modulate an RF carrier are complex waveforms. Recall that complex waveforms contain many frequencies.

2-25. Figure 2-8A shows a complex waveform. This waveform contains four frequencies, 1 kHz, 2 kHz, 3 kHz, and 4 kHz. When this signal is used to modulate a 600 kHz carrier signal, four upper and four lower frequencies appear around the carrier frequency. These signals along with the carrier signal are shown in figure 2-8B.

2-26. The upper frequencies are 601 kHz, 602 kHz, 603 kHz, and 604 kHz, and are the upper sideband (USB) signals. The lower frequencies are 596 kHz, 597 kHz, 598 kHz, and 599 kHz, and are the lower sideband (LSB) signals.

2-27. Bandwidth of an AM Signal.

2-28. The bandwidth (BW) of an AM signal refers to the space the transmitted signal will occupy in the frequency spectrum. Recall the transmitted frequencies in AM are the carrier signal, and the upper and lower sidebands. Look at figure 2-8, we see the USB and LSB are each 4 kHz wide. Therefore, the BW of the transmitted signal is 8 kHz.

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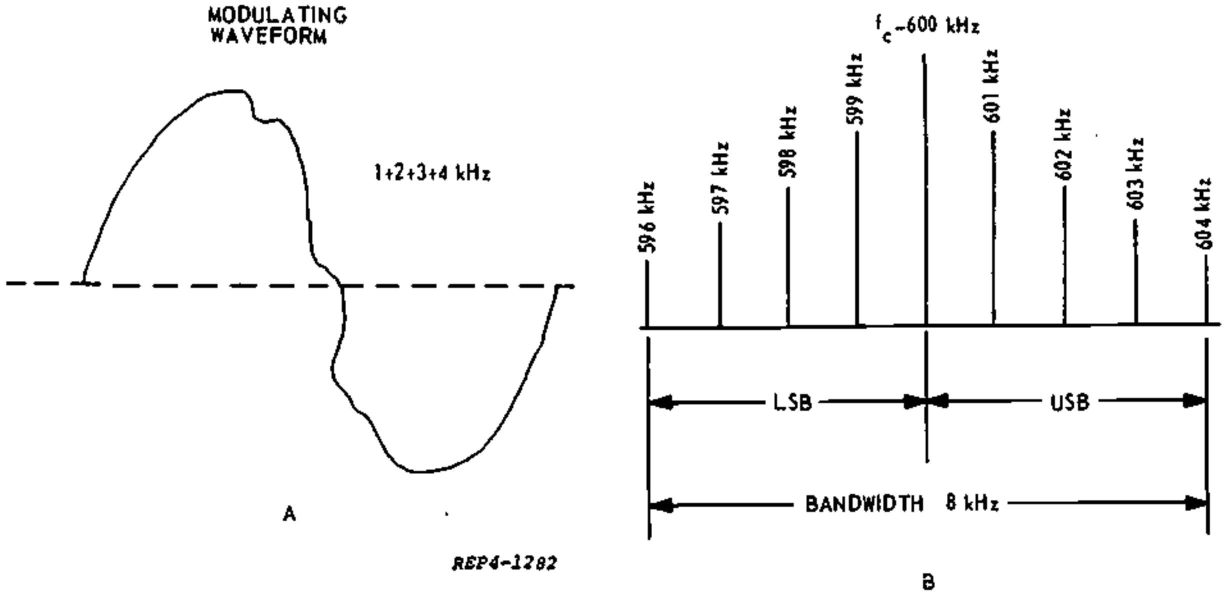


Figure 2-8. Development of Sidebands

2-29. From the preceding analysis we can say the BW of an AM signal is two times the highest signal frequency contained in the modulating waveform. The above rule holds true only when the carrier signal is modulated up to and including 100 percent.

2-30. Percent of Modulation.

2-31. Modulation factor in AM is the ratio of the difference between maximum and minimum peak-to-peak variations of the modulated carrier and the sum of the maximum and minimum peak-to-peak variations of the modulated carrier. Multiplying the modulation factor by 100 gives the percent of modulation.

2-32. Percentage of modulation can be calculated by using the oscilloscope presentation of the modulated waveform and the following formula:

$$\text{Percent of modulation} = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \times 100$$

where: $E_{max}$ = maximum peak-to-peak amplitude of the modulated carrier wave

$E_{min}$ = minimum peak-to-peak amplitude of the modulated carrier wave

2-33. An AM waveform is shown in figure 2-9. Using the formula, and the voltage given in figure 2-9, calculate the percent of modulation.

$$\% \text{ of modulation} = \frac{100 - 25}{100 + 25} \times 100$$

$$= \frac{75}{125} \times 100 = .6 \times 100$$

$$= 60\%$$

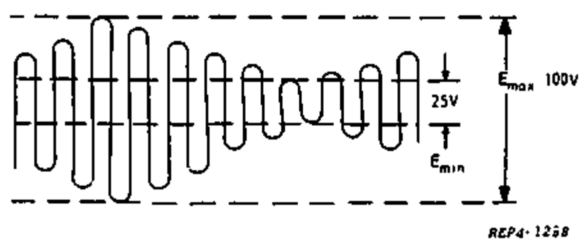


Figure 2-9. AM Composite Waveform Showing 60 Percent Modulation

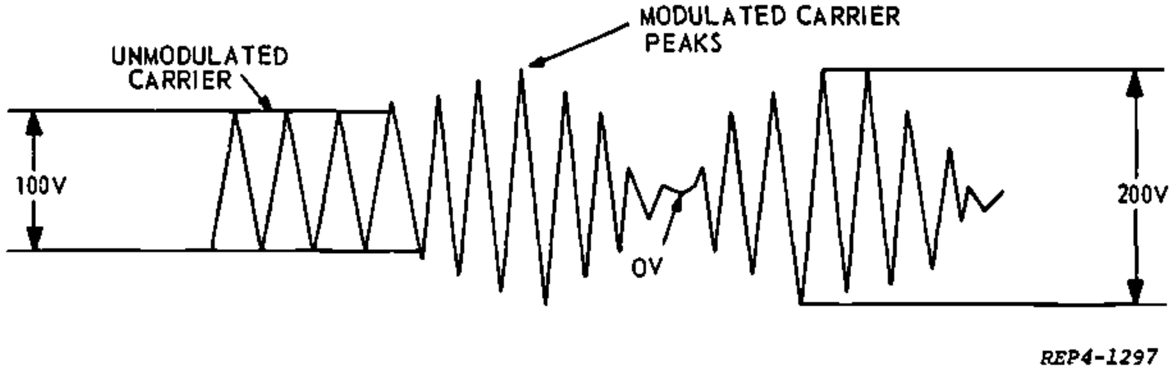


Figure 2-10. AM Composite Waveform Showing 100% Modulation

2-34. Now use the formula and the oscilloscope presentation in figure 2-10 to calculate the percent of modulation.

$$\% \text{ of modulation } = \frac{200 - 0}{200 + 0} \times 100$$

$$= 1 \times 100$$

$$= 100\%$$

2-35. A percent of modulation of less than 100% is under modulation. A percent of modulation greater than 100% is over modulation. Over modulation will produce severe distortion.

2-36. Close observation of the waveform in figure 2-10 shows the unmodulated carrier signal to be 100 V peak-to-peak, while the maximum peak-to-peak carrier voltage after modulation is 200 V. The minimum carrier voltage after modulation is 0 V. Recall in the composite waveform there were two new frequencies produced during the modulation process. These two frequencies contain the same intelligence, and are equal in amplitude. If the unmodulated carrier in figure 2-10 is 100 V peak-to-peak and the modulated carrier is 200 V peak-to-peak, then the sum of the sidebands must be 100 V peak-to-peak. Since these two signals are equal then each side frequency must be 50 V peak-to-peak.

2-37. With over modulation the BW of an AM signal will be increased considerably due to the severe distortion produced. This distortion produces new modulating frequencies which modulate the carrier and increase the bandwidth of the transmitted signal.

2-38. Figure 2-11A shows a modulating signal that is 150 V peak-to-peak, which is used to modulate a carrier signal that is 100 V peak-to-peak in figure 2-11B. Notice that during much of the negative half-cycle of the modulating signal, the amplitude of the modulated wave (figure 2-11B) is zero. Thus, the negative half-cycle of the modulating signal has been clipped. This then would cause unwanted harmonics of the modulating signal to be generated during the modulating process. These harmonics would appear as unwanted frequencies in the transmitted spectrum, thus, the BW of the transmitted signal is increased.

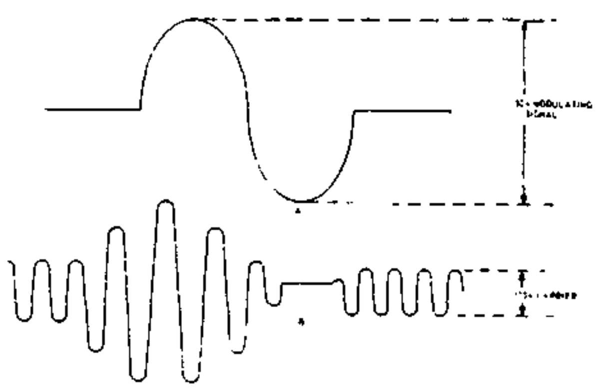

Figure 2-11. Over Modulating an AM Carrier

2-39. Power Distribution in the AM Wave.

2-40. The total power radiated in the modulated carrier wave is equal to the sum of the power contained in the separate components of the modulated wave.

2-41. From figure 2-12 we can calculate the total power transmitted for a 100 percent modulated carrier wave. Figure 2-12A shows the peak voltage contained in the carrier and each sideband. The resistance of the load is assumed to be 100 ohms. We know from earlier studies that to compute power we use the formula: $P = \frac{E^2}{R}$.

2-42. Using the voltage given for the carrier in figure 2-12A, calculate carrier power:

$$P = \frac{(100)^2}{100} = \frac{10000}{100} = 100 \text{ W}$$

Peak carrier power is equal to 100 W and is shown in figure 2-12B. The peak sideband power then would be found using the same formula and the peak amplitude of one sideband.

$$P = \frac{(50)^2}{100} = 25 \text{ W}$$

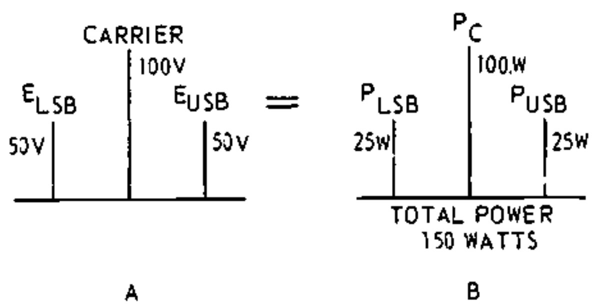


Figure 2-12. Power and Voltage at 100% Modulation

The power of the other sideband is the same or 25W. Total sideband power is the sum of the USB and LSB powers. We find the peak sideband power is equal to 50 watts. Total peak transmitted power then is found by adding carrier power to sideband power. Using the power given for the carrier and sidebands in figure 2-12B, total transmitted power equals 100 + 50 or 150 W.

2-43. Under modulation reduces total power by reducing the power in the sidebands.

2-44. Figure 2-13 shows the power distribution of an AM waveform modulated 50%. Using the power formula with the voltage given for the carrier in figure 2-13A, we find:

$$P = \frac{(100)^2}{100} = \frac{10000}{100} = 100 \text{ W}$$

The power in the carrier is still 100 W. Computing the power for each sideband using the values given in figure 2-13B gives 6.25 W for each sideband or the total sideband power is 12.5 W. Total power in the modulated waveform then is found by adding carrier power to sideband power. Total power is 112.5 watts.

From the preceding analysis of power distribution we find at 100 percent modulation:

a. Total sideband power is one half the carrier power.

b. The carrier contains two thirds of the total power.

c. Total sideband power is one third of the total transmitted power.

d. The sideband power is distributed equally in two sidebands.

e. Each sideband contains one sixth of the total power.

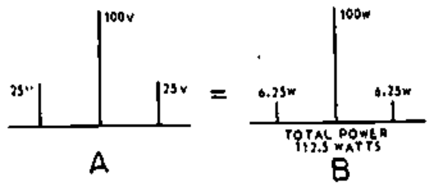


Figure 2-13. Voltage and Power Distribution at Fifty Percent Modulation. The Resistance of the Load is 100 Ohms

Reducing modulation to less than 100% (under modulation) gives:

a. No reduction in carrier power.

b. Less power in the sidebands.

c. Less total power.

2-45. Amplitude Modulation of Radio Frequency Signals.

2-46. Figure 2-14 shows an RF amplifier stage with an audio modulating signal applied to the collector circuit. In this circuit, the emitter-base is held constant and the voltage between the emitter and collector is varied at the modulating rate.

2-47. Assume there is a carrier signal applied through T1 to the base circuit of Q1, and there is no audio signal applied to T3. Because the stage is biased class B, transistor Q1 will conduct only on the positive alternation of the carrier input signal. The amplified output carrier pulses at the collector of Q1 then will cause the tank circuit, C2 and primary of T2, to oscillate at the carrier frequency. This unmodulated carrier signal is shown on the output waveform from $t_1$ to $t_2$.

2-48. When an audio modulating signal is applied through T3 to the collector circuit, the modulating voltage across the secondary transformer T3 is in series with the collector battery voltage $V_{CC}$. The positive half cycle of the audio signal voltage series aids battery voltage $V_{CC}$, increasing the emitter-collector voltage. The negative half cycle of the audio voltage series-opposes battery voltage $V_{CC}$, decreasing the emitter-collector voltage. When the emitter to collector voltage increases, the output of the RF amplifier increases; and when the emitter to collector voltage decreases, the output decreases. Looking at the waveforms from $t_2$ to $t_3$ (figure 2-14) we see the output of the amplifier increased on the positive half cycle of the modulating signal and decreased on the negative half cycle. Looking

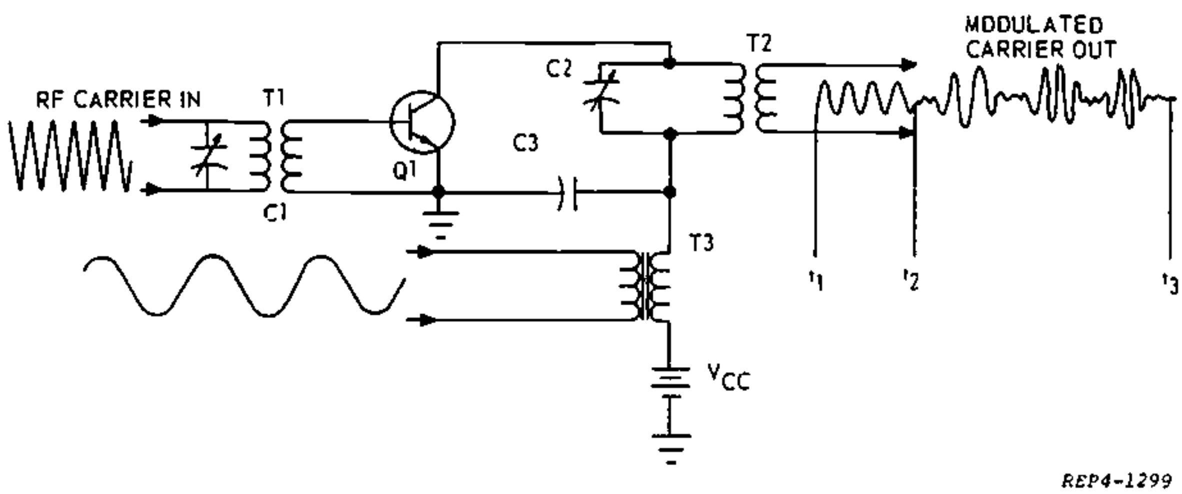


Figure 2-14. Simplified Circuit Using Amplitude Modulation

at the output RF waveform at $t_2$ to $t_3$ we see the amplitude variations resulting from the output of the amplifier increasing and decreasing.

2-49. Notice that the amplifier in figure 2-14 is being modulated 100%. Decreasing the amplitude of the modulating signal causes under modulation. Increasing the amplitude of the modulating signal would cause over modulation. The output modulated waveform at T2 contains the carrier frequency, the USB, and LSB.

2-50. Single-Sideband Modulation.

2-51. Single-Sideband (SSB) is a term used to describe the process of single-sideband communications operation and the equipment required for this type of operation. Within the transmitter of such a system the carrier is suppressed, either partially or completely and restored at the receiver. In single-sideband operation, only one sideband is transmitted.

2-52. From the preceding statement we can say that during SSB modulation:

a. a carrier is modulated with an intelligence signal.

b. the carrier is suppressed.

c. one of the resulting two sidebands is eliminated.

2-53. In conventional AM, the transmitter output contains the carrier frequency, a USB, and a LSB. If a filter was installed at the output of the transmitter to remove the carrier and one sideband, we would have SSB transmission.

2-54. This procedure is not a practical method to obtain a SSB signal. The waste of the transmitter power would be unjustified. A more practical method would be to modulate the RF carrier signal at some low power stage in the transmitter, suppress the carrier and one of the sidebands, then use the power amplifiers of the transmitter to amplify the remaining sideband. In this manner, maximum use of the available power of the transmitting system is insured. The process used to obtain SSB signals is called SSB generation.

2-55. Single-Sideband Generation.

2-56. To generate a single-sideband signal we need:

a. an intelligence signal.

b. a carrier signal.

c. a balanced modulator.

d. a sideband filter.

These items when properly connected together will produce a single-sideband signal.

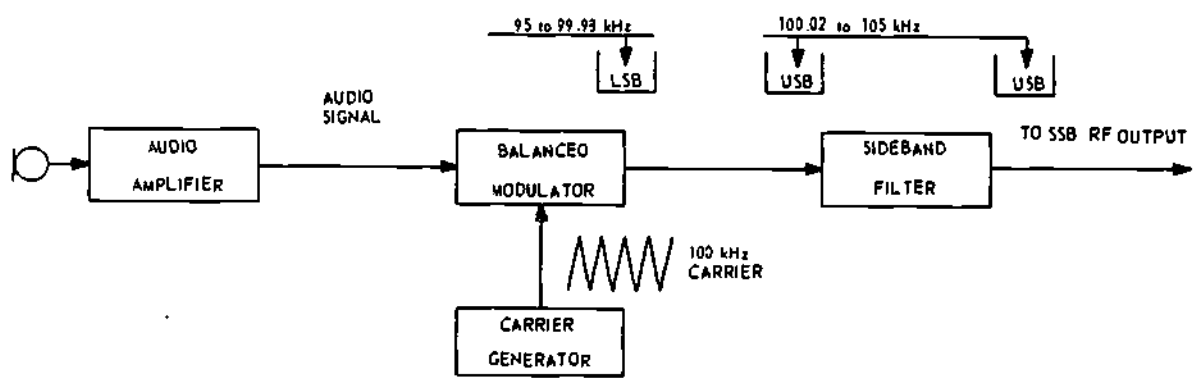


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Figure 2-15. Circuits Used to Generate a Single-Sideband Signal

Figure 2-15 is a block diagram showing a circuit connected to convert the intelligence signal, 20 Hz to 5 kHz, to a SSB RF signal.

2-57. Assume that the audio amplifier amplifies the audio signal from the microphone. This signal is coupled to the balanced modulator where it will modulate the 100 kHz carrier signal from the carrier generator. The audio and RF signals are then heterodyned in the balanced modulator to produce the LSB signal 95 to 99.98 kHz, and a USB signal 100.02 to 105 kHz. This double-sideband signal is applied to the sideband filter. Notice the carrier signal is not applied to the sideband filter. The sideband filter will select the one sideband signal. In this example, the USB was selected and the LSB was eliminated.

2-58. Carrier Elimination.

2-59. The balanced modulator circuit is shown in figure 2-16. Transformer T1 is used to couple the audio signal to points A and B. Transformer T2 couples both the USB and LSB outputs to R1. T3 couples the 100 kHz carrier signal to points C and D. Diodes CR1 through CR 4 have matched forward and reverse resistances. G1 generates the carrier signal.

2-60. We can use figure 2-16 to show how carrier elimination is accomplished in the balanced modulator. The primary of T2 is connected electrically across the bridge circuit at points A and B. Assume there is no modulating signal applied across T1, and the 100 kHz carrier signal is applied to T3 with the polarity shown in figure 2-16. This carrier signal applied to points C and D of the diode bridge will forward bias the diodes. The diodes conduct equally as shown by the arrows. There is also no difference in potential between points A and B. The conducting diodes represent a very low resistance, and there is no current flow through the primary of T2. When the carrier signal at the secondary of T3 reverses, point C on the bridge is positive and point D is negative. The diodes are reverse

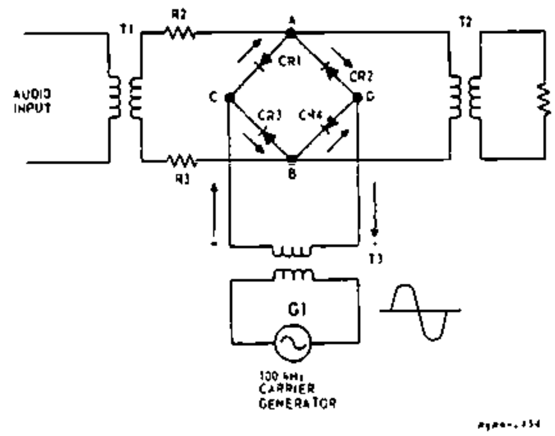



Figure 2-16. Modulator Circuit of a Single Sideband Generator

biased. Again, there is no difference in potential between points A and B, and carrier current does not flow through the primary of T2. The carrier signal was not coupled through T2 to R1, because the bridge in the modulator remained balanced. The carrier was suppressed.

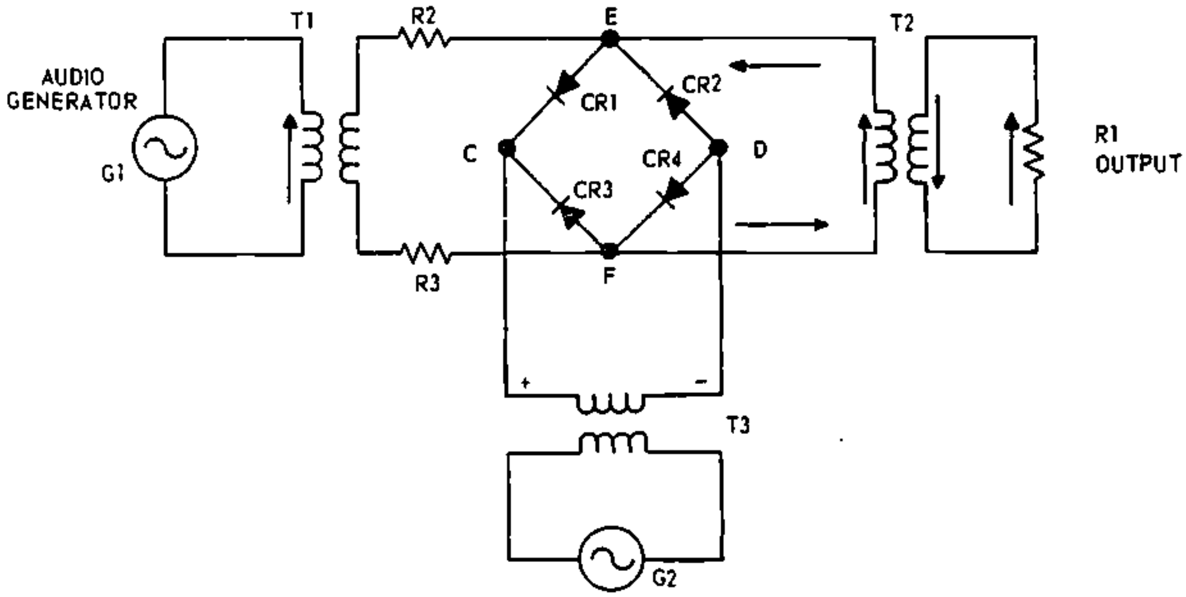
2-61. Within the balanced modulator the carrier signal causes the diodes to switch on and off at the carrier frequency rate.

2-62. Double-Sideband Output.

2-63. Figure 2-17 illustrates the action that occurs when the balanced modulator has an audio signal and an RF carrier signal applied simultaneously. Operation requires isolating impedances R2 and R3 to prevent interaction between the two signal sources.

2-64. The waveforms (figure 2-17 show one cycle of the audio signal with many cycles of the RF carrier signal on the same time axis, but not combined in the modulator. The positive and negative signals indicate the carrier polarity. For clarity, the peak value of the carrier is slightly greater than that of the voice signal; in actual operation the carrier signal is much greater.

2-65. When both waveforms (figure 2-17 are applied to the modulator, the diodes CR1, CR2, CR3, and CR4 will be reverse biased when the polarity of the carrier signal is as shown on T3. This polarity is shown as positive on the RF waveforms. Now the audio signal applied through T1 makes point E positive, and point F negative. Current flows in the circuit as shown by the arrows for the duration of the positive alternation of the carrier shown on the waveforms. On the next alternation of the carrier, the polarity of the secondary voltage at T3 becomes negative. The diodes are forward biased and the low forward resistance effectively places a short across the primary of T2 and prevents the signal from coupling through T2. This procedure is repeated for each carrier cycle.



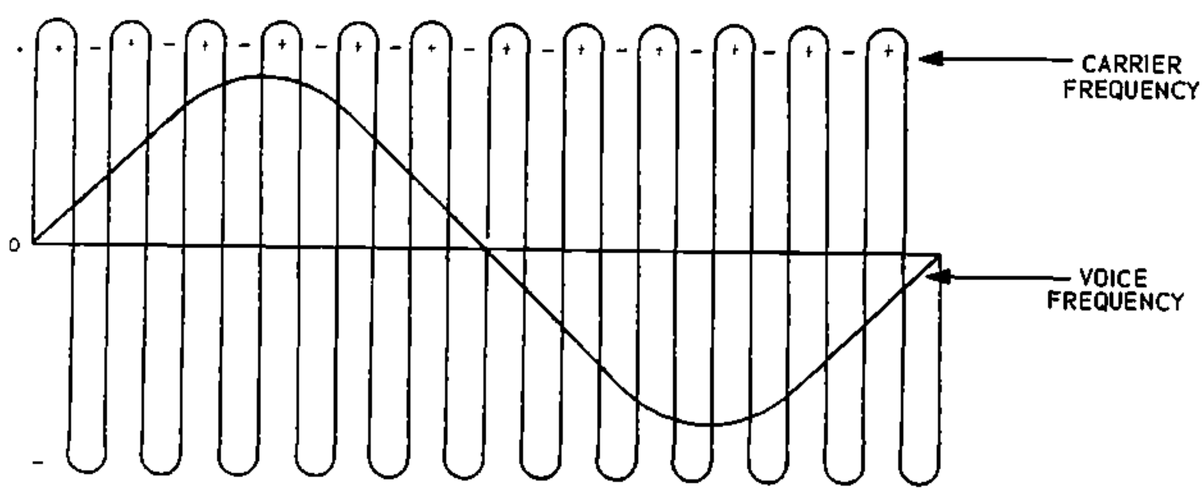




Figure 2-17. Modulator Circuit of a Single Sideband Generator with Waveforms

Figure 2-18. Waveforms of a Balanced Bridge Modulator

2-66. The shaded areas on the waveform in figure 2-18 show when the diodes are reverse biased and there is an output frcm the modulator. The unshaded areas show when the diodes are forward biased and there is no output from the modulator. The shaded areas also represent the amplitude polarity of the modulator output across R1 (figure 2-17).

2-67. The signal at the modulator output is shown in figure 2-19. The waveform contains the upper and lower sidebands. The carrier frequency is not in the output because carrier current does not flow in the primary of T2 (figure 2-17) at any time.

2-68. Sideband Filters.

2-69. Sideband filters are bandpass filters. Recall a bandpass filter allows only a selected band of frequencies to pass.

2-70. The filter can be of the LC, crystal, or mechanical type. A mechanical type filter is shown in figure 2-20.

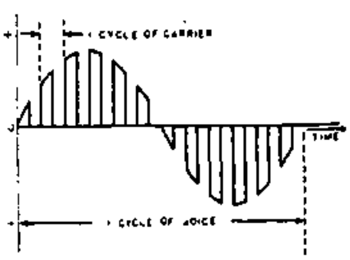


Figure 2-19. Modulator Output

The filter is a cylindrical arrangement with disk resonators interconnected by coupling rods. The mechanical filter is a resonant device, which receives electrical energy, converts it into mechanical energy, and then converts this mechanical energy back into electrical energy. The basic elements of this device are:

a. an input transducer which converts electrical energy into mechanical energy.

b. metal disks which are mechanically resonant.

c. coupling rods which couple energy between the disks.

d. an output transducer which converts the mechanical energy back into electrical energy.

2-71. The input and output transducers operate on the principle of magnetostriction. Magnetostriction is the property of certain ferromagnetic materials to change dimensions when placed in a magnetic field.

2-72. When a signal is applied to the input transducer coil, the driving rod will vibrate in accordance with the signal frequency. Since the rod is attached to the first resonant disk, these rod vibrations will excite the disk. The input signal is usually the two sidebands; maximum transfer of energy, however, will be at the resonant frequency of the disk. The bias magnet's magnetic field either aids or opposes the magnetic field set up by the input signal, and results in a more linear change in rod dimensions.

2-73. As the remaining disks are physically coupled to the first disk by the metal coupling rods, they will go into vibration. When the mechanical energy causes the last disk to vibrate, this motion is transferred to the output driving rod. This rod is also of magnetostrictive material and the variations in its length causes its permeability to vary. Since permeability is one factor that determines the number of magnetic lines of force, a variation in rod permeability will

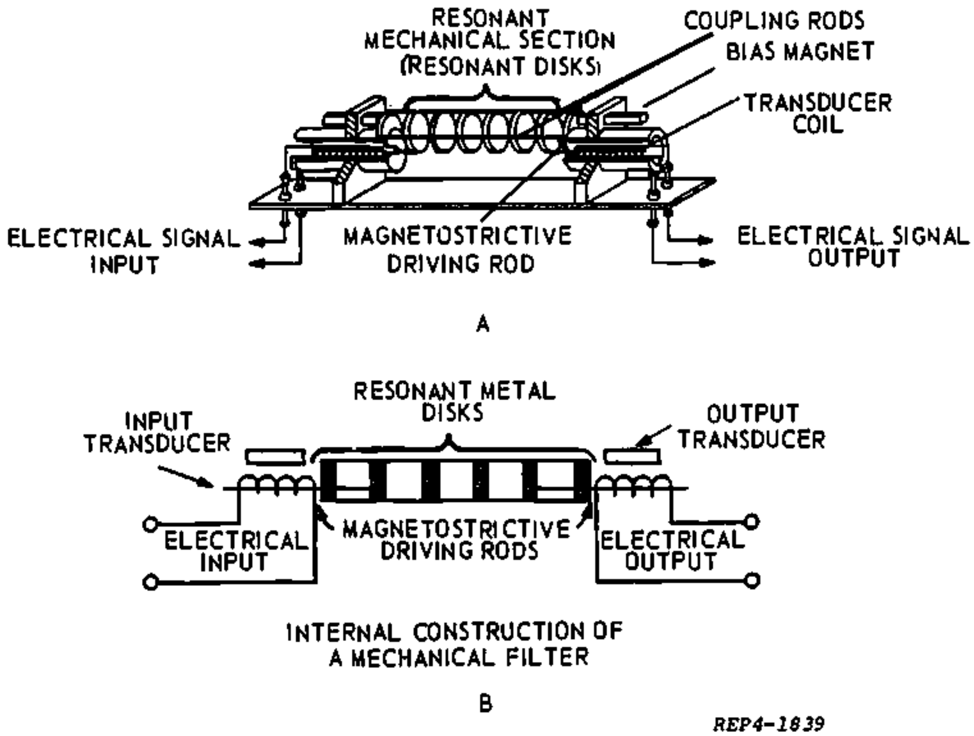



Figure 2-20. Mechanical Filter

vary the total number of flux lines in the output circuit. These varying flux lines, in turn, induce a voltage into the output coil. The output will be the desired sideband frequency.

2-74. Bandwidth of a Single-Sideband Signal.

2-75. The BW of the SSB signal is approximately one half the BW of the conventional AM signal. Figure 2-21A shows the transmitted spectrum of a conventional AM signal. Figure 2-21B shows the transmitted spectrum of a SSB signal. When the 100 kHz carrier signal of the conventional AM transmitter is modulated with the 20 Hz to 5 kHz signal the 100 kHz carrier, LSB 95 to 98.98 kHz, and the USB 100.02 to 105 kHz signal is transmitted. The BW required in the frequency spectrum is 10 kHz. When the SSB transmitters 100 kHz carrier signal is modulated with the same audio signal, only one sideband is transmitted. Thus, the BW required in the spectrum is 4.98 kHz.

2-76. The modulator in the SSB transmitter suppressed the 100 kHz carrier and the sideband filter eliminated one sideband.

2-77. Pulse Modulation.

2-78. Another type of amplitude modulation is Pulse Modulation (PM). PULSE MODULATION is defined as the modulation of a carrier by a pulse train. Pulse modulation is used for many things; from telegraphy to radar and telemetry to multiplexing. There are far too many applications of pulse modulation to elaborate on any one of them, but in this chapter we will cover the basic principles of pulse modulation.

2-79. In figure 2-22, observe the modulating square wave, and recall it contains an infinite number of odd harmonics in addition to its fundamental frequency. Assume that this square wave has a fundamental frequency of 1 kHz, and will be used to modulate an RF carrier signal of 1 MHz. When

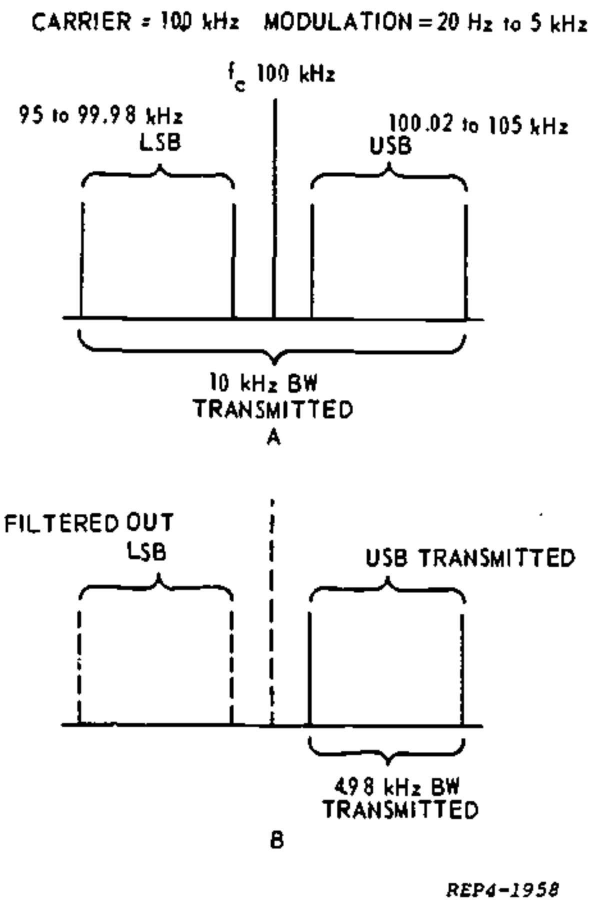



Figure 2-21. Bandwidth Comparison of Conventional AM and SSB Signals

these signals heterodyne, two frequencies will be produced-a sum frequency (1.001 MHz), and a difference frequency (.999 MHz). Not only will the fundamental frequency of the square wave heterodyne with the carrier, but all of the harmonics contained in the square wave will heterodyne with the carrier, and sum and difference frequencies associated with those harmonics are produced. For example, the third harmonic of the modulating square wave (3 kHz) when heterodyned with the carrier will produce an upper frequency of 1.003 MHz, and a lower frequency of .997 MHz. Another set of sum and difference frequencies are produced for the fifth harmonic of the square wave, and so on to infinity.

2-80. Sidebands.

2-81. Now refer to figure 2-22 and observe the relative amplitude of the sidebands as they relate to the amplitudes of the harmonics contained in the square wave. Notice the first set of sum and difference signals; these are directly associated with the amplitude of the square wave. The second set of sum and difference signals are related to the third harmonic content within the modulating square wave. The third set is associated with the fifth harmonic and is only one-fifth the amplitude of the first set of sum and difference signals. This rule will apply for each sum and difference signal to infinity. Notice the upper and lower sidebands (figure 2-22) are made up of the sum and difference signals produced during the modulation process.

2-82. Recall in AM when a carrier is modulated, the resultant complex waveform as viewed on an oscilloscope appears to change in amplitude. Figure 2-23A shows a carrier modulated with a square wave. The peak voltage of the square wave signal is less than the peak voltage of the unmodulated carrier signal. The resultant amplitude modulated carrier signal above the modulating square wave (figure 2-23A) increases in amplitude when the square wave is positive. Notice when the square wave is negative, the resultant modulated carrier wave decreases in amplitude. In figure 2-23B the modulating square wave is increased in amplitude; the RF peaks increase as the complex waveform increases during the positive alternation of the square wave and decreases during the negative half of the square wave. In figure 2-23C the amplitude of the square wave is further increased, until it is almost equal to the unmodulated carrier voltage. Notice the modulated wave is almost zero during the negative alternation of the square wave. Now refer to figure 2-23D where we increase the square wave modulating voltage so it is greater in amplitude than the carrier. Notice during the negative alternation of the square wave the modulated wave is not present.

2-83. In the frequency spectrum associated with each of these conditions, notice that the carrier amplitudes remain constant

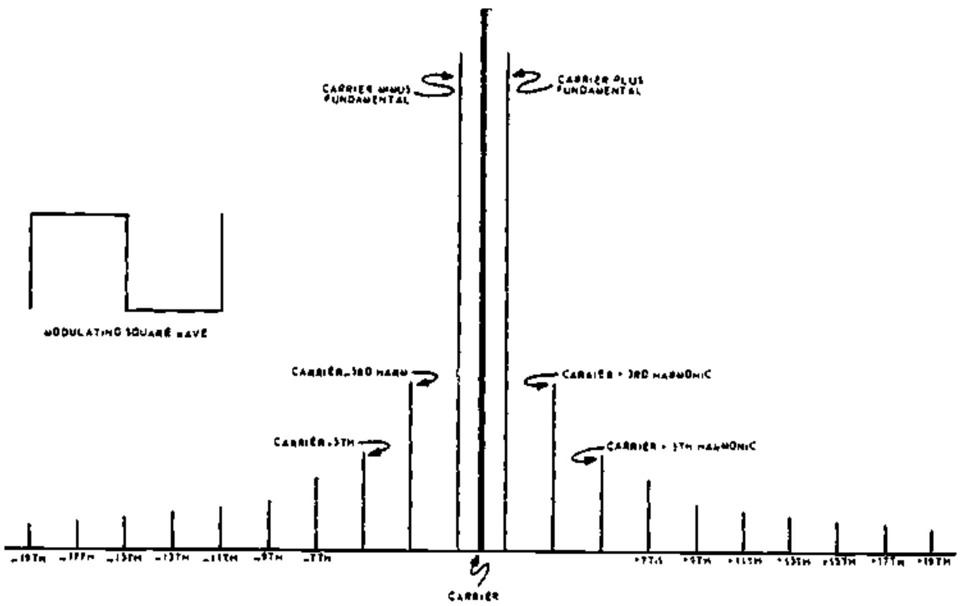



Figure 2-22. Spectrum Distribution When Modulating with a Square Wave

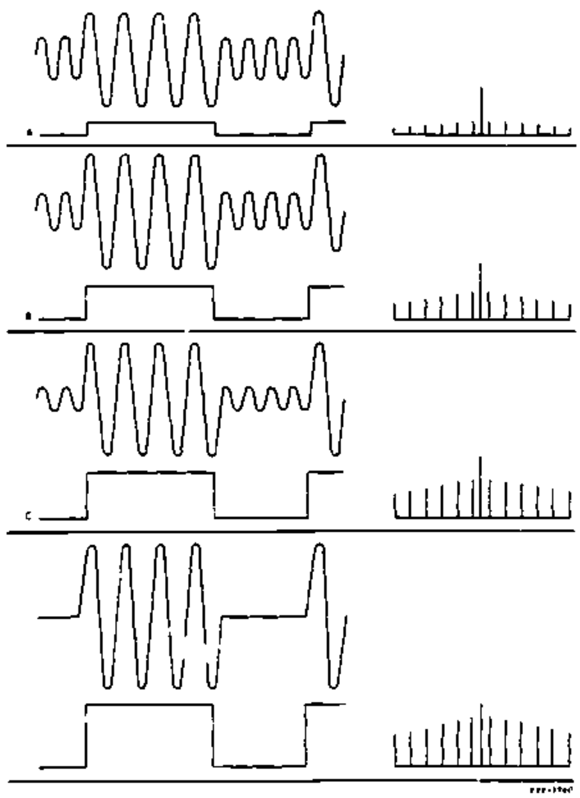


Figure 2-23. Various Square Wave Modulation Levels with Frequency Spectrum Carrier and Sidebands

in figure 2-23A, B, and C, but the sidebands are increasing in amplitude as the amplitude of the modulating square wave increases. In figure 2-23D, however, we increase the square wave modulating voltage so it is greater in amplitude than the carrier. Notice that the sideband distribution does not change, but as they take on more of the transmitted power, so will the carrier.

2-84. So far in pulse modulation the same general rules apply as in AM. In figure 2-23C where the peak amplitude of the square wave is about equal to the peak amplitude of the unmodulated carrier, we have about 100% modulation.

2-85. Recall in AM the bandwidth of the transmitted waveform was always two times the highest modulating signal frequency contained in the modulating waveform. The same holds true for PM.

2-86. Pulse Transmission.

2-87. Thus, far we have established a carrier; and then we caused its peaks to increase and decrease as a square wave is applied. Some pulse modulation systems modulate a carrier in this manner. Other systems produce no RF carrier until pulsed, and RF occurs during the pulse. As an example, look at figure 2-24 and establish a carrier frequency of 1 MHz. Each cycle of the RF energy requires a certain amount of time, if we allow oscillations to occur for a given period of time, only during selected intervals as shown in figure 2-24A, we are PULSING the system as shown in figure 2-24B.

2-88. Frequency Modulation.

2-89. FREQUENCY MODULATION (FM) is defined as angle modulation of a sinsusoidal carrier in which the instantaneous frequency of the modulated wave differs from the carrier frequency by an amount proportional to the instantaneous amplitude of the modulating signal. The modulating signal is the intelligence signal.

2-90. When a frequency-modulated wave is viewed on an oscilloscope, the frequency of the modulated wave can be seen to constantly change as the amplitude of the modulating signal changes while the amplitude of the modulated wave remains constant.

2-91. In frequency modulation the unmodulated carrier frequency is designated the center frequency.

2-92. Figure 2-25A shows a single sine wave of audio signal. This signal will be used to frequency-modulate an RF carrier signal. Figure 2-25B shows the resulting frequency-modulated waveform. Both waveforms have been drawn on a common scale with respect to time. From T0 to T1, there is no modulation of the RF carrier wave by the modulating signal. Thus, the carrier wave remains on the center frequency. During the T1 to T2 interval, the modulation signal increases from zero toward a maximum positive peak amplitude. The RF carrier wave departs from the center frequency, and increases toward a higher frequency. From T2 to T3, the modulating waveform decreases back to zero. The FM waveform decreases in frequency toward the center frequency. At T3, the modulated carrier will have the same frequency as the unmodulated carrier signal. From T3 to T4 the modulating waveform increases from zero to a maximum negative peak amplitude. The FM waveform will depart from center frequency

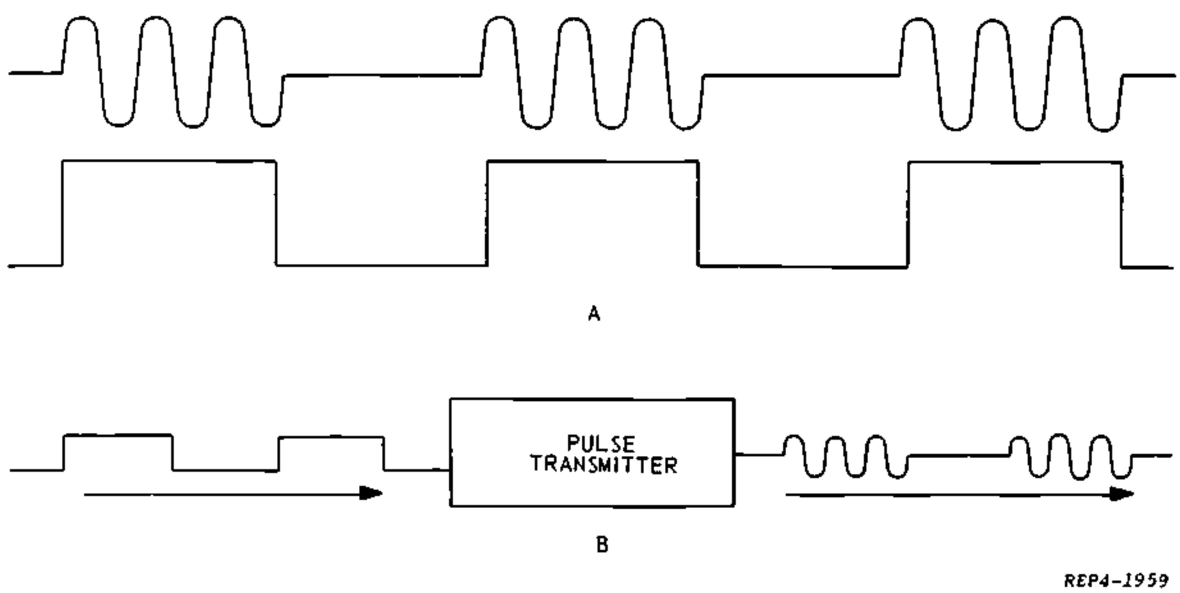



Figure 2-24. Pulse Transmission

and decrease to a lower frequency. From T4 to T5 the modulating signal will decrease from its maximum negative peak amplitude toward zero. The FM waveform will increase in frequency back toward the center frequency. From T5 to T6 there is no modulation, thus, the carrier frequency remains on the center frequency.

2-93. During the complete modulation cycle of the RF waveform in figure 2-25, we find that:

a. The center frequency was present only when there was no modulation applied, or the modulating signal has zero amplitude.

b. When the modulating waveform has a positive amplitude the frequency of the modulated waveform was higher than the center frequency.

c. When the modulating waveform has a negative amplitude the frequency of the modulated waveform was lower than the center frequency.

d. The amplitude of the modulated RF carrier did not change throughout the modulation process.

2-94. Frequency Deviation.

2-95. FREQUENCY DEVIATION is defined as the difference between the instantaneous frequency of the modulated wave and the carrier frequency.

2-96. In the FM transmitter the oscillator oscillates at the center frequency when there is no modulating signal from the modulator. An intelligence signal from the modulator will cause the oscillator to change frequency above and below the center frequency. Maximum deviation in oscillator frequency will occur at the voltage peak of the modulating signal.

2-97. The amount of deviation of the oscillator is determined by the amplitude of the modulating signal as shown in figure 2-26. The modulating signal with 2V peak amplitude is used to modulate a carrier signal of

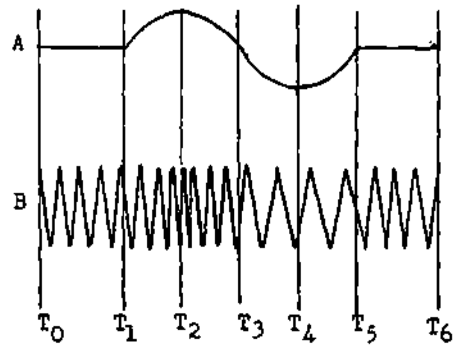



Figure 2-25. FM with a Modulating Signal

10 MHz. As the modulating signal increases its peak amplitude, the carrier oscillator frequency deviates from its center frequency to a maximum frequency of 10.1 MHz. As the modulating signal decreases in amplitude back to zero, oscillator deviation becomes zero. As the modulating signal changes to its maximum peak negative amplitude, the oscillator frequency deviates below its center frequency to 9.9 MHz. As the modulating signal goes from its maximum peak negative amplitude back to zero, the oscillator signal deviation decreases to zero. Using the 4 V peak amplitude modulating signal causes the carrier to deviate as previously explained. However, the oscillator deviates from its center frequency to 10.2 MHz, and back to the center frequency during the positive half cycle of the modulating

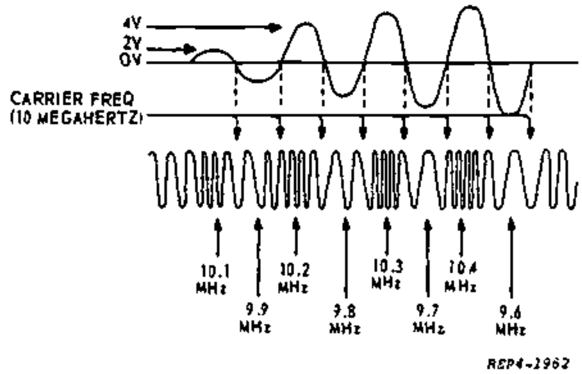



Figure 2-26. Deviation with Respect to Modulating Amplitude

signal. During the negative half-cycle of the modulating signal, the oscillator will deviate from the center frequency to 9.8 MHz and back to its center frequency.

2-98. Look again at figure 2-26 and see that the maximum amount the oscillator deviated from its center frequency using the 2 V peak amplitude signal was 100 kHz.

| | | |
|---|---|---|
| Maximum oscillator frequency | 10.1 | MHz |
| Oscillator center frequency | 10 | MHz |
| Maximum deviation | 100 | kHz |

When the 4 V peak amplitude signal was used, the maximum amount of deviation to the oscillator signal was 200 kHz. From this analysis we can conclude that maximum frequency deviation of the oscillator signal from its center frequency is determined by the peak amplitude of the modulating signal.

2-99. Rate of Frequency Changes.

2-100. The frequency of the modulating signal determines the frequency of deviation of the oscillator above and below the center frequency.

2-101. Notice that in figure 2-27 the frequency of the audio signal determines the rate of carrier frequency deviation. Figure 2-27A shows a high frequency audio signal used to modulate the RF carrier and figure 2-27B shows the same carrier modulated with a low frequency audio signal. Notice the modulating signal in figure 2-27A is twice the frequency of 2-27B. Also notice that the frequency of deviation is directly proportional to the frequency of the modulating signal. As the frequency of the modulating signal is increased the frequency of deviation will also increase.

2-103. The FM waveform contains an infinite number of sidebands. In FM a sideband must contain at least one percent of the total transmitted power to be a significant sideband. The number of significant sidebands determine the BW of the transmitted signal. The number of significant sidebands is determined by the modulation index (MI).

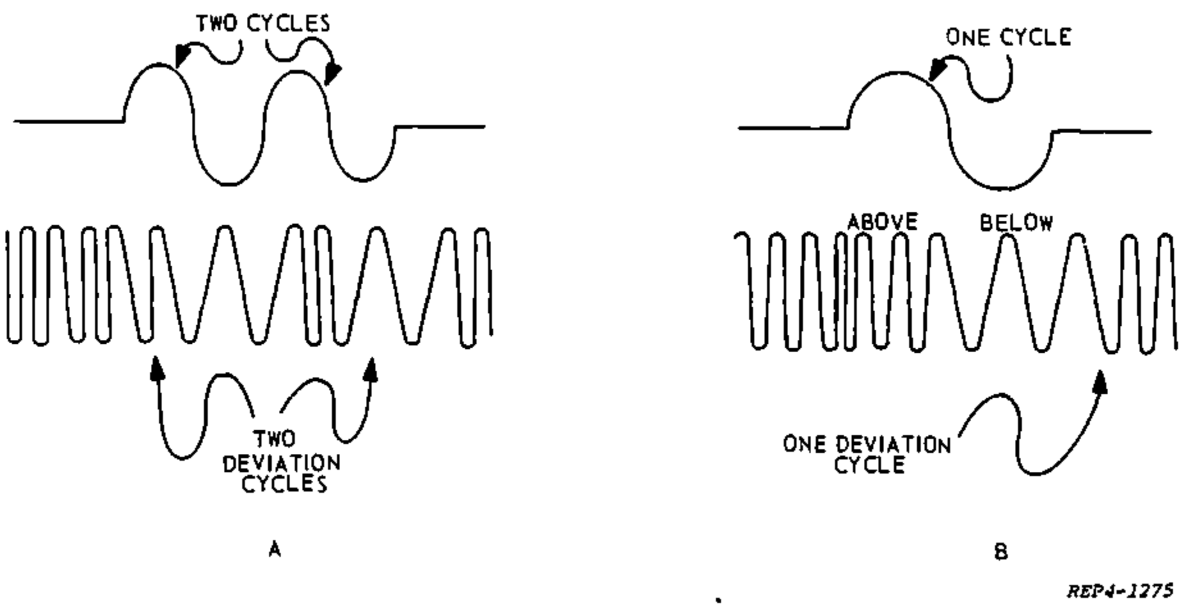



Figure 2-27. Rate of Frequency Deviation

2-104. MI is a ratio of the frequency deviation to the modulating signal frequency causing the deviation. The formula for MI is:

$$MI = \frac{f_d}{f_m}$$

where:

$f_d$ = frequency deviation

$f_m$ = frequency of the modulating signal

2-105. For example, assume we are using the 1 V modulating signal, and the frequency of the signal is 15 kHz. The 1 V modulating signal will cause the oscillator frequency to deviate 30 kHz from the oscillator center frequency. We see the MI is 2.

$$MI = \frac{30 \text{ kHz}}{15 \text{ kHz}} = 2$$

2-106. A question now is how do we use the MI to determine the number of significant sidebands? The chart in figure 2-28 lists the number of significant sidebands contained in the modulated waveform when the MI is known. For a MI of 2, there would be 8 significant sidebands, 4 USB and 4 LSB signals, in the transmitted spectrum.

2-107. Now, let's look at our transmitted spectrum. Figure 2-29 illustrates the frequency-modulated output spectrum for a MI of 2. The spectrum is the sum of the center frequency component and the sideband components. The center frequency component has the same frequency as the unmodulated carrier. The two components of the first sideband pair have frequencies respectively higher and lower than the center frequency by the amount of the modulating frequency. The second set of sidebands have frequencies respectively higher and lower than the center frequency by an amount of two times the modulating frequency. The third set is three times and the fourth set is four times the modulating frequency.

| MODULATION INDEX | SIGNIFICANT SIDEBANDS |
|---|---|
| .01 | 2 |
| .4 | 2 |
| .5 | 4 |
| 1.0 | 6 |
| 2.0 | 8 |
| 3.0 | 12 |
| 4.0 | 14 |
| 5.0 | 16 |
| 6.0 | 18 |
| 7.0 | 22 |
| 8.0 | 24 |
| 9.0 | 26 |
| 10.0 | 28 |
| 11.0 | 32 |
| 12.0 | 32 |
| 13.0 | 36 |
| 14.0 | 38 |
| 15.0 | 38 |

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Figure 2-28. Modulation Index Chart

2-108. Look again at figure 2-29 and note that the BW of the transmitted FM signal is 120 kHz. In FM, increasing the frequency or amplitude of the modulating signal increases the BW of the transmitted signal.

2-109. Reactance Tube Modulator.

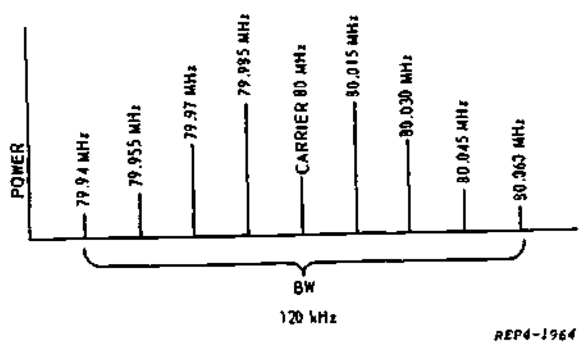


Figure 2-29. Spectrum Distribution for a Modulation Index of "2"

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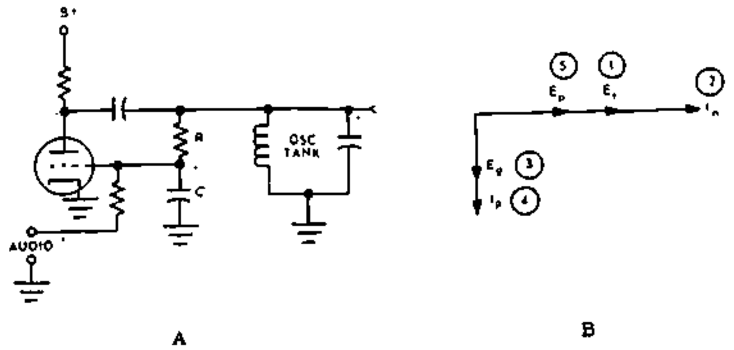


Figure 2-30. Reactance Tube Modulator (Inductive Reactance)

2-110. Observe the basic circuit (figure 2-30A), and notice the arrangement of R and C in the circuit. This network is a phase shifting network and the heart of the reactance tube circuit. The resistance of R is much larger than the capacitive reactance of C. This causes the circuit to act resistively to the RF.

2-111. Now examine the effects of this arrangement:

a. The tank voltage ($E_t$) will establish the reference vector as shown in figure 2-30B.

b. Since the tank is in parallel with the RC network, the current in the network ($I_n$) will be nearly in phase with the tank voltage. (Remember that the network is primarily resistive.)

c. Network current ($I_n$) will develop a voltage across C that lags current $I_n$ by 90°. The voltage developed across C is the grid voltage ($E_g$) for the reactance tube.

d. Grid voltage ($E_g$) and plate current ($I_p$) are in phase, and both lag $E_t$ by 90°.

e. Since the tube is in parallel with the tank, the plate voltage ($E_p$) of the tube is in phase with the tank voltage ($E_t$). Since $I_p$ lags $E_p$ by 90°, the tank sees the reactance tube circuit as an inductor placed in parallel with the tank.

2-112. Now, consider what happens when an audio voltage is applied to the input jack. On the positive alternation, reactance tube current will increase, and the inductive reactance reflected to the tank decreases (figure 2-31). When inductive reactance decreases, the resonant frequency of the tank increases.

2-113. When the audio input goes negative current decreases. The inductive reactance then increases, and the tank frequency decreases (figure 2-32).

2-114. Now, consider a circuit which simulates capacitive reactance instead of inductive reactance. To do this, the phase shifting network changes, as shown in figure 2-33. Note that the capacitor is now between the

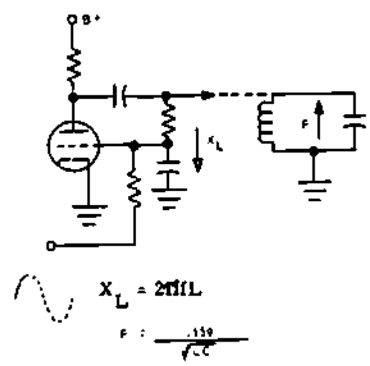


Figure 2-31. Reactance Tube Modulator With Positive-Going Input

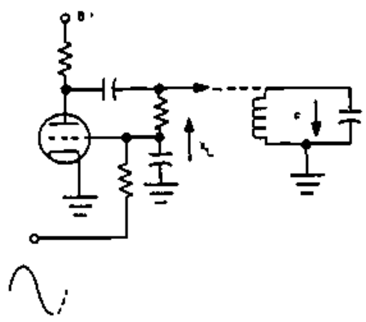

Figure 2-32. Reactance Tube Modulator with Negative-Going Input

plate and grid, and the resistor is between grid and ground. Another change has been made to the circuit that does not show in the diagram - the capacitive reactance is now much greater than the resistance. The circuit will now act in the following manner.

a. Tank voltage will again be the reference vector.

b. Since the RC network is now capacitive, the network current will lead tank voltage by nearly 90°.

c. Voltage across the resistor will be in phase with network current and lead tank voltage by nearly 90°. This voltage is felt on the grid ($E_g$). (Tank voltage is the voltage across the capacitor which lags network current by 90°.

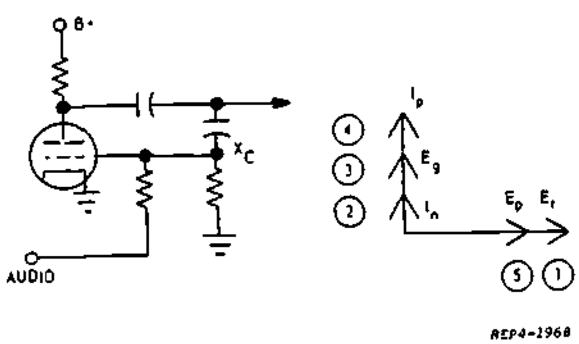


Figure 2-33. Reactance Tube Modulator (Capacitive Reactance)

d. Since plate current and grid voltage are in phase, plate current will lead plate voltage by 90°.

e. Plate voltage ($E_p$) will be in phase with tank voltage since the tank and tube are conncected in parallel.

2-115. You can see by this vectoral analysis that $I_p$ leads $E_p$ by 90°. The circuit is therefore, acting capacitively, and reflects a capacitive reactance to the tank. This circuit, acts differently from the inductive circuit, because inductive and capacitive reactances differ:

$$X_L = 2\pi fL$$

and

$$X_C = \frac{1}{2\pi fC}$$

2-116. In the capacitive circuit, a positive voltage from the intelligence source will cause the output frequency to decrease, while a negative voltage will increase output frequency.

2-117. Varactor Modulator.

2-118. Another FM modulator which is widely used in transistorized circuitry employs a voltage variable capacitor, called a VARACTOR. The varactor is simply a diode, or a PN junction, designed to have a certain amount of capacitance across the junction. Figure 2-34 shows the schematic symbol and a diagram of a varactor in a simple oscillator circuit. (This is not a working circuit, but merely a simplified illustration.) The capacitance of a varactor, as with all capacitors, is determined by the area of the capacitor plates and the distance between the plates. The depletion region in the varactor determines the distance (dielectric) between the P and N elements (plates).

2-119. In all PN junctions when reverse bias is varied, we change the thickness of the depletion region, and thereby, the

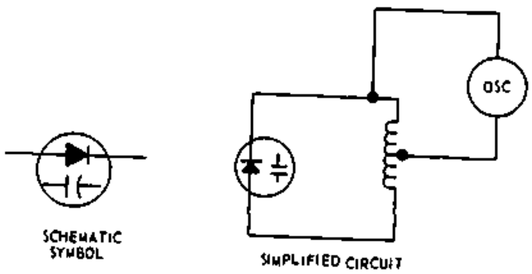


Figure 2-34. Varactor Symbol and Schematic

capacitance changes. The varactor is designed so the change in the capacitance is linear with a change in the applied voltage. Proper circuit design prevents the application of forward bias.

2-120. Notice the simplicity of operation of the circuit in figure 2-35. An audio signal applied to the input results in the following action:

a. On the positive alternation, reverse bias increases and the dielectric (depletion region) width increases. This decreases capacitance, which increases the frequency of the oscillator.

b. On the negative alternation of the audio signal, the reverse bias decreases, resulting in an oscillator frequency decrease.

2-121. Phase Modulation.

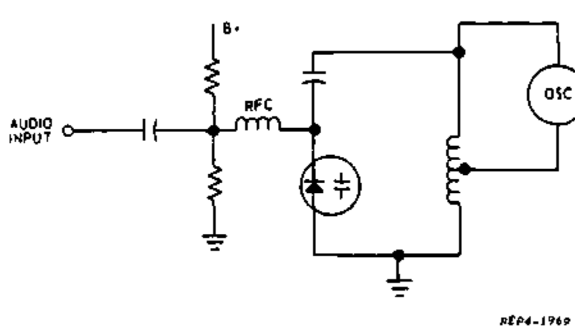


Figure 2-35. Varactor FM Modulator

2-122. In FM, the transmitter oscillator changes frequency above and below the center frequency as the modulating signal is applied. In phase modulation (PM), the transmitter oscillator frequency is not changed during modulation. In fact the PM system usually employs a crystal oscillator.

2-123. Phase modulation implies that the phase angle of a carrier is varied in accordance with the modulating audio voltage, whereas the current amplitude of the resulting phase modulated wave is maintained constant.

2-124. When a phase-modulated wave is viewed on an oscilloscope, it has the appearance of a frequency-modulated wave; namely, the phase-modulated wave appears to vary in frequency and has a constant current amplitude. Thus, as in a frequency-modulated wave the power in the phase-modulated wave does not vary.

2-125. A PM wave is produced by shifting the phase of the carrier with respect to the modulating voltage while maintaining the amplitude of the carrier constant. A transmitter utilizing phase modulation uses phase-shifting circuits following the oscillator which, to accomplish modulation slows down or speeds up the frequency of the carrier.

2-126. Figure 2-36A illustrates the unmodulated RF carrier. The amplitude and frequency of the carrier are constant.

2-127. Figure 2-36B illustrates a sine-wave audio voltage which modulates the carrier. During time interval A to B no modulating voltage is applied to the carrier. During time interval B to C the single sine-wave of audio voltage modulates the carrier.

2-128. Figure 2-36C illustrates the phase shifting of the carrier to the resulting phase-modulated wave. The unmodulated carrier is represented as a thin line. The thin line wave is used as the reference wave to show the phase shifting of the carrier to the resulting phase-modulated wave. The resulting phase-modulated wave is represented by the heavy-line wave in figure 2-36C.

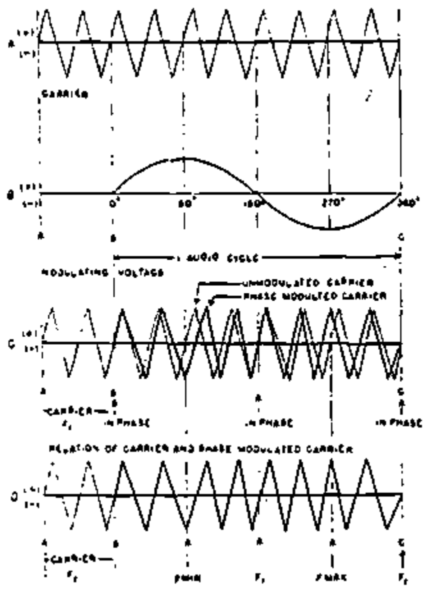

Figure 2-36. The Phase-Modulated Wave

2-129. In figure 2-36D we see the resulting phase modulated waveform. This waveform is the output waveform of the phase modulator. Notice during time interval from A to B when the carrier is not modulated, the output of the modulator is the carrier frequency ($F_C$). During the time interval from B to C the carrier is modulated and the resulting output waveform of the modulator is seen to be varying in frequency.

2-130. Notice when the carrier is modulated by the positive half cycle of the modulating signal in figure 2-36B (0° to 180°), the phase of the modulated wave in figure 2-36C lags the phase of the original reference carrier. Likewise, when the carrier is modulated by the negative half cycle of the modulating voltage in figure 2-36B (180° to 360°) the phase of the modulated wave in figure 2-36C leads the phase of the original reference carrier.

2-131. The rate at which a phase-modulated wave shifts from one phase value to another is proportional to the frequency of the modulating voltage. The higher the frequency, the more rapidly the phase of the modulated wave shifts from one phase value to another.

2-132. The number of degrees through which the phase of the carrier is shifted is proportional to the amplitude of the modulating voltage. The greater the amplitude of the modulating voltage, the greater the number of degrees through which the phase-modulated carrier is shifted during modulation.

2-133. Sidebands in Phase-Modulation.

2-134. When an RF carrier is modulated in phase modulation we generate sidebands. The sidebands produced in phase-modulation are spaced on either side of the carrier signal by an amount equal to the modulating signal frequency. These sidebands contain the intelligence.

2-135. The amplitude of the modulating signal determines the number of significant sidebands in phase-modulation. Increasing the amplitude of the modulating signal increases the number of significant sidebands.

2-136. Increasing the frequency of the modulating signal leaving amplitude constant will not increase the number of significant sidebands.

2-137. Figure 2-37A shows the spectrum for a carrier modulated with a 10 kHz signal. Figure 2-37B shows the spectrum for a carrier modulated with a 5 kHz signal. Both modulating signals had the same amplitude. Notice there are 10 significant sidebands in each spectrum. Also notice only the BW of the transmitted spectrum changes as the frequency changes. In PM, increasing the frequency or amplitude of the modulating signal increases the BW of the transmitted signal.

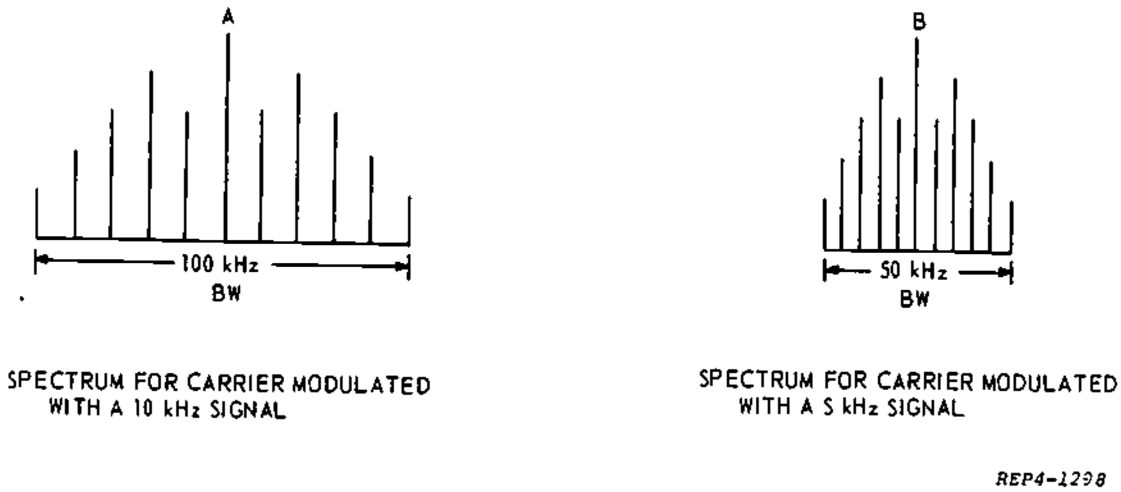


Figure 2-37. PM Spectrum

Chapter 3

# DEMODULATION

3-1. One of the functions of a radio receiver is the demodulation of a radio wave picked up by the receiving antenna.

3-2. Demodulation is the process of extracting the signal intelligence from a modulated carrier wave.

3-3. Recall the modulated waveform at the transmitter did not contain the original intelligence signal as a distinct frequency. The intelligence was carried in the sideband signals. The sideband signals were the new signals produced during the modulation process. The original intelligence signal must be recovered from the modulated waveform at the receiver. This is the purpose of demodulation.

3-4. The requirements for demodulation are as follows:

a. The demodulator input circuit must be sensitive to the modulation characteristics.

b. Nonlinearity must be present to cause heterodyning.

c. An RF carrier signal must be present at the input of the demodulator to heterodyne with the sideband signals to reproduce the original intelligence signal.

d. Filtering is required at the output of the demodulator to select the desired intelligence signal and reject the unwanted RF frequencies.

3-5. AM Demodulation.

3-6. AM demodulation is the process of extracting the signal intelligence from an AM carrier.

3-7. An amplitude modulated RF carrier can be demodulated by several types of demodulators. The circuits which demodulate AM signals are called detectors.

3-8. Diode Detector.

3-9. The diode detector circuit shown in figure 3-1A meets the requirements for AM demodulation. The input tank circuit L2 and C1 will be tuned to the carrier frequency. This tank circuit will be tuned so that its BW is wide enough to pass all of the signals contained in the complex waveform. The diode tube will furnish the nonlinearity required for heterodyning. C2 will be used to filter out the unwanted components after heterodyning takes place. R will develop the intelligence signal.

3-10. Assume that we have modulated a 455 kHz carrier signal with a 5 kHz modulating tone at the transmitter. The transmitted waveform would contain the original carrier signal of 455 kHz, the USB signal 460 kHz, and the LSB signal 450 kHz. This transmitted waveform is also the received waveform present at the input to the detector and is shown in figure 3-1B.

3-11. Current flows through the diode when the plate is positive with respect to the cathode. As a result of this rectifying action the output waveform present at the cathode will be a series of RF current pulses as shown in figure 3-1C. The output waveform contains frequencies other than the carrier and sideband frequencies contained in the input waveform. They are:

a. 905 kHz, the sum of the carrier and LSB signal.

b. 915 kHz, the sum of the carrier and USB signal.

c. 5 kHz, the difference between the carrier and sideband signals.

3-12. The filter capacitor C2 selects the 5 kHz signal by charging very rapidly to nearly the peak value of the applied RF voltage, as indicated by point A in figure 3-1D. As the applied RF voltage falls below its peak value,

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C2 begins to discharge very slowly through R as indicated at point B. When the peak RF voltage on the next cycle exceeds the peak voltage of the previous cycle, the capacitor charges up to a higher potential shown at point C. This action continues through the two complete output waveforms in figure 3-1C. Thus, the filtered output across C2 is a DC voltage that varies at the audio frequency rate of 5 kHz shown by the solid black line in figure 3-1D.

3-13. Although the curve of the average DC output voltage appears to be somewhat jagged, the RF component can be made negligible, and the modulating signal originating at the transmitter can be faithfully reproduced.

3-14. The RF components contained in the waveform are filtered out because C2 charges rapidly through the diode and discharges slowly through R.

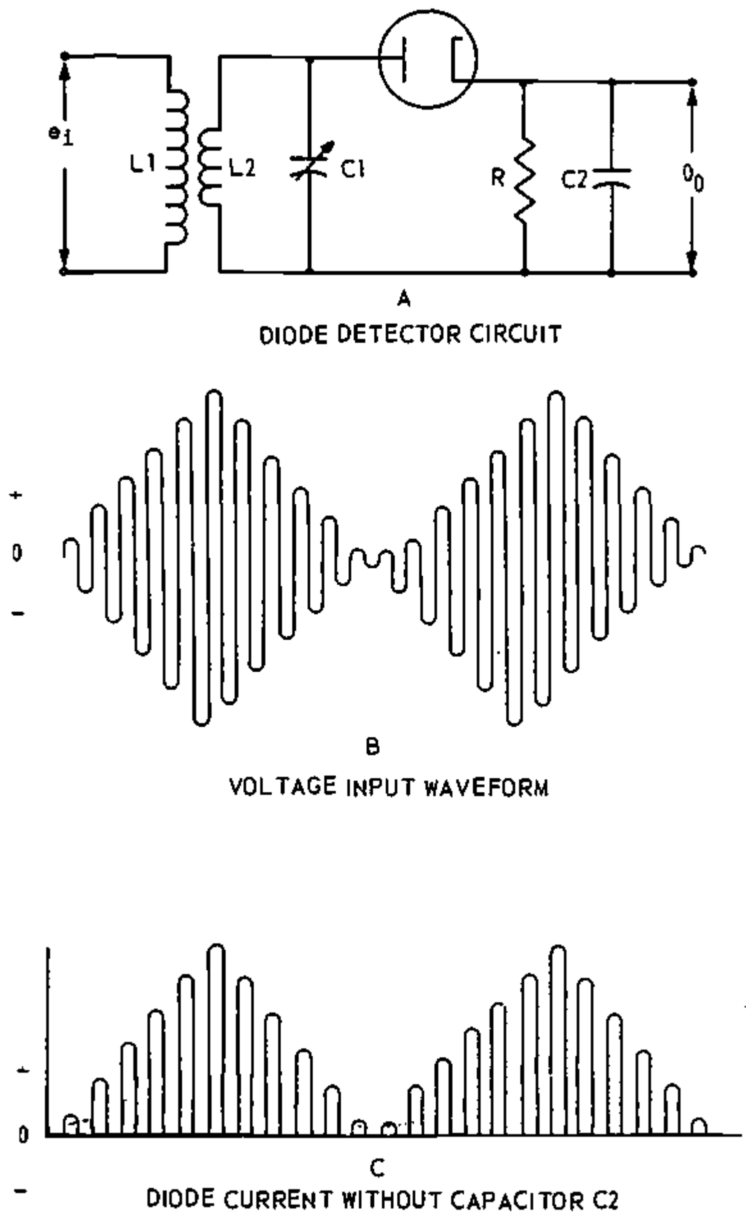


Figure 3-1. Diode Detector Circuit and Waveforms

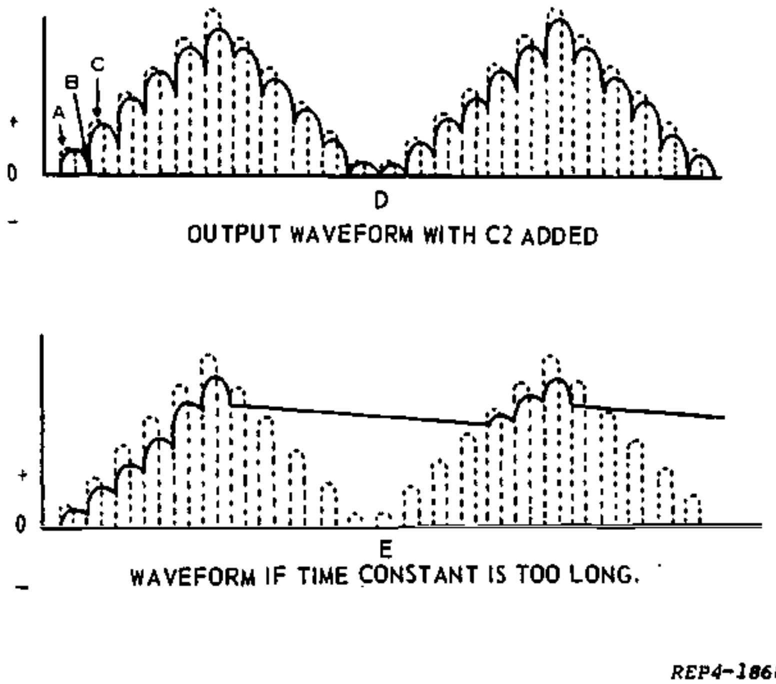


Figure 3-1. Diode Detector Circuit and Waveforms (Continued)

3-15. Grid Leak Detector.

3-16. The grid leak detector in figure 3-2 functions like the diode detector combined with a triode amplifier. However, it is convenient to consider detection and amplification as two separate functions. The grid of the triode tube will function as the detector plate. The triode section then provides amplification of the detected signal.

3-17. The circuit components of the grid leak detector satisfy the requirements for demodulation. The input circuit L2 and C1 will be sensitive to the modulated carrier. Nonlinearity is provided by the diode section because the grid leak bias network R1 and C2 will cause heterodyning within the grid circuit. Filtering of the RF signals from the output is accomplished by C3 and L3.

3-18. The input signal is applied through T1. The grid leak capacitor charges very rapidly through the small grid to cathode resistance during the peaks of the positive half cycles. During the negative half cycles of the RF input signals, the grid capacitor discharges very slowly through R1. This clamping action of the grid leak bias then causes the grid to cathode waveform shown in figure 3-2. The grid to cathode waveform contains the original RF components of the input waveform, the sum and difference frequency. The grid waveform is amplified by the triode section of the electron tube. The plate voltage waveform is the result of the filtering of the RF components by C3 and L3. The output voltage waveform is the received intelligence signal.

3-19. In the grid leak detector, the input impedance is low because grid current must flow to perform the heterodyning action within the grid circuit.

3-20. Plate Detector.

3-21. The plate detector shown in figure 3-3A has a high input impedance because grid current does not flow during the entire input cycle of RF variations at L1.

3-22. The circuit components satisfy the requirements for amplitude demodulation. The tank circuit L2 and C respond to amplitude variations. Heterodyning occurs within

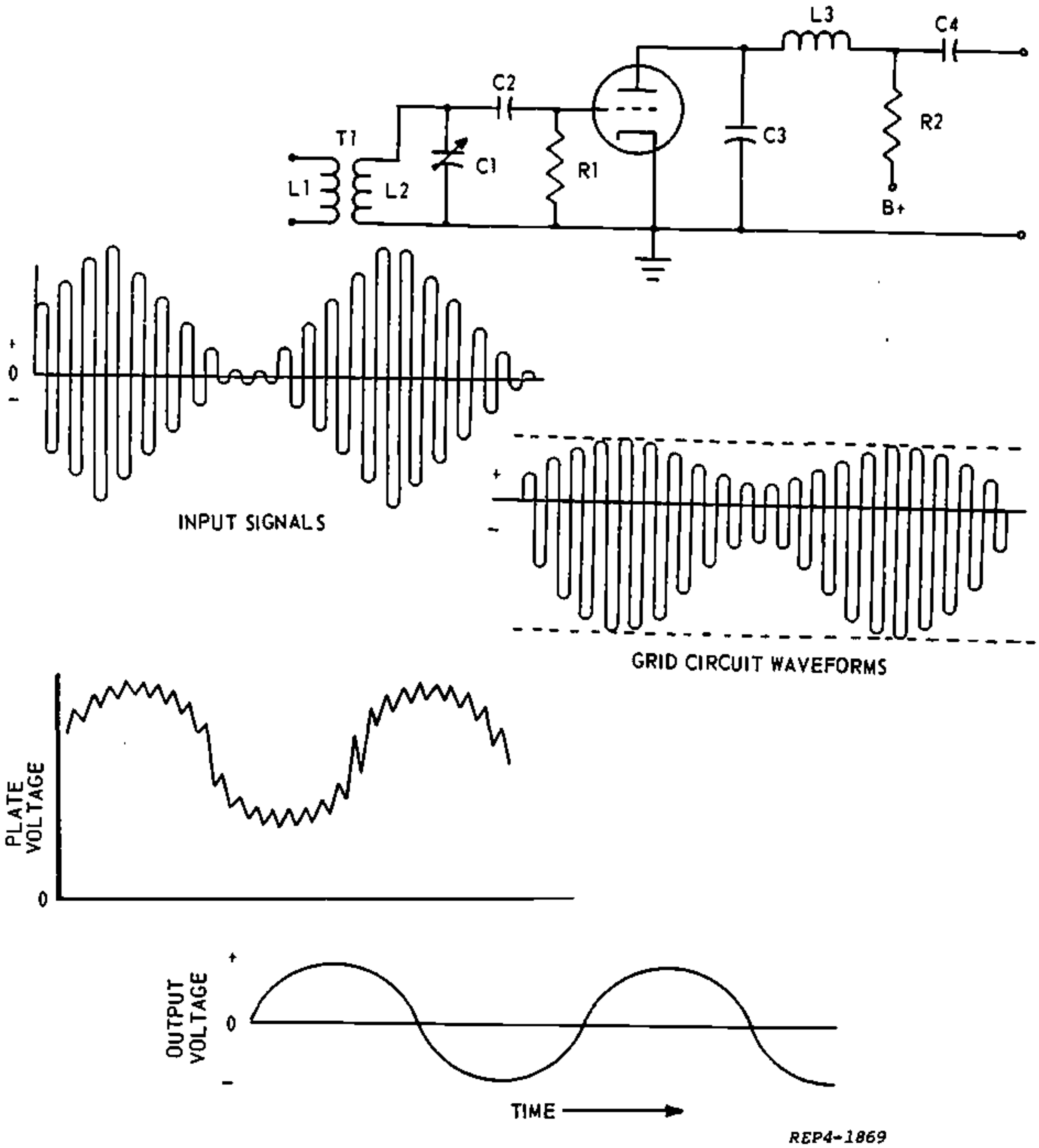


Figure 3-2. Grid-Leak Detector, Schematic and Waveforms

the triode tube because the cathode self bias resistor is large enough to insure the stage will be biased at approximately cutoff. Cathode bypass capacitor C1 is large enough to hold the voltage across R1 steady at the lowest audio frequency detected. Filtering is accomplished by C2 and L3.

3-23. The action of the plate detector may be demonstrated by the use of the tube characteristic curve and waveforms in figure 3-3B. On the positive half-cycle of the RF input signal, the plate voltage falls below the B+ supply voltage because of the increased drop across R2 and L3. C2

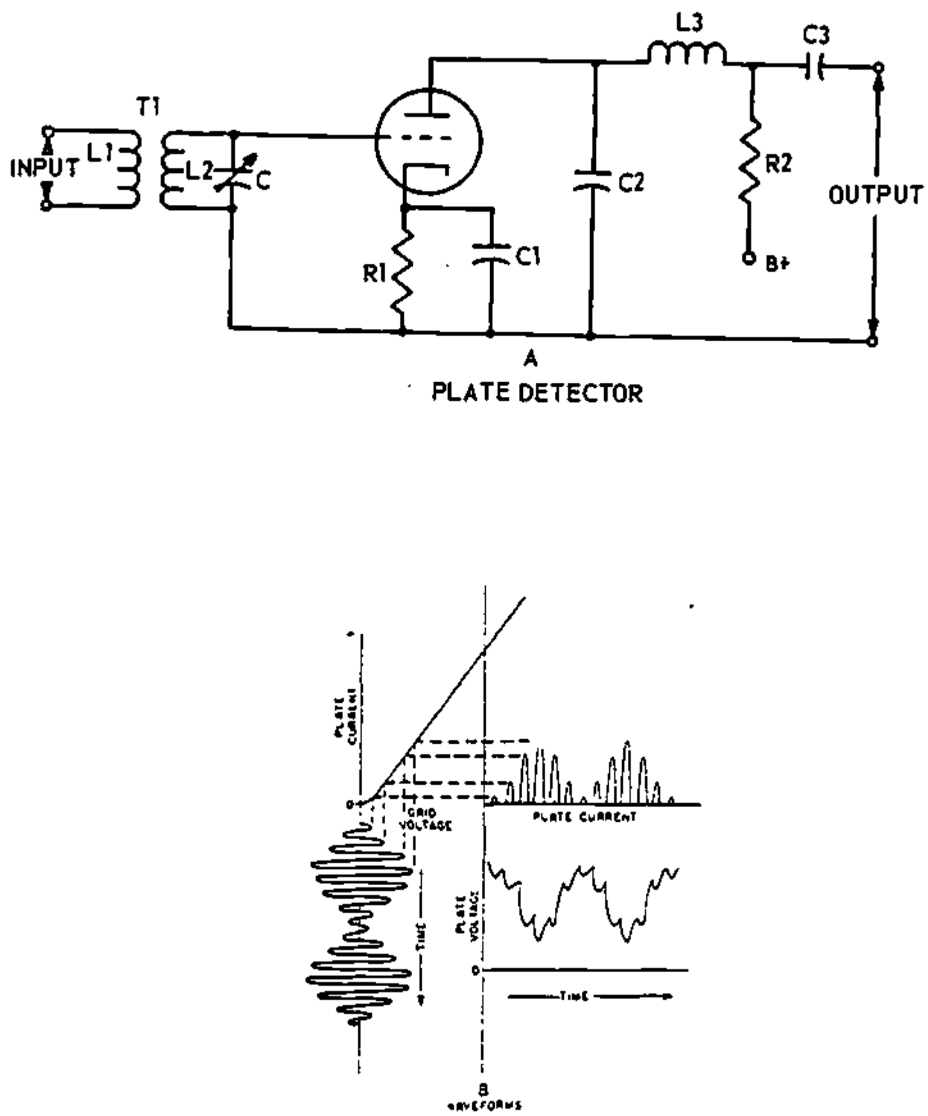


Figure 3-3. Plate Detector Schematic and Waveforms

discharges through the conducting tube. Thus, plate current is furnished by C2 rather than the B+ supply. The drop across R2 and L3 is limited and the decrease in plate voltage is slight. On the negative half-cycle of the RF input signal, the plate current is cutoff and the plate voltage rises. C2 charges through L3 and R2. The drop across R2 and L3 limits the rise in plate voltage; thus, C2 resists a voltage change at the RF rate. Because C2 and R2 have a short time constant with respect to the lowest audio frequency signal, the voltage across C2 will vary at the audio frequency output.

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3-24. Infinite Impedance Detector.

3-25. The infinite impedance detector shown in figure 3-4 resembles the plate detector with the exception that the load resistor R1 is connected from the cathode to ground. This arrangement makes the infinite impedance detector essentially a cathode follower.

3-26. The circuit components satisfy the requirements for amplitude demodulation. The tank L2 and C1 respond to amplitude variations. The input impedance is extremely high. therefore, grid voltage remains negative even for the strongest input signals. Filtering of the RF components from the output provided by C2. Filtering of radio frequencies and audio frequencies from the B+ power supply is provided by C3 and R2 in the plate circuit.

3-27. Single Sideband Demodulation.

3-28. Recall that in the generation of SSB signals the carrier is suppressed. The transmitted intelligence is either a USB or an LSB. Thus, the reference carrier is not present in the received waveform. Before detection of the SSB signal can take place; the carrier signal must be restored at the receiver. The carrier signal must be at least ten times the amplitude of the received single-sideband signal. This ratio of the two signals prevents distortion of the intelligence signal at the detector output.

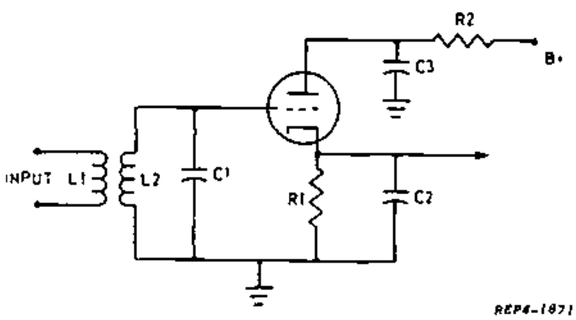



Figure 3-4. Infinite Impedance Detector

3-29. Observe figure 3-5 and assume an original carrier signal frequency of 100 kHz is modulated with an intelligence signal of 5 kHz at the SSB transmitter. Assume the USB (105 kHz) was transmitted. This 105 kHz RF signal is the input signal at G3. The crystal oscillator V2 must furnish the 100 kHz carrier signal at G1. These two signals when heterodyned together in V1 will produce four signals in the V1 output. The are:

105 kHz, the original USB signal.

100 kHz, the carrier oscillator signal.

205 kHz. the sum of the USB and carrier oscillator signal.

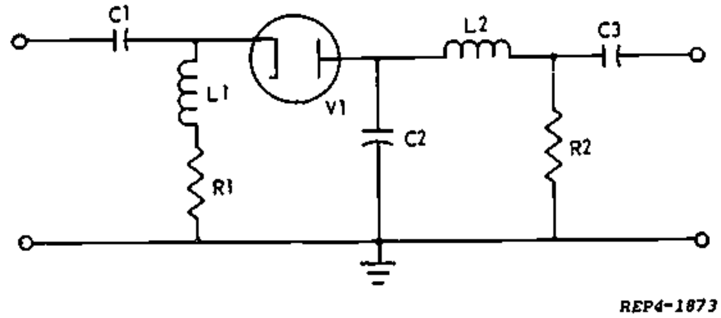
5 kHz, the difference frequency of the USB and carrier oscillator signal.

The capacitor C filters out the three RF signals. The original 5 kHz intelligence signal is developed across R and is the audio frequency output.

3-30. Pulse demodulation.

3-31. Pulse demodulation is the process of extracting a pulse from a pulse modulated waveform.

3-32. The detector used in pulse demodulation is essentially an amplitude detector. Recall that in pulse modulation there are many sideband components in the modulated waveform. Thus, the transmitted waveform had a very wide bandwidth. The pulse detectors input circuit must be wide enough to pass the carrier signal and the many sideband components to recover the original pulse used during the modulation process.



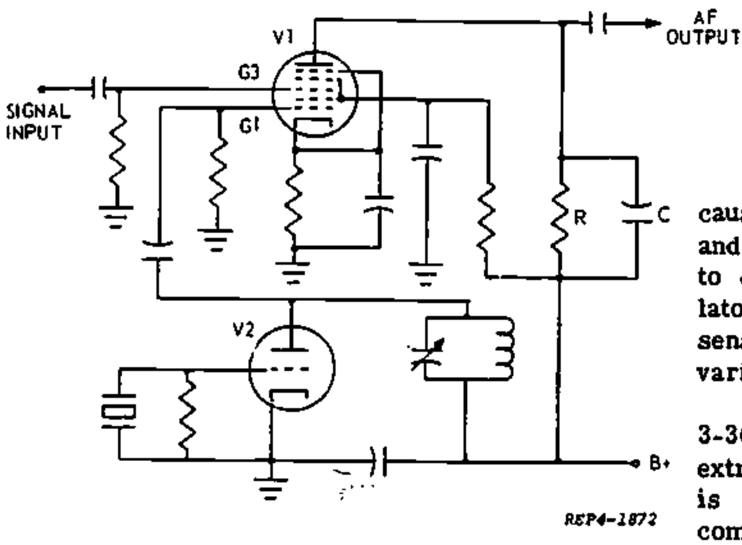




Figure 3-5. Product Detector Schematic

Figure 3-6. Pulse Detector

3-33. Figure 3-6 shows a detector used to demodulate a pulse modulated waveform. The circuit operates like the regular AM detector previously discussed. If the input is a pulse modulated waveform, the output will be the same as the original pulse used during the modulation process.

3-34. FM Demodulation.

3-35. In frequency modulation you learned that during the process of modulation the varying amplitude of the intelligence signals caused the carrier signal to deviate above and below its center frequency. In order to demodulate the FM signal, the demodulator stage must be a circuit which can sense frequency variations and convert these variations to voltage changes.

3-36. In the FM receiver the stage that extracts the intelligence from the FM signal is also the demodulator stage, or more commonly called a frequency discriminator.

3-37. The requirements for FM demodulation are:

a. The input circuit to the demodulator circuit must change frequency variations into amplitude variations.

b. A nonlinear impedance is necessary so heterodyning of the carrier and sidebands can occur.

c. A filter must be present to filter out the unwanted RF in the output.

d. A load must be present to develop the intelligence signal.

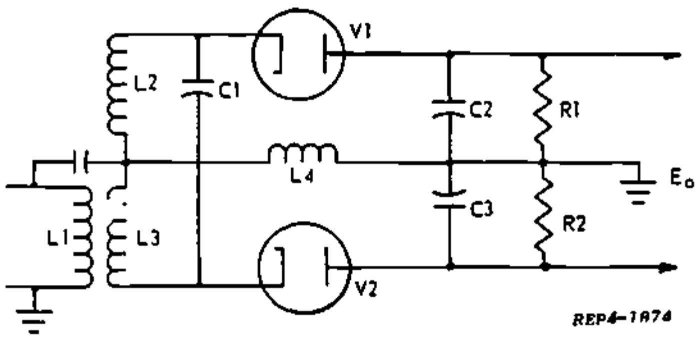



Figure 3-7. Foster-Seely Discriminator

3-38. Foster-Seely Discriminator.

3-39. The Foster-Seely discriminator shown in figure 3-7 answers the requirements for FM demodulation. The input tank circuit, L2, L3, L4, and C1 changes frequency variations into amplitude variations. The diodes V1 and V2 are the nonlinear impedances necessary for heterodyning. RF filtering is provided by C2 and C3. The intelligence signal is developed across load resistors R1 and R2.

3-40. The Foster-Seely discriminator is the phase-shift type, since demodulation depends on the phase-shift obtained across the transformer secondary.

3-41. To understand the input circuit of the Foster-Seely discriminator, let's first review some principles of transformer action with a tuned secondary.

3-42. In figure 3-8A, a signal applied to the primary winding at the frequency to which the secondary is tuned produces the following current and voltage relationships:

a. Primary voltage ($E_p$) will establish the reference vector.

b. Induced voltage ($E_i$) will be 180° out of phase with $E_p$.

c. Current in the secondary circuit (S) will be in phase with the induced voltage ($E_i$), because the secondary tank acts resistive at resonance.

d. Tank voltage ($E_t$) will lag by 90°, because $E_t$ is the capacitor voltage, which lags capacitor current by 90°.

3-43. Now, observe the vector relationship between $E_t$ and $E_p$. They are 90° out of phase. The vector sum of $E_t$ and $E_p$ produces the output voltage $E_o$ for the Foster-Seely discriminator (figure 3-8C). To arrange the two voltages so that the voltage applied to the detector circuit ($E_o$) will be the vector sum of $E_t$ and $E_p$, another inductor is placed electrically in parallel with the transformer primary winding as shown in figure 3-8B.

NOTE. The voltage felt across the new inductor will be the same as $E_p$, and not the same as the induced voltage.

3-44. If we now take this parallel inductor and place it in series with the tank circuit output, we cause $E_o$ to be the vector sum of $E_t$ and $E_p$ (figure 3-8C).

3-45. This is a basic circuit which will give us a voltage-varying signal at the output for a frequency-varying signal at the input. Let's see how this happens.

3-46. Remember we said that the tank circuit acts resistively as long as it is resonant. This causes $E_o$ to be a constant amplitude. If we shift the input frequency above the resonant frequency of the tank, we know the tank will act inductively, since $X_L$ will increase and $X_C$ will decrease. Since the circuit is inductive, the current ($I_S$) and voltage ($E_i$) in the secondary will no longer be in phase. Current will lag the voltage (figure 3-8E.)

3-47. Remember that the output voltage from the tank ($E_t$) is still developed across the capacitor and will always lag the

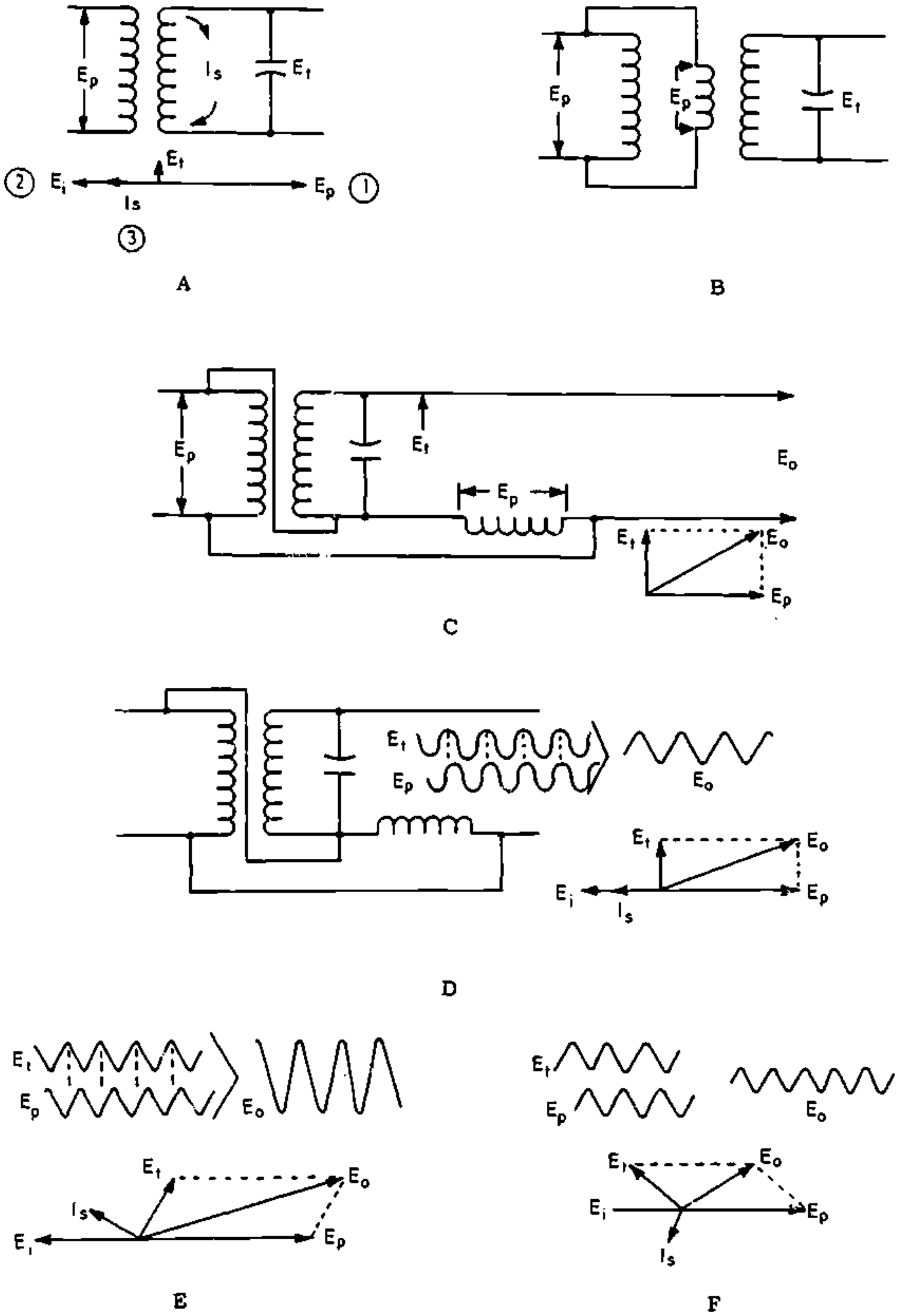



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Figure 3-8. Basic FM Input Circuit (Single-Tuned)

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secondary current ($I_S$) by 90°. As $E_t$ moves out of phase with induced voltage ($E_i$), the tank voltage ($E_t$) becomes more in phase with the primary voltage ($E_p$). Once again $E_t$ and $E_p$ combine, and $E_o$ will be the vector sum of the two. Naturally, since these two are now more in phase, the output voltage increases (figure 3-8E).

3-48. With the signal reaching its maximum deviation and then returning to the resonant frequency, the output voltage again returns to the smaller value. As the signal passes through resonance and starts decreasing in frequency, the tank circuit starts to act capacitively, since a decreasing frequency increases $X_C$ and decreases $X_L$. Now, secondary current ($I_S$) will lead the induced voltage ($E_i$). The output from the tank ($E_t$) will be more than 90° out of phase with respect to $E_p$. The vector sum of the two will now decrease; thus, $E_o$ will be less (figure 3-8F).

3-49. To improve linearity, another identical circuit is placed in push-pull with the first (figure 3-9). Note that the reference voltage $E_p$, is common to both circuits. Since the push-pull outputs are 180° out of phase with each other, they are both 90° out of phase with $E_p$ (at resonance). Across the output we produce the vector sum voltages $E_{o1}$ and $E_{o2}$.

3-50. This is a basic input circuit used in many FM demodulators. If we modify it slightly and replace the two secondary inductors with one that is center-tapped, we still have the same circuit action. If we remove the two capacitors and replace them with one that is one-half the value of either one of the others, we still have the same circuit as shown in figure 3-9, only now the configuration is that of L2, L3, L4, and C1 of figure 3-7. All that is necessary now is to add an amplitude detector and filter (V1, V2, C2, C3, and the resistors) and we have a basic FM demodulator, known as the Foster-Seely (phase-shift) discriminator.

3-51. A limitation to the Foster-Seely discriminator is that the circuit passes any amplitude variations at the input to the output, resulting in noise and distortion in the reproduced signal. For this reason, the circuit should have an amplitude limiter stage preceding it.

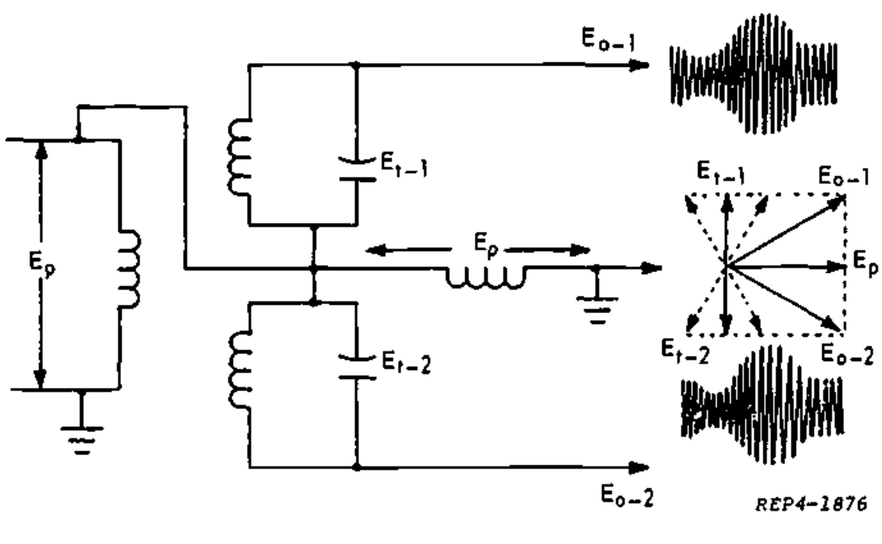


Figure 3-9. Making the Converted Wave Linear

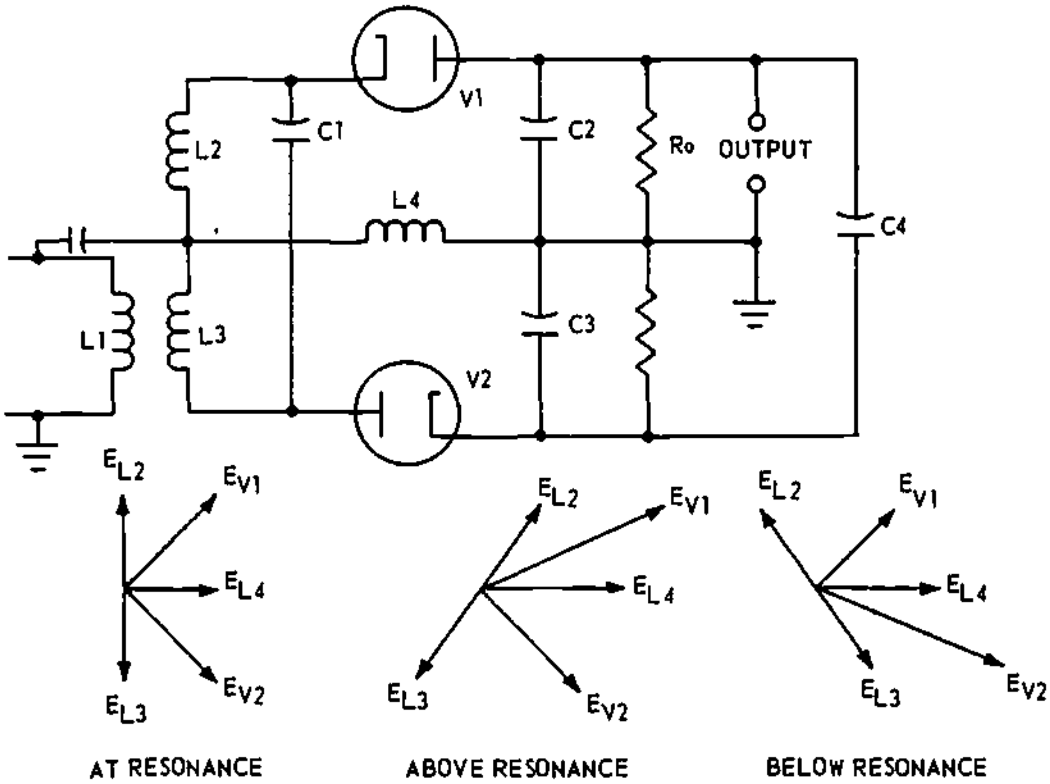


Figure 3-10. Ratio Detector REP4-1877

3-52. Ratio Detector.

3-53. The ratio detector is similar to the Foster-Seely discriminator. An advantage of the ratio detector over the Foster-Seely discriminator is that it does not respond to changes in amplitude, and thus, eliminates the need for a limiter stage. It does not produce amplitude changes in the output when amplitude changes occur in the input. The manner in which this is done is relatively simple, but, before discussing this, let's look at the circuit to see how it operates.

3-54. Figure 3-10 shows the ratio detector circuit. You'll note that the diodes are placed in the circuit in a different manner than they were in the Foster-Seeley circuit. In the ratio detector the cathode of one diode is connected to the input transformer and the plate of the other diode is connected to the opposite side of the transformer.

3-55. Again, exactly as in the Foster-Seely, we have an input circuit which uses phase combined voltages applied to the diode circuits. The combination of the voltages across L4 and that across L2 produces the voltage applied to V1. At resonance, the input voltage will cause these two to be 90° out of phase. When the input frequency increases, the two become more in phase producing an increase in amplitude in the resultant vector ($E_{V1}$), along with a slight phase shift in that voltage. However, it is the amplitude variation that concerns us. When the input frequency decreases, during deviation below carrier frequency, the phase difference between $E_{L2}$ and $E_{L4}$ becomes greater, and the amplitude of the resultant vector decreases. Again, it is the amplitude change that concerns us.

3-56. By the analysis of a complete cycle of frequency deviation in the input of this circuit, you can see that we produce a complete cycle of amplitude change at the output. This circuit converts a constant amplitude signal to one which has amplitude variations. The diode (V1) and the low-pass filter ($R_o$-C2) in the output detect the amplitude variations and reproduce the modulating signal. But, as in the Foster-Seely, the length of the resultant vector applied to one diode does not change linearly with the change in frequency input. Therefore, we add another section, the same as we did in the Foster-Seely circuit. The diode (V2) in the second section (figure 3-10) operates by the vector sum of the voltage across L4 and L3. Note that the diode currents through the combined resistance in the output are in the same direction, and they establish an average voltage across the circuit that is not zero, as in the Foster-Seely. A large capacitor (C4) placed across the output charges to the average voltage across the combined outputs. This charge tends to hold the average voltage constant across the resistors. If the input to the tank should suddenly increase in amplitude, the capacitor would have to charge to that new value before the increase could appear across the resistor in the output. Since the capacitor cannot charge instantly, the voltage across the resistors will not respond to sudden amplitude changes from the signal source.

3-57. The output is taken from across only one of the resistors ($R_O$). This is where the ratio detector gets its name. Even though the sum of the voltages across both resistors remains constant, the ratio of the voltage across each resistor to that constant value may be constantly changing.

3-58. Quadrature Detector.

3-59. An FM demodulator employing a completely different principle is the quadrature detector. The quadrature detector is shown in simple diagram form in figure 3-11A. The quadrature detector is self-limiting and, therefore, does not require the use of a separate limiter. The quadrature detector employs a specially designed gated beam tube illustrated in figure 3-11B.

3-60. In this tube the focus electrode forms a shield around the cathode except for a narrow slot through which the electron beam flows. The beam flows toward the limiter grid. The limiter grid acts like a gate and when the gate is opened, electrons flow through toward the screen grid. When closed, the gate stops the beam completely.

3-61. After the electron beam passes the limiter grid, the screen grid refocuses the beam toward the quadrature grid. The quadrature grid acts much the same as the limiter grid; it either opens or closes to the passage of electrons. Either grid can cut off plate current. Plate current can flow only when both gates are open.

3-62. Now, looking again at the circuit in figure 3-11A, note that in the diagram, the screen grid has been eliminated for simplicity of circuit explanation. An input signal will appear as the one shown in figure 3-11C. The limiter grid gate action creates a waveshape like figure 3-11D. Note that we now have a square wave. This is the current waveform passing the limiter grid.

3-63. When the quadrature grid is cut off the electron beam moving near the quadrature grid will induce a current into the grid which will develop a voltage across the high Q tank circuit. The current induced is through space charge coupling and will lag the space current by 90° (figure 3-11E).

3-64. Since the quadrature grid also has the same conduction and cutoff levels as the limiter grid, the resultant wave will also be transformed into a square wave (figure 3-11F).

3-65. Since both grids must be positive at the same time in order to have plate current, we can see by overlaying the current waveforms how much conduction time occurs for each cycle of the input (figure 3-11G).

3-66. Figure 3-11H shows the actual output plate current waveshape from this circuit. The basic frequency is the same as the applied frequency at the limiter grid.

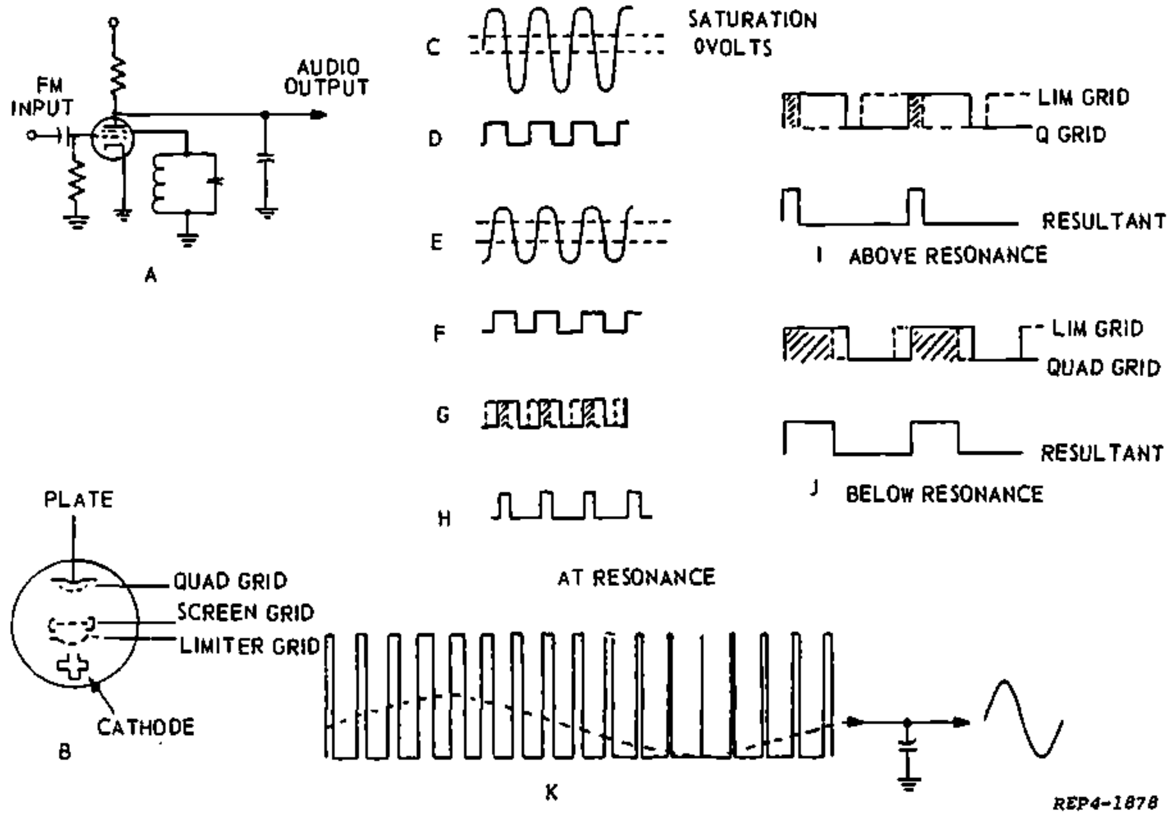


Figure 3-11. Quadrature Detector

3-67. Now consider what would happen with a deviation in frequency at the input. If the frequency decreases, the voltage across the quadrature tank also decreases in frequency. The tank appears inductive to the induced current and the voltage will then lag the applied voltage by less than 90° (figure 3-11J). Note that the resultant output time increases and so does the average current in the plate circuit.

3-68. As the input frequency increases, the opposite action takes place with the two grid signals moving more out of phase and the average current level decreases (figure 3-11I).

3-69. The filter capacitor in the plate circuit will eliminate the undesired frequency elements. The charge on the capacitor will follow the deviation of input FM. Thus, we have extracted the intelligence from the modulated FM wave (figure 3-11K).

3-70. Phase Demodulation.

3-71. Phase demodulation is the process of extracting the intelligence signal from a phase modulated waveform.

3-72. Under certain conditions, the FM discriminator can be used for phase-demodulation. However, a true reproduction of the intelligence signal can be obtained only by additional processing of the signal. One of the best methods of demodulating the phase modulated wave is to modify an FM detector.

3-73. Let's refer back to the FM quadrature detector (figure 3-11). Remember that the phase of the signals present at the grids causes amplitude variations in the output of the filter. A quadrature detector for phase modulation is the same with the exception of the signal source for the quadrature grid. Refer to figure 3-12. The

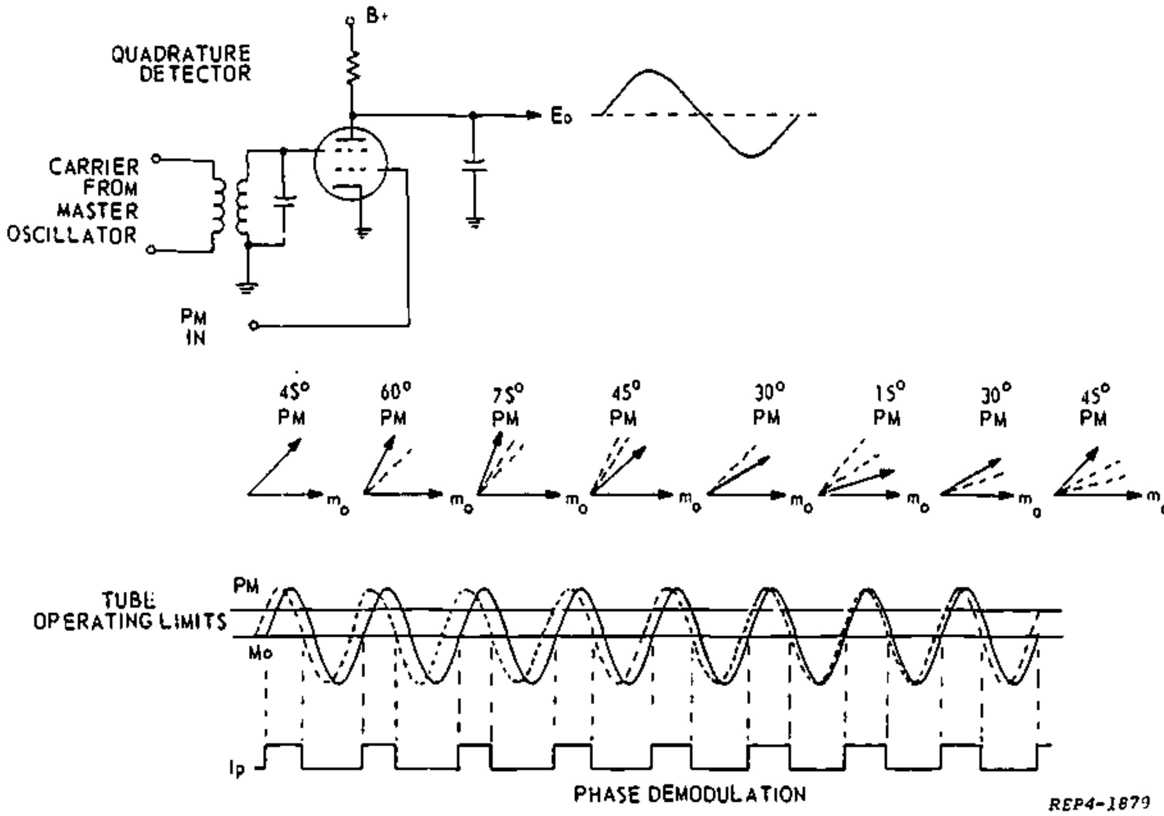


Figure 3-12. Phase (Quadrature) Detector

quadrature grid signal is NOT provided by a space-charge-excited tank circuit, but is excited by a reference from the transmitter, which may be a sample of the unmodulated master oscillator signal.

3-74. The modulated waveform is then applied to the limiter grid and the combined output is a series of pulses which vary in width with the phase of the modulation.

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## Chapter 4

## TRANSMISSION LINES

4-1. In many electronic systems, such as radio communications, radar, computers, or nav-aids, it is necessary to send electrical impulses or signals from one part of the system to another. The device through which these signals pass is called a transmission line. By definition, a transmission line is: (1) a material structure forming a continuous path from one place to another, and used for directing the transmission of electromagnetic energy along this path; (2) a conductor or series of conductors used to carry energy from a source to a load. All of us are familiar with transmission lines and may not realize it. The AC line cord on your radio, television, or other electrical appliance is a transmission line. The lead between a television set and its antenna or the lead on a telephone are transmission lines. The purpose of this chapter is to provide you with the basic facts and principles of transmission lines and their use.

4-2. Transmission Line Losses.

4-3. As stated previously, a transmission line is a conductor or series of conductors used to carry electrical energy from a source to a load. This electrical energy is primarily in the form of RF energy and we normally desire maximum transfer with minimum loss. Losses do occur and are due to resistive, inductive, and capacitive properties of the line.

4-4. Resistive Loss.

4-5. The ideal transmission line is one that has a no-power loss. This of course is a theoretical situation since, any time a conductor transfers energy, there is a power loss due to the resistance of the conductor. The power loss in a short line may be negligible. In lines of considerable length, however, the power loss due to resistance becomes considerable. This is called COPPER LOSS or $I^2R$ loss.

4-6. Another loss, called SKIN EFFECT, is a tendency for high frequency currents to flow near the outer surface of the conductor. The higher frequencies increase the change in magnetic flux surrounding each moving electron. This changing flux induces a CEMF, which is in opposition to electron flow. Electrons at the center of the conductor encounter the greatest opposition, and flow more easily on the skin of the wire. The increased opposition at the center of the conductor effectively reduces the cross-sectional area of the conductor. You may find that some high-frequency conductors are hollow (because of the high opposition at the center of the conductor); this saves material and reduces weight.

4-7. Skin effect is directly proportional to frequency. The greater the frequency, the greater the CEMF and resulting skin effect.

4-8. Energy losses due to skin effect are dissipated in the form of heat. Thus, skin effect loss is considered a resistance (or $I^2R$) loss, also called copper loss. Power loss due to skin effect can be reduced by increasing the diameter of the conductor (more SKIN available).

4-9. Radiation and Induction Losses.

4-10. When a transmission line is used to transfer high frequency energy, there are additional losses to be considered. These losses are a major factor in determining the type of line used for a particular application.

4-11. Up to this point we have considered the movement of energy along a wire as being the movement of electrons. This is, of course, a true and natural assumption. However, there is another factor which must be considered. This is the movement of electromagnetic waves that are guided by the transmission line. These electromagnetic waves are composed of two ingredients,

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the electric (E) field and the magnetic (H) field. The electric field is associated with the voltage on the line and the magnetic field is associated with the current flow through the line. These two fields always exist perpendicular to each other and to the direction of travel, and neither can exist without the other.

4-12. A perfect inductor (containing zero resistance) converts the energy from a source into potential energy during current rise, and the same amount of potential energy is converted back into kinetic energy during current-decay. Likewise, a perfect capacitor returns all the energy stored during voltage rise to the circuit during voltage decay.

4-13. When the current is varying, particularly at frequencies of 20 kHz and greater, a number of the expanding flux lines never return to the coil. Expanding and collapsing the flux field at even faster rates tends to increase the number of flux lines which never return to the inductor. In such cases, a portion of the electric energy which was converted into stored or potential energy, also, never returns to the circuit. The source will see this loss, which is called RADIATION LOSS, as a resistance in addition to the copper losses of the transmission line. Even though it is not a resistive loss, radiation losses are a direct function of frequency.

4-14. Radiation losses are desirable in the antenna, but undesirable in a transmission line.

4-15. Another loss due to the electromagnetic field along the transmission line is caused by induction. The expanding and collapsing magnetic fields induce a voltage and current into conducting surfaces near the transmission line. This causes a power loss called INDUCTION LOSS. One method of reducing this loss is commonly used on television antenna masts. A STANDOFF INSULATOR is used to prevent the lead-in from coming close to the metal mast. SHIELDED conductors also reduce induction and radiation losses. Shielding is a metal housing around the conductor to prevent interaction with other circuits. Shielding prevents external signals from being induced into the transmission line, causing interference.

4-16. Capacitive Losses.

4-17. Insulation of a two-wire transmission line is the dielectric for the capacitance of the line. As the capacitor charges and discharges, orbits of electrons in the dielectric material are continuously changing. This causes heat dissipation in the dielectric. This type of energy loss, called DIELECTRIC LOSS, which APPEARS as a resistive loss to the power source, increases with frequency.

4-18. Transmission lines with an air dielectric have a very low dielectric loss when compared to those which use a polyethylene plastic material. Because no insulation is perfect, some electrons move through the dielectric as LEAKAGE current. Leakage losses are held to a minimum through use of very high resistance dielectric. Losses caused by leakage generate heat which, to the power source, is another resistive loss. Some ceramics and mica have a higher resistance and thus, have less leakage loss than air.

4-19. Types of Transmission Lines.

4-20. There are several types of transmission lines and many variations of each type. Each job to be performed will determine the type or variations to be incorporated. Some of the factors that may be considered in selecting a given type of line are cost, breakdown voltage, power loss at the required frequency, characteristic impedance, stability of the dielectric, flexibility, bulk, balance, and electrical constants. These factors cannot be listed in any order of importance because any one of them might be the determining factor in a given case. Figure 4-1 shows the basic types of transmission lines.

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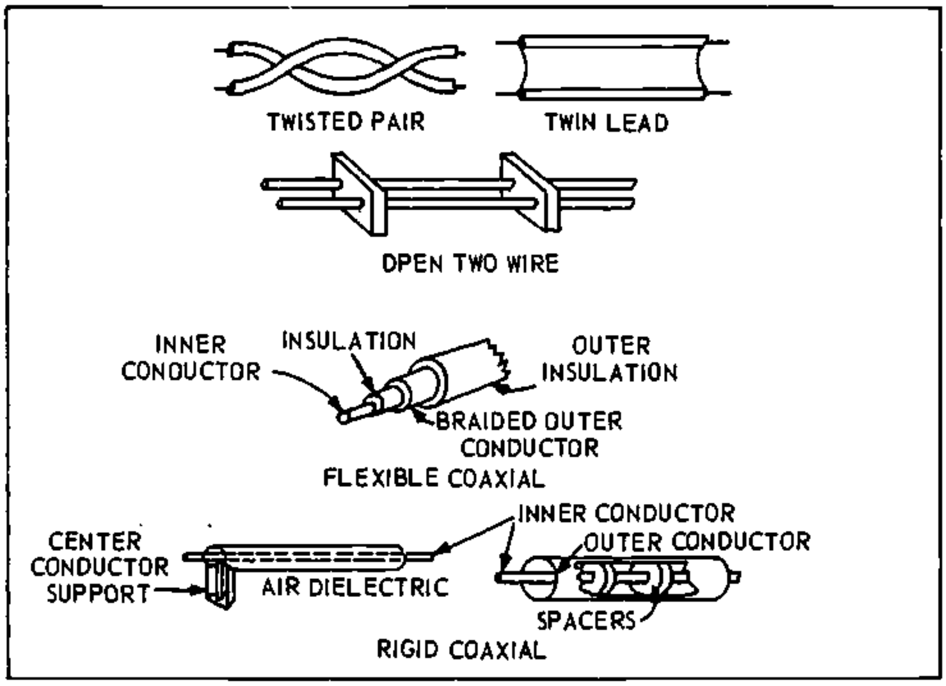


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Figure 4-1. Basic Types of Transmission Lines

4-21. Twisted Pair.

4-22. The twisted pair line is constructed of two insulated conductors twisted together to form a flexible line. It is one of the simplest and cheapest to build, and is commonly used for telephone circuits, audio connections in radio, small household appliances, and other low frequency purposes. The close spacing of conductors reduces radiation loss, and the twisting of the wires equalizes the effects of stray fields on both conductors as well as reduces the induction loss to nearby circuits. This type of line is not used for high frequency transmission because of the high dielectric loss. It has neither the high breadkdown voltage nor high conductivity required to handle large amounts of power. Its best use is for low voltage and low frequency transmission.

4-23. Twin Lead.

4-24. The twin lead line consists of two conductors molded into the edges of a polyehtylene plastic ribbon. Installation of this type line is simplified because of its flexibility. The plastic is solid enough to maintain a constant distance between the two conductors, yet bends around corners. The twin lead is commonly used as the lead-in from the antenna to the television receiver. It is not suitable for a high power transmission because of the small size of the conductors and the narrow spacing between the conductors. The twin lead line can be used for frequencies up to approximately 200 MHz. The major loss is dielectric loss.

4-25. Open Two-Wire.

4-26. The open two-wire transmission line consists of two conductors which are kept the same distance from each other by means of spacers or spreaders. The distance between the two conductors is approximately one-tenth of a wavelength or less at the operating frequency. The actual distance between the two conductors will depend on the:

1. Frequency of the energy being transmitted.

2. Characteristic impedance required.

3. Diameter of the conductors.

The open two-wire line is used for frequencies up to approximately 200 MHz. When used at frequencies higher than 200 MHz, the power losses are too great to be practical. The major power loss is a result of radiation.

4-27. Flexible Coaxial Cable.

4-28. The flexible coaxial cable transmission line consists of an inner conductor of solid or stranded wire, and an outer concentric conductor of braided wires. The conductors are separated from each other by polyethylene plastic or other similar insulating material. This type line is capable of transferring large quantities of power at high frequencies with minimum losses. There is very little radiation loss from this type of line because the outer conductor shields the inner conductor and confines the radiation to the space between the two conductors. The major power losses are due to the dielectric and skin effect. The flexible coaxial cable is commonly used in television, microwave radio, and radar.

4-29. Rigid Coaxial Cable.

4-30. Rigid coaxial cable transmission line consists of a center conductor placed inside of a rigid metal tube that functions as the outer shield.

4-31. One type has the center conductor fixed along the central axis of the outer tube by means of disk-shaped spacers. The insulating disks are polyethylene plastic or similar types of material. Another type of rigid coaxial cable is constructed with an air dielectric. The center conductor is supported by metallic insulators which are quarter-wave sections of coaxial line. The space inside the line is often pressurized to eliminate moisture. Quarter-wave metallic insulators make this line useful only at the designed frequencies.

4-32. Rigid coaxial cable transmission line is used primarily for high power at frequencies up to 3 GHz. This type line has very little radiation loss because the energy is confined between the two conductors. The major power loss is due to copper loss.

4-33. Transmission Line Characteristics.

4-34. Transmission lines are basically two conductors in parallel and thus, can produce some value of inductance and capacitance. Exactly how much inductance and capacitance a line has is dependent upon its construction. The amount of capacitance is primarily determined by the size of the conductors, the space between them, plus the dielectric material. These inductance and capacitance values that are present in all transmission lines affect the signal applied to the line.

4-35. Characteristic Impedance.

4-36. Impedance is, of course, the opposition to the flux of alternating current. Characteristic impedance is the opposition to alternating current due to the inductance and capacitance of the line. Characteristic impedance is commonly called "$Z_O$".

4-37. Figure 4-2 shows how $Z_O$ is developed in a transmission line. A battery, switch, and ammeter are connected to an infinitely long line, with its series inductance and shunt capacitance. When the switch is closed and the DC voltage is applied to the line, current flows and a field builds up around a unit section of inductance (L1), and the unit section of distributed capacitance (C1) begins to charge. As the charge on C1 approaches a full charge, C2 begins to charge through L2; the current through ammeter A will remain constant. Current continues to flow through the inductance to charge the capacitance on down the line. Since the line is infinitely long, there will always be capacitance to be charged, and current will continue flowing into the line. Therefore, the line will have the same effect on the battery as a fixed resistance of a specific value which is called the CHARACTERISTIC IMPEDANCE ($Z_O$) of the line. Since $Z_O$ of a line is determined by the

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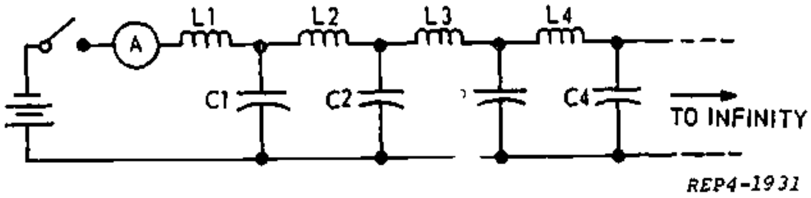


Figure 4-2. Development of $Z_o$

series inductance and shunt capacitance of the line, the value of $Z_o$ does not change when you shorten the line. The $Z_o$ is characteristic of any unit length section of the line.

4-38. A definition of characteristic impedance is the impedance of a transmission line which would be measured if that line were uniform in all respects throughout its infinitely long length. Factors that change the $Z_o$ of a line include the cross-sectional area of the conductors and the spacing between them. Disregarding resistance, we can say that values of L and C determine $Z_o$. This is true whether we are talking about a real or artificial transmission line. The L and C values are identical for the same unit length. The actual L and C (lumped) components of artificial transmission lines usually simulate very long lines.

4-39. Characteristic impedance may be calculated by using the formula:

$$Z_o = \sqrt{L/C}$$

Figure 4-3 shows a transmission line of unknown length with inductors and capacitors to represent the distributed inductance and capacitance. In computing $Z_o$, we consider the total inductance and capacitance of one section only. The reason is that the inductance and capacitance are evenly distributed along the lines and do not change when some portion is removed from the line.

4-40. If L1 is 2 millihenrys and C1 is 5 picofarads, we can solve for $Z_o$ as follows:

$$Z_o = \sqrt{L/C}$$

$$Z_o = \sqrt{\frac{2 \times 10^{-3}}{5 \times 10^{-12}}} = \sqrt{.4 \times 10^{9}}$$

$$Z_o = \sqrt{4 \times 10^{8}}$$

$$Z_o = 2 \times 10^{4} \text{ or } 20 \text{ k ohms}$$

4-41. Another example: L1 is 5 millihenrys and C1 is 2 microfarads; solve for $Z_o$ as follows:

$$Z_o = \sqrt{L/C}$$

$$Z_o = \sqrt{\frac{5 \times 10^{-3}}{2 \times 10^{-6}}} = \sqrt{2.5 \times 10^{3}}$$

$$Z_o = \sqrt{25 \times 10^{2}} \text{ or } 50 \text{ ohms}$$

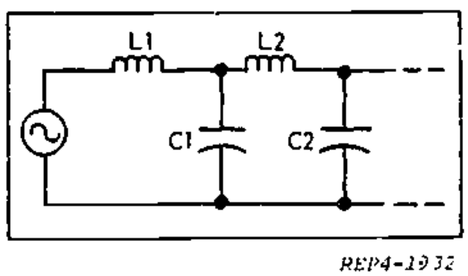


Figure 4-3. Computing $Z_o$

4-42. Cutoff Frequency.

4-43. Cutoff frequency is the highest frequency that will pass down the line. Each line does have series inductance and shunt capacitance therefore, the values of inductive and capacitive reactance will change if the applied signal frequency is changed. Recall that the line will possess a certain value of inductance and capacitance due to its construction. Thus, if we apply a signal at some frequency to the line, then we will have some value of $X_L$ and $X_C$ produced. If we, then, increase the frequency of the signal, the value of $X_L$ will increase and $X_C$ will decrease.

4-44. Refer to figure 4-3 and visualize the signal as moving from left (generator) to the right (load). If the value of $X_L$ is small and $X_C$ is large, then the signal will in fact move from source to load. If, however, the value of $X_L$ is large and $X_C$ is small, then, the signal would be developed across the series inductance and shunted across the line by the capacitance and it would not pass along the line. The frequency at which this occurs, and the line becomes unstable, is called the cutoff frequency.

4-45. Length of Line.

4-46. All transmission lines are measured in physical length and electrical length. The physical length of the line is measured in units of linear measure, such as meters. Electrical length, on the other hand, is a comparison of physical length and wavelength, symbolized by lambda ( $\lambda$). Wavelength is usually expressed in meters or centimeters. Figure 4-4 shows how far energy travels down the line as the generator puts out one cycle. The distance traveled is one wavelength. The transmission line shown is several wavelengths long; other lines may be only a fraction of a wavelength long.

4-47. Energy travels down a transmission line at a speed slightly less than the speed of light (300,000 kilometers or 186,000 miles per second).

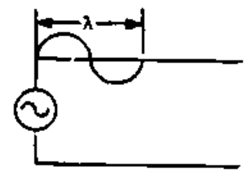


Figure 4-4. One Cycle - One Wavelength

4-48. Velocity Factors.

4-49. We commonly consider the speed of RF energy as the same as the speed of light. This is true with reference to its speed in free space. However, RF signals are delayed as they pass through a transmission line; this delay is caused by the series inductance and shunt capacitance of the line. Since this is true, then the RF signals in the line must move slower than the speed of light.

4-50. In order to accurately measure the electrical length of a transmission line, we must consider the decrease in signal speed through the line. We do this by measuring the speed and the energy through a specific line and comparing it with the speed of light. The ratio between the two is called the VELOCITY FACTOR (K) for that specific line. Velocity factor can be expressed in formula form as:

$$K = \frac{\text{Speed of energy through a line}}{\text{Speed of light}}$$

4-51. The velocity factor will vary from line to line and even between lines of the same type. We can see the reason for this by observing the factors that control the speed of energy through the line. We know that the time delay of a line is determined by the amount of series inductance and shunt capacitance of a specific line. As the signal charges the shunt capacitance through the series inductance, the energy is delayed or slowed down as it passes through the unit lengths of the line ($T_d = N\sqrt{LC}$). Increasing or decreasing the diameter of the conductors will vary the amount of inductance and, therefore, the speed of the energy down the line. Also, changing the spacing between the lines will change the shunt capacitance and, therefore, the speed of energy down the line.

4-52. The transmission line with the highest velocity factor is the open two-wire line. This type allows energy to pass approximately 97% as fast as the speed of light. The slowest speed is through a twisted pair line with rubber insulation. The speed of this type line is approximately 60% as fast as the speed of light. All other types permit energy to pass between 60% and 97% as fast as the speed of light. If the frequency and velocity are known, the distance the energy travels in one cycle can be calculated by the following formula:

$$\text{Wavelength } (\lambda) = \frac{\text{Velocity}}{\text{Frequency}}$$

4-53. The velocity can be determined by multiplying the Velocity Factor (K), for the type of line to be used, times the speed of light. Remember that the velocity factor for the line concerned must be used to calculate wavelength accurately. The calculations that follow assume a velocity factor of 100%.

4-54. To obtain transmission line lengths in meters, we must use the speed of light expressed in meters; this is 300,000,000 meters per second. The wavelength formula, therefore, becomes:

$$\text{Wavelength (in meters)} = \frac{300{,}000{,}000}{\text{Frequency (Hz)}}$$

4-55. Observe that as the frequency changes, the wavelength also changes. Wavelength varies inversely with frequency; the higher the frequency, the shorter the wavelength.

4-56. To work with high frequency transmission lines, convert the formula to a more convenient form as follows:

$$\text{Wavelength } (\lambda) = \frac{300}{\text{Freq (MHz)}}$$

4-57. The electrical length of a transmission line is expressed as the number of wavelengths and/or factions thereof, on a given physical length of line. The frequency of the energy applied to the line will determine whether the line is electrically long or electrically short. Electrical length is computed by the following formula:

$$\frac{\text{Electrical length}}{\text{(In wavelengths)}} = \frac{\text{Physical Length}}{\text{Wavelength}}$$

4-58. Figure 4-5 shows a transmission line that is physically 10 meters long with an applied frequency of 60 MHz. The wavelength of this frequency is:

$$\text{(meters)} = \frac{\text{300 (speed of light in meters)}}{\text{(freq of generator in MHz)}}$$

$$= 5 \text{ meters}$$

4-59. Therefore, the electrical length of the transmission line is:

$$\text{Electrical length} = \frac{\text{10 meters (physical length)}}{\text{5 meters (freq wavelength)}}$$

Electrical length = 2 wavelengths

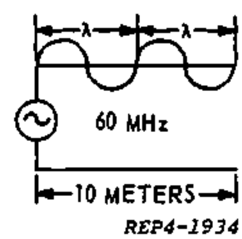


Figure 4-5. Electrical Length, Two Wavelengths

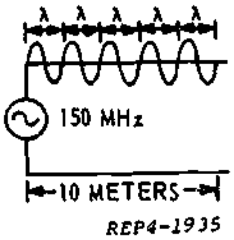


Figure 4-6. Electrical Length, Five Wavelengths

4-60. If we increase the frequency of the energy applied to this 10 meter line, what happens to the electrical length? Figure 4-6 shows a 10-meter line with an applied frequency of 150 MHz. The wavelength for this frequency is:

$$\text{(meters)} = \frac{300}{150}$$

$$\lambda = 2 \text{ meters}$$

Therefore, the electrical length of the 10-meter line is

$$\text{Electrical length} = \frac{10 \text{ meters}}{2 \text{ meters}}$$

$$= 5 \text{ wavelengths}$$

4-61. We can now say that this line, with a physical length of 10 meters, has an electrical length of 2 wavelengths at 60 MHz and 5 wavelengths at 150 MHz. We can also say that if the physical length remains constant and frequency increases, the electrical length increases. And vice versa: as frequency decreases on a given transmission line, electrical length decreases.

4-62. Nonresonant Lines.

4-63. A NONRESONANT transmission line is a transmission line having no REFLECTED waves and no STANDING waves. An infinitely long line is a non-resonant transmission line. If a transmission line is terminated in a load of the same resistive value as its characteristic impedance, all of the energy transferred down the line is absorbed by the load resistance. This line will have no REFLECTED voltage, so it is a nonresonant line. The voltage and current waves are in phase as they move from the source to the load, and are called INCIDENT waves. Figure 4-7 shows two nonresonant transmission lines. Since all of the energy is absorbed by the load, none is left to be reflected back toward the source. Thus, nonresonant lines are often referred to as FLAT lines. This term is sometimes used to differentiate between nonresonant and resonant transmission lines.

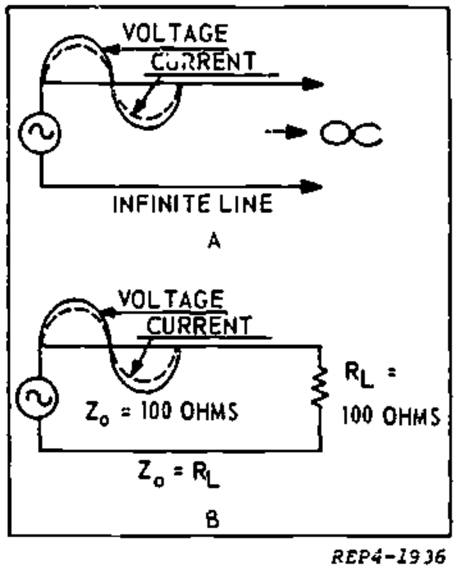


Figure 4-7. Two Nonresonant Lines

4-64. Resonant Lines.

4-65. Transmission lines are often terminated in a load impedance other than the $Z_0$ of the line. This may be either intentional or unavoidable. When the impedance of the load differs from the $Z_0$ of the line, the transmission line is MISMATCHED. When there is a mismatch of impedance between the line and load, part of the energy will be reflected back toward the source. These are called REFLECTED waves. The amount of mismatch determines the amount of reflected energy; the greater the mismatch, the greater the reflected energy. Energy moving on the line as incident or reflected waves are called TRAVELING waves.

4-66. Any type impedance termination other than $Z_0$ will cause reflected waves to occur on the lines. We will discuss the special terminations shown in figure 4-8.

a. Open.

b. Short.

c. Capacitive

d. Inductive

e. Resistance less than $Z_0$ (approaching a short).

f. Resistance greater than $Z_0$ approaching an open).

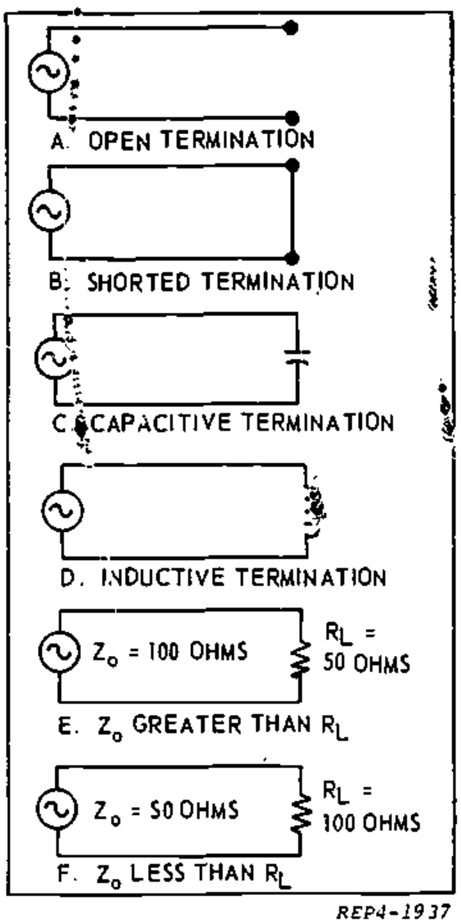


Figure 4-8. Various Terminations

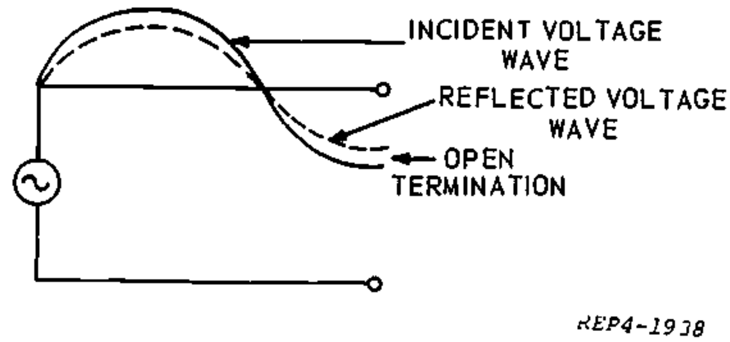


Figure 4-9. Reflected Voltage from Open Termination

4-67. Regardless of the termination, if there is reflected energy on the line, the line is resonant. The reflected energy represents a loss in signal energy.

4-68. Open Termination.

4-69. On a transmission line with an open termination, the wave is reflected back to the source. Figure 4-9 shows incident and reflected voltage waveforms. Observe that the two waves are in phase, at the open termination.

4-70. Figure 4-10 shows the development of a standing wave of voltage. Assume, at a given point in time, a positive alternation of voltage is fed to the line. The incident wave travels the length of the line, encounters an open, and reflects back to the source. Observe that the incident wave (heavy line) and reflected wave (dotted line) are in phase. At the next half cycle, the negative alternation incident wave (solid line), travels down the line to the open end and reflects back (dotted line) in phase. Remember, the positive- and negative-going incident waves (as shown in this diagram) are occurring in two different time periods. Actually, the voltage is being constantly generated and fed at an alternating rate into the transmission line. Each alternation will produce voltage reflections back toward the source. Figure 4-10 shows a STANDING WAVE of voltage, maximum at the open end and at half-wavelengths back; that is, $\lambda/2$

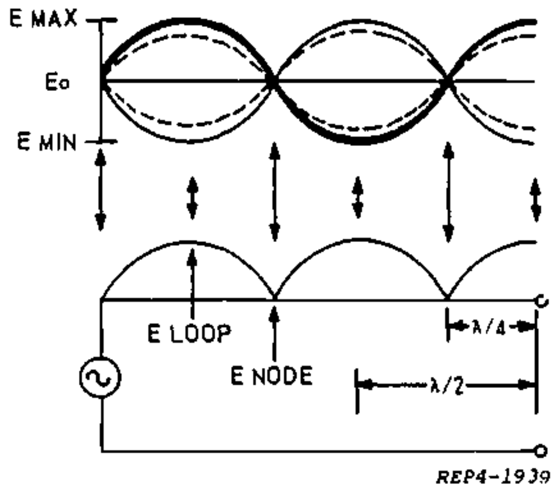


Figure 4-10. Development of Standing Wave of Voltages

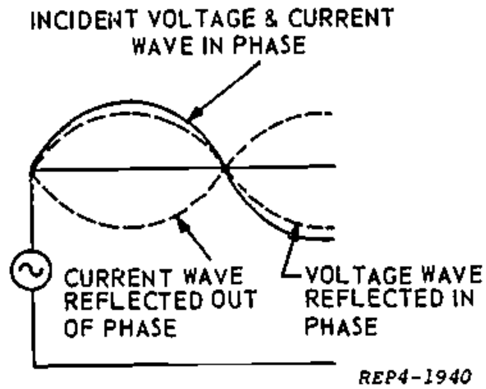


Figure 4-11. Reflected Voltage and Current from an Open Termination

from the end and one λ from the end. The standing wave of voltage will be minimum at odd quarter-wavelengths from the open end; that is, λ/4, 3 λ/4 from the open end and 5 λ/4 from the open end. The maximum voltage points are called voltage LOOPS.

4-71. The standing wave does not move along the line since it is the sum of the incident and reflected waves. The position of the standing wave will change along the line only if the frequency of the input signal or the line termination changes.

4-72. Up to this point, we have talked about only the standing wave of voltage, yet we know that the voltage and current are in phase as they move from the generator toward the end of the line. On reaching the end of the line, the incident wave finds the open termination as shown in figure 4-11. Since current cannot flow through an open, the open will always have minimum current and the voltage will always be maximum. Reflected current is 180° out of phase with the incident wave of current, while the reflected wave of voltage is in phase with the voltage incident waves.

4-73. Figure 4-12 shows the development of a standing wave of current. The heavy black line shows the incident current wave as it travels down the line. At the open end, current is reflected back 180° out of phase as indicated by the heavy dotted line. On the next alternation of the generator the incident wave is of opposite polarity and travels down the line as shown by the solid thin line. At the termination, current is again reflected 180° out of phase and moves back toward the source. Each alternation of the generator produces another incident wave, and each incident wave is reflected in the same manner. A standing wave is the sum of the incident and reflected waves. At the open termination, there is always a point of minimum current or CURRENT NODE; one-quarter wavelength back there is a point of maximum current or CURRENT LOOP. One-half wavelength (λ/2) back is another current node. Notice in figure 4-12 that the standing waves of current and voltage are 90° out of phase with each other. This phase relationship will always exist, regardless of the type of termination, as long as there is an impedance mismatch between the line and the load.

4-74. Shorted Termination.

4-75. A line terminated in a short also causes reflections. We know that voltage across a short is minimum and that current

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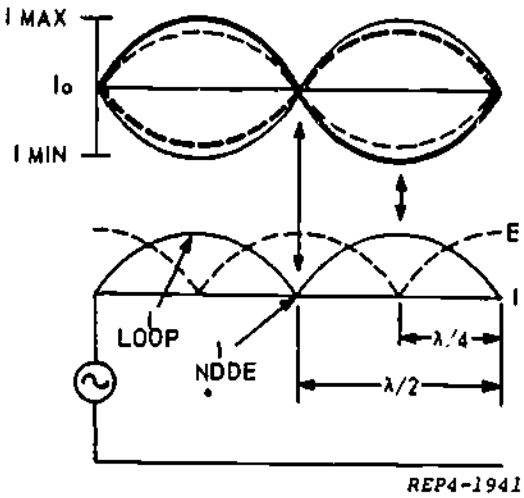


Figure 4-12. Development of Standing Wave of Current

through a short is maximum. Since voltage and current are in phase as the incident wave reaches the termination, a phase shift takes place. With a shorted termination, voltage is reflected 180° out of phase and current is reflected in phase with the incident wave. The resulting standing waves are shown in figure 4-13. Notice at the shorted termination that the standing wave of current is maximum and the standing wave of voltage is minimum. Notice also that one-quarter wavelength back from the short is a current node and a voltage loop. One-half wavelength back from the termination is a current loop and a voltage node.

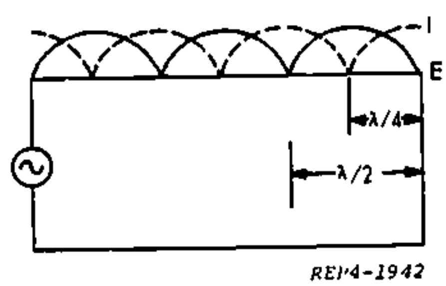


Figure 4-13. Standing Waves from Shorted Termination

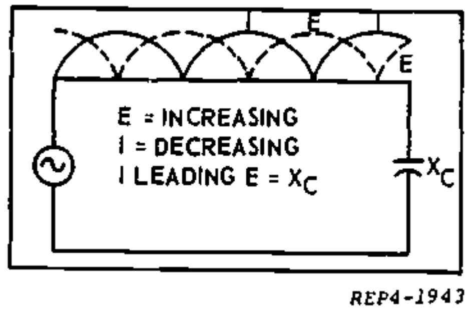


Figure 4-14. Capacitive Reactance Termination

4-76. Capacitive Termination.

4-77. When a transmission line is terminated in a reactance, the load is capable of storing energy during some parts of the input cycle and releasing energy at other times during the cycle. The termination produces a phase difference between reflected current and voltage.

4-78. Figure 4-14 shows a line with a capacitive termination. The type of reactance at the termination can be determined by observing the relationship between the standing waves of current and voltage at the termination. As shown in figure 4-14, the standing wave of current at the termination has been maximum and is declining, while voltage has been minimum and is increasing. Therefore, current is leading the voltage, which is characteristic of capacitive reactance.

4-79. Inductive Termination.

4-80. Figure 4-15 shows the standing waves on a line that has an inductive termination. By observing the relationship between the current and the voltage waves, we can identify this termination as inductive. Notice that current at the termination has been minimum and is increasing and voltage has been maximum and is decreasing at the termination. Therefore, voltage is leading current, which is characteristic of inductive reactance.

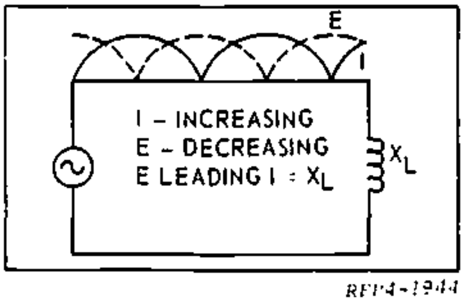


Figure 4-15. Inductive Reactance Termination

4-81. Resistive Terminations.

4-82. When a line is terminated in its characteristic impedance ($Z_0$), all the energy fed down the line is absorbed by the load and none is reflected back. Now, let's see what happens if the load resistance is smaller or larger than the $Z_0$ of the line. In either case, there will be a mismatch of impedance, which causes reflections and creates standing waves.

4-83. Figure 4-16 shows a transmission line with a resistive termination greater than the $Z_0$ of the line. Notice how the standing waves are presented graphically. They are drawn above the line to indicate that the load resistance is larger than the $Z_0$ of the line, approaching an open. You will also notice that voltage is maximum and current is minimum at the termination to indicate that the line has a resistive termination. Therefore, the standing waves appear the same as for an open termination, except that they are raised above the reference line.

4-84. Figure 4-17 shows a transmission line terminated in a resistance that is less than the characteristic impedance of the line. Again, the standing waves are drawn above the line, but this time the current is maximum and the voltage minimum. The standing waves appear the same as for a shorted termination when $R_L$ is some value less than the characteristic impedance of the line.

4-85. Varying Line Impedance.

4-86. We have discussed five types of transmission line termination - the open, short, capacitance, inductive, and resistive terminations. Each of these can be identified by the relationship of standing waves of current and voltage at the termination. Figure 4-18 is a transmission line terminated in an open. We know this is an open because the standing wave of voltage is maximum and the standing wave of current is minimum at the termination. This is the same relationship between voltage and current that is found across a parallel resonant tank circuit, so this symbol is placed at that point. One-eighth of a wavelength back from the termination current is decreasing and voltage is increasing. Thus, current is leading voltage, symbolized by a capacitor. One-quarter of a wavelength from the termination,

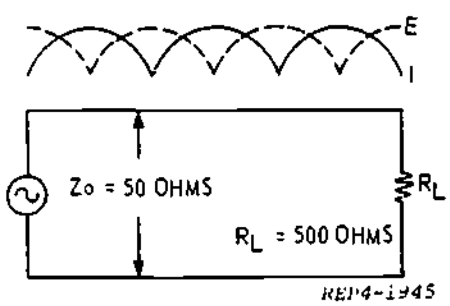


Figure 4-16. Resistive Termination, $R_L$ Greater than $Z_0$

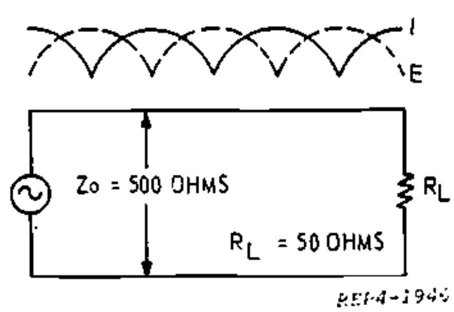


Figure 4-17. Resistive Termination Less than $Z_0$

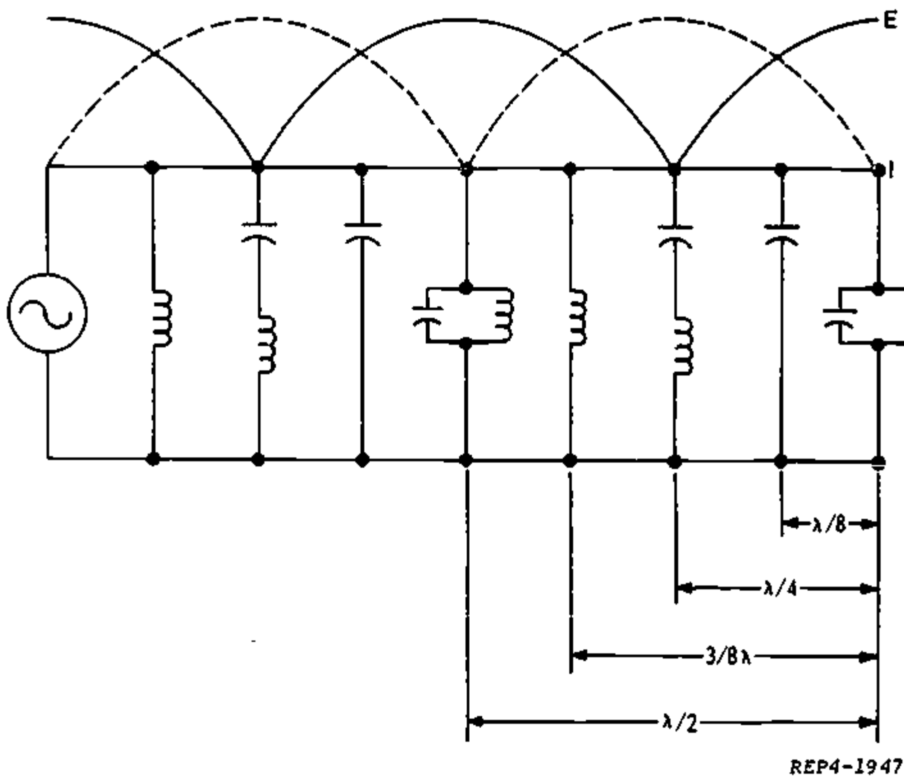


Figure 4-18. Line Terminations Symbolized by Circuit Terminations

current is maximum and voltage is minimum. This is the condition found at a shorted termination and also across a series resonant circuit. At three-eighths of a wavelength back from the termination, the voltage is decreasing and current is increasing, symbolized by an inductor. One-half of a wavelength away from the termination, we again find that voltage is maximum and current is minimum. These are, again, the standing wave relationships that indicate an open. Therefore, we can say that one-quarter wavelength back from an open is a short, and one-half wavelength from any termination we will find the same standing wave condition as the termination.

4-87. Figure 4-19 shows the distribution of impedance along the resonant transmission line. The open end has maximum impedance of a parallel resonant tank or open circuit. One-quarter wavelength back from the open end is a short circuit or series resonant circuit with minimum impedance. Now, we can construct the impedance curve from maximum at the open points along the

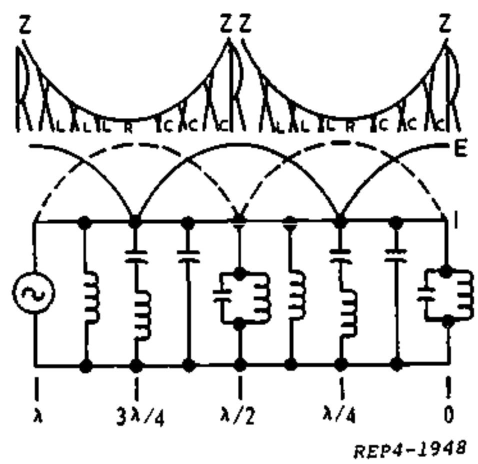


Figure 4-19. Distribution of Impedance

line to minimum impedance at the shorted points. At the maximum impedance points a large R is shown, and at the minimum points a small R is shown. As the impedance curve increases from minimum to maximum, $X_C$ is shown increasing in size to the maximum point. As the impedance decreases from maximum to minimum, $X_L$ is shown decreasing to minimum. These are the impedances that are found along a line with an open termination. Figure 4-20 shows the impedance points on an open ended line which is varied in length. In this illustration, you can see that the various impedance points will not change (with respect to the end of the line) as the line is made longer or shorter. The generator will see the different impedance values, depending upon line length; the impedance points remain stationary. This can be summarized by saying the relationship between standing waves of current and voltage at the termination will indicate (1) the type of termination on a line and (2) the impedance at points along the line. The length of the line determines the impedance at the generator.

4-88. Standing Wave Ratio.

4-89. Keep in mind that the purpose of a transmission line is to transfer electrical energy from a source to a load. If a mismatch of impedance produces standing waves due to reflected energy, some of the source energy is not used by the load. Therefore, standing waves represent a loss in power and are undesirable on a transmission line. Now, let's see how we can monitor and measure the standing waves on a line.

4-90. Standing waves are measured by determining the maximum and minimum voltage or current present and comparing them to establish a ratio. Another method that may be used compares the values of the characteristic impedance of the line with the load resistance. In either case, a STANDING WAVE RATIO is established, known as SWR.

4-91. The first method described is expressed by the following formula:

$$SW = \frac{E\ Max}{E\ Min} \text{ or } \frac{I\ Max}{I\ Min}$$

4-92. Regardless of which formula is used, the standing wave ratio will be the same on a given transmission line.

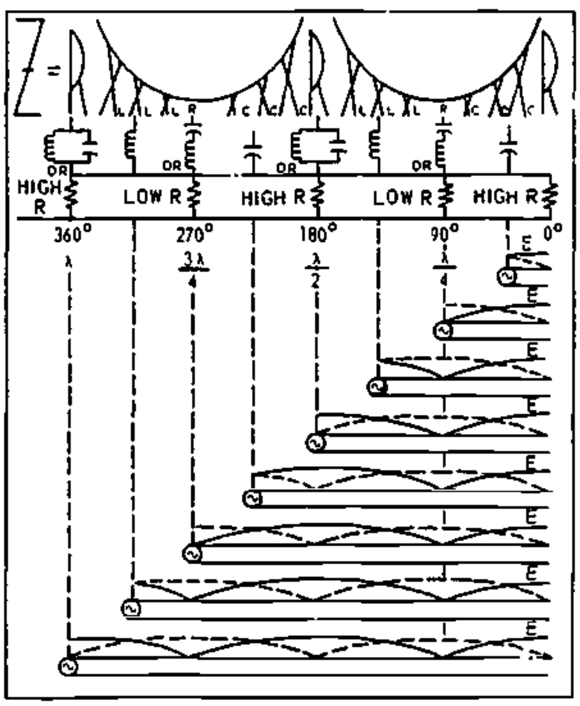


Figure 4-20. Impedance at Points on an Open-Ended Line

4-93. The other method can be used as follows:

$$SWR = \frac{R_L}{Z_o} \text{ or } \frac{Z_o}{R_L}$$ (the larger value is placed on top)

For example:

$$SWR = \frac{R_L}{Z_o} = \frac{300}{100} = 3:1$$

$$SWR = \frac{Z_o}{R_L} = \frac{600}{300} = 2:1$$

4-94. As $Z_o$ and $R_L$ come closer in value, the standing waves become smaller. When $Z_o$ and $R_L$ reach the same value, there are no standing waves developed and the line becomes nonresonant.

4-95. Uses of Transmission Lines.

4-96. A nonresonant transmission line is a line which has no standing wave; or in other words all of the energy traveling down the line is transferred to the load. That is the use of a nonresonant line, to transfer RF energy from its source to the load. If a resonant transmission line does have standing waves and various amounts of impedance distributed along its length, it is well suited as an impedance matching device. Figure 4-21 shows a varying impedance along a one-quarter wavelength section of a shorted transmission line. At the shorted end the current is high, the voltage is low, and the impedance is low. One-quarter wavelength back from the shorted end, the conditions are reversed. The current is low, the voltage is high, and impedance is high. Using this quarter-wavelength section, it is possible to match almost any impedance.

4-97. Matching Transformers.

4-98. Sections of transmission line can be used to match the characteristic impedance of the line to that of the load. Quarter-wavelength sections actually serve as step-up or step-down transformers, such as those commonly used in low-frequency circuits.

4-99. Figure 4-22 shows a quarter-wavelength matching transformer connecting a line to a load and its equivalent circuit. This illustration shows the $Z_o$ of the line as 1000 ohms and the $R_L$ as 250 ohms. The problem is to find a quarter-wavelength section with the characteristic impedance that will correctly match $Z_o$ to $R_L$. $Z_t$ for explanation purposes is the characteristic impedance of a transmission line used as a matching transformer. The formula and processes are as follows:

$$Z_t = \sqrt{Z_o \times R_L}$$

$$= \sqrt{1000 \times 250} = \sqrt{250{,}000}$$

$$Z_t = 500 \text{ ohms}$$

4-100. Therefore, a quarter-wavelength of line having a characteristic impedance of 500 ohms will match the 1000-ohm line to

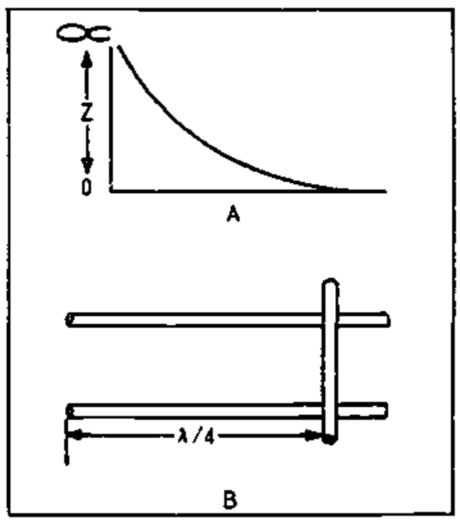


Figure 4-21. Impedance Along a Quarter-Wave Line

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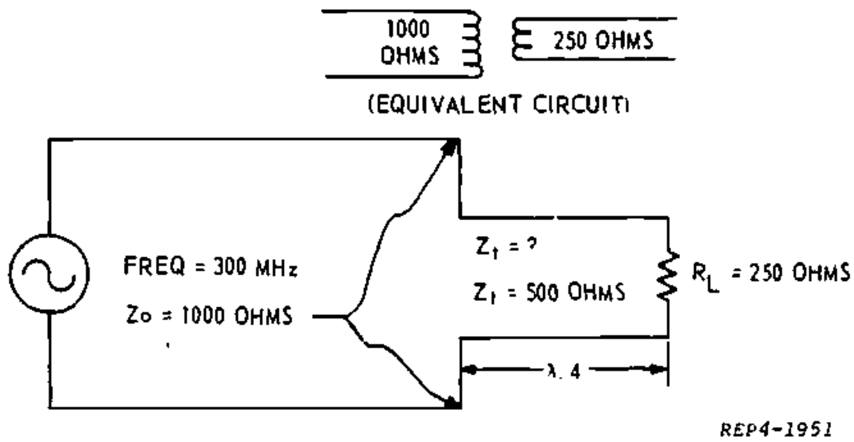



Figure 4-22. Quarter-Wave Matching Transformer

the 250-ohm load. One other step is still necessary. We must determine the length of the quarter-wave section of the 500-ohm line. For this we use the frequency of 300 MHz to determine a wavelength, using the following calculation:

$$\text{(meters)} = \frac{300}{F\ (\text{MHz})}$$

$$\text{(meters)} = \frac{300}{300}$$

$$= 1 \text{ Meter or } 100 \text{ cm}$$

$$\lambda/4 = 25 \text{ centimeters}$$

4-101. Therefore, the quarter-wave transformer section will be a piece of 500 ohm transmission line 25 cm long. This matching section will function similarly to a stepdown transformer, matching a primary impedance of 250 ohms.

4-102. Delta Matching.

4-103. Another method of accomplishing maximum transfer of power from a transmission line to a load is by use of a delta match. Figure 4-23 illustrates a delta match between a transmission line connected to a source (transmitter) and a load (antenna). The center (input) impedance of a dipole antenna is approximately 73 ohms and increases to approximately 2500 ohms at the ends. The purpose of the delta match is to match the transmission line impedance to the input impedance of the antenna.

4-104. A delta match is accomplished by gradually spreading apart the two wires of twin lead or open two wire. This spreading gradually increases the impedance of the line. Increasing tne impedance gradually does not produce a large discontinuity on the line, therefore, the amount of reflected

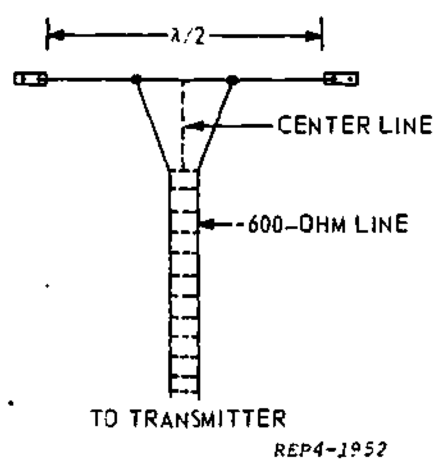



Figure 4-23. Delta Matching

energy is small. However, an abrupt change in distance between the conductors would cause discontinutity and a larger amount of reflected energy. Two points can be found on the antenna where the impedance equals the output impedance of the transmission line. If the line is connected to the antenna at that point the maximum transfer of energy can be accomplished.

4-105. Stub Matching.

4-106. A third method of matching impedance from a source to a load is by stub matching. A stub is 1/4 wavelength section of transmission line. As we have previously learned the impedance across a 1/4 section of line can vary from minimum impedance to maximum impedance. Figure 4-24 illustrates a quarter wave stub connected to a dipole antenna. The input impedance of the antenna is equal to the impedance of the stub. The stub is terminated at its other end in an open, thus, standing waves and variations in impedance are developed along the stub. If a transmission line of a different value of impedance is connected to the stub where the transmission line impedance equals the impedance of the stub, then maximum power transfer is accomplished.

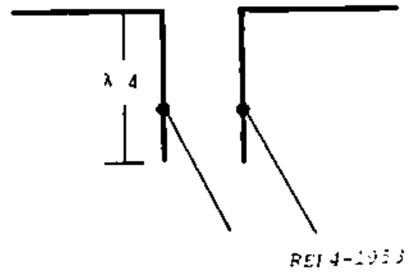



Figure 4-24. Stub Matching

# Chapter 5

# ANTENNAS

## 5 1. Antenna Function.

5-2. An antenna is a conductor or set of conductors used to radiate electromagnetic energy into space or to collect electromagnetic energy from space. To communicate by radio, energy in the form of electromagnetic fields must be radiated into space.

5-3. The power required to develop these fields is provided by the radio transmitter. The transmitter produces a modulated RF signal and the output is in the form of current oscillations, normally in a tank circuit. You must convert this current into electromagnetic fields which can be radiated through space. This is the function of a transmitting antenna. The antenna can be considered to be a transducer because it converts energy in the form of current oscillations to electric and magnetic fields of force. These fields, moving through space at approximately the speed of light, transmit to distant locations a portion of the energy originally produced by the transmitter.

5-4. Receiver equipment must be used to convert these fields back into an intelligent form. The receiving antenna converts the received fields, representing the transmitted intelligence, back into RF currents. This step is accomplished automatically by the nature of the receiving antenna; when the electromagnetic fields traveling through space cut across the receiving antenna, they impress a voltage across the antenna, which causes an RF current to flow. The receiver accepts and amplifies the current from the antenna, demodulates, and reproduces the intelligence signal.

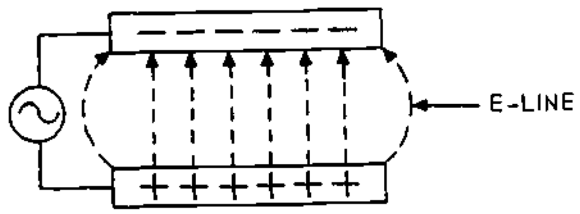
5-5. Antennas take many forms. Some antennas are high towers, hundreds of feet tall, erected on large tracts of land. Other antennas consist of several metal rods, perhaps a few inches to a few feet long, mounted atop towers and possibly arranged so that they can be rotated. Some antennas use parabolic reflectors which rotate in a horizontal plane or vertical plane or both. Still others may be inconspicuous slots cut into the skin of a metal cylinder or aircraft fuselage. The physical size, construction details and appearance depend primarily on the final use to which the antenna will be put.

## 5-6. Electromagnetic Waves.

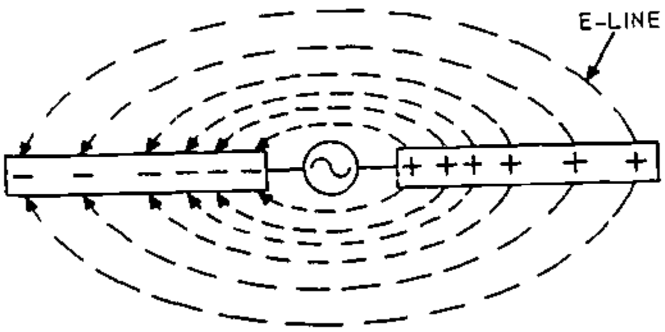
5-7. An electromagnetic wave consists of two primary components, an electric field and a magnetic field. The electric field results from the force of voltage and the magnetic field results from the flow of current.

5-8. Normally, the electric field is represented on an illustration by lines which are drawn to show the paths along which the electric force acts. The lines representing the electric field are pointed in the direction that a single positive charge would normally move under the influence of that field. Figure 5-1 illustrates the use of lines to represent the electric field that exists between two charged elements. Electric lines of force are called E lines. In figure 5-1, two rods are charged by a source of voltage (AC generator). The electric field is represented by the E lines extending from the positively charged rod to the negatively charged rod. Electrons flowing from the generator into the top rod in part A of figure 5-1 or into the left-hand rod part B of figure 5-1 cause these rods to have an excess of electrons and they are negatively charged. At the same time, electrons are flowing from the bottom rod in part A and the right-hand rod in part B toward the generator, thus these rods have a deficiency of electrons and are positively charged. Because of this difference of potential between the two rods in either part A or B, and electric field exists between the two rods.

5-9. Now that you realize the direction of electron flow in the rods and the resulting E line placement between the rods, recall that the charging voltage source is an AC




A. Parallel Rods




B. In-Line Rods

Figure 5-1. E-Field Distribution Between Charged Elements

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generator. The polarity of charges and the direction of the electric fields will reverse polarity and direction periodically at the frequency of the voltage source. The electric field will build up from zero to maximum in one direction and then collapse back to zero. Next, the field will build up to maximum in the opposite direction and then collapse back to zero. This complete reversal occurs during a single cycle of the source voltage. The half-wave dipole antenna (two separate rods in line as illustrated in part B of figure 5-1) is the fundamental element normally used as a starting point of reference in any discussion concerning the radiation of electromagnetic energy into space.

5-10. When current flows through a conductor, a magnetic field is set up in the area surrounding the conductor. In fact, any moving electric charge will create a magnetic field. The magnetic field is a region in space where a magnetic force can be detected and measured. There are two other fields involved, an induction field exists about the conductor carrying the current and another field, called the radiation field, which becomes detached from the current carrying rod and travels through space.

5-11. To represent the magnetic field, lines of force are again used to illustrate the energy. Magnetic lines are not drawn between

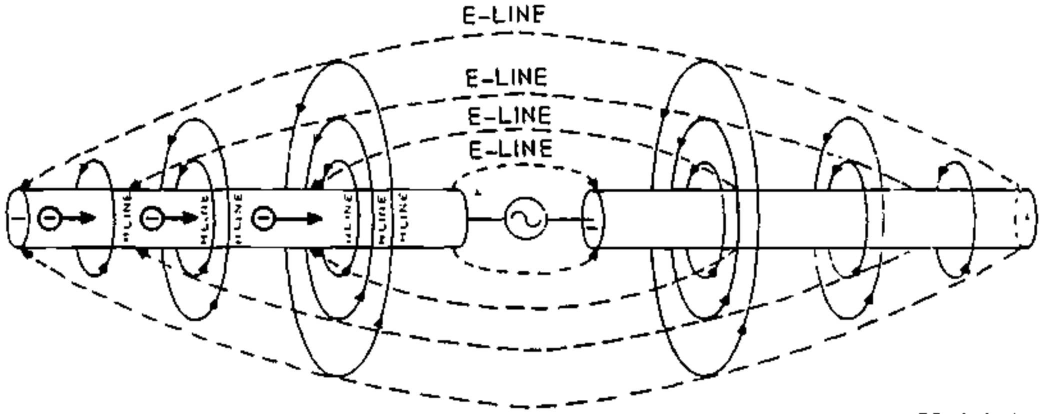
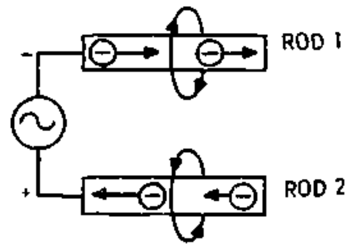


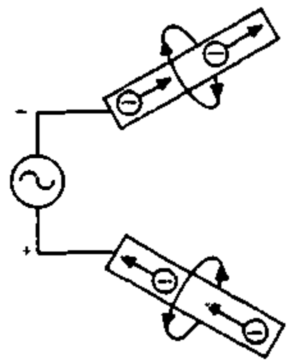

Figure 5-2. Relationship of E-Lines, H-Lines, and Current Flow

the rods, nor between a high and low-potential points as were the E lines. Magnetic lines are created by the flow of current rather than the force of voltage. The magnetic lines of force, therefore, are drawn at right angles to the direction of current flow. Also, as shown in figure 5-2, the magnetic lines of force are perpendicular, or at right angles, to the electric lines of force. Magnetic lines of force are indicated by the letter H and are called H lines. The direction of the magnetic lines may be determined by use of the left hand rule. Point the thumb on your left hand in the direction of the current flow and normal curvature of your fingers will point in the direction of the H lines around the conductor. The generator shown in figure 5-2 provides voltage, which creates an electric field, and current, which creates a magnetic field. This source voltage and current builds up to maximum value in one direction during one half-cycle. Both the electric and magnetic fields alternate from minimum through maximum values in synchronization with the changing voltage and current.

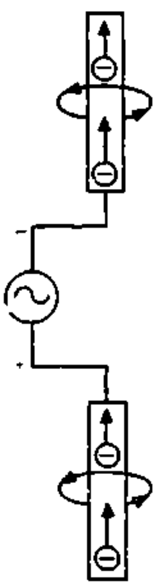
5-12. The magnetic fields which are set up around two parallel rods, as shown in part A of figure 5-3, are in maximum opposition. Rod 1 contains a current flowing from the generator, while rod 2 contains a current flowing towards the generator. As a result, the direction of the magnetic field surrounding rod 1 is opposite to the direction of the magnetic field surrounding rod 2. This will cause cancellation of a part or all of both magnetic fields, with a resultant decrease in radiation of the electromagnetic energy. Part B of figure 5-3 illustrates the fact that if the far ends of rods 1 and 2 are separated from each other while the rods are still connected to the generator at the near ends, more space and consequently less opposition will occur between the magnetic fields of the two rods. Part C of figure 5-3 illustrates the fact that placing the rods in line makes the currents through both rods flow in the same direction. Therefore, the two magnetic fields are in the same direction and thus, maximum electromagnetic radiation into space can be obtained.




A. Maximum Opposition



B. Medium Opposition

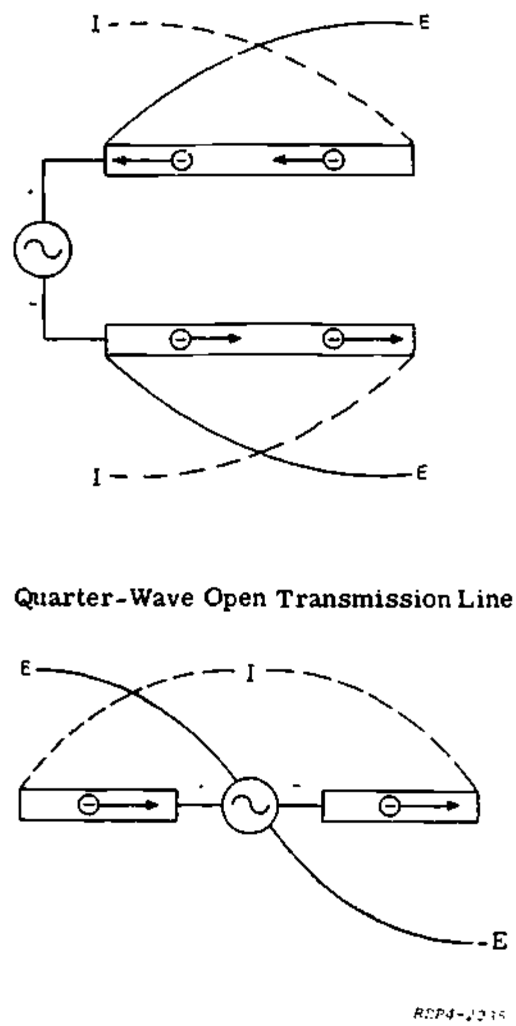


C. Minimum Opposition

Figure 5-3. Opposition of Magnetic Fields

5-13. In the foregoing discussion, the electric and magnetic forces are at right angles to each other and the fields reach their maximum intensity a quarter-cycle apart. The E and H fields are 90 degrees out of phase in time, and the lines of force are at right angles to each other in space. The time relationship between the electric field and magnetic field can be understood more easily by an illustration showing the standing wave on a transmission line and antenna. Figure 5-4 illustrates the standing waves on both a quarter-wave transmission line and a half-wave dipole antenna. Using an open-circuited, quarter-wave transmission line, it will appear as a series resonant circuit to the source and a parallel resonant circuit at the end. In part A of figure 5-4, the voltage on the upper rod is increasing in a positive or upward direction while the voltage on the lower rod is increasing in a negative or downward direction. The currents in the two rods are in opposite directions; therefore, the electric and magnetic fields are effectively cancelled. Part B of the figure shows that placing the quarter-wave rods in line forms a half-wave antenna. The currents through both rods are in the same direction and the two standing waves can be represented as one. As stated in paragraph 5-9, the half-wave dipole is the basic element of an antenna.

5-14. INDUCTION AND RADIATION FIELDS. The previous discussion established the fact that when a source of power causes current to flow in a conductor, a magnetic field is created around the conductor, and an electric field is created as a result of the accumulation of charges on the conductor. As the source of power (RF generator) changes polarity, the energy supplied to the conductor alternately and continuously changes in form. The resulting electromagnetic field, made up of electric and magnetic lines of force, is usually divided into two parts. The portion of the electromagnetic field which immediately surrounds the antenna and which collapses completely when the antenna voltage and current reverse is termed the INDUCTION FIELD. This field is associated with the stored energy in the antenna, and is mainly responsible for the behavior of the antenna as a tuned circuit element. Although this field is intense in the immediate vicinity of the antenna, its strength drops off rapidly at increasing distances from the antenna. The induction field strength varies inversely as the square of the distance from the antenna. At one instant of time all of the supplied source generator energy is stored about the conductor (antenna) in the form of an electric field, and at another instant of time (one quarter-wavelength later) all of the supplied energy is stored about the conductor in the form of a magnetic field. These fields associated with the stored energy are chiefly




A. Quarter-Wave Open Transmission Line

B. Half-Wave Antenna

Figure 5-4. Standing Waves

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responsible for the behavior of the antenna as a resonant circuit, and are termed the induction field. The strength of the induction field decreases with the square of the distance from the antenna. This induction field represents the stored energy about the antenna, and is responsible for the resonant effects the antenna reflects to the generator.

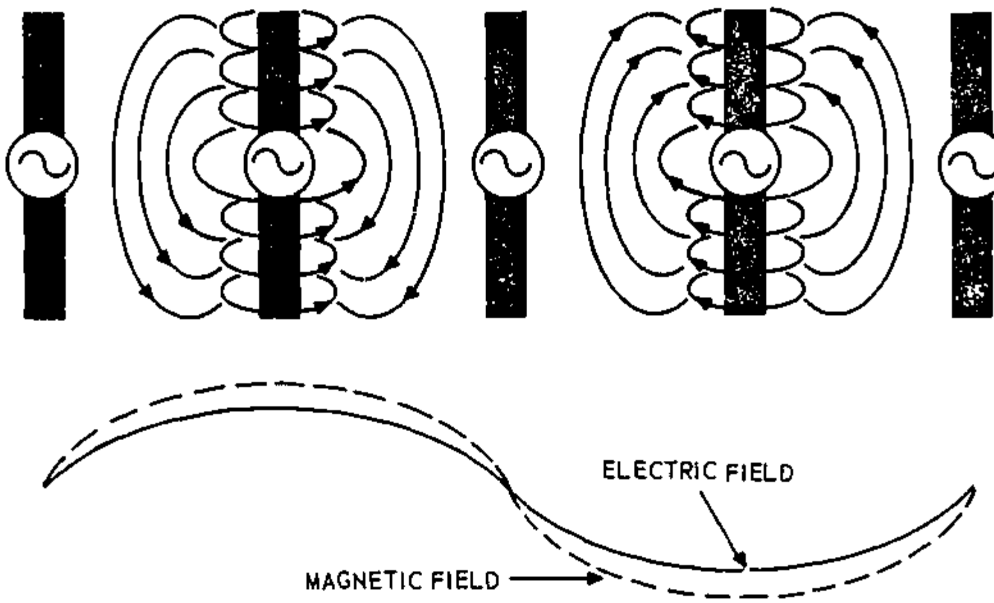
5-15. In addition to the induction field surrounding the antenna, there is also a field called the RADIATION FIELD, which becomes detached from the antenna and travels through space to make radio communication possible. The radiation field varies inversely with the distance from the antenna, and therefore, reaches much greater distances than the induction field. It is this radiation field which is responsible for ELECTROMAGNETIC RADIATION. Figure 5-5 illustrates the time phase of the induction and radiation fields.

5-16. As has been stated, the electromagnetic field consists of two parts: the induction field immediately surrounding the antenna, and the radiation field sent into space. At a distance of a sixth-wavelength from the antenna, the induction field and the radiation field are equal in strength (power). However, beyond this distance the induction field decreases as the square of the distance and rapidly disappears, while the radiation field decreases linearly with distance, and therefore, does not disappear entirely. Thus, it is the radiation field which is intercepted by receiving antennas within the range. That part of the electromagnetic field called the RADIATION FIELD induces both electric lines of force, which cause a build-up of potential (voltage) across a receiving antenna, and magnetic lines of flux, which cause a buildup of current within the antenna.

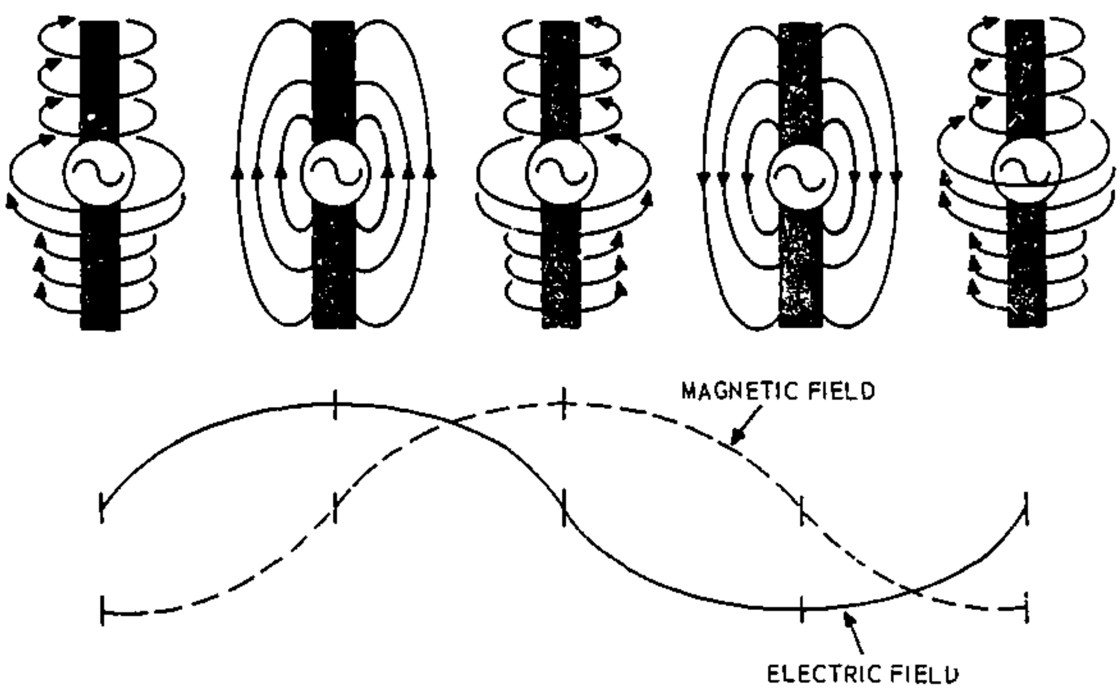
5-17. The ease with which radiation occurs from a transmitting antenna varies directly with the source generator frequency at lower frequencies, such as 60 hertz. The antenna voltage changes so slowly that the component of energy radiated is extremely small and is of no practical value. At higher frequencies, such as 50,000 Hertz, the radiated energy is great enough to meet communication requirements.

5-18. In the direction at right angles (perpendicular) to a half-wave transmitting antenna, both the E-field and H-field are strong. In the direction toward either end of the antenna (off the ends), no H-field forms at all, and only a very small E-field exists. The flux density is, therefore, small in the direction of either antenna end. Both the E-field and H-field expand away from the antenna at the speed of light. At every point in space, a varying magnetic field induces a voltage difference in space, which is the electric field. This electric field varies with time (frequency) and causes a displacement of the charge in space. This displacement current (space charge) sets up a magnetic field just as electrons flowing through a conductor set up a magnetic field around that conductor. This space magnetic field sustains the original varying magnetic field. Therefore, no moving E-field can exist without an H-field, and no H-field can be propagated without an associated E-field. Similarly, when electromagnetic energy is radiated into space, no moving electrostatic force can exist without an associated magnetic stress, and no magnetic force in motion can exist without an associated electrostatic stress. Each creates the other; therefore, neither can exist without the other. The antenna current associated with the transmitted field does not flow spaceward because no conductor exists in space; however, the magnetic field does exist in space. You can visualize a field existing without current flow if you think of a glass rod or other insulator being in the path of a moving magnetic field. An electrostatic stress voltage will be induced in the rod, but current will not pass easily through the rod. Magnetic lines move in space and set up electric stress voltages in the same manner.

5-19. The concept of a moving wave front directed between a transmitting antenna and a receiving antenna is important. A radio wave may be described as a moving electromagnetic field, having velocity in the direction of travel, and composed of electric and




A. Time Phase of E and H Components in The Radiation Field




B. Time Phase of E and H Components in The Induction Field

Figure 5-5. Time Phase of E- and H- Components in The Induction and Radiation Fields

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magnetic fields arranged at right angles to each other. Figure 5-6 shows the direction of wave travel and the angular displacement of the E and H components of the electromagnetic field. The electric field is illustrated in an upward direction, while the magnetic field is illustrated as coming out of the paper toward you.

5-20. Polarization.

5-21. A dipole radiates electromagnetic energy with magnetic and electric lines in space quadrature (perpendicular to each other), and both the magnetic field and electric field are perpendicular to their direction of travel (figure 5-7). Since the magnetic lines cause voltage to be induced in a conductor as the magnetic lines cut across the conductor, then the angle at which the lines cut the conductor is important. Recall in the theory of induction, that a conductor moving in a magnetic field produces the greatest voltage in the wire when the field and the conductor are perpendicular to each other. If the conductor and the field are parallel to each other. there is no cutting of the lines and no induced voltage. In antennas. the angle is just as important.

5-22. Linear Polarization.

5-23. If a radiating antenna and a receiving antenna are positioned so that the end of the dipole of the receiving antenna is pointed in the direction of the transmitting antenna (figure 5-8), little or no current will be induced. Likewise, when the radiating antenna and the receiving antenna are perpendicular to each other, the energy will not exist at the proper angles and little voltage will be induced (figure 5-9). For maximum volage to be induced, the two antennas have to be perfectly aligned with each other. The transmitter antenna must point toward the receiver antenna and the receiver antenna must point toward the transmitter. The antennas must be polarized with each other. Polarization of the antenna is directly associated with wave propagation, in that the propagated wave is polarized. When the electric lines travel vertically to the earth (perpendicular), the wave is vertically polarized. A vertically polarized antenna transmits a vertically polarized wave.

5-24. When an electromagnetic wave is transmitted so that its electric lines are

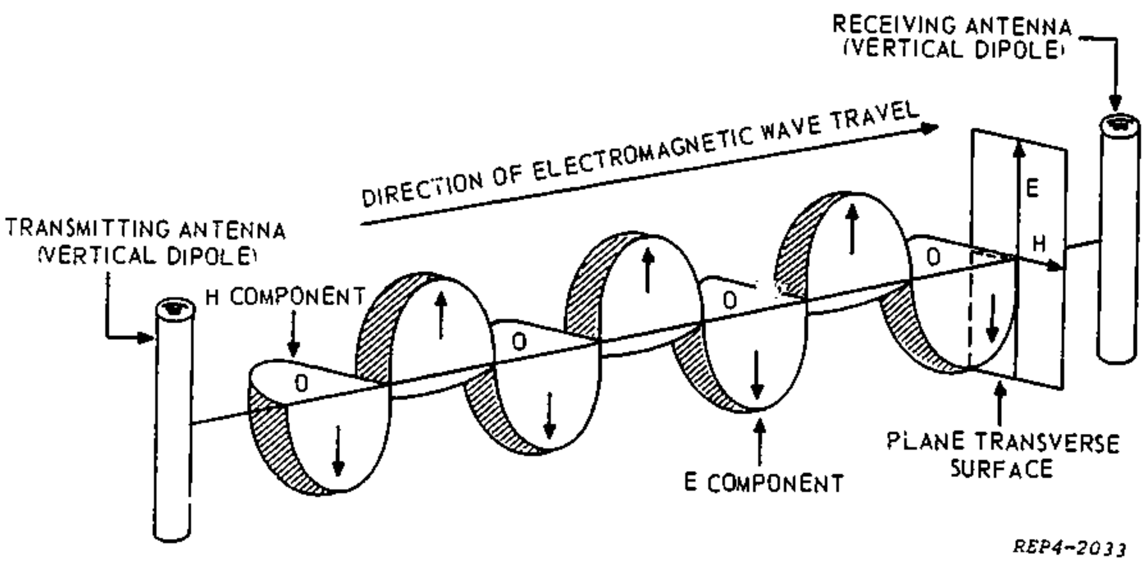


Figure 5-6. E and H Fields of a Radiated Wave

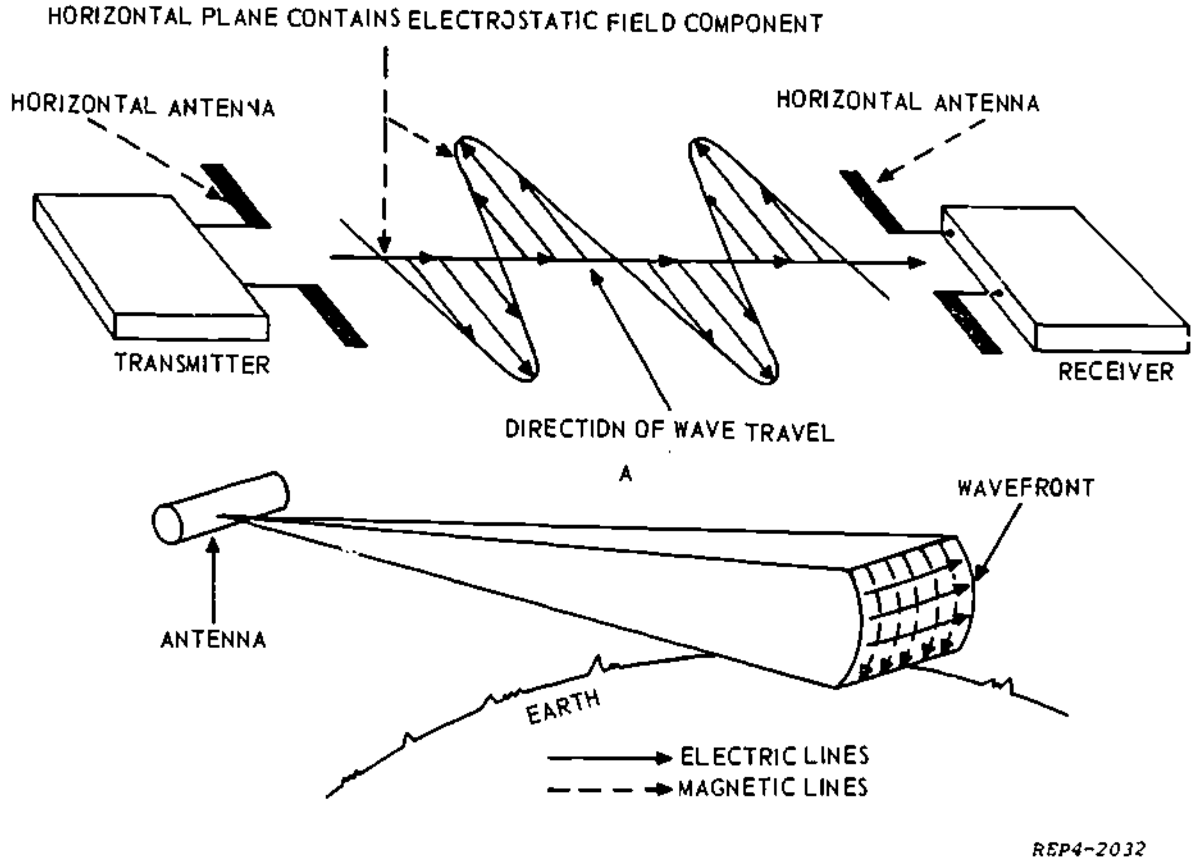


Figure 5-7. Electromagnetic Waveform

horizontal to the earth (parallel), the wave is horizontally polarized (transmitted from a horizontally polarized antenna).

5-25. If a dipole is placed so that its length is perpendicular to the ground, or so that its physical length is at right angle to the earth immediately beneath it, the antenna is vertically polarized.

5-26. If the dipole is positioned so that its physical length is horizontal, that is parallel to the earth immediately beneath it, then the antenna is horizontally polarized. Refer to figure 5-10.

5-27. Circular Polarization.

5-28. In linear polarization we found that the transmitting and receiving antennas must lie in the same plane to produce maximum energy transfer. Sometimes in radar, satellite communications and in radio astronomy the plane is not fixed and may change. This can cause a loss in energy transfer. To overcome this, circular polarization is used. Imagine the E field in vertical polarization being changed from their fixed position in space and rotated through 360 degrees with every cycle of the RF energy fed to the antenna. Constant amplitude electric lines

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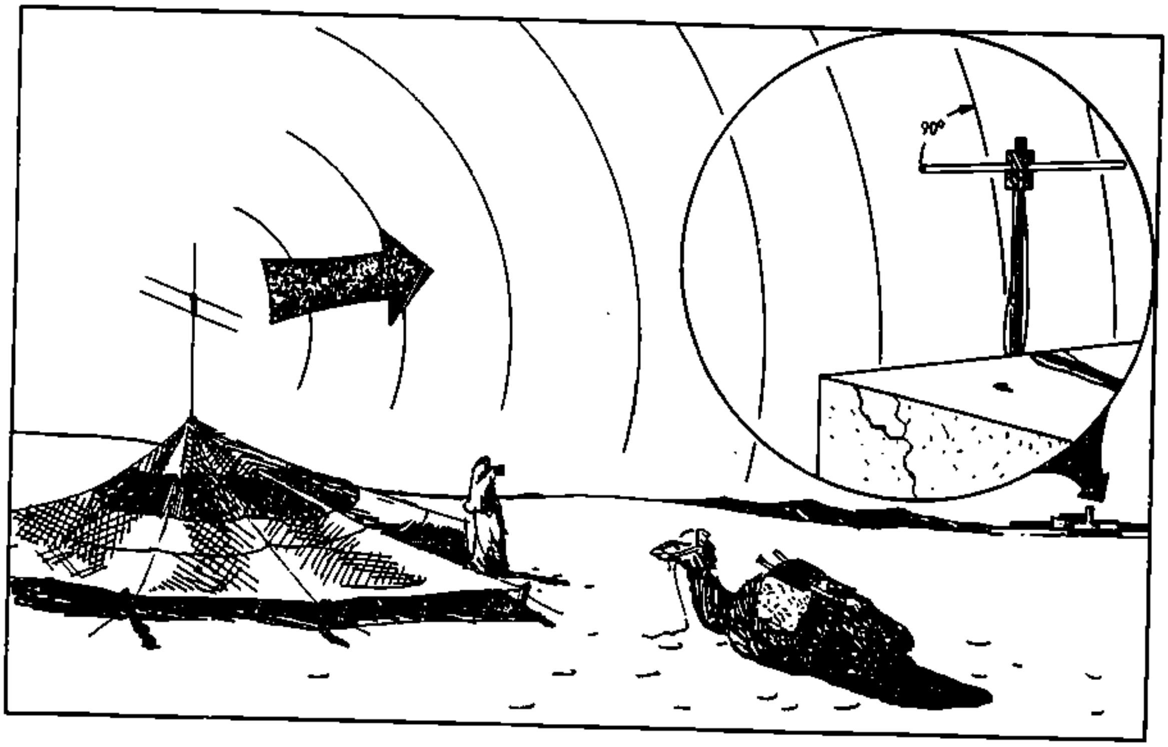



Figure 5-8. End of Receiving Antenna Pointing Toward Transmitting Antenna

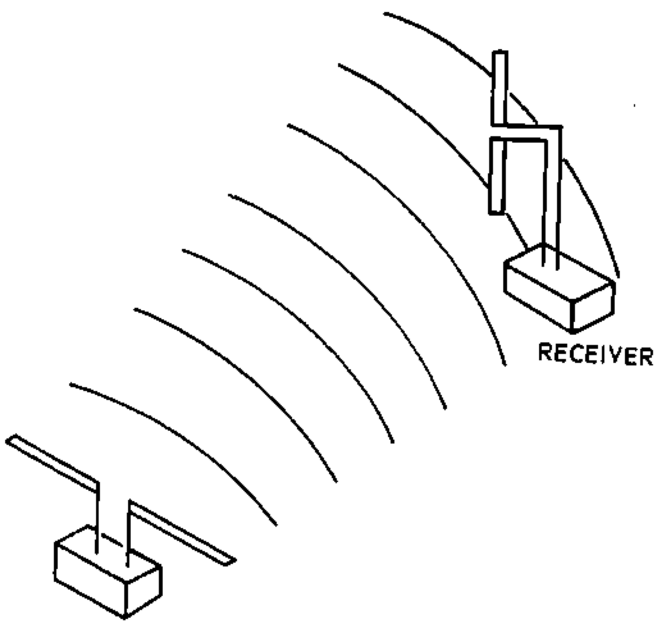



Figure 5-9. Receiving Antenna Perpendicular to E-Field

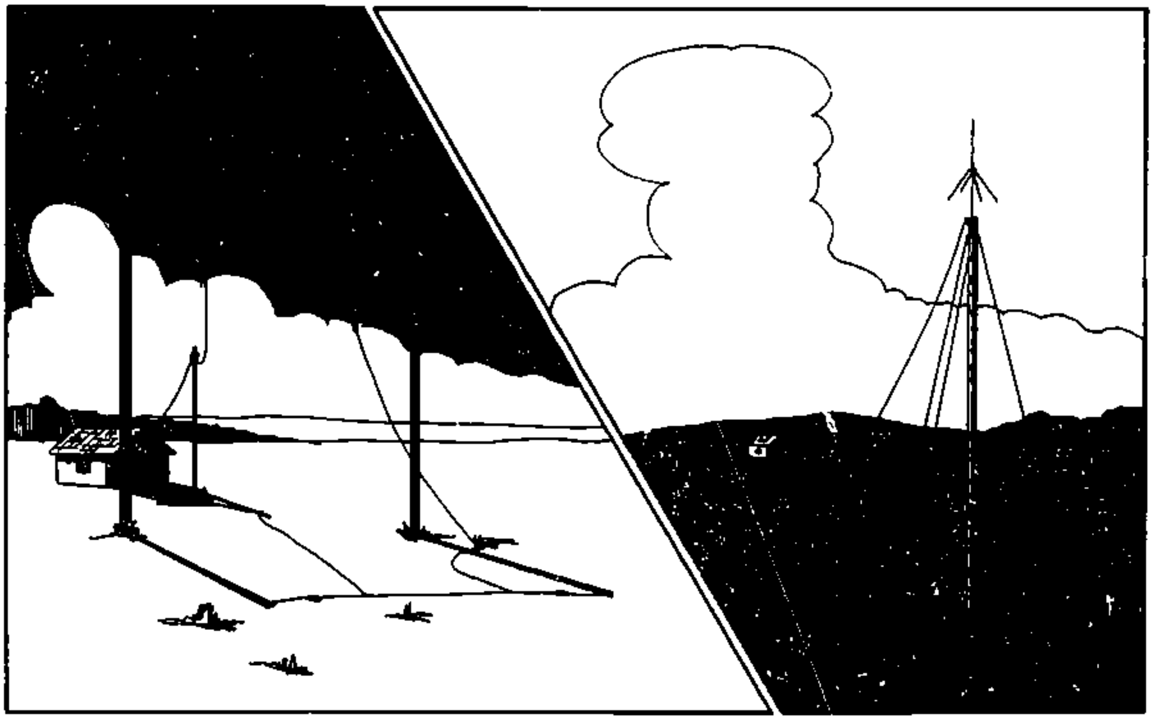



Figure 5-10. Horizontal and Vertical Polarization

of force are continuously changing their angular position as they are radiated into space. The resulting effect of this circular motion of the electric field is called circular polarization. Figure 5-11A illustrates the resultant waveform with the arrows depicting the electric field. Figure 5-11B shows the direction of the E field at a point in space at various instants of time over a complete cycle.

5-29. When the circularly-polarized energy strikes a receiving antenna, some portion of the circularly-polarized wave will be in the same plane as the antenna and maximum energy is transferred. Figure 5-12 illustrates an antenna array that will produce a circularly-polarized wave.

5-30. Antenna Length.

5-31. As stated previously in the discussion of electromagnetic radiation, a half-wave conductor is the simplest of the radiating

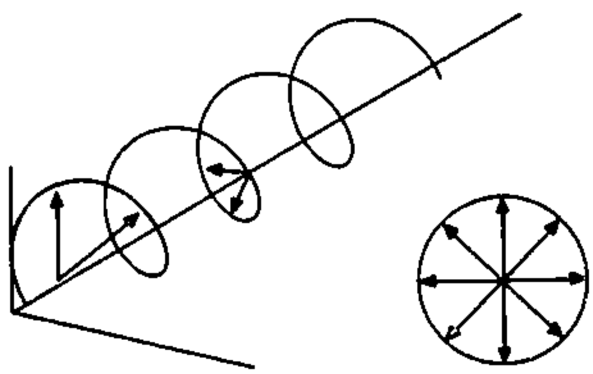



Figure 5-11. Wave Depicting Circular Polarization and Vectors

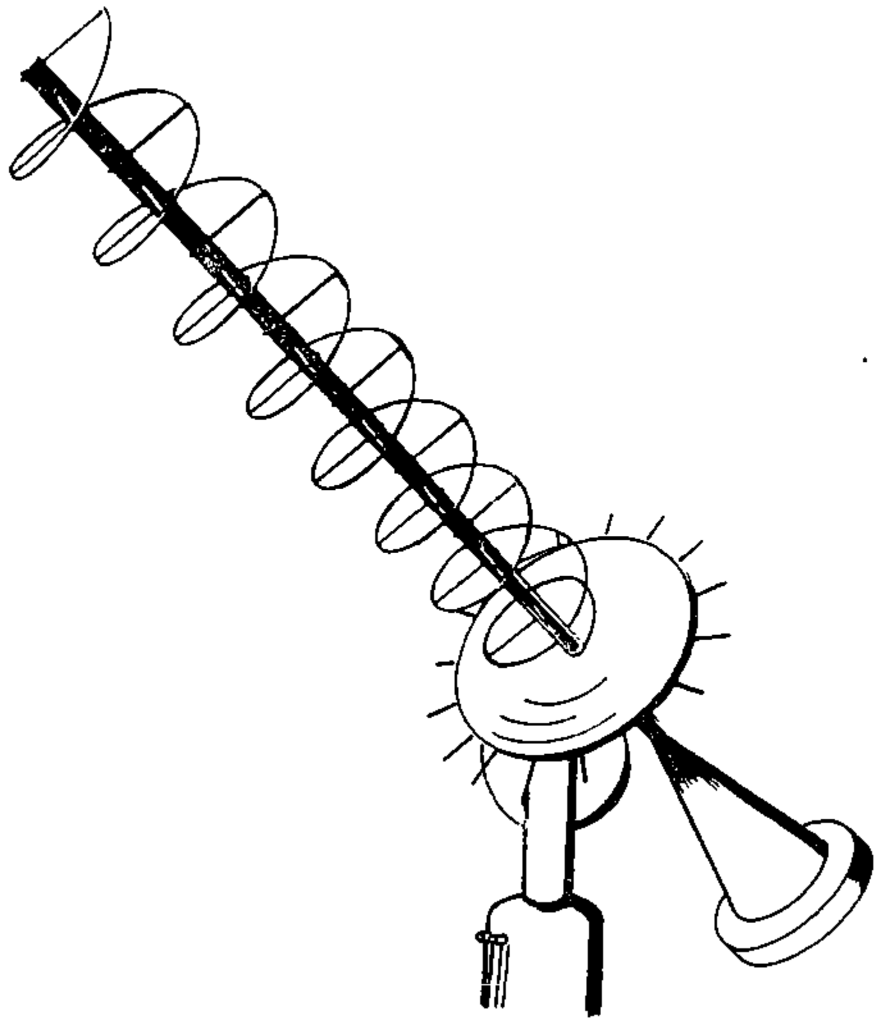
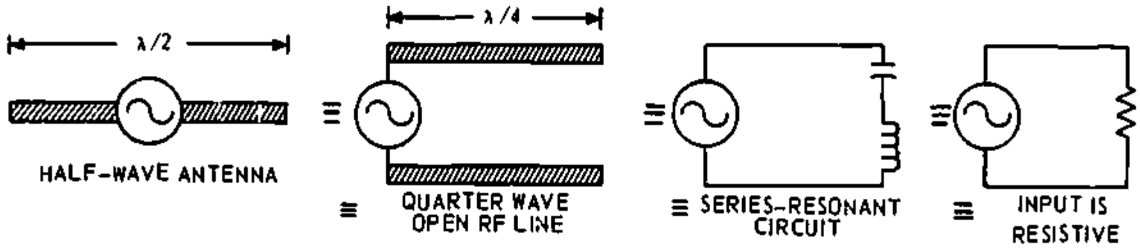


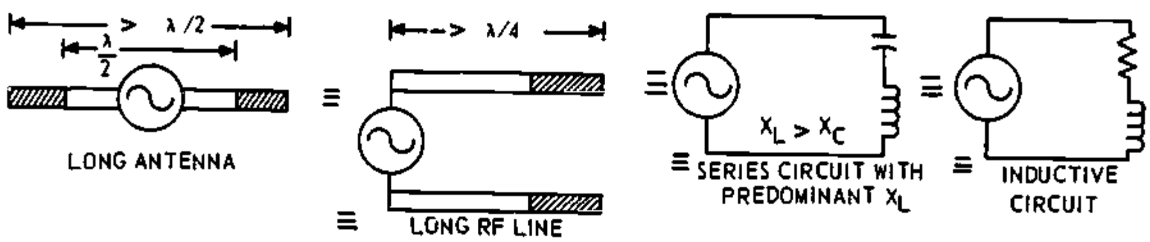

Figure 5-12. Antenna Using Circular Polarization

elements. Considerable radiation occurs in this element because of its resonant characteristics and its ability to store large amounts of energy in induction fields. Resonance causes high voltages and high circulating currents and they, in turn, produce strong (induction and radiation) fields around the antenna.

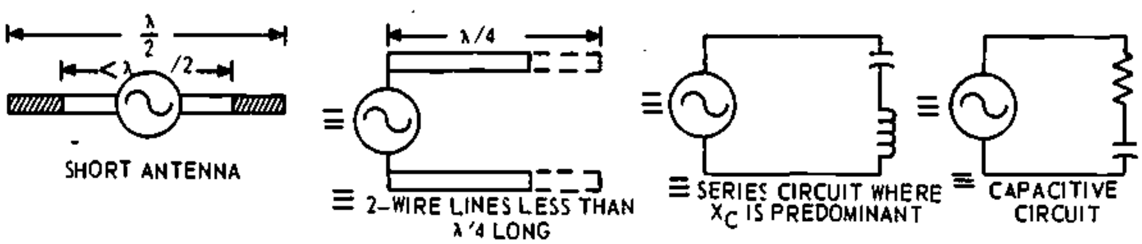
5-32. An antenna which is a multiple of one half-wavelength acts as a resonant circuit. In such an antenna, the capacitive currents cancel the effects of the inductive currents, and the antenna presents only pure resistance to any applied or induced current, as shown in part A of figure 5-13. Any antenna which is either longer or shorter than a multiple of one half-wavelength will oppose any current flow with an impedance composed of both resistance and reactance. For example, an antenna which is longer than some multiple of a half-wavelength will act as an inductive circuit, as shown in part B of the figure, while a shorter antenna will act as a capacitive circuit, as shown in part C. The remedy for excess antenna length is either to cut the antenna shorter or to add a physical capacitor in series with the line, as shown in part E of the figure. The capacitance must be of the proper value to




A. Correct Length is a Resistive Load to Generator

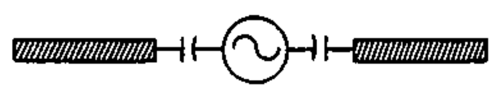



B. Antenna Longer than a Half-Wave is an Inductive Load to Generator




C. Antenna Shorter than a Half-Wave is a Capacitive Load to Generator

D. Add Series Inductance to Make Antenna Electrically Longer



E. Add Series Capacitance to Make Antenna Electrically Shorter

Figure 5-13. Effect of Physical Length on Antenna Impedances REP4-2026

provide the capacitive reactance needed to cancel the unwanted results from the inductive reactance. To correct an antenna which is too short, add a physical coil in series with the antenna, as shown in part D of the figure. The coil will effectively lengthen the antenna by causing the inductive reactance to cancel the effects of the capacitive reactance.

5-33. The field intensity pattern (radiation lobe) of a half-wave Hertz antenna is illustrated in figure 5-14. The Hertz antenna may be erected horizontally or vertically, depending upon which direction the energy is to be radiated. One disadvantage of the Hertz antenna is that its length for low radio frequencies becomes excessive. One of its main advantages is that it requires no ground (earth) and can be mounted high above the ground.

5-34. The basic Marconi antenna is a quarter-wave grounded radiator. The grounded antenna may be cut shorter than a quarter-wave length and still be resonant at the desired frequency if an inductor (called a loading coil) is placed in series with the antenna. By adjusting the loading coil, very short lengths of wire may be made resonant. Decreasing the length of the antenna, however, decreases the efficiency because the resistance of the inductor will dissipate excessive power as heat rather than allow it to be radiated.

5-35. The operation of the Marconi antenna can be explained by the use of an image to make an effective half-wave antenna. Assume that the surface of the earth is a perfect mirror and will produce an image antenna one-quarter wavelength long in the ground. This will occur if the ground is a good conductor. Assume that the quarter-wavelength below ground will be maximum negative due to the image antenna. The voltage and current distribution will be as shown in figure 5-15. The field intensity pattern will be one-half that of a vertically polarized Hertz antenna. If the earth is not a good conductor the field intensity pattern will be smaller.

5-36. Antenna Arrays.

5-37. There are uses for antennas where it is desirable that the radiation be nondirectional, and other uses where the antenna must be very directional. In the latter case, the antenna system usually consists of two or more simple half-wave elements so spaced that the fields from the elements add in some directions and cancel in others. This set of antenna elements is called an array.

5-38. The array includes more than one element, but the basic element is generally a half-wave dipole. Sometimes it is made to have more or less than this length, but usually the deviation is not great. A DRIVEN ELEMENT is connected directly to the transmission line. It obtains its power directly from the transmitter, or in reception, it applies the received energy directly to the

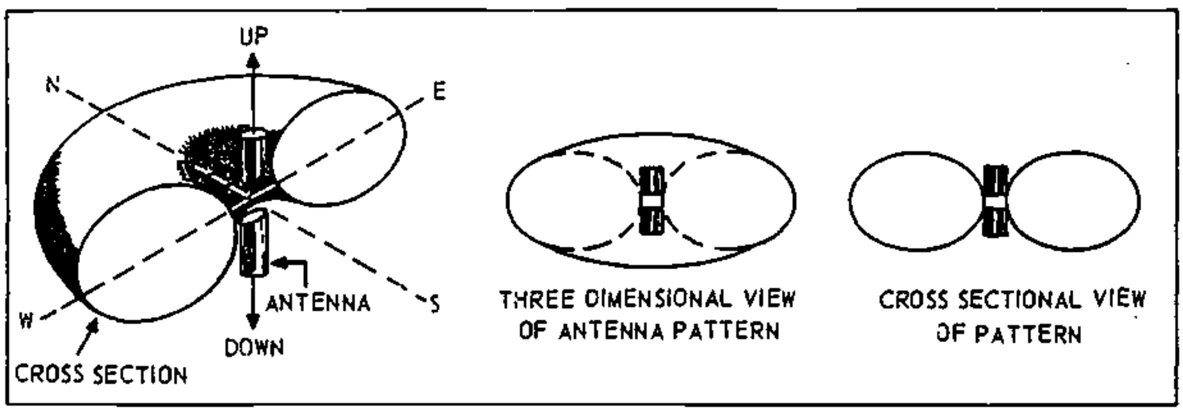



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Figure 5-14. Hertz Antenna

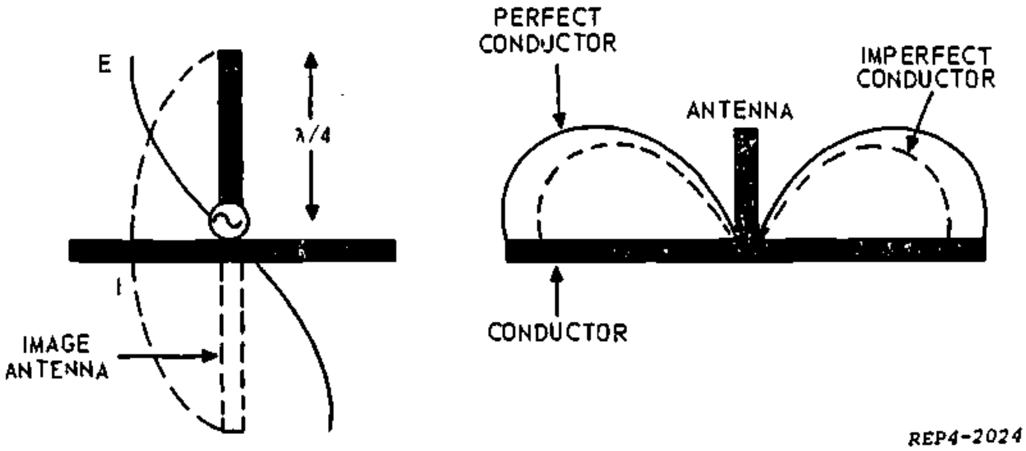


Figure 5-15. Marconi Antenna

receiver. A PARASITIC ELEMENT, on the other hand, derives its power from another element in the same array. It is placed close enough to the other element to permit coupling, and it is excited by means of the close coupling. If all of the elements in a given array are driven, the array is called a DRIVEN ARRAY. The term CONNECTED ARRAY is sometimes used to describe this type. If one or more elements are parasitic, the entire arrangement is usually considered to be a PARASITIC ARRAY. A parasitic element is sometimes placed so that it will produce maximum radiation (in transmission) from its associated driver, and it operates to reinforce the energy going from the driver toward itself. When so used, the parasitic element is referred to as a DIRECTOR. If a parasitic element is placed on the other side of the driven element so that it causes maximum radiation in the direction from itself toward the driven element, it is called a REFLECTOR.

5-39. Broadside.

5-40. When two or more half-wave elements are placed one-half wavelength apart, parallel to each other and are excited in phase. most of the radiation is broadside to the plane of the antenna. The term, excited in phase, simply means that the antenna elements are connected so that the currents flowing in all the elements will be in the same direction at any instant of time.

5-41. In order to understand how a directional field is produced, we will observe an end view of the elements. Since the spacing between the elements is one-half wavelength, this will constitute a phase change of 180°.

5-42. In figure 5-16A, notice that the direction of current in all elements is the same. This means that the fields produced will also have the same direction. In figure 5-16B, broadside array, note the fields that are shown. The solid circle is shown one-half cycle after it was started, and it has traveled one-half wavelength. The broken circle is shown one cycle after it was started and it has traveled one wavelength. Assume that the solid circle is a positive wavefront and the broken circle is a negative wavefront. As the positive wavefront travels from conductor 1 to conductor 2, it will cover a distance of one-half wavelength. At this time, the polarity of conductor 2 will be negative and will start to produce a negative wavefront. The two wavefronts of unlike polarities will cancel. Therefore, the direction of cancellation will be as shown. Refer now to the angles that are perpendicular to the antenna array.

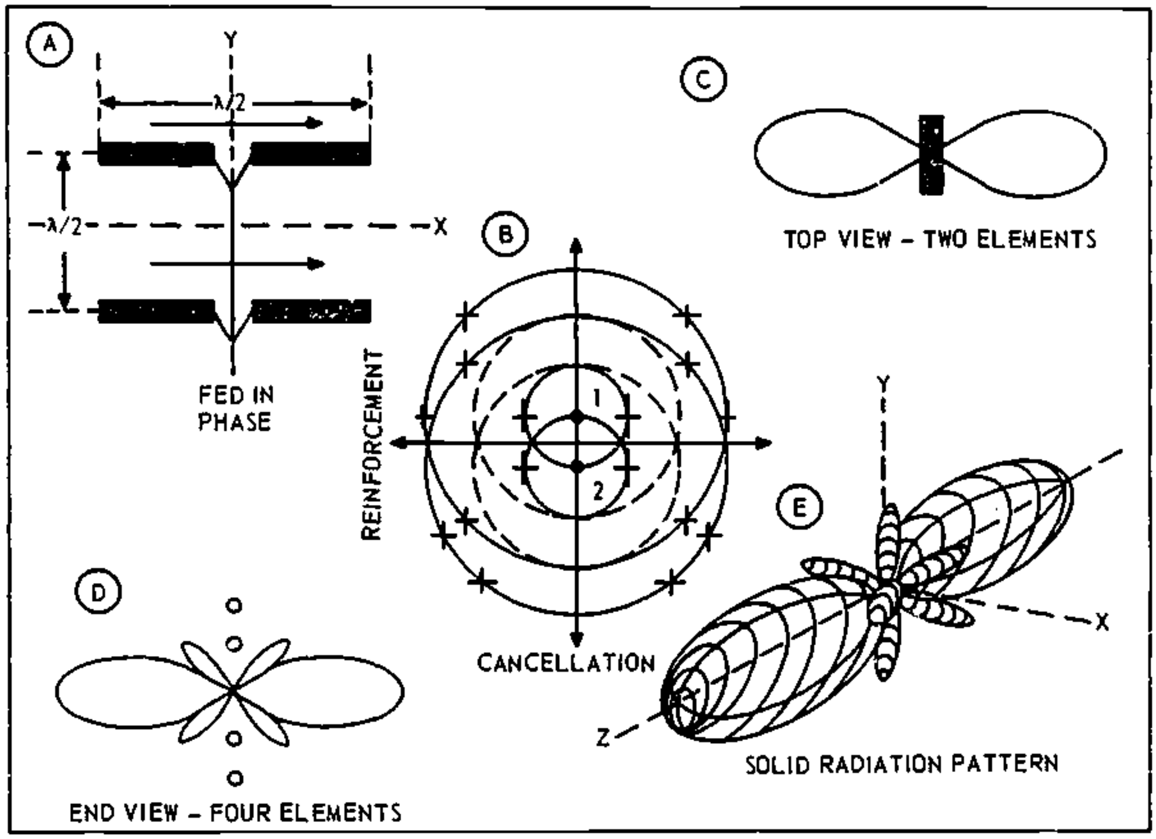


Figure 5-16. Broadside Array

Note that the solid lines indicate the same polarity. There will be reinforcement in this direction. Figure 5-16C is a representation of the antenna pattern observed in line with the axis of the array. Figure 5-16D is an end view of four elements showing that the direction of radiation is broadside to the array.

5-43. Figure 5-16E shows the radiation pattern as bidirectional, that is the antenna will radiate in two directions at one time. Notice that there are two major lobes, or points of maximum radiation, and several minor lobes or points of minimum radiation.

5-44. End-Fire Array.

5-45. An end-fire array is one in which two or more elements, one-half wavelength long, spaced one-half wavelength apart, in parallel. are fed 180° out of phase. In figure 5-17A, note that the current flow, indicated by arrows, is opposite in each element. Again, the broken circle represents a negative wavefront and the solid circle represents a positive wavefront. For the purpose of simplicity, consider one element radiating at a time, starting with element 1 in figure 5-17B. As the positive wavefront moves toward element 2, the polarity of element 2 will be changing from a negative value to a positive value. The positive wavefront from element 1 reaches element 2 one-half cycle later when element 2 is producing a positive wavefront. This will give us a reinforcement of the energy radiated by element 2 at this time. Now note element 2 and consider its affect on the radiation pattern. You will recall that when element 1 was producing a positive wavefront, element 2 was producing a negative wavefront because

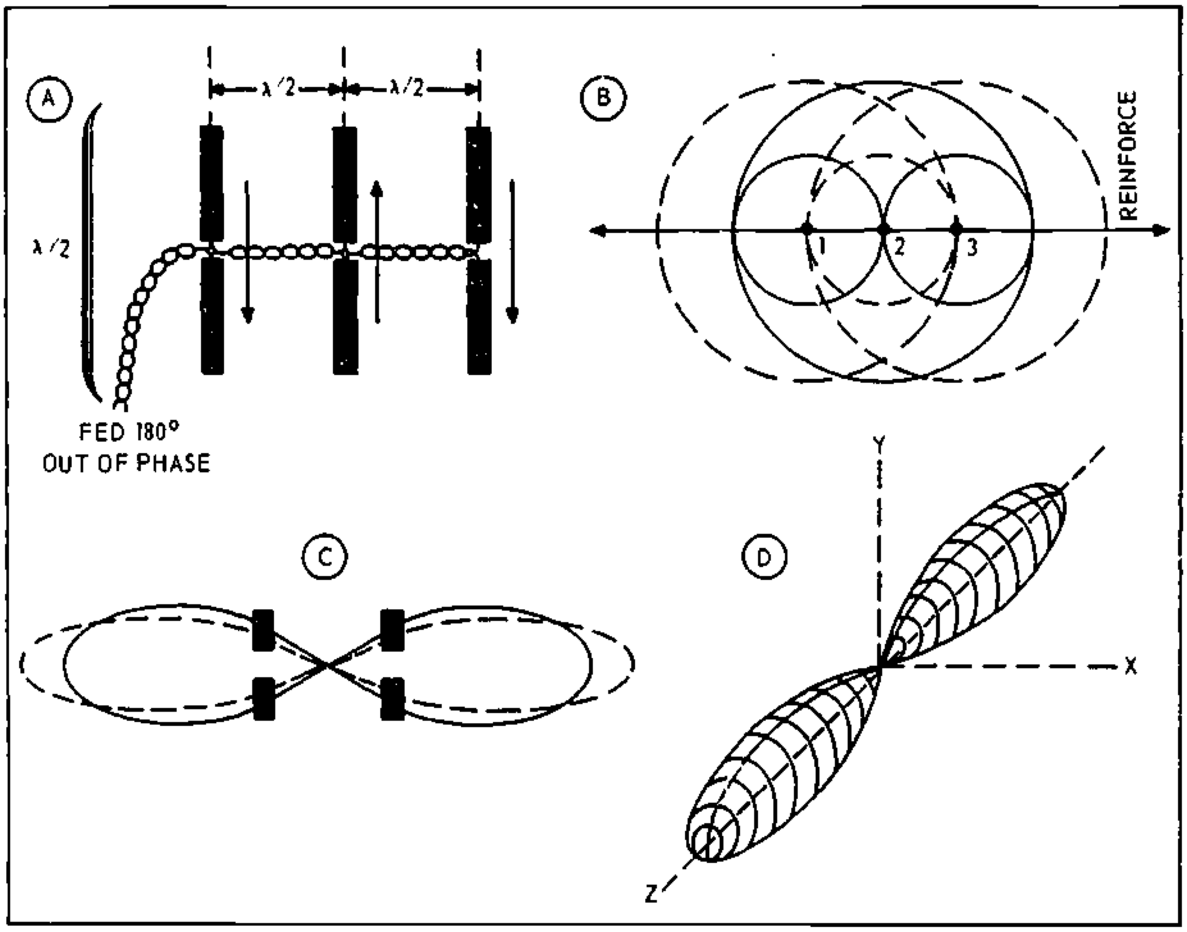


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Figure 5-17. End-Fire Array

of the distance between them. This negative wavefront will move toward elements 1 and 3. Because of the spacing, the phase of each element will have reversed at the time this negative wavefront reaches these two elements. Element 1 and 3 are producing a negative wavefront when the wavefront from 2 reaches them. These two negative wavefronts will also reinforce each other. The diagram should be simple to understand if you remember that the polarity of the elements are also changing. The endfire array also produces a bidirectional radiation pattern. When more elements are added to the array, the beam is narrowed. The antenna will also operate with two elements but in order to show the affect of additional elements, three elements are used. Figure 5-17C is a top view of the radiation pattern. The solid line shows the radiation pattern with two elements while the broken line shows the pattern with three elements. Figure 5-17D is a three dimensional view of the actual radiation pattern to show bidirectional characteristics of the end-fire array.

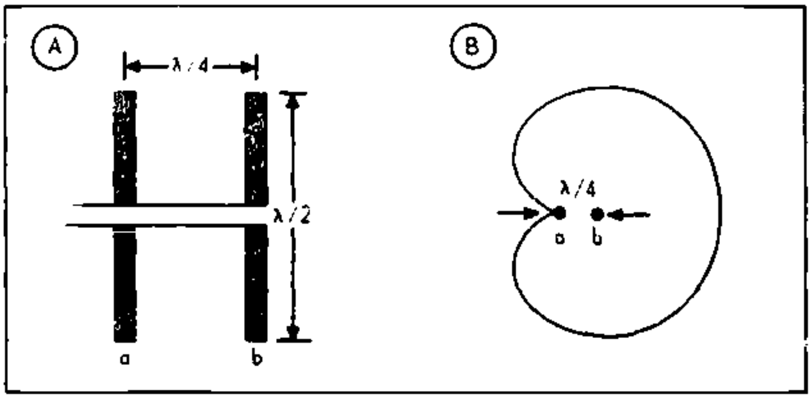


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Figure 5-18. Cardioid Array

5-46. Cardioid Array

5-47. If two dipoles are spaced one-quarter wavelength apart and are excited 90° out of phase, a unidirectional radiation pattern results. This type of an antenna is known as a cardioid array. In figure 5-18A, the excitation of element a leads that of element b by 90°. For purpose of explanation, assume that element a is a maximum positive, then element b will be zero because of the quarter-wavelength spacing. The positive field radiated by element a travels toward element b. At the same time, the polarity of element b is changing from zero to maximum positive. The positive will be reinforcement. This reinforcement will be in the direction of the lagging element. This explains why there is an increase in the field strength in one direction. You will recall that a dipole antenna by itself radiates in all directions. Now consider the energy moving to the left. The positive wavefront produced by element b also moves toward element a. As the positive wavefront moves to the left one-quarter wavelength, the polarity of element a is changing from zero to a maximum negative. This can be seen by drawing two sine waves 90° out of phase and labeling the leading phase element a and the lagging phase element b. This results in a decrease in the field intensity in the direction of the leading element. Due to the phase difference at right angles to the array, there is neither complete cancellation or addition. The radiation pattern is heartshaped, therefore, the name cardioid array. The radiation pattern is shown in figure 5-18B.

5-48. Colinear Array.

5-49. If two half-wave elements are placed end to end as shown in figure 5-19A, and excited in phase, they form a COLINEAR array. Looking at the end of the array, the

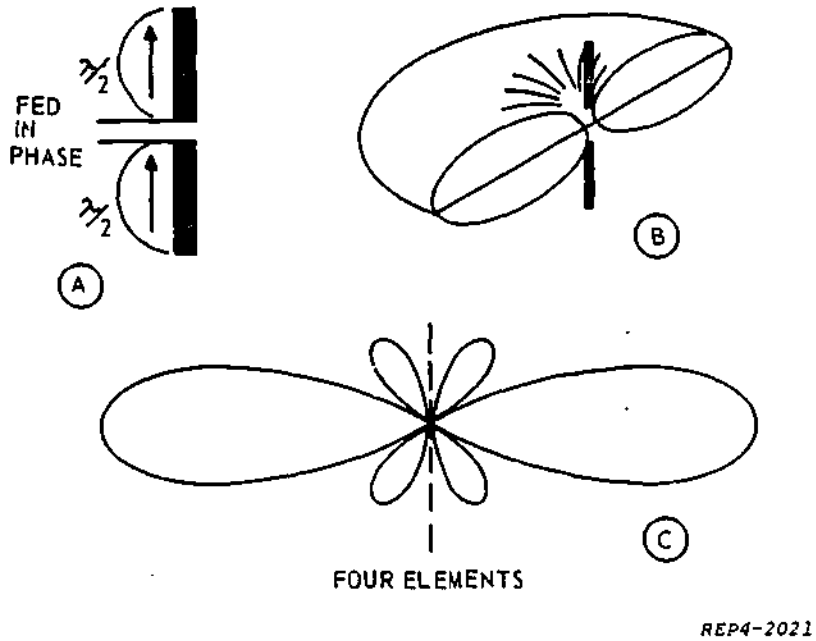



Figure 5-19. Collinear Array

pattern is circular, just as is that of a single dipole. The effect of the collinear array is to squeeze the doughnut pattern into a flat disc (figure 5-19B). As more elements are added, the disc of radiation becomes flatter and small secondary lobes appear. The radiation pattern of a four-element collinear array is shown in figure 5-19C.

5-50. Parasitic Elements.

5-51. GENERAL. The use of parasitic arrays is another method of achieving high antenna gain. A parasitic array consists of one or more parasitic elements placed in parallel with each other, and, in most cases, in the same line-of-sight level. The parasitic element is fed inductively by radiated energy which comes from the driven element connected to the transmitter. The transmitter is connected directly to the driven element. When you place the parasitic element so that radiation is in the direction shown in part A of figure 5-20A, the element is termed a DIRECTOR. When you place the parasitic element so that radiation is in the direction shown in part B, the element is termed a REFLECTOR. The directivity pattern which results from the action of parasitic elements depends on two factors. These factors are the tuning, which is determined by the length of the parasitic element, and the spacing between the parasitic and driven elements.

5-52. Operation.

5-53. When a parasitic element is placed a fraction of wavelength away from the driven element, and is of approximately resonant length, it reradiates the energy it intercepts. The parasitic element is effectively a tuned circuit coupled to the driven element, much the same as the two windings of a transformer are coupled together. The radiated energy from the driven element causes a voltage to be developed in the parasitic element, which, in turn, sets up a magnetic field. This magnetic field extends to the driven element, which then has a voltage induced in it. The magnitude and phase of the induced voltage depend on the length of the parasitic element, and also upon the spacing between the elements. In actual

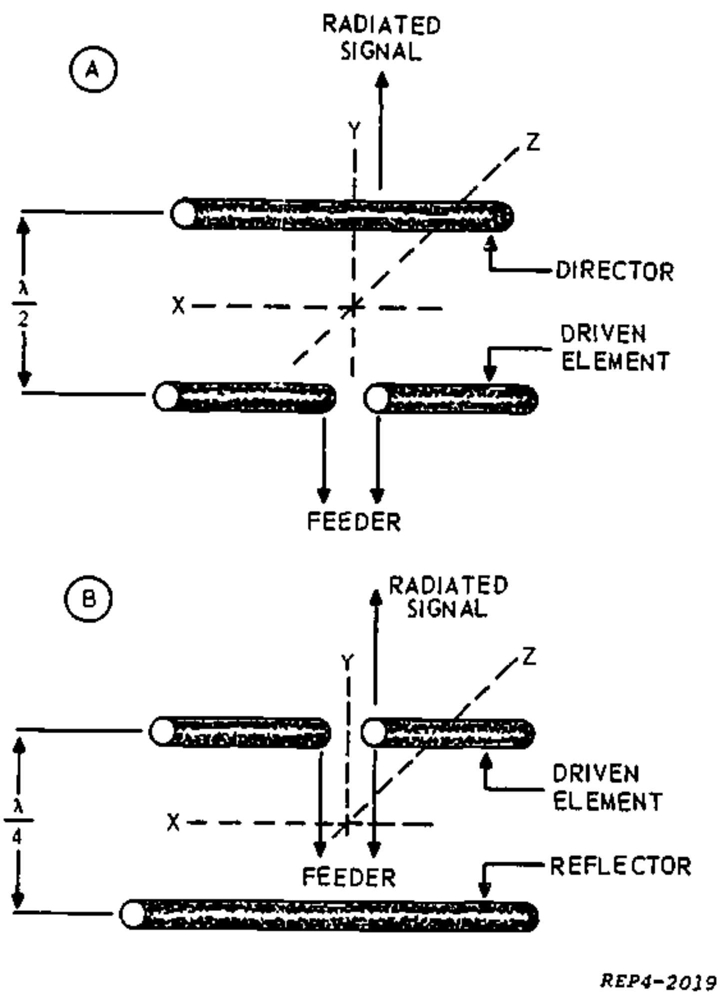
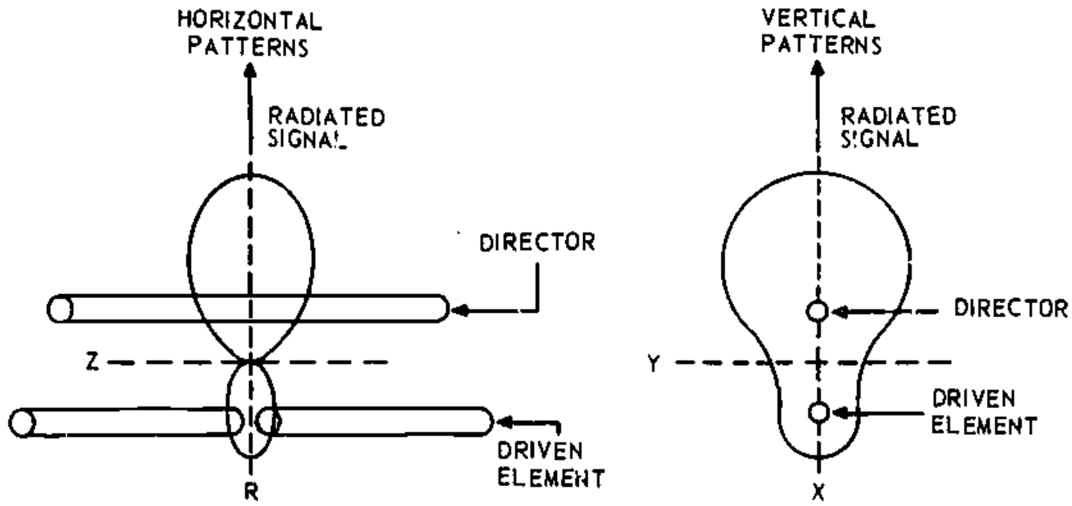


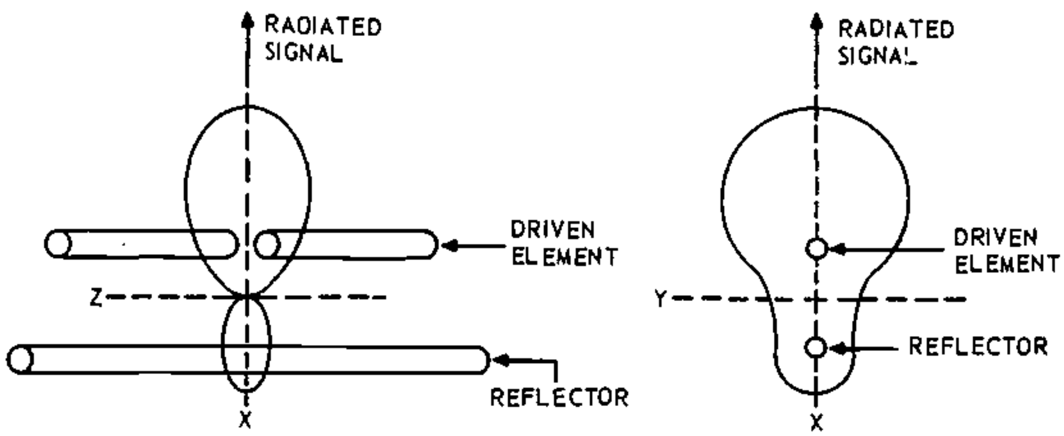

Figure 5-20. Position of Director and Reflector with Reference to Driven Element

practice, you can arrange the length and spacing so that the phase and magnitude of the induced voltage cause a unidirectional, horizontal radiation pattern, with an increase in gain.

5-54. In the parasitic array shown in part B of figure 5-20, the reflector and driven elements are spaced a quarter-wavelength apart. The radiated signal which comes from the driven element strikes the reflector after a quarter-cycle. The voltage developed in the reflector is 180 degrees out of phase with the driven element voltage. The magnetic field set up by the reflector induces a voltage in the driven element a quarter of a cycle later, since the spacing between the elements is a quarter-wavelength. The induced voltage is in phase with the driven element voltage, which causes an increase in voltage in the direction of the radiated signal indicated. This induced voltage forms the horizontal pattern shown in part B of figure 5-21. Since the voltage induced in the parasitic element is 180 degrees out of phase with the signal produced by the driven element, you can see that there is a substantial reduction in signal strength behind the reflector. In practice, the magnitude of an induced voltage never quite equals that of the inducing voltage, even in very closely coupled circuits; thus, the energy in the minor lobe is not reduced to zero. In addition, very little radiation is produced in the direction at right angles to the plane of elements. When the parasitic element is a director, the horizontal and vertical radiation patterns are as shown in part A of figure 5-21. The radiation patterns shown have several advantages and disadvantages. The two main advantages of a parasitic array are increased gain and unidirectivity. There is a reduction of transmitted energy in all but the desired direction. This makes the parasitic array useful in antenna arrangements that can be rotated to a given direction. These are known as ROTAR ARRAYS. The gain and directivity of a parasitic array are greater than those for a driven array of the same size. However, note that parasitic arrays have the disadvantages of critical adjustment and operation over a narrow frequency range.




A. Patterns Obtained Using Director




B. Patterns Obtained Using Reflector

Figure 5-21. Patterns Obtained when Using a Parasitic Element REP4-2018

# Chapter 6

# SYSTEMS

## 6-1. Communication Systems.

6-2. A system whose purpose it is to transmit information from one point to another is called a communication system. Radio is a communications system in which information is sent from one point through space and received at another point. Radio is a practical means for communications with moving vehicles such as boats, airplanes and autos, as well as with fixed locations. A radio communications system is illustrated in figure 6-1. The transmitter generates radio-frequency power and modulates it with the information to be transmitted. Transmission lines carry this radio-frequency power from the transmitter to the transmitting antenna which radiates energy into space in the form of electromagnetic waves. A receiving antenna in the path of these waves picks up some of the radiated energy. Transmission lines carry the received power to the receiver, which converts the radio frequency power into a form from which the information can be extracted.

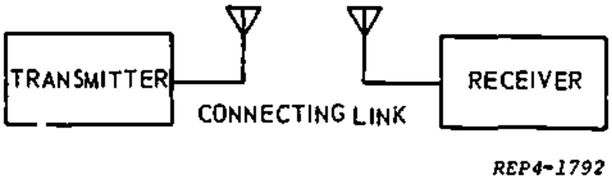



Figure 6-1. Radio Communications System

6-3. An oscillator can become an AM transmitter if a microphone and antenna are added as illustrated in figure 6-2. Sound waves applied to the diaphragm of the microphone cause the diaphragm to vibrate. The frequency and intensity of vibrations depend upon the frequency and intensity of the sound waves. These vibrations vary the electrical resistance offered to the battery current by the carbon granules of the microphone, causing fluctuations of current in the primary of the transformer. The fluctuating currents in the primary of the transformer

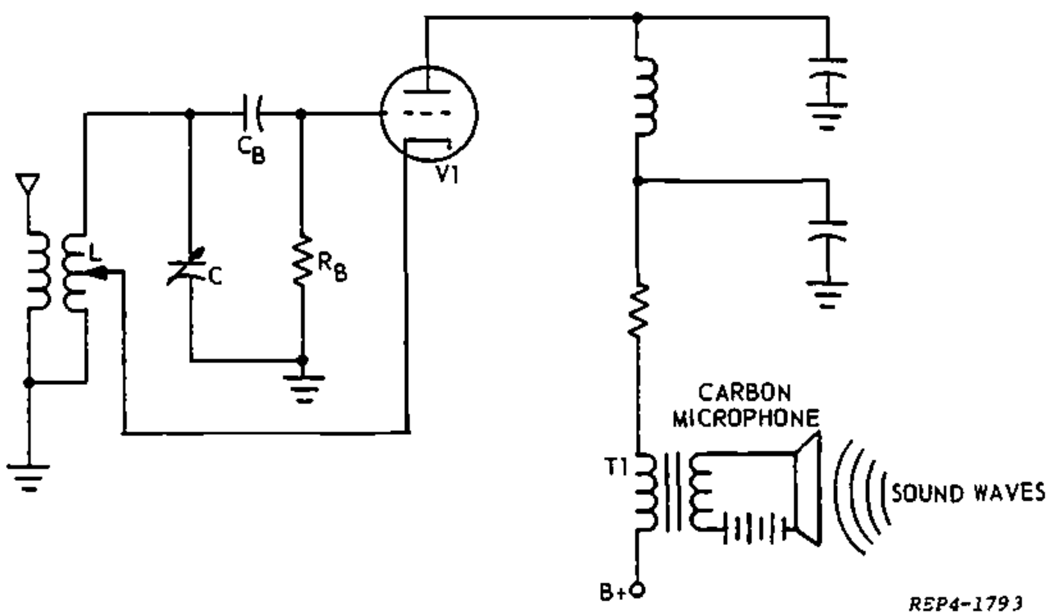



Figure 6-2. Making an Oscillator a Transmitter

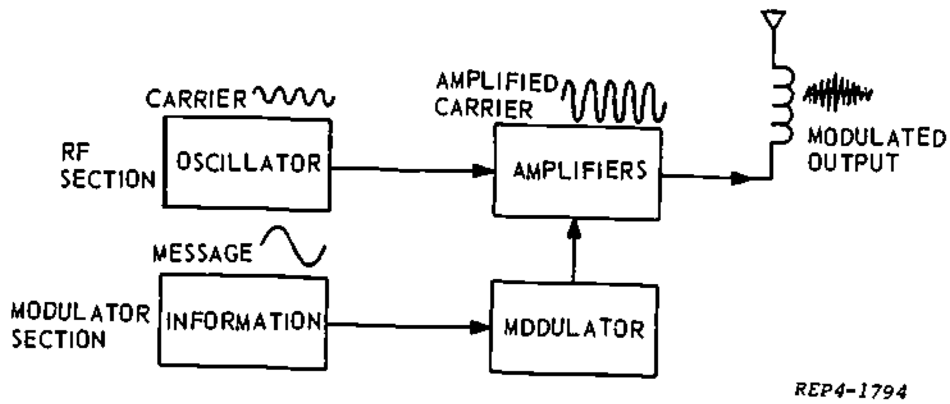



Figure 6-3. Block Diagram of a Transmitter

induce corresponding AC voltage changes in the secondary, which cause the plate voltage of the tube to vary. The plate voltage changes produce amplitude changes in the resultant RF wave to be transmitted by the antenna. As you have seen an oscillator has become a transmitter by the addition of a modulating device. In the early days of radio such oscillators were used as transmitters by coupling them directly to the antenna circuit. To increase the power output, larger tubes were used and higher voltages applied to the antenna. For present day demands, an oscillator used alone is not satisfactory. Too many factors limit its usefulness.

6-4. One of the major limitations of an oscillator as a transmitter is its lack of frequency stability. The frequency of an electron tube oscillator is controlled by the inductance and capacitance of its oscillatory circuit. Therefore, coupling a load (such as an antenna) to the oscillatory circuit of an oscillator has a great effect on its stability. The effective impedance of an antenna system is often changed by variations in the weather; the wind may shift the relation of the antenna to ground, rain, sleet, snow or ice may collect on the antenna; these and other conditions may change the impedance of the antenna. A varying load reflected into the oscillatory circuit will cause a change in the frequency of the oscillator. Though the frequency stability required can be attained by a crystal oscillator, the frequency range is limited. In frequencies above approximately 100 MHz the crystal oscillator cannot stand alone. To provide the needed frequencies, the oscillator must be followed by frequency multipliers. Another form of frequency instability occurs when the oscillator is modulated directly as illustrated in figure 6-2. The sound waves changed the plate voltage on V1, and by doing so changed the amount and phase of the feedback. This not only changes the amplitude of the output, but will also cause a change in the frequency.

6-5. Another limitation of an oscillator as a transmitter is power output. To provide sufficient power for modern radio transmission, the oscillator is usually followed by a buffer and power amplifiers. This arrangement produces the needed oscillator stability as well as suitable power out. Frequency stability is the ability of a transmitter to maintain the desired operating frequency. The required frequency stability or tolerance of a standard broadcast station is within 20 Hz of the assigned frequency.

6-6. A practical transmitter circuit consists of a radio-frequency section and a modulation section. As you can see in figure 6-3, the radio-frequency section consists of an oscillator and amplifier whose function it is to produce a carrier wave of the proper frequency and with sufficient power to be radiated over a given area. The oscillator produces an RF signal. The amplifier has four functions it can perform.

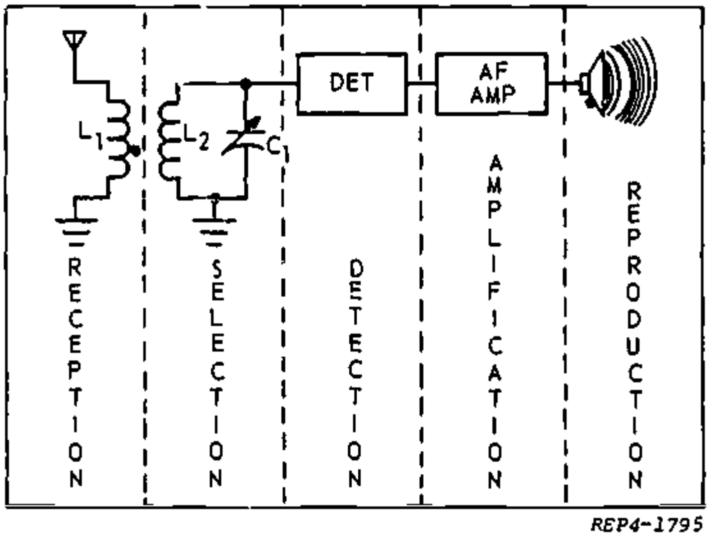



Figure 6-4. Simple Receiver Block Diagram

One, as a buffer, to isolate the changing impedance of the antenna from the oscillator. Second, as a frequency multiplier, to raise the frequency to be transmitted by some multiple of the oscillator frequency. Third, as a power amplifier, to produce the RF power required by the system. Fourth, as a non-linear device for modulation, to produce the modulated waveform. The amplifier section may perform one, two, three or all four of the functions in one or more stages. The modulation section of the transmitter usually consists of a microphone, voltage amplifiers and power amplifiers. The microphone converts sound waves into changes of voltage, the voltage amplifier amplifies these signals and the power amplifier produces the power required for modulation.

6-7. A receiver must perform certain basic functions; these are interception, detection, and reproduction. A typical receiver performs the following functions; reception, selection, demodulation, amplification and reproduction.

6-8. RECEPTION involves the transmitted electromagnetic wave passing through the receiver antenna in such a manner as to induce a voltage in the antenna.

6-9. DEMODULATION or DETECTION uses the received signal and recreates the intelligence signal which modulated the RF carrier wave.

6-10. AMPLIFICATION increases the intelligence signal (audio in the case of a radio) to the level required for operation of the reproducer.

6-11. REPRODUCTION converts the amplified intelligence signal to energy waves, such as sound, which can be interpreted by the ear, or light, which can be interpreted by the eye.

6-12. The ability of a receiver to reproduce the intelligence of a very weak signal is determined by the receiver's sensitivity. In other words, the weaker a signal may be and still be reproduced, the better the receiver's sensitivity.

6-13. The ability of a receiver to select and reproduce a desired signal from among several closely spaced stations, or from among interferring frequencies, is determined by the receiver's selectivity. In other words, the better a receiver is at differentiating between desired and undesired signal frequencies, the better is the receiver's selectivity.

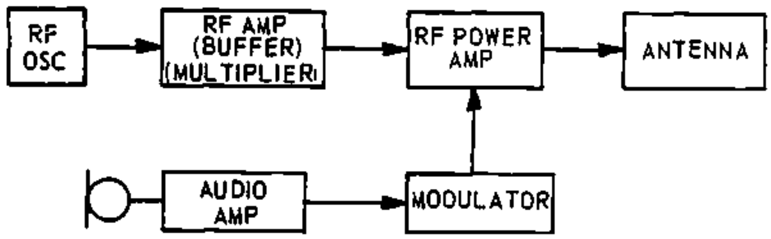



Figure 6-5. AM Transmitter

6-14. Figure 6-4 shows a simple radio receiver which performs all the functions required of a receiver. The example is a receiver used for audio communications.

6-15. Figure 6-4 also illustrates the functions performed by the various sections of the receiver. The input to the receiver is the electromagnetic wave propagated from the antenna of the transmitter. This wave passes through the antenna of the receiver and induces small AC currents and voltages. The section of the receiver formed by the antenna and L1 performs the function of reception. Current through L1 produces an electromagnetic field which induces AC voltages into the secondary, L2. L2 and C1 form a tuned circuit, with C1 being variable to permit tuning across the desired band. Thus, the tuned input circuit selects a specific frequency from among those present in the antenna circuit. The output of the tuned circuit is the modulated RF signal.

6-16. This modulated RF signal is then applied to the detector, where demodulation takes place. The output of the detector is a weak audio signal. This signal is normally too weak to operate a speaker; therefore, an AF amplifier increases the signal amplitude. The output of the amplifier is fed to the speaker, which reproduces the intelligence. Reproduction converts the electrical signals to a replica of the original audio input to the transmitter.

6-17. AM Systems.

6-18. A great number of communications systems being used at present are of the double sideband, unsuppressed carrier (conventional broadcast) type. A block diagram of a typical transmitter used in this type system is illustrated in figure 6-5. Let us discuss the purpose and characteristics of each block.

6-19. RF Oscillator.

6-20. An AM transmitter needs an oscillator to produce an RF wave called a CARRIER. In order to transmit intelligence by radio waves, it is necessary to combine the intelligence with a carrier.

6-21. Two main requirements exist for the oscillator: AMPLITUDE STABILITY and FREQUENCY STABILITY. The rigidity with which these requirements must be met depends on the accuracy demanded of the communications system.

6-22. Frequency stability refers to the ability of the oscillator to maintain the desired operating frequency. The less the oscillator drifts from its assigned operating frequency, the better the frequency stability.

6-23. RF Amplifier.

6-24. The oscillations from the oscillator may not be of sufficient amplitude to provide the proper percentage of modulation in the power amplifier. If this is the case, then the RF amplifier, as a voltage amplifier is used to raise the voltage level of the oscillations to the proper amplitude to drive

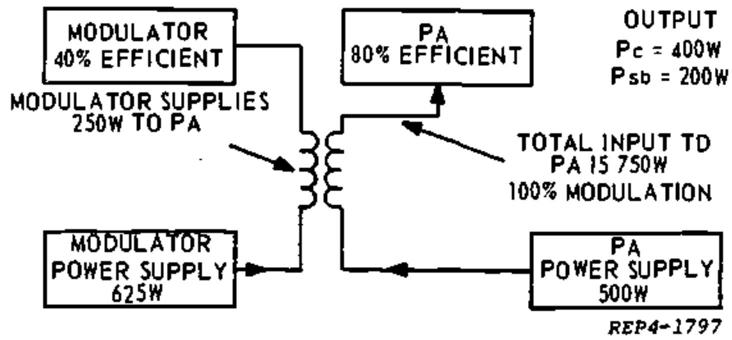



Figure 6-6. AM Transmitter Efficiency

the power amplifier. The RF amplifier stage can also be used as a buffer and/or multiplier. A buffer provides isolation so that one circuit does not interfere with another. A frequency multiplier is used to increase the frequency to a desired value.

6-25. In an AM transmitter, where the oscillator couples directly to the power amplifier (PA), the PA acts as a load on the oscillator. Modulating the PA, therefore, changes the load on the oscillator which causes oscillator instability. A buffer, therefore, isolates the oscillator from the PA.

6-26. Some transmitters operate the oscillator at a low frequency and use frequency multipliers to reach the desired output frequency. It is usual practice to keep the multiplication factor for a single stage to two or three, because the efficiency of a multiplier decreases as the factor increases. Though some multipliers have a multiplication factor as high as eight, their output tends to contain troublesome harmonics.

6-27. Audio Amplifier and Modulator.

6-28. The audio signal must be amplified to a sufficient power level to provide the proper amount of modulation. The audio amplifier is a voltage amplifier, and the modulator is a power amplifier. In order to have an efficient system, we should have 100% modulation. The level of the audio signal applied to the power amplifier must be sufficient to develop all of the power required for the sidebands. If the modulating signal is too large, then distortion will occur.

6-29. The audio amplifier (figure 6-5) is a wideband amplifier so that all frequencies within the audio signal may be amplified. The input audio signal is usually a very low level signal. The modulator output, on the other hand, is used to drive the power amplifier.

6-30. Power Amplifier.

6-31. The power amplifier (PA) in figure 6-5, is the stage in which the carrier is modulated by the intelligence signal. Remember that the modulation process is a heterodyning process. Heterodyning is the production of sum and difference frequencies by combining two or more different frequencies. The additional two frequencies are called sidebands or sideband frequencies. One sideband has a frequency that is higher than the carrier frequency by an amount equal to the modulating frequency. The other sideband is lower in frequency than the carrier by an amount equal to the modulating frequency. The power output circuit passes the carrier and the two sidebands, but not the modulating signal.

6-32. The power amplifier is a tuned amplifier and develops the required power for the carrier and the two sideband frequencies. This power is obtained through a conversion process in which power from the modulator is converted into sideband power.

6-33. The power distribution for a 400 watt transmitter is shown in figure 6-6. For this example, assume that the transmitter is modulated 100%, and that the power amplifier's efficiency is 80%. The efficiency of an amplifier can be computed using the following equation:

$$Eff = \frac{P_o}{P_{in}} \qquad (3\text{-}1)$$

which can be transposed into the following two forms:

$$P_o = P_{in}Eff \qquad (3\text{-}2)$$

and

$$P_{in} = \frac{P_o}{Eff} \qquad (3\text{-}3)$$

where

Eff = the efficiency of the amplifier

$P_o$ = the output power in watts

$P_{in}$ = DC input power ($E_b \times I_b$) to the plate of the amplifier

6-34. If the modulating signal is reduced to zero, only the 400-watt carrier will exist in the output of the power amplifier. Since the power amplifier has an efficiency of 80%, the PA power supply must deliver more than 400 watts of carrier output. The power drawn from the PA power supply is computed using equation (3-3) as follows:

$$P_{in} = \frac{P_o}{Eff} = \frac{400}{.80}$$

$$P_{in} = 500 \text{ watts}$$

6-35. This computation shows that, in order to generate the carrier, 500 watts of DC Power must be supplied by the PA power supply. Because the tube is 80% efficient, 20% of the 500 watts is dissipated by the tube as heat. The remaining 400 watts are converted into carrier power and appear at the output.

6-36. When the transmitter is 100% modulated, the two sidebands together containing one half as much power as the carrier, appear at the output. Since the sidebands occur as a result of modulation, the power which they contain is supplied by the modulator. Numerically, the sideband power at the output is 200 watts. This represents 80% of the audio power applied to the PA by the modulator. Equation (3-3) can be applied to determine the exact amount of power the modulator must supply for 100% modulation.

$$P_{in} = \frac{P_o}{Eff} = \frac{200}{0.80}$$

$$P_{in} = 250 \text{ watts}$$

Therefore, the modulator must supply 250 watts of audio power to the power amplifier to produce 100% modulation. Of this 250 watts, only 200 watts reach the output because the 80% efficient PA loses 50 watts by the plate of the tube, as plate dissipation. Note that the same power relationship exists between the PA and modulator input powers as exists between the carrier and sideband powers. Observe, also, that the modulator input power of 250 watts is exactly one-half of the PA input power of 500 watts.

6-37. The power amplifier must have a bandwidth sufficiently broad to pass the carrier and the sidebands.

6-38. The power output of the power amplifier may not be of the level required for transmission. Some AM systems employ amplification after the power amplifier. This is not shown in figure 6-5. This amplifier is called either the Final Power Amplifier or a Linear Power Amplifier. Its purpose is to bring the power level of both the carrier and the sidebands up to the desired power level for transmission. The relationship "between" carrier and sideband power must not be changed. The bandwidth of this amplifier must be wide enough to assure that all the sidebands receive the same degree of power amplification as did the carrier.

6-39. The output of the transmitter is the carrier and the sidebands, the power of which may be low, intermediate, or high. The output frequency may range from a few kilohertz to thousands of megahertz. The output of the transmitter must be transferred to the load, which is usually an antenna. The transmission line conducts or guides the energy from the transmitter to the load. The transmission line must be capable of handling the power output of the transmitter, and must pass the required frequencies with little attenuation.

6-40. A transmitting antenna converts electrical energy into electromagnetic waves which radiate away from the antenna at the speed of light. The electrical and physical features of antennas are determined by the functions they serve. Such features will vary with operating frequency, power handling capability, plane of polarization, and desired radiation field pattern. The physical size of an antenna element is determined primarily by its operating frequency and power handling capability, while its overall shape and size, relative to the wavelength, are determined by the desired radiation field pattern.

6-41. Circuit Operation.

6-42. Figure 6-7* illustrates an AM transmitter schematic diagram. The transmitter is broken down into three major sections, the first being the radio frequency section. The first stage in this section is a Hartley RF oscillator. The direct current flows from ground through the lower windings of T1, through R2, V1, L1, and R3 to B+. The RF oscillations that are present at the top of T1 are coupled to the grid of V1 which causes the direct current to increase and decrease at the oscillator RF frequency, this produces the necessary feedback. The oscillations are also coupled through C3 and R4 to the grid of V2. V2 is an RF voltage amplifier. The DC path is from ground, through R5, V2 and L2 to B+, also DC flows from ground through R5 to the screen grid through R6 to B+. The RF signal on the grid of V2 causes the DC in V2 to increase and decrease at the oscillator signal frequency. The variations in the DC through the tube produces an AC signal at the top of L3 and C9, this signal is coupled to the grid of V3. V3 is a class C Power Amplifier. The DC flows from ground through R8, V3, through the primary of T2, L5, and secondary of T3. The AC signal on the grid causes the DC to vary at the oscillator frequency, which is the resonant frequency of the tank C12 and T2 which produces maximum signal at that frequency.

*Figure 3 in KEP-GP-68

6-43. The intelligence signal (audio) is developed by the microphone, coupled through C-14 and R9 to the grid of V4, which is a voltage amplifier. The amplitude of the audio signal which is applied to V4 control grid is controlled by R9. R9 is in fact the percentage of modulation control. The DC path is from ground through R10, V4 and R11. The audio signal on the grid causes the DC to vary at the audio rate. The amplified audio signal is coupled from the plate of V4 by C16 and R12 to the grid of the modulator (audio power amp) V5. The DC is from ground through R13, V5, and T3 to B+, there is also current flow into the screen grid through R14, to B+. The audio signal on the grid of V5 causes the current flow through the primary of T3 to vary at the audio rate. These variations are coupled to the secondary and cause the plate voltage of V3 to vary at the audio rate. This produces sidebands in the plate circuit of V3. These are developed in the resonant tank circuit of V3. The carrier and the sidebands are then coupled to the antenna by T2. The antenna converts the voltage and current changes into electromagnetic fields which radiate out into space.

6-44. The power supply, V6, provides the power required for each stage. The DC from each stage flows through R15, L6, the conducting half of V6 and through the secondary of the power transformer to ground, completing the DC loop.

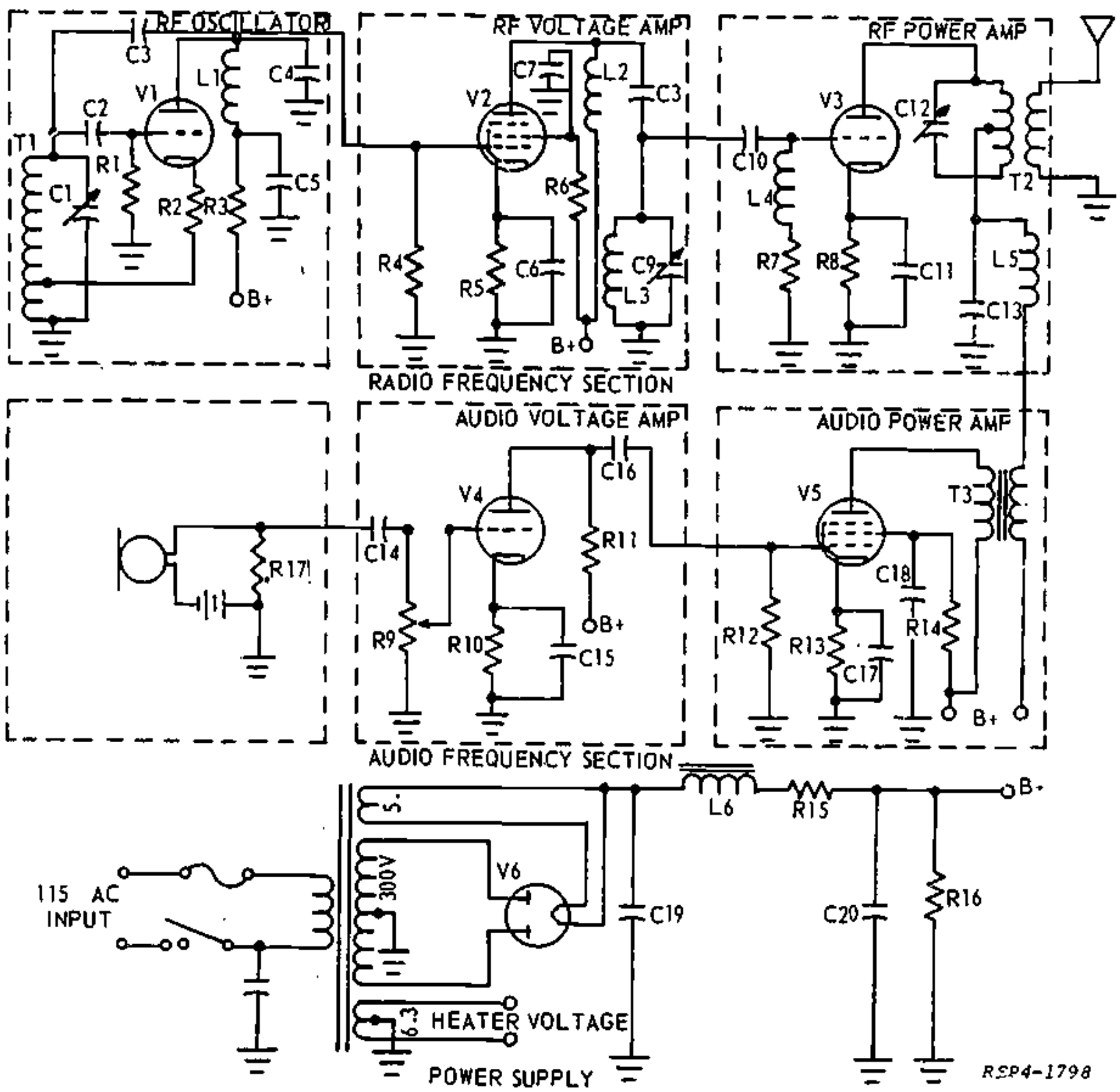



Figure 6-7. Schematic Diagram of an AM Transmitter

6-45. AM Receiver.

6-46. The block diagram of a typical superheterodyne receiver is shown in figure 6-8. The RF signal from the antenna passes through an RF amplifier, where the amplitude of the signal is increased. A locally-generated, unmodulated RF signal of constant amplitude then mixes with the modulated RF signal in the converter (sometimes called the FIRST DETECTOR) stage.
The heterodyning of these two frequencies produces an IF signal which contains all of the modulation characteristics of the incoming modulated RF signal. The IF is equal to the difference between the frequency of the modulated signal and the local oscillator signal. The IF is then amplified in one or more IF amplifiers and fed to a demodulator (Second detector). The demodulated signal is amplified in the AF amplifier section and then fed to a speaker.

6-47. RF Amplifiers.

6-48. The RF amplifier stage amplifies the small AC voltages induced in the antenna by the electromagnetic wave. The tuned circuit between the antenna and the input of the RF amplifier permits selection of the desired frequency from among the many that may be present in the antenna.

6-49. Besides amplifying the RF signal, the RF amplifier has other important functions. For example, it isolates the local oscillator from the antenna system. If the antenna were connected directly to the mixer (frequency converter) stage, a part of the oscillator signal might be radiated into space. This signal could be received by other receivers, causing interference.

6-50. Also if the frequency converter were connected directly to the antenna, unwanted signals, called IMAGES, might be received. This is because the input circuit of the converter has a very wide bandwidth when compared with the other circuits in the receiver. The converter stage will produce the intermediate frequency of the desired signal by heterodyning the local oscillator signal with the desired signal. However, if the image frequency is present at the input of the converter, it will also heterodyne with the local oscillator signal to produce another intermediate frequency. The output of the receiver would then be both the desired station and the image station. The use of an RF amplifier stage between the antenna and the converter stage will improve the image frequency rejection of the receiver since the RF amplifier has a narrower bandwidth.

6-51. The image frequency always differs from the desired received frequency by twice the intermediate frequency: Image Frequency = Desired Frequency ±2 IF. The image frequency is higher than the desired received frequency (+2 IF) if the local oscillator operates above the desired received frequency. The image frequency is lower than the desired received frequency (-2 IF) if the local oscillator operates below the desired received frequency.

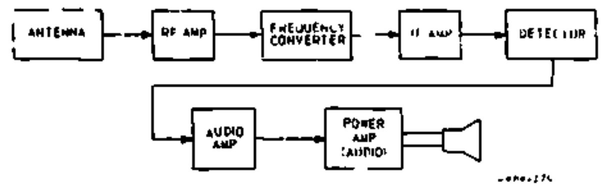


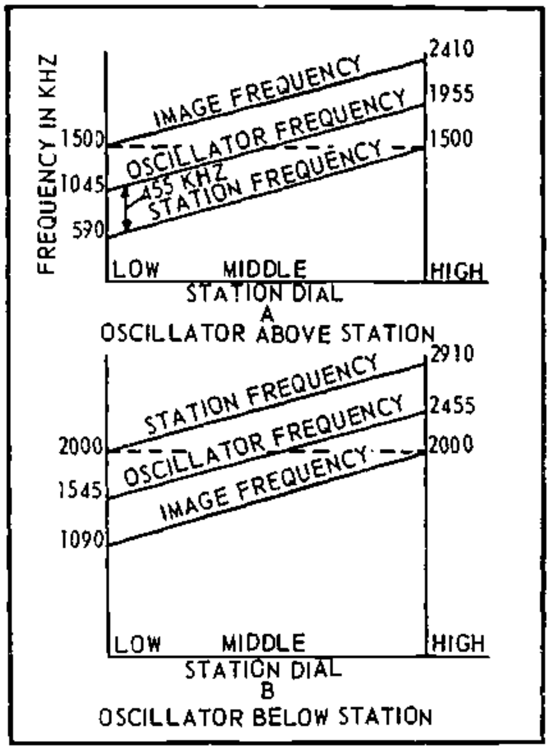

Figure 6-8. AM Receiver

6-52. The frequency relationships between image frequency, oscillator frequency, and station frequency are illustrated in figure 6-9. As an example, if a receiver has an intermediate frequency of 455 kHz and the desired signal is at 1500 kHz, the local oscillator will be at a frequency of 1955 kHz. The image frequency, in this case, is 2410 kHz. A station operating at 2410 kHz could heterodyne with the 1955 kHz oscillator signal and produce a difference frequency of 455 kHz. This image station is out of the broadcast range but could consist of other types of transmission, such as police calls or marine signals.

6-53. It is also possible for any two signals, having sufficient strength and separated by the Intermediate Frequency, to produce an unwanted IF signal. This unwanted signal results from heterodyning these two signals in the frequency converter stage.

6-54. The selectivity of the tuned circuits preceding the frequency converter reduces the strength of these images and unwanted signals. However, there is a practical limit to the degree of selectivity obtainable in the RF stage. The RF stage must have a much wider bandwidth than the bandwidth of the desired signal.

6-55. The ratio of the amplitude of the desired station signal to that of the image signal in the RF stage is the signal-to-image ratio, or the "image rejection" ratio. This is normally expressed in decibels. A large image rejection ratio is required if spurious (unwanted) reception is to be suppressed.




REP4-1800

Figure 6-9. Image Frequency

6-56. Local Oscillator.

6 57. The function of the local oscillator is to produce a sine wave of a frequency which differs from the desired station frequency by an amount equal to the intermediate frequency of the receiver. The operation of the oscillators was previously discussed.

6-58. Although the oscillator may be operated above or below the desired station frequency. in most receivers the oscillator is operated above the station frequency. In order to allow selection of any frequency within the frequency band of the receiver, the tuned circuits of the RF amplifier stage and the local oscillator are variable. By using a common shaft for the variable components for these tuned circuits, both circuits are tuned to maintain the intermediate frequency difference between them. The RF amplifier is tuned to the frequency indicated on the receiver tuning dial.

6-59. Frequency Converters and Mixers.

6-60. The superheterodyne. receiver has uniform gain and selectivity, as the receiver is tuned over a wide range of frequencies. These advantages are possible because the incoming RF signal is converted to an IF having a constant center frequency. This change of frequency takes place in the frequency conversion stage of the receiver. There are two basic types of frequency conversion stages used in the ''superhet'' receiver, one type being the MIXER and the other type being the CONVERTER. The frequency conversion process is the heart of the superheterodyne principle.

6-61. The basic difference between a mixer and converter is that the mixer requires two input signals (radio frequency and oscillator) whereas, the converter has its own self-contained oscillator and requires only one input signal (radio frequency).

6-62. Figure 6-10 illustrates the block diagram of a specific mixer stage and the frequencies involved in the process of mixing. For simplicity, let's use a single 5 kHz audio frequency as the original modulating frequency with a station carrier signal of 1000 kHz. The AM signal from the transmitter will contain energy at three distinct frequencies: 1000 kHz carrier frequency, 1005 kHz upper sideband frequency, and 995 kHz lower sideband frequency. This AM signal is used as one of the input signals to the mixer stage and is indicated in figure 6-10 as the AM signal from the RF amplifier. The other input to the mixer stage is a constant amplitude 1455 kHz signal from the local oscillator. A prerequisite of the mixer is that it be nonlinear. Using a transistor in the curved portion of its dynamic transfer curve achieves proper mixing action.

6-63. The local oscillator frequency beats or heterodynes with all the individual components of the modulated wave. For example, the upper sideband frequency of 1005 kHz and the local oscillator frequency of 1455 kHz produce the sum frequency (2460 kHz), the difference frequency (450 kHz), and the original two (1005 kHz and 1455 kHz)

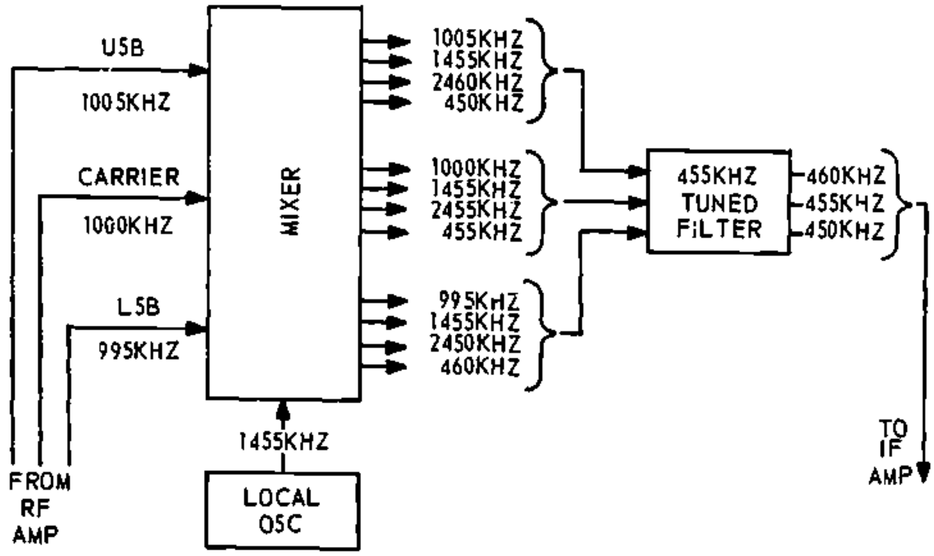



Figure 6-10. Block Diagram of a Mixer Stage

frequencies. Repeat this process using the carrier and local oscillator, and the lower sideband and local oscillator frequencies. The net result of all these actions is an output which contains 10 significant frequency components. The output will also contain harmonics of the original frequencies; for simplicity of explanation, however, harmonics will be neglected.

6-64. Figure 6-10 shows all of the frequency components present in the mixer output feeding to the filter. A tuned resonant tank circuit acts as the filter and selects the desired difference frequencies. This filter will pass a band of frequencies centered around 455 kHz. Those frequencies outside the bandpass of the tank circuit do NOT develop sufficient voltage across the tuned circuit to pass on to the IF amplifier. The response curve of a typical tuned circuit is shown in figure 6-11. This tank circuit has relatively high gain within the 0.707 points and increasingly less gain for frequencies further from (above and below) the center frequency. Therefore, only frequencies closely associated with the resonant frequency of the tuned circuit will pass on to the IF amplifier.

6-65. Figure 6-11 represents the bandwidth of just the mixer tank circuit, and not the overall bandwidth of a complete receiver. The half-power points are dependent on receiver circuit design.

6-66. The output of the tuned filter (figure 6-10) is 450 kHz, 455 kHz, and 460 kHz. These constitute the modulated IF signal. Note that, even though the sidebands and carrier have been converted to lower frequencies, the relationship between the sideband frequencies and the carrier has been maintained.

6-67. IF Amplifier.

6-68. The receiver circuits studied, thus far, have included the RF amplifier, the oscillator, and the mixer circuits. The amplitude of the signal from the mixer (or converter) is still comparatively weak. Due to its small amplitude, it is normally considered impractical to feed this signal directly to a detector stage for demodulation. For this reason, the superheterodyne receiver usually includes one or more stages of intermediate frequency amplification between the mixer and the detector stages.

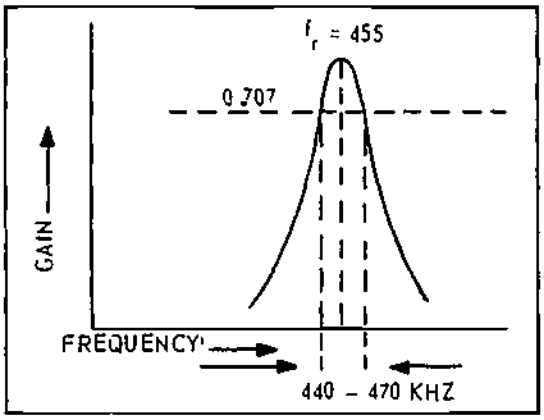



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Figure 6-11. Response Curve of a Mixer Tank

6-69. The block diagram of figure 6-8 shows that the IF amplifier receives its input signal from the mixer stage. This signal retains the modulation associated with the received RF signal. The IF amplifier amplifies the mixer output signal (a band of frequencies centered around the IF) and applies it to the detector stage.

6-70. In many ways the operation of the IF amplifier is similar to that of the RF amplifier. The signals being amplified, however, are at a lower frequency than for the RF amplifier. Unlike the RF tuned circuits (whose frequency is variable over a wide range), the tuned circuits used in IF amplifiers are fixed at a definite resonant frequency, adjustable tank components being incorporated for alignment purposes only. Since they operate at a fixed frequency, the IF amplifiers have optimum gain and bandwidth characteristics.

6-71. Many factors are involved in the choice of a receiver's intermediate frequency. For broadcast band receivers, intermediate frequencies of 262 kHz and 455 kHz are common. For receivers used to receive high frequencies, the IF may be much higher, such as 10 MHz, or 60 MHz. The use of a low frequency IF results in slightly better gain, stability, and selectivity. However, the low IF is more susceptible to image frequency reception. This occurs because lowering the value of the IF moves the image frequency closer to the frequency to which the receiver is tuned, thus decreasing the attenuation of the image signal by the RF stage.

6-72. As stated previously, the IF amplifier has the function of determining receiver selectivity and providing the major portion of the receiver's gain prior to demodulation. An additional function of the IF amplifier is to preserve all the original modulating intelligence by maintaining a sufficiently wide overall bandwidth.

6-73. Superheterodyne receivers employ one or more IF amplifiers, depending on design and quality of the receiver. Transformers are usually used for interstage coupling in the IF section. The IF circuits are permanently tuned to the difference frequency for maximum gain, consistent with the desired bandpass and frequency response. For example, if we want an IF of 455 kHz and 10 kHz bandwidth, then the amplifier must pass frequencies between 450 kHz and 460 kHz. These stages operate as Class A voltage amplifiers and determine practically all of the selectivity of the superheterodyne receiver.

6-74. Detector.

6-75. Demodulation or detection is the process of recovering intelligence from the modulated wave. The amplified IF plus the upper and lower sideband signals are applied to the detector. The detector is a nonlinear impedance; therefore, heterodyning will occur, causing new frequencies to be developed. These frequencies are the sum and difference between the applied frequencies. The difference frequency is a reproduction of the intelligence. The signal is developed and applied to the audio amplifier, while the sum and original frequencies are filtered out.

6-76. Audio Amplifier.

6-77. The function of the intelligence amplifier section of the receiver is to further amplify the intelligence signal. In an AM

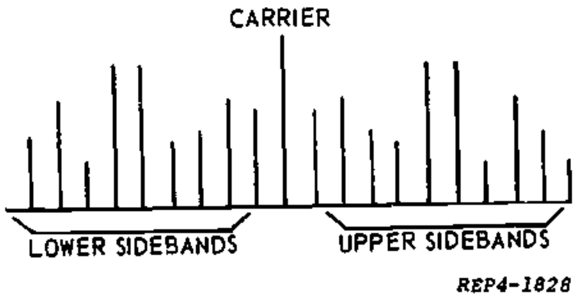


Figure 6-12. Bandpass without Distortion

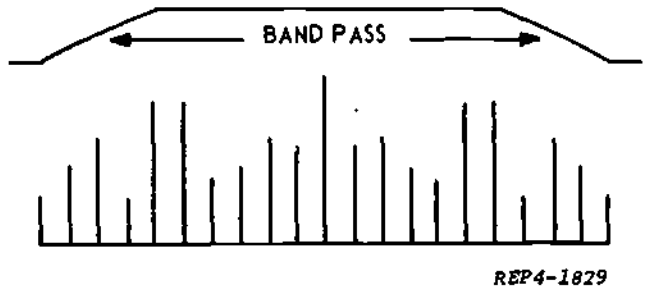


Figure 6-13. Bandpass without Distortion

receiver used to reproduce sound waves this section is called an AUDIO AMPLIFIER. In most cases, the amount of amplification necessary depends on the type of reproducer used. If the reproducer consists of earphones, only one stage of amplification may be necessary. If the reproducer is a large speaker requiring a large amount of power, several stages may be necessary. In most receivers, the last stage is operated as a power amplifier. The reproducer converts the audio signal to sound waves.

6-78. Distortion.

6-79. Caution must be exercised to prevent modification of the complex wave; this would result in distortion of the demodulated signal. Bandpass is one consideration which could cause distortion to the audio intelligence. Until now all we have talked about is a carrier with a single upper and lower sideband frequency. In actuality, intelligence might contain many frequencies, which explains why all voices sound different. To reproduce an audio signal which does not change the sound of a human voice, the demodulator must extract the exact same frequencies included in the original signal.

6-80. For example, assume a particular voice modulates a carrier producing a sideband distribution, such as shown in figure 6-12. Any amplifying device used in the receiver must pass all these frequencies, as shown in figure 6-13. Using an inadequate bandpass, such as shown in figure 6-14 would cause the outer frequencies to be eliminated or drastically reduced in amplitude. This would change the characteristics of the voice being transmitted. This is why it is sometimes hard to recognize a voice you hear on the radio or telephone. Such distortion is called bandpass distortion. The demodulator circuits must have a bandpass capable of reproducing all the original frequencies to prevent bandpass distortion from occurring.

6-81. "Square law" distortion is another factor we have to take into consideration in AM. To understand the principle it is first necessary to understand the difference between linear and square-law demodulation (detection). Detection converts the modulated wave to intelligence. This may be linear or square-law detection.

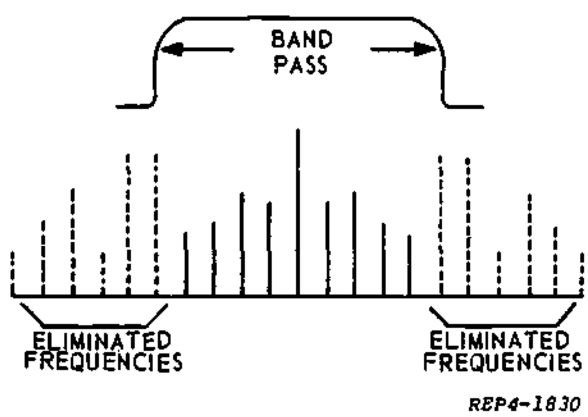


Figure 6-14. Bandpass with Distortion

6-82. Linear detection develops an output voltage proportional to the voltage of the input wave. Linear detection provides the necessary nonlinearity for heterodyning to occur, but at the same time does not amplitude-distort the output voltage from the detector. For example, a modulated waveform present in the input of a linear detector has certain amplitude variations. If the detector is linear, the output voltage is proportional to the changing amplitude of the RF input to the detector. A linear detector is basically a rectifier circuit, operating in the linear portion of its characteristic curve. With a square law detector this is not the case.

6-83. A square law detector is a circuit in which the output signal current is proportional to the SQUARE of the RF input voltage. The demodulation depends on the curvature or nonlinearity of the voltage-current curve, rather than on linear rectification. This means that not only does the carrier heterodyne with the sidebands to produce the modulating signal, but also the sidebands heterodyne with each other and generate the second harmonic of the modulating signal. This causes distortion in the output commonly referred to as square law distortion. Square law distortion is a direct result of second harmonic distortion. The amount of distortion can be as great as 25%, depending on percent of modulation. Remember that square law distortion produces an output which is proportional to the square of the input. The fidelity of a square law detector is poor, compared to a linear detector, so it is used only in special applications.

6-84. Cochannel Interference.

6-85. Cochannel interference is an interfering signal of the same frequency as the desired signal. Figure 6-15 illustrates the cochannel interference. Both transmitters are operating on the same frequency, producing the same amount of power, and the receiver is tuned to their operating frequency. Even though transmitter 1 is located nearer the receiver than transmitter 2, both signals MAY be selected, amplified,


Figure 6-15. Cochannel Interference

demodulated, and reproduced. Cochannel interference can be reduced by using highly directional antennas.

6-86. Circuit Operation.

6-87. To get an overall view of the operation of the superheterodyne receiver used for AM, examine the diagram illustrated in figure 6-16.* Notice that it contains all of the stages that we discussed in the block diagram.

6-88. The first stage is the antenna. The primary of L101 is the antenna; it and C101 and C102A form a resonant circuit. This circuit is tuned to resonate at the desired RF frequency by tuning the main tuning dial of the radio which changes the value of C102-A. Notice that C102-A, C102-B, and C102-C are all connected together so they change value simultaneously as the main tuning dial is adjusted. As an example, assume the desired station is 1000 kHz modulated with a 5 kHz tone, the resonant circuit will be tuned to 1000 kHz. These signals are inductively coupled into the secondary of L101 through C103 developed across R101 and felt on the base of Q101, the RF Amplifier. Direct current flows from ground through R102, the emitter-base junction, R101 and R106 to the AVC voltage which is the forward bias network, then through R108, R109, R107, and R115 to $V_{CC}$. Direct current is also flowing from ground through R102, emitter-collector and the primary tap of L102. The RF signals on the base cause the forward bias to increase and decrease causing the collector current to vary, these variations are developed by the resonant circuit of L102, C102-B and C106. In our example, this resonant circuit would be tuned to 1000 kHz and have a

*Figure 7 in KEP-GP-68

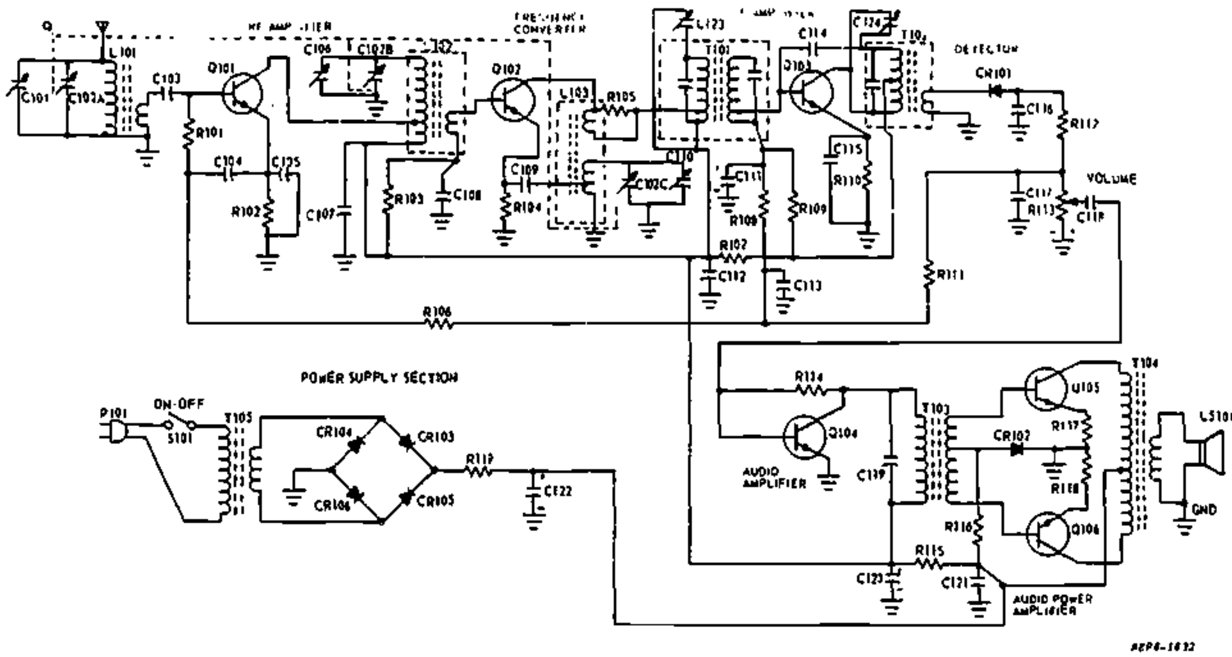


Figure 6-16. AM Receiver

bandwidth at least 10 kHz wide. Maximum signal at the desired frequencies would then be inductively coupled to the secondary of L102, the input of the frequency converter.

6-89. The Frequency Converter, Q102, acts as the heterodyning (mixer) and local oscillator stages. The frequency of the local oscillator signal is determined by the value of L103, C102-C and C110. Direct current flows from ground through R104, emitter-collector, through R105 and the primary of L103, which are in parallel, and then the primary of T101 to $V_{CC}$. The oscillator portion of the frequency converter is a basic Armstrong oscillator. Oscillations start the moment the DC power ($V_{CC}$) is applied to the circuit. At that moment a surge of current flows through the transistor, and the tank circuit goes into oscillation. The oscillations of the tank are coupled through C109 to the emitter; this causes variations in the forward bias which in turn causes the DC to vary at the oscillator rate. These variations in DC through the primary of L103 are inductively coupled to the secondary of L103. The feedback is regenerative and of sufficient magnitude to sustain oscillations. The secondary of L103 is tapped to achieve an impedance match between the high impedance tank circuit and the low impedance of the emitter circuit. The modulated RF signal is inductively coupled to the base of Q102 and the unmodulated local oscillator signal is coupled to the emitter of Q102. Transistor Q102 is biased in the nonlinear portion of its operating range. Collector current is controlled simultaneously by the oscillator signal and the incoming RF signal. The collector current will be a complex waveform consisting of many frequencies including: the local oscillator frequencies, the received RF frequencies, the sum and difference of the local oscillator and the received RF frequencies. C123 in parallel with the primary of T101 allows for tuning of the resonant circuit to the desired IF frequency. Thus, this tuned circuit will develop a relatively large voltage at the IF frequency while the remaining frequencies develop very little voltage. If the IF frequency is 455 kHz. then our oscillator should be oscillating at 1455 kHz.

6-90. The oscillator frequency should always differ from the selected station frequency by an amount equal to the IF. Therefore, when tuning the receiver, the oscillator's frequency must change by the same amount as the resonant frequency of the tank circuit of the RF amplifier. When this occurs, the oscillator is said to "track" the RF. The dotted line (figure 6-16) connecting the RF amplifier tuning capacitor C102-A and C102-B and the oscillator tuning capacitor C102-C shows they are gang tuned.

6-91. For proper operation of the receiver, the frequency difference between the two tank circuits must remain constant over the entire tuning range of the receiver. In other words, if the IF of a particular receiver is 455 kHz, then the difference frequency must be 455 kHz when the receiver is tuned to the low end of the range (540 kHz) as well as to the high end of the range (1600 kHz).

6-92. Improper tracking will result if the RF amplifier is not accurately tuned to the proper signal. This will attenuate the signal.

6-93. Several methods have been developed to improve tracking. One of these methods is the use of a trimmer capacitor. The trimmer capacitor is usually of the compression mica type, and is mounted on the top of the main tuning capacitor. Electrically, trimmer capacitors are in parallel with each section (oscillator and RF). The schematic diagram of the oscillator capacitor and trimmer is shown in figure 6-17. The value of the trimmer capacitor is usually smaller than its associated capacitor.

6-94. The trimmer compensates for tracking variations at the HIGH end of the tuning range. The reason for this can be demonstrated by the following example: An oscillator capacitor, having a range of 10.6 pF to 172.6 pF, is paralleled with a trimmer, having a range of 2 pF to 17 pF (figure 6-17).

> NOTE. Values are taken from a typical ganged tuning capacitor used in broadcast receivers.

6-95. To determine the effect of trimmer variation on total tank capacitance at the high frequency end of the tuning range, set both capacitors at minimum C2 = 10.6 pF and C1 = 2 pF). Thus, the minimum capacitance of the parallel combination will be:

$$2 + 10.6 = 12.6 \text{ pF}$$

Maintaining the oscillator capacitor at mimimum and setting the trimmer to maximum (C1 = 17 pF) will cause capacitance of the combination to increase to:

$$17 + 10.6 = 27.6 \text{ pF}$$

Thus, at the high frequency end of the range, the trimmer capacitor can cause a change in total tank capacitance of:

$$27.6 - 12.6 = 15 \text{ pF}$$

Dividing the change in capacitance by the original minimum capacitance and multiplying by 100 will result in the percentage of change in tank capacitance caused by the trimmer:

$$\frac{15.0}{12.6} \times 100 = 119\%$$

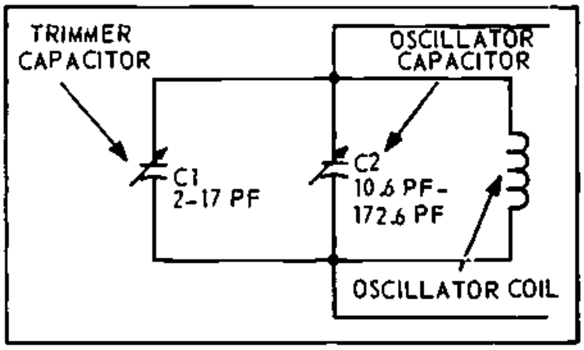


Figure 6-17. Oscillator Tuning Capacitor with Trimmer

9-96. The effect of trimmer variation on total tank capacitance at the low end of the tuning range is determined by setting the oscillator capacitor to maximum and the trimmer to minimum (C1 = 2 pF and C2. 172.6 pF). The total tank capacitance with these settings will be:

$$2 + 172.6 = 174.6 \text{ pF}$$

Holding the oscillator capacitor at maximum and setting the trimmer at maximum will increase the tank capacitance to:

$$17 + 172.6 = 189.6 \text{ pF}$$

The change in tank capacitance at the low frequency end caused by varying the trimmer will be:

$$189.6 - 174.6 = 15 \text{ pF}$$

The change in capacitance of 15 pF is the same as the high end: the percentage of change, however, is vastly different.

$$\frac{15.0}{174.6} \times 100 = 8.59\%$$

6-97. Therefore, you can see that varying the trimmer capacitor affects the percentage of tank capacitance to a much greater extent (119%) at the high end of the tuning range and has relatively little effect (8.5%) at the low end. For this reason, the trimmer is adjusted at the high frequency end of the receiver's tuning range.

6-98. The modulated signal is IF transformer coupled to the secondary of T101, another tank circuit tuned to the IF frequency. The purpose of this tuned circuit is to further improve the ability of the receiver to pass the desired frequencies and to reject the undesired. T101 is tapped to match the base impedance of Q103 the IF Amplifier. The DC flows from ground through R110, through the emitter-base junction, the secondary of T101, R109, R107, and R115 to $V_{CC}$. Direct current also flows from ground through R110, the emitter-collector, primary of T102, R107, and R115 to $V_{CC}$. The signal on the base causes the collector current to increase and decrease at the IF rate. The tuned circuit in the collector circuit is tuned to the IF rate. The tuned circuit in the collector circuit is tuned to the IF frequency and develops maximum signal at that frequency (455 kHz). This signal is coupled through T102 to the demodulator.

6-99. CR101 is the detector. The DC path is from ground through the secondary of T102 through the diode, R112, R111, R108, R109, R107, and R115 to $V_{CC}$. Due to the nonlinear characteristics of CR101, the IF signal will be demodulated and the audio signal will be developed across the volume control R113. C116 and R112 filter out the IF frequencies.

6-100. The AVC voltage is a positive voltage developed by a voltage divider network between $V_{CC}$ and the negative audio signal developed at R113. The purpose of the AVC is to change the gain of Q101 and Q103 automatically with received signal strength. The voltage developed across R113 is averaged out by C117, R111, C113, R108, R109, C111, R106 and C104. Averaging out this voltage produces a DC voltage to be used as forward bias for Q101 and Q103. As the received signal strength increases, the amplitude of the audio signal at R113 would get larger. This would cause the AVC voltage to become less positive reducing the gain of the receiver. The amplitude of the signal at R113 would then return to the original value. Note that this is a closed loop arrangement resulting in regulation.

6-101. The audio signal is coupled from the volume control through C118 and applied to the base of the Audio Amplifier Q104. Moving the wiper of R113 away from ground will couple a greater amount of signal to Q104 and increase the volume. The DC path in the audio amplifier is from ground through the emitter-base junction, R114 and through the primary of T103 to $V_{CC}$. This forward biases Q104. DC also flows from ground through the emitter-collector, and the primary of T103. The audio signal applied to the base causes the forward bias to change at the audio rate which in turn causes the collector current to vary at the audio rate. The variations in current in the primary induce the audio signal into the secondary of T103.

6-102. The audio signal that is coupled into the secondary of T103 is applied to the bases of Q105 and Q106, 180 degrees out of phase. Q105 and Q106 make up a push-pull power amplifier. The DC path in Q105 is from ground through R117, emitter-base junction, one half the secondary of T103 and R116 to $V_{CC}$ this forward biases Q105. There is a similar circuit for Q106. The other DC path for Q105 is from ground through R117, emitter-collector and one half of the primary of T104 to $V_{CC}$. There is a similar path for Q106. The audio signal applied to the base of the transistors will cause the forward bias to increase and decrease, as one increases the other is decreased. This produces a large current change in the primary of T104 which produces a large current change in the secondary, T104 is a step down transformer to match the low impedance of the speaker to the higher impedance of the collector circuits of Q105 and Q106. The speaker produces the desired audio signal.

6-103. The power supply supplies $V_{CC}$. Each stage is connected to $V_{CC}$ and the DC from each stage flows through R119 and bridge rectifier and T105 to complete the DC loop.

6-104. FM Transmitter and Receiver Systems.

6-105. The intelligence to be transmitted may be imposed as changes in the frequency being transmitted. This type of modulation is called FREQUENCY MODULATION (FM) and has certain inherent advantages over AM transmission.

6-106. In FM, intelligence is conveyed by varying the frequency of a constant amplitude RF carrier. The modulating signal varies the carrier frequency to develop the transmitted frequency. The AMOUNT of carrier frequency deviation depends on the amplitude of the modulating signal. The louder the sound, the greater the audio amplitude and, therefore, the more the transmitted frequency differs from the carrier frequency the greater the deviation. The RATE at which the modulated frequency varies from the carrier frequency--that is, the number of excursions above and below the carrier frequency--depends on the frequency or tone of the modulating signal. A high frequency tone causes rapid variation from the carrier as compared to a low frequency tone. The amplitude of the transmitted FM wave remains virtually constant.

6-107. A very important characteristic of FM when compared to AM is that FM is comparatively noise free. Noise interference, for the most part, is due to sources that are external to the receiver. Noise randomly adds to the amplitude of the RF wave. AM systems are limited in their effectiveness to suppress or eliminate this interference because the noise (amplitude) variations are demodulated with the intelligence. In an FM system, amplitude variations are clipped off; only changes in FREQUENCY are demodulated as the intelligence. This ability of an FM system to reduce noise interference also provides for very good co-channel interference rejection. At the receiver, the desired signal need be only twice as large as the undesired signal to suppress the interference completely.

6-108. Transmitter.

6-109. Figure 6-18 illustrates a block diagram of a typical FM transmitter. Each of the blocks has been covered in detail in this course. The heart of the transmitter is the modulated oscillator; an applied audio signal causes the frequency of this oscillator to change.

6-110. The intelligence signal is usually very weak and is amplified by the audio signal amplifier to drive the reactance modulator (figure 6-18). The modulator converts the audio signal into variations in reactance. This reactance change is applied to the oscillator, causing the frequency of the oscillator to change. If the audio signal is a sine wave, the frequency out of the modulated oscillator will deviate the same amount above and below the center frequency of the oscillator. How far it deviates depends on the amplitude of the modulating signal; how fast it deviates depends on the frequency of the modulating signal.

6-111. In a commercial FM broadcast system, the Federal Communication Commission (FCC) has established that the maximum deviation shall be limited to ±75 kHz. This is designated arbitrarily as 100% modulation. In a military FM broadcast system, the frequency deviation allowed may be reduced to ±40 kHz. In this case, ±40 kHz is 100% modulation.

6-112. Let us relate figure 6-18 to an FM system using a ±75 kHz frequency deviation. Assume the output from the modulated oscillator is 5 MHz with a frequency deviation of 4.2 kHz. Further, assume that the transmitter has been assigned an output frequency of 90 MHz. The most common method to get 90 MHz from the 5 MHz oscillator would be to use two frequency triplers and a doubler. The total amount, then, by which the oscillator frequency is increased is 18 times (18 x 5 = 90 MHz).

6-113. Now, with the FCC limitation, dividing ±75 kHz by 18, we find that the maximum deviation at the oscillator for 100% modulation is 4.167 kHz.

6-114. A frequency multiplier is nothing more than an amplifier, usually operated class C, with the output tuned to a harmonic of the input. Operating these stages class C eliminates any amplitude variations that may be caused by the modulator.

6-115. The driver is an intermediate amplifier used to develop the power necessary to drive the power amplifier. The power amplifiers are usually heavy current devices and require a large input signal. The power amplifier increases the power of the RF signal so that it can be radiated by the antenna, and produce an electromagnetic wave of proper magnitude. An important fact to remember is the wide bandwidth necessary. Whether operating with ±75 kHz or ±40 kHz deviation, the driver, power amplifier and the antenna must have a bandwidth wide enough to pass all of the desired sidebands.

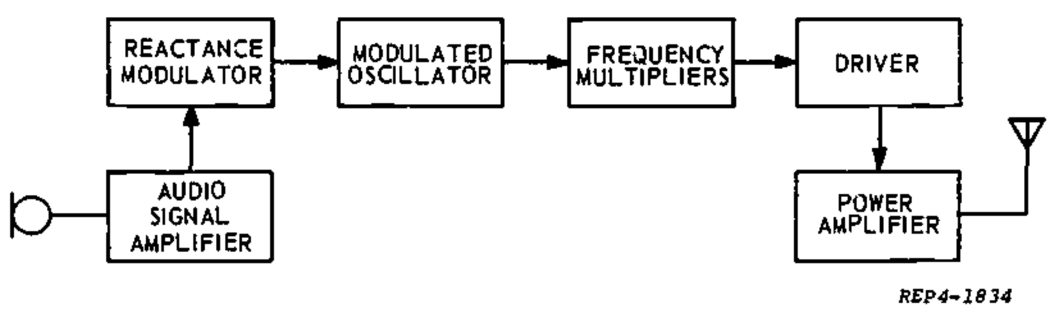


Figure 6-18. FM Transmitter

6-116. Receiver.

6-117. Figure 6-19 illustrates a block diagram of a typical FM receiver. You can see that it is a superheterodyne receiver very similar to those discussed earlier. In fact, there is very little difference in AM and FM receivers. Due to the similarity between AM and FM receivers the discussion of the block diagram will be centered on the limiter and demodulator. You will be referred back to the AM receiver where the circuits are similar.

6-118. The RF amplifier and antenna system are similar to AM, see paragraph 6-47. The main difference would be the frequency and bandwidth. The band for commercial FM is from 88 to 108 MHz, and has a bandwidth of at least 200 kHz. FM is not restricted to these frequency ranges, these are used as examples only. The frequency conversion stage is also similar to AM, see paragraph 6-59. Again the main difference would be frequency and bandwidth. The IF amplifiers also are very similar to AM, see paragraph 6-67. The frequency and bandwidth again being the difference.

6-119. The function of the limiter in an FM receiver is to remove any amplitude variations that may be present in the IF signal. These amplitude variations may be caused by noise or other transmitters on the same frequency. These changes in amplitude of the IF signal can be demodulated by the demodulator and be heard in the speaker as noise or interference. The limiter removes these amplitude variations thus the noise and interference is removed. The demodulator stage is designed to produce the audio signal from changes in the IF frequency. As the IF frequency deviates above and below the center IF frequency the demodulator senses these frequency changes and produces a corresponding change in voltage. If the amount of IF frequency change increases, the amplitude of the audio signal out will increase. If the IF frequency deviates faster, the audio signal out will increase in frequency. Thus the demodulator produces an audio signal whose frequency is determined by how fast the incoming frequency deviates, and whose amplitude is determined by how much the incoming frequency deviates. The audio amplifiers and reproducers are the same as AM, see paragraph 6-76.

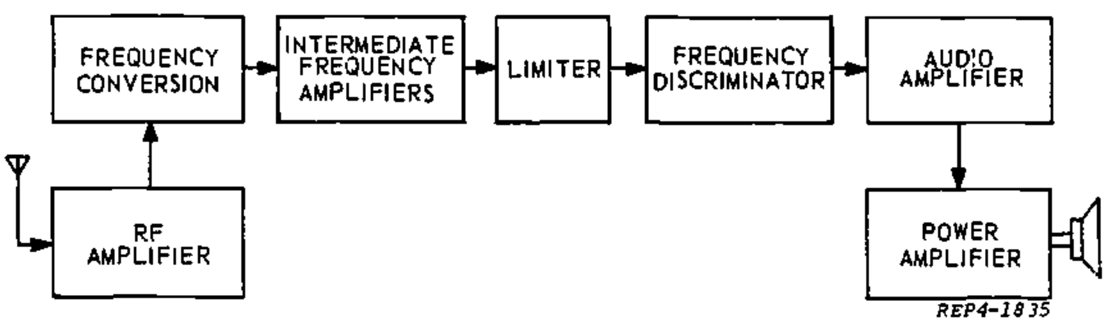


Figure 6-19. FM Receiver

6-120. Circuit Operation.

6-121. Figure 6-20* illustrates an FM transmitter. Let us first establish the direct current loop in each stage and then trace a signal from input to output. The direct current in the audio amplifier, V13, is from ground through R32, V13 and R30 to B+ also from ground through R32 to the screen grid and R31 to B+. The direct current for the reactance modulator, V2, is from ground through R19, V2 and RFC3 to B+, also from the ground through R19, the screen grid and R20 to B+. The DC circuit for the oscillator, V1, is from ground through RFC1, V1, and L2 to B+, also from ground through RFC1 to the screen grid and R2 to B+. The direct current for the first frequency mulitplier, V7, is from ground through V7 and L4 to B+. The DC path for

*Figure 3 in KEP-GP-69

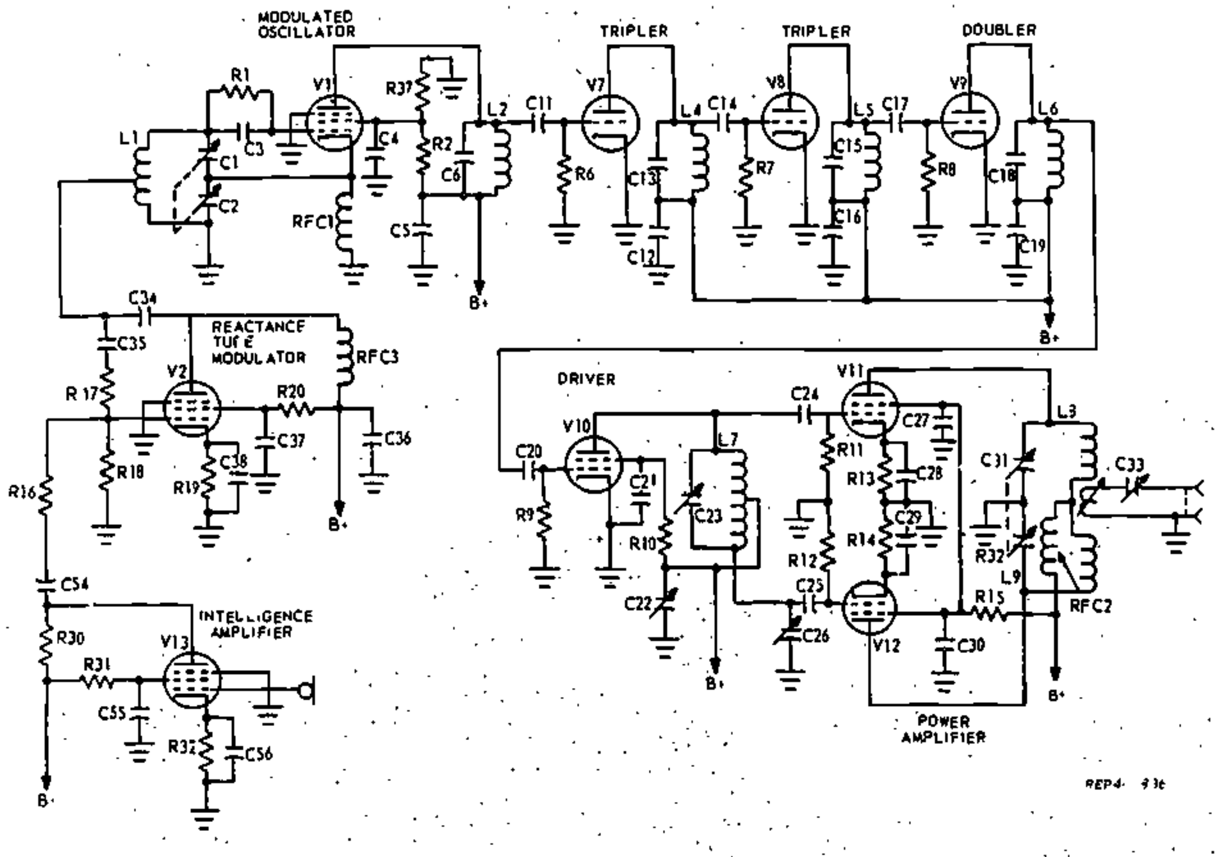


Figure 6-20. FM Transmitter

the second multiplier, V8, is from ground through V8 and L5 to B+. The DC path for the third frequency multiplier, V9 is from ground through V9 and L6 to B+. The direct current flow for the RF driver, V10, is from ground through V10 and one half of L7 to B+, also current flows from ground to the screen grid and R10 to B+. Direct current in the RF power amplifier is through two tubes, V11 and V12. First V11, the current flows from ground through R13, V11, L8, and RFC2 to B+, also through R13 to the screen grid and R15 to B+. The direct current for the other tube, V12, is from ground through R14, V12, L9, and RFC2 to B+, also through R14 the screen grid and R15 to B+. The B+ connections of each stage are all connected to a common power supply and the current from each stage flows through the power supply to ground to complete the circuit.

6-122. Let us now trace a signal through the transmitter. The audio signal is applied to the control grid of V13, the audio amplifier, taken from the plate and coupled to the grid of V2, the reactance modulator. The audio signal on the grid of V2 causes the capacitive reactance V2 represents, to change. This change in reactance is felt in the tank circuit of V1, the oscillator, causing it to change frequency. For example if the grid of V13 goes in a positive direction, its plate swings in a negative direction. This negative signal causes V2 to conduct less, the value of $X_c$ becomes greater, the total capacitance of the tank becomes less and the frequency increases. The oscillations are coupled from the plate of V1 to the grid of V7, a frequency tripler. The plate of V7 is tuned to the third harmonic of the grid signal. This higher frequency is applied to the grid of V8, another frequency tripler. The plate circuit is again tuned to the third harmonic of its grid signal. The signal on the plate of V8 is now 9 times the oscillator frequency, and is applied to the grid of V9, a frequency doubler. The plate of V9 is tuned to the second harmonic of its grid signal or 18 times the oscillator frequency. Remember the frequency of the oscillator is being changed at the audio rate by the reactance modulator. This varying RF signal is coupled to the grid of V10, the driver, coupled from its plate to the grids of V11 and V12, 180 degrees out of phase. The current changes in V11 and V12 being out of phase, produce a large current change in L8 and L9 and induce a correspondingly large current in the secondary, which travels down the transmission line to the antenna. The antenna converts the current and voltage into an electromagnetic field which can be radiated into space.

6-123. Figure 6-21* illustrates an FM receiver. Let us first establish the direct current loop in each stage, then trace a signal from input to output. The direct current flow in Q101, the RF amplifier, is from ground through R102, the emitter-base of Q101 junction, R101 and R106 to a positive voltage. Current also flows from ground through R102, emitter-collector of Q101 and primary of L102 to $V_{CC}$. Direct current flow in Q102, the frequency converter, is from ground through R104, emitter-base junction of the transistor, through the secondary of L102 and R103 to $V_{CC}$. DC also flows from ground through R104, emitter-collector of the transistor, through the parallel combination of L103 and R105 and then through the primary of T101 to $V_{CC}$. The DC path in Q103, the IF amplifier, is from ground through R110, the emitter-base junction, the secondary of T101, through R109 and R107 to $V_{CC}$, also from ground through R110 and emitter-collector of the transistor, through the primary of T102 and R107 to $V_{CC}$. In the limiter, Q107, the direct current flow is from ground through R120 the emitter-base junction of Q107, through the secondary of T102, R122 and R123 to $V_{CC}$. Current also flows from ground through R121 and R122 to form the forward bias network for Q107 and from ground through R120, emitter-collector, primary of T106 and R123 to $V_{CC}$. The DC flow in Q104, the audio amplifier, is from ground, through the emitter-base junction, R114 and the primary of T103 to $V_{CC}$. Current also flows from ground, through emitter-collector of Q104 and primary of T103 to $V_{CC}$. The DC flow in the audio power amplifier is from ground through

*Figure 4 in KEP-GP-69

R117, emitter-base junction of the transistor, one half of secondary of T103 and through R116 to $V_{CC}$. DC also flows from ground through R117, emitter-collector junction, and one half the primary of T104 to $V_{CC}$. The audio power amplifier is a push-pull circuit. The current flows from ground through R118, through the emitter-base junction of the transistor, one half of T103, R116 to $V_{CC}$, also from ground through R118, emitter-collector and one half of the primary of T104 to $V_{CC}$. The $V_{CC}$ points are all common.

6-124. Using figure 6-21 let us now trace a signal through the FM receiver. The RF signal is received by the antenna and the RF voltage and current are developed in the tuned circuit, L101, C101 and C102. The tuned circuit develops maximum signal at the desired frequency. The signal is inductively coupled to the base of Q101, the RF amplifier. The amplified RF signal is developed in the tuned collector circuit of Q101 and inductively coupled to the base of Q102, the frequency converter. The local oscillator signal which is present on the emitter of Q102 is heterodyned with the incoming RF signal which is applied to the base. The collector circuit is tuned to the difference frequency. This difference frequency is transformer coupled to the base of Q103, the IF amplifier. The IF signal is amplified and coupled from the tuned collector circuit to the base of the limiter. The signal in the collector circuit of the limiter is amplitude limited. For example if the incoming signal increases in amplitude, the signal in the collector does not increase accordingly. This limiter is driven to cutoff and saturation. The constant amplitude IF signal in the collector is, however, changing in frequency and is applied to the frequency discriminator through C127 and T106. The frequency discriminator produces an audio voltage across R113, the volume control. The audio signal is coupled from the volume control through C118 to the base of the audio amplifier Q104. The amplified audio signal is developed in the collector circuit and is coupled to the bases of Q105 and Q106 180 degrees out of phase. This produces a large change in current in the collector circuits of Q105 and Q106 at the audio rate. This change in current in the primary of T104 produces an audio signal in the secondary which is coupled to the speaker. The speaker converts the audio signal into sound waves.

6-125. Single Sideband System.

6-126. You will remember that a conventional amplitude-modulated signal consists of the carrier and the sidebands. There are two sideband frequencies for each modulating frequency, one above and one below the carrier. Since the same intelligence is present in both the upper and lower sidebands, eliminating one sideband before transmission results in the advantage of using half the spectrum space. Amplitude modulated transmission with frequencies on one side of the carrier suppressed while those on the other side are transmitted is called SINGLE SIDEBAND (SSB) transmission.

6-127. Transmitter.

6-128. SSB transmitters suppress one sideband; the carrier, also, can be eliminated because it contains no intelligence. A carrier must be present in the transmitter to produce the sidebands, and a carrier must be present in the receiver to produce the intelligence but they need not be precisely the same carrier. In a SSB system, the receiver generates a signal that represents the carrier so that the sideband may be heterodyned with it for detection to take place.

6-129. Let us compare the relative performance of a conventional AM system and a SSB system. Under long range propagation conditions, selective fading is likely to occur, and its effects are far more harmful to the conventional AM signal than to the SSB signal. Selective fading results from a combination of signals at the receiver arriving over two or more propagation paths of differing lengths. These may result in partial cancellation of the carrier signal relative to the sidebands. Phase distortion of the sidebands, with respect to each other and the carrier, may also occur. Tests indicate that, under excellent long-range propagation conditions, AM and SSB systems perform identically if the power of the SSB transmission is equal to the power in ONE of the two sidebands of the AM transmission. Under conditions in which severe fading has been observed, successful SSB communications have been established when conventional AM communications are ineffective.

6-130. The SSB system is less subject to interference than an AM system because it occupies only half the bandwidth of the AM system. Remember that noise occurring in the bandwidth of the system causes interference; half the bandwidth results in half the noise.

6-131. The differences between SSB and AM systems that we have discussed, thus far, include the reduction or elimination of the high power carrier, a reduced spectrum requirement, and a more useful signal in the presence of selective fading and interference.

6-132. Benefits of the SSB system arise primarily from the higher overall efficiency of generation and use of sideband power. For example, an AM transmitter transmitting 150 watts average power has 100 watts in the carrier and 25 watts in each sideband. The 25 watts in one sideband is, therefore, 1/6 the total power transmitted. Since the energy of the intelligence is contained in the sidebands only, then only 50 watts of the 150 watts is useful power. By suppressing the carrier and one sideband, the SSB transmitter need only produce 25 watts of power for the same intelligence power as a 150 watt AM transmitter. In order to more clearly distinguish between the maximum useable power of an AM signal and an SSB signal, we must first determine the peak power of the two signals and then determine their peak intelligence power.

6-133. Up to now, we have usually referred to the power in the AM wave as the "average" power. To describe the power of the SSB signal, we refer to "peak" power, or the effective power at the crest of the modulated wave. First, let us determine the peak power of an AM transmitter. Peak power occurs the instant the carrier and the sidebands are in phase and add. Using the 150 watt AM transmitter mentioned above, there are only 50 watts of useful intelligence power. To find peak power, we use the formula:

$$P = \frac{E^2}{R}$$

The values of resistance and voltage can be any ratio that will equal power. Since power of the carrier is 100 watts, if we assume R to be 100 ohms, we find the carrier E to be 100 volts and each sideband E to be 50 volts, as follows:

$$P = \frac{E^2}{R}$$

$$100W = \frac{E^2}{100}$$

$$E^2 = 10{,}000\,V$$

$$E = 100\,V$$

$$25W = \frac{E^2}{100}$$

$$E^2 = 2500\,V$$

$$E = 50\,V$$

To compute peak power, we add the voltage of the carrier and the two side bands. Thus,

$$P_{pk} = \frac{(100+50+50)^2}{100} = \frac{200^2}{100} = \frac{40000}{100} = 400\,W$$

Observe that the peak power is 400 watts. We can see, therefore, that the 150-watt AM transmitter must be capable of supplying 400 watts. If we now compute the peak power in the sidebands only, we find that it is 100 watts.

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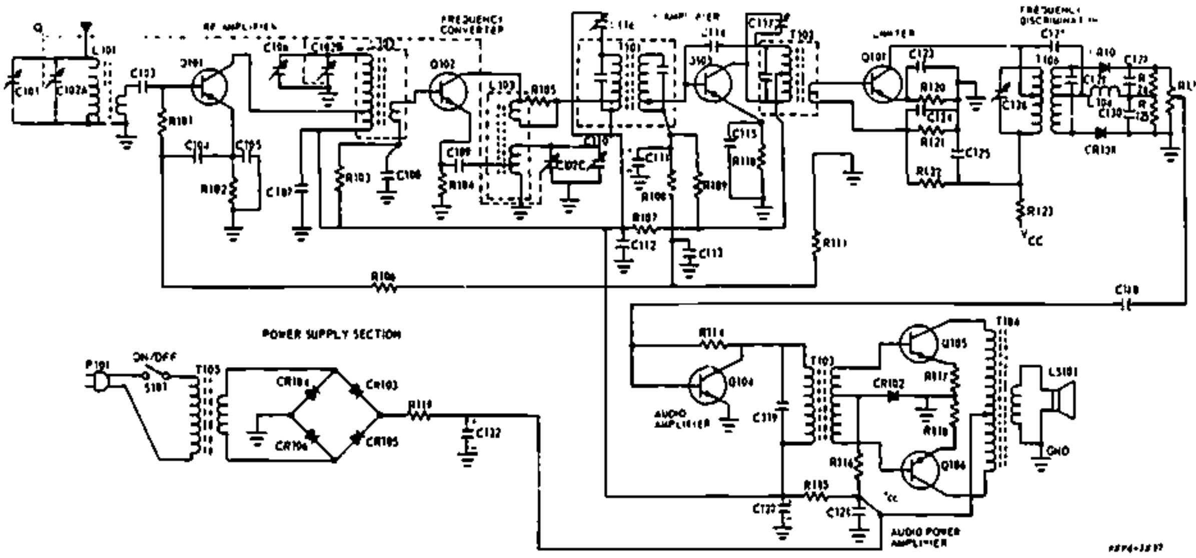



Figure 6-21. FM Receiver

$$P_{pk} = \frac{(50+50)^2}{100} = \frac{100^2}{100} = \frac{10000}{100} = 100 \text{ watts}$$

Therefore, the intelligence peak power is only 1/4 the total transmitted peak power.

6-134. To show how SSB transmission increases maximum useable power, we will use an AM transmitter as an SSB transmitter. Eliminating the carrier and one sideband allows the full capability of the transmitter to be used for transmitting a single sideband. Thus, one sideband will now have the entire 400 watts of peak power for intelligence, as compared to 100 watts in AM transmission. This increase in power (4 times) referred to in decibels is equivalent to a 6 dB increase.

6-135. The primary disadvantage of the SSB system is complexity. Part of the complexity is due to the SSB modulators and filters required in the transmitter, but the main source of complexity is the requirement for generating a representative carrier frequency in the receiver. The SSB system requires frequency stability between the transmitter and receiver; if the transmitter frequency is 1 megahertz, the maximum amount of frequency drift between transmitter and receiver is 2 hertz.

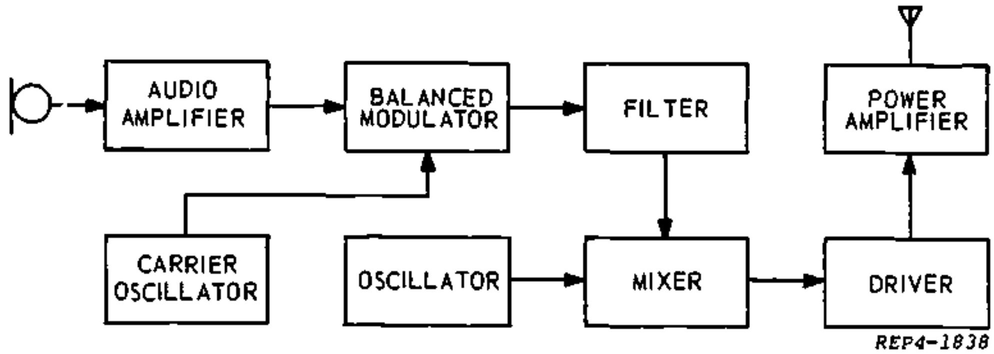



Figure 6-22. Single Sideband Transmitter

6-136. Figure 6-22 illustrates a basic single sideband transmitter. Let us discuss the purpose and characteristics of each block. A single sideband transmitter needs an oscillator to produce the RF carrier as did an AM transmitter. The carrier will be used to produce the desired sidebands. In single sideband the need for FREQUENCY STABILITY is very important. Remember that we will not transmit the carrier but that it must be reinserted in the receiver. The receiver will have an oscillator that will reinsert the carrier and it must be the SAME frequency as the carrier oscillator in the transmitter. Thus the carrier oscillator must be very stable and its exact frequency known so the receiver oscillator can be tuned to that frequency. The carrier oscillator produces the desired RF frequency and couples it to the balanced modulator. The balanced modulator is used to combine the intelligence signal (audio) with the carrier and produces the sidebands. The audio signal originated as soundwaves converted to an audio signal by the microphone and amplified to the proper level by a linear wideband audio amplifier. The amplified audio is coupled to the balanced modulator. The balanced modulator is a nonlinear impedance that combines the audio and carrier which will produce the sidebands. The modulator is balanced so the carrier is not present in the output. Thus, the balanced modulator produces the sidebands but also eliminates the carrier. The output of the balanced modulator is the upper and lower sidebands. In single sideband we want to transmit only one sideband, either the upper or the lower, depending on the system.

6-137. The output of the modulator is applied to a filter (figure 6-22). In SSB equipment, this filter is usually referred to as a bandpass filter. (Recall that a bandpass filter allows only a selected band of frequencies to pass.) The SSB filter will pass one sideband and highly attenuate the other sideband (and the carrier, if present).

6-138. The filters can be of the LC, crystal, or mechanical type. Present mechanical filters cover the frequency range from 200 to 600 kHz. They have excellent rejection characteristics and are extremely rugged. Because of their advantages, they have been employed in most SSB systems.

6-139. One type of mechanical filter is the cylindrical arrangement with disk resonators interconnected by coupling rods, as shown in figure 6-23. This filter is a mechanically-resonant device, which receives electrical energy, converts it into mechanical energy, and then converts this energy back into electrical energy. The basic elements of this device are:

1. An input transducer which converts electrical energy into mechanical energy.

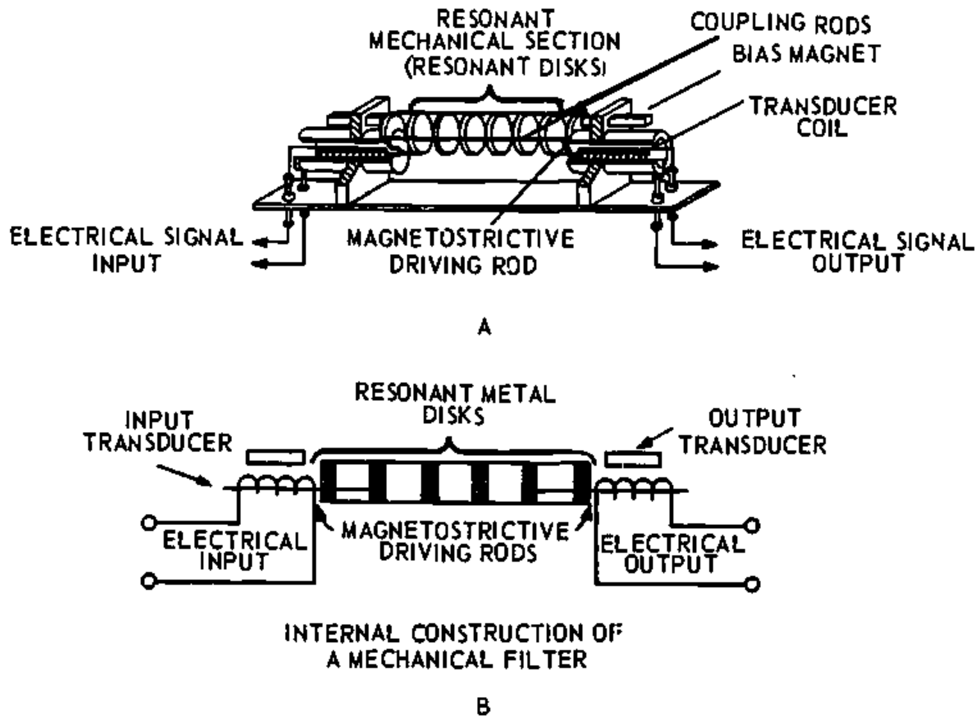



Figure 6-23. Mechanical Filter

2. A resonant section which contains mechanically resonant metal disks and coupling rods which couple energy between the disks.

3. An output transducer which converts the mechanical energy back into electrical energy.

6-140. The input and output transducers operate on the principle of magnetrostriction. Magnetostriction is the property of certain ferro-magnet materials to change dimensions when placed in a magnetic field. Each transducer has a permanent (bias) magnet, electromagnet, and drive rod for coupling energy.

6-141. When a signal is applied to the input transducer coil, the driving rod is attached to the first resonant disk, these rod variations will excite the disk. The input signal is usually the two sidebands; maximum transfer of energy, however will be at the resonant frequency of the disk. The magnetic field set up by the input signal either aids or opposes the magnetic field set up by the bias magnet, and results in a linear change in rod dimensions.

6-142. As the remaining disks are physically coupled to the first disk by the metal coupling rods, they will go into vibration. When the mechanical energy causes the last disk to vibrate, this motion is transferred to the output driving rod. This rod is also of magnetostrictive material and the variations in its length causes its permeability to vary. Since permeability is one factor that determines the number of magnetic lines of force, a variation in rod permeability will vary the total number of flux lines in the output circuit. These varying flux lines, in turn, induce a voltage into the output coil. The output will be the desired sideband frequency.

6-143. The amount of energy coupled to a disk is determined by the coupling rod dimensions. Increasing the rod diameter results in a larger amount of energy applied to the following disk. By varying the rod diameter, the bandwidth of the filter is changed. A larger diameter coupling rod increases the filter bandwidth.

6-144. The response curve of a typical mechanical filter is shown in figure 6-24.

Note the narrow bandwidth and how rapidly the curve drops from 3 dB to 60 dB attenuation.

6-145. In most single sideband transmitters modulation is accomplished at a low frequency level for stability. But the actual transmitted frequency may need to be much higher. The output of the filter (desired sideband) is applied to a frequency converter (mixer), to raise the sideband frequency. Note the mixer stage is a heterodyning stage, and combining the sideband with RF oscillations of a higher frequency produces new sidebands of high frequencies. The heterodyning action of the mixer produces a sum and difference frequency, but as before we desire only one set. The mixer has a tuned circuit that will develop and couple to the driver only the desired set. The driver is an intermediate amplifier used to develop the power necessary to drive the power amplifier. The driver is a tuned linear amplifier to assure the amplification of the desired band of frequencies. The power amplifier is a tuned linear amplifier used to increase the power level of the desired RF signal so that it can be radiated by the antenna and produce an electromagnetic wave of proper magnitude. The driver and the power amplifier are linear amplifiers so that unwanted harmonics are not generated.

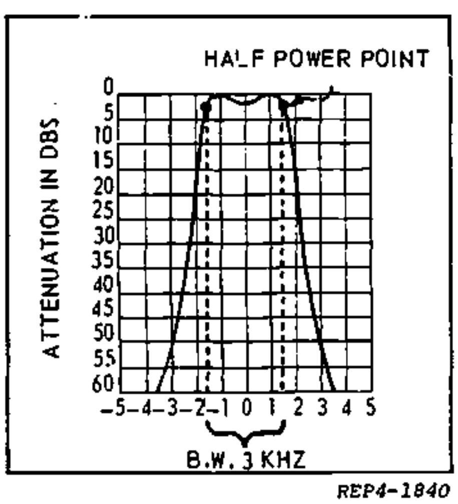



Figure 6-24. Response Curve

6-146. SSB Receivers.

6-147. Figure 6-25 illustrates a block diagram of a typical SSB receiver. You can see that it is a superheterodyne receiver, very similar to those discussed earlier. In fact, there is very little difference in AM and SSB receivers. The only real difference is that SSB uses an oscillator to reinsert the carrier, and a product demodulator. Due to the similarity between AM and SSB receivers the discussion of the block diagram will be centered on the oscillator and demodulator. You will be referred back to the AM receiver when the circuits are similar.

6-148. The RF amplifier and antenna system are similar to AM, see paragraph 6-47. The main difference would be the bandwidth, SSB is narrow compared to AM. The frequency converter stage is also similar to AM, see paragraph 6-59, as is the IF amplifier, see paragraph 6-67. The main difference in the converter and IF amplifier would be the bandwidth of the stages. They are narrow when compared to AM. In fact they would have a bandwidth one-half that of AM to pass the same intelligence signal.

6-149. The function of the demodulator is to remove the intelligence (audio) signal from the carrier. In order to accomplish this, it must be supplied with the sidebands and the carrier. The sidebands are supplied by the IF amplifier and the carrier by the reference frequency oscillator. This oscillator is tuned to exactly the same frequency as the carrier oscillator in the transmitter. Because of this requirement this oscillator must also have a high degree of amplitude and frequency stability. The oscillations from this oscillator are heterodynded with the sidebands from the IF amplifier in the demodulator which is a nonlinear device. The difference frequency produced is the same as the original intelligence (audio) signal in the transmitter. As the audio is developed the carrier and sideband frequencies are filtered out. The audio signal is coupled to the audio amplifier. The audio amplifiers and reproducer are the same as AM, see paragraph 6-76.

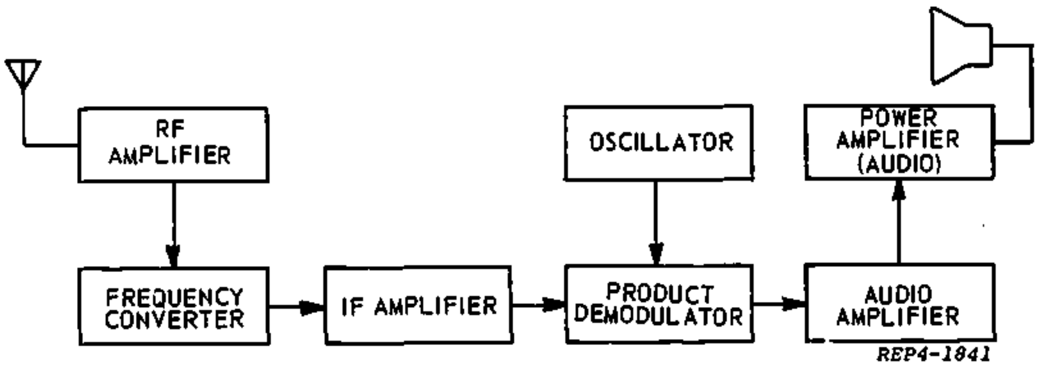



Figure 6-25. Block Diagram SSB Receiver

6-150. Circuit Operation.

6-151. Figure 6-26* illustrates a SSB transmitter. Let us first establish the direct current loop in each stage and then trace a signal from input to output. The direct current in the audio or speech amplifier Q101 is from ground through R102 the emitter-base junction of Q101, in parallel with R101, then R118 and primary of T102 to $V_{CC}$ for forward bias. Current also flows from ground through R102, emitter-collector and T102 to $V_{CC}$. The DC path in the carrier oscillator Q102, is from ground through R105 and the emitter-base junction which is in parallel with R104, then through R103 to $V_{CC}$ for forward bias. Current also flows from ground through R105, the emitter-collector of the transistor and the primary of T103 to $V_{CC}$. The direct current flow in the mixer Q104, is from ground through R111, the emitter-base junction of Q104, R110 to $V_{CC}$ for forward bias. Direct current also flows from ground through R111, the emitter-collector and the primary of T106 to $V_{CC}$. The direct current flow in Q103 the second oscillator is from ground through R107, the emitter-base junction of the transistor in parallel with R106, then through R108 to $V_{CC}$ for forward bias. Direct current also flows from ground through R107, through the emitter-collector, RFC101 and R109 to $V_{CC}$. The DC path for the driver stage, V101, is from ground through R113, V101, and RFC102 to B+. The screen current flows from ground thru R113, V101, R114 to B+. The DC path for the last stage, the power amplifier V102, is from ground thru R116, V102, and RFC103 to B+. Screen current flows from ground thru R116, V102, and R117 to B+.

6-152. The $V_{CC}$ connections of Q101, Q102, Q103 and Q104 are all connected to a common low voltage power supply. The current from each stage flows through the power supply to ground to complete the closed DC loop. The B+ connections of V101 and V102 are connected to a common high voltage DC power supply. The current from each stage flows through the power supply to ground, completing the loop.

6-153. The intelligence signal (audio) is coupled through T101 to the base of Q101, the audio amplifier. The amplified signal in the collector circuit is transformer coupled through T102 into the balanced modulator. The carrier is produced by the oscillator stage, Q102. The oscillator frequency is controlled by the crystal, Y101. The oscillator signals are transformer coupled by T103 to the balanced modulator. The balanced modulator produces upper and lower sidebands and these sidebands are transformer coupled through T104 to the sideband filter. Remember, the balanced modulator eliminates the carrier. The sideband filter will only pass a very narrow band of frequencies, our desired sideband, either the upper or the lower. Thus the output of the filter is just the desired sideband and it is transformer coupled by T105 to the mixer. The sideband frequencies are developed on

*Figure 3 in KEP-GP-70

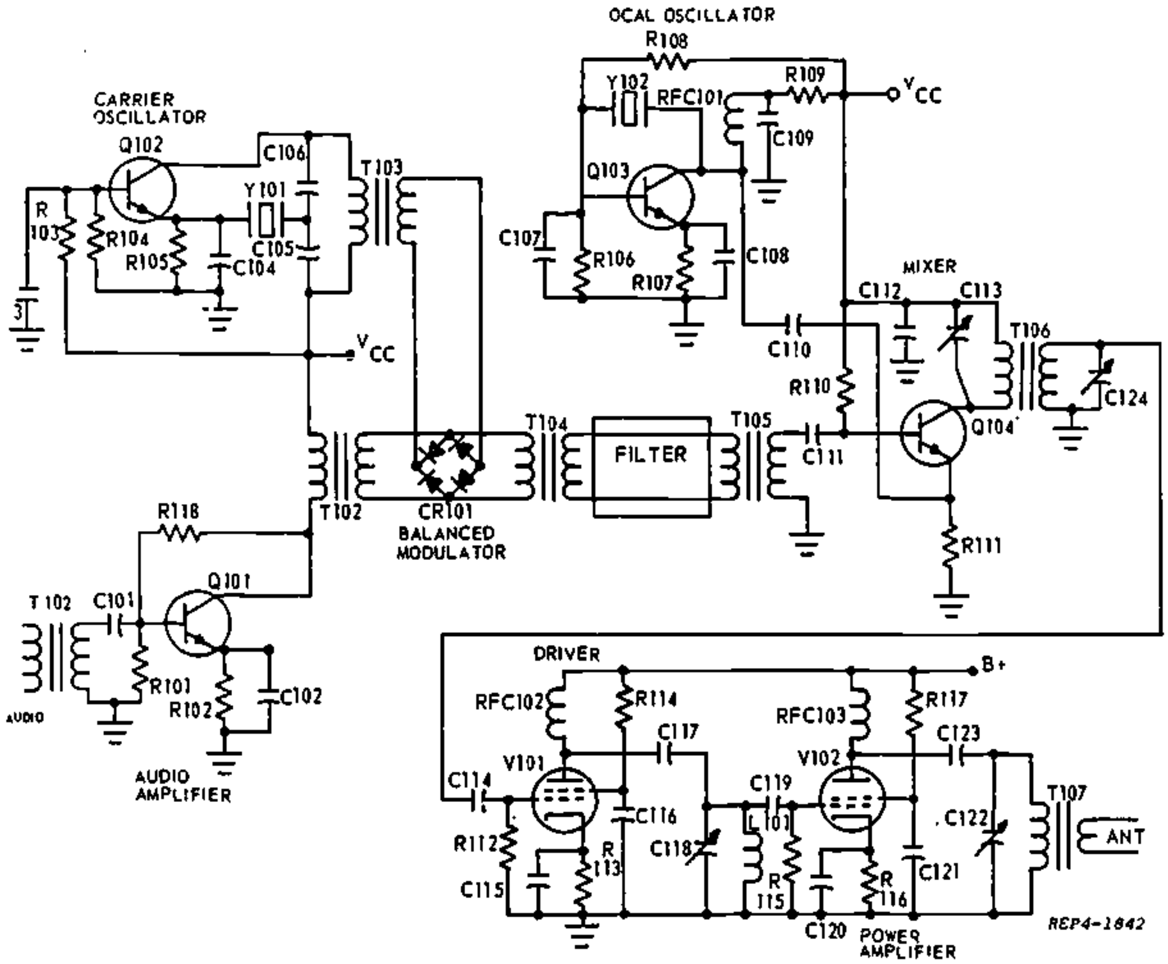



Figure 6-26. SSB Transmitter

the base of Q104, while higher frequency oscillations are applied to the emitter. These higher frequency oscillations are developed in the second oscillator stage, Q103. The frequency of oscillations is controlled by Y102, and the output is coupled through C110 and developed across R111. The mixer, Q104, having two different frequencies applied and operated as a non-linear device will produce new frequencies. The collector load of Q104 is tuned to the frequency of the desired sideband which is transformer coupled by T106 into the tuned grid circuit of V101, the driver. The desired sideband developed on the grid of V101 is amplified and developed in its plate. This amplified RF signal is applied to the grid of the power amplifier, V102. The signal on the tuned grid produces a large current change in the tuned plate circuit. This signal is transformer coupled by T107 to the antenna. The antenna converts the current and voltage into an electromagneic field.

6-154. Figure 6-27* illustrates a SSB receiver schematic diagram. Let us first establish the direct current loop for each stage, then trace a signal from input to output. The direct current flow in Q101, the RF amplifier, is from ground through R102, through the emitter-base junction, R101 and R106 to the AVC circuit. For the development of the AVC voltage see paragraph 6-100. Current also flows from ground through R102, the emitter-collector and the primary of L102 to $V_{CC}$. The DC path in Q102, the frequency converter, is from ground through R104, emitter-base junction, the secondary of L102 and R103 to $V_{CC}$. DC also flows from ground through R104, emitter-collector, through the primary of L103 and R105 which are in parallel, and then through the primary of T101 to $V_{CC}$. The DC path in Q103, the IF amplifier circuit is from ground through R110, through the emitter-base junction, the secondary of T101, R109 and R107 to $V_{CC}$, also from ground through R110, emitter-collector, primary of T102 and R107 to $V_{CC}$. The direct current in Q107, the product demodulator circuit, is from ground through R120, the emitter-base junction and the secondary of T102 which is in parallel with R121, and then through R122 to $V_{CC}$ to establish forward bias for Q107. Current also flows from ground through R120, emitter-collector, L104, and R123 to $V_{CC}$. DC in the reference frequency oscillator Q108 is from ground through a part of L105, R125, emitter-base junction, R124 and RFC101 to $V_{CC}$ for forward bias of Q108. Also DC flows from ground through a part of L105, R125 emitter-collector and RFC101 to $V_{CC}$. The direct current flow in Q104, the audio amplifier, is from ground, through the emitter-base junction, R114 and the primary of T103 to $V_{CC}$ as forward bias for the transistor. Current also flows from ground, through to the emitter-collector, and the primary of T103 to $V_{CC}$. The DC flow in the audio power amplifier Q105 and Q106, is from ground through R117, emitter-base junction of Q105 one half of the secondary of T103 and R116 to $V_{CC}$ for forward bias. DC also flows from ground through R117, emitter-collector and through one half of T104 to $V_{CC}$. The audio power amplifier is a push-pull amplifier, therefore current flows from ground through R118, emitter-base junction of a Q106, the other half of T103 and R116 to $V_{CC}$ as forward bias. Current also flows from ground through R118, emitter-collector and the other half of T104 to $V_{CC}$. The $V_{CC}$ points are common and all current flows through the power supply to ground, completing the closed DC loop.

6-155. Using figure 6-27 let us now trace a signal through the SSB receiver. The RF signal is intercepted by the antenna which produces RF voltages and currents. The desired RF signal is developed in the antenna's tuned circuit. The signal is inductively coupled to the base of Q101, the RF amplifier. The amplified RF signal is developed in the tuned collector circuit and inductively coupled to the base of Q102, the frequency converter. A local oscillator signal is present on the emitter of Q102 and the incoming sideband RF signal is on the base. The difference frequency is developed by the tuned tank of the collector circuit and transformer coupled to the tuned base of Q103, the IF amplifier. The IF signal is amplified and coupled from the tuned collector circuit through T102 to the base of Q107, the product demodulator. Q108 is the reference frequency oscillator which is tuned to the exact same frequency as the carrier oscillator in the transmitter. The oscillations produced are coupled through C125 and developed across R120, the emitter resistor of the demodulator. With the sideband frequencies on the base the carrier frequency on the emitter, and the transistor Q107 operated in the nonlinear portion of its operating range, new frequencies are produced by heterodyning. Of these frequencies, the difference frequency will be equal to the original audio signal used in the transmitter.

*Figure 4 in KEP-GP-70

The sidebands and carrier are filtered out by the filter in the collector circuit and the audio is developed across R112 and the volume control, R113. The signal is coupled from the volume control through C116 to the base of Q104, the audio amplifier. The amplified audio signal is developed in the tuned collector circuit and is coupled by T103 to the bases of Q105 and Q106, 180 degrees out of phase. This produces a large change in current in the collector circuits of Q105 and Q106 at the audio rate. This change in current in the primary of T104 produces an audio signal in the secondary which is coupled to the speaker. The speaker converts the audio signal into sound waves.

6-156. Pulse Modulation System.

6-157. Pulse modulation is defined as modulation of a carrier by pulses. Pulse modulation is used in many applications; such as telegraphy, telemetry, multiplexing and radar. In pulse modulation a pulse is used to control when and for how long the transmitter produces an output and how much of an output is produced. An example of pulse modulation is in time-division multiplexing. Multiplexing is a technique of combining multiple independent intelligence channels into a composite signal which in turn is transmitted to companion receiving system and restored to individual channels.

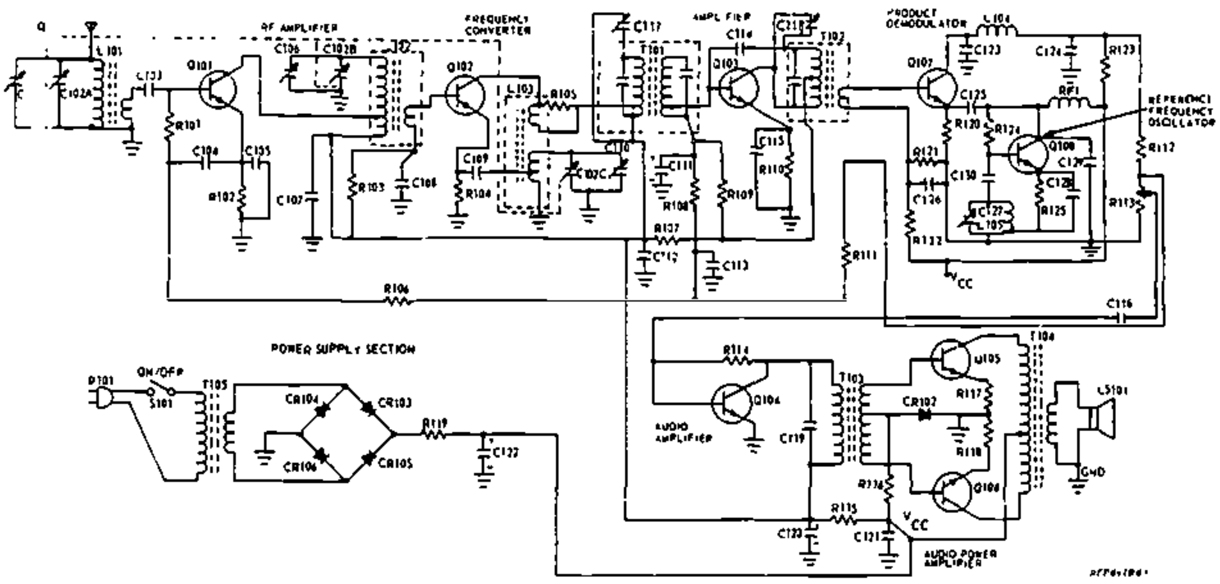



Figure 6-27. SSB Receiver

6-158. In order to separate the messages in time, each message is transmitted for a brief period of time in a regular sequence. This process is called SAMPLING. The receiver separates the samples and reconstructs the original message from these samples. Various types of pulse modulation can be used to accomplish time-division multiplexing.

6-159. PULSE-AMPLITUDE MODULATION (pam) is used for time-division multiplexing. In this method, the signal is sampled periodically, producing a pulse whose amplitude is proportional to the amplitude of the signal at the instant of sampling. A pam signal is shown in part B of figure 6-28. The rate of sampling is based on the highest AF signal to be transmitted. Experiments have shown that a minimum sampling rate for good receiver reproduction is 2 1/2 times per cycle. In the figure, note that the sampling produces pulses at regular, predetermined sampling points, and that the amplitude of each pulse is proportional to the amplitude of the modulating signal at the point of sampling. The receiver, sensing the changing amplitude of the evenly spaced pulses, can reproduce the modulating audio-frequency signal.

6-160. Another method of time-division multiplexing is called PULSE-DURATION MODULATION (pdm). A pdm signal is shown in part C of figure 6-28. Here, the pulse width, or duration, of each sample pulse is proportional to the amplitude of the modulating signal at the point of sampling. Thus the receiver, sensing the changing width of the pulses can reproduce the modulating signal. This method is less affected by noise than the previously discussed pam method. The sampling rate is determined in the same manner as for pam. One disadvantage of the pdm method is that, because of the variations in pulse width, the transmitter output will vary or be irregular. Another disadvantage, which also applies to the pam method, is that any distortion in pulse shape amplitude, or duration, will affect the intelligence to some extent.

6 161. A third method of time-division multiplexing used in military equipments is PULSE POSITION MODULATION (ppm). To overcome the disadvantage of distortion, as discussed for pam and pdm, the pulses are maintained at a constant amplitude and pulse width. A ppm signal is shown in part D of figure 6-28. The trailing edge of the ppm pulse is used to determine the sampling rate and, consequently the maximum frequency of the modulating signal. This multiplexing method can be varied by shifting the leading edge at the sampling time and allowing it to return to center position when no modulation is present. This form of modulation is a variation of ppm.

6-162. Each type of pulse modulation discussed in this section is succeedingly less affected by noise than the preceding type. Thus, pdm is less affected by noise than pam, and ppm is less affected by noise than pdm. The method which is least affected by noise is PULSE-CODE MODULATION (pcm). When using this method, a predetermined code based on an arbitrary number of steps or degrees of amplitude in the modulation voltage establishes the pulses.

6-163. The pulse code used is complex. The number of steps required to satisfactorily reproduce the modulation voltage has been determined by research and experimentation. A pcm signal is shown in part E of figure 6-28. The number of pulses in each pulse group represents the amplitude of the modulating signal at the point of sampling. Therefore, the receiver can detect and reproduce the modulation component.

6-164. Another form of pulse modulation, and one that is widely used, is line pulsing modulation as used in radar. Let us use a pulse modulated radar system to illustrate how a pulse modulated system functions. Remember this is just an example to illustrate the principles of pulse modulation. Figure 6-29 illustrates a block diagram of a simple radar system.

6-165. The principles of radar are relatively simple. A transmitter sends out RF waves. An object in the path of these waves reflects some of the wave energy back toward the transmitter. A receiver, located near the transmitter, receives this reflected wave energy, amplifies and demodulates it, and sends intelligence to an indicator.

6-166. A radar transmitter may send out CW, FM, or pulse modulated signals. However, pulse modulated systems are the most common radar systems used. In pulse radar, the frequency of the RF wave radiated is usually in the microwave region and the RF signal is transmitted at definite time intervals. It is this form of pulse system that we will discuss in this text.

6-167. The master timer acts as a master control for synchronizing the entire system. It determines pulse recurrent frequency (PRF).

6-168. The modulator, as a separate component, shapes the voltage wave that is applied to the transmitter. The power that drives the transmitter comes from the modulator.

6-169. The transmitter produces the RF wave to be radiated; the power amplifier increases the RF power.

6-170. The duplexer is a switching unit to provide a means of using a single antenna for transmitting and receiving. During transmission, the duplexer connects the antenna to the transmitter; then, during reception the duplexer connects the antenna to the receiver. A pulse radar system transmits a pulse and "listens" for a return echo of part of that pulse energy. Pulse radar cannot receive while transmitting; it transmits, then receives.

6-171. The receiver, ususally a superheterodyne type, receives, amplifies, and demodulates the returned signal.

6-172. The three remaining blocks are part of the indicator: The sweep circuit causes the trace on the CRT to move at the desired rate and in the desired direction. The range mark generator develops signals used as time or distance markers. The indicator is the CRT which displays the intelligence information. A mechanical linkage (dotted line) is part of the synchro system to provide synchronization between the antenna and the indicator.

6-173. Any pulse modulated radar transmitter is turned on to radiate a pulse of energy, and is then turned off while the receiver receives reflected energy.

6-174. Pulse recurrence frequency (PRF) is the frequency at which pulses are transmitted by a pulse modulated system. PRF is expressed in pulses per second. Pulse recurrence time (PRT) is the time between the start of one transmitted pulse and the start of the next transmitted pulse. PRT can be found by taking the reciprocal of the PRF.

$$\text{PRT} = \frac{1}{\text{PRF}}$$

6-175. In 1 second, RF energy travels 161,750 nautical miles, 6.18 microseconds per mile. The time required for an RF pulse to travel 1 mile out to a target and return, therefore, is 12.36 microseconds; this is called a "radar mile."

6-176. A radar transmitter cannot be allowed to fire at just any time; its pulse recurrence must be carefully controlled. There is a definite maximum and minimum PRF for each radar set. For great distances the PRF will be low and for short ranges the PRF will be high. For a system with a maximum range of 100 miles, the minimum PRT is in excess of 1236 microseconds. A typical time for 100 miles would be 1250 microseconds of which 1236 microseconds is needed to receive and present received signals, leaving 14 microseconds for the transmitted pulse and necessary recovery of the indicator system. Since frequency is equal to one divided by the time interval:

$$\text{PRF} = \frac{1}{\text{PRT}}$$

$$\text{PRF} = \frac{1}{1250 \times 10^{-6}}$$

$$\text{PRF} = \frac{1{,}000{,}000}{1250}$$

$$\text{PRF} = 800 \text{ pps}$$

Thus, the pulse recurrence frequency for a 100 mile range radar is 800 pps.

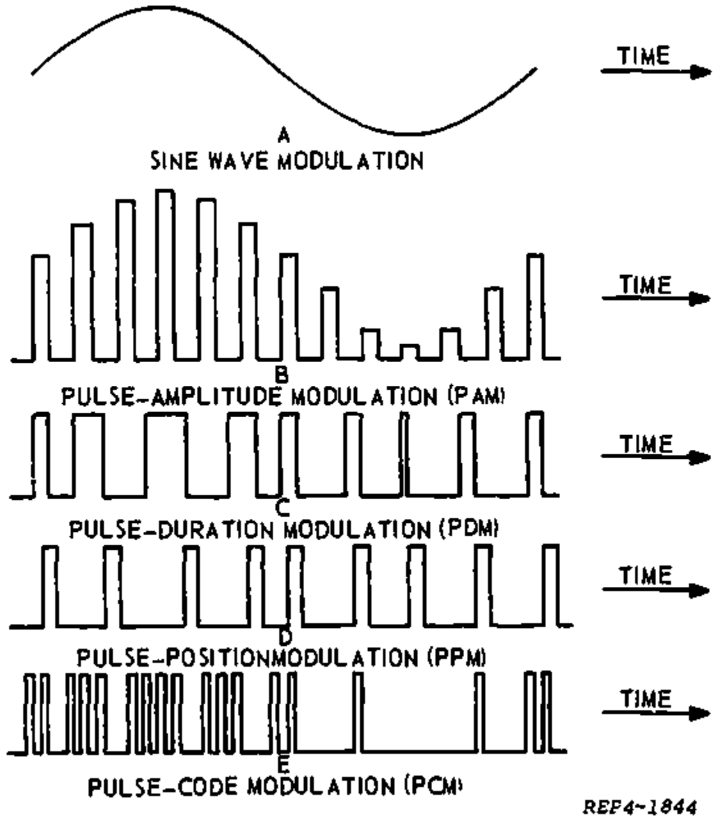



Figure 6-28. Pulse Modulation, Waveforms

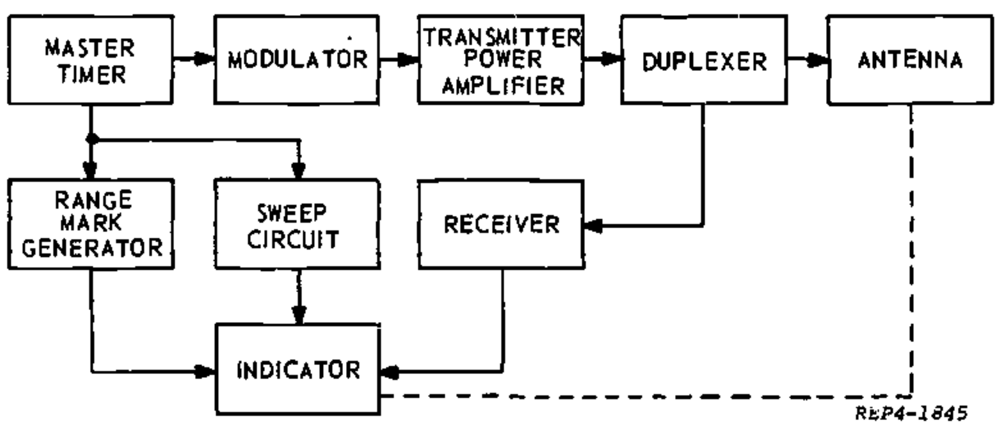



Figure 6-29. Typical Pulsed Radar System

6-177. Pulse width is a prominant factor of pulse formation. A minimum range difference at which two targets can be resolved varies directly with the width of the transmitted pulse. With a microsecond pulse, targets at the same angle from the transmitter can be resolved if they differ in range by more than 164 yards. With a 5 microsecond pulse, this limit for separating the targets becomes 820 yards.

6-178. Another important item is the shape of the pulse. Theoretically, the pulse must be rectangular. In practice, the dimensions are exacting. For instance, the leading edge must have a definite rise time to properly start the transmitter. The pulse applied to the transmitter is the excitation voltage of the oscillator. The pulse must be as flat as possible, or the change in voltage will modulate the RF wave. Stable functioning of any oscillator demands that the excitation voltage be constant. This holds true in radar, even though the time the voltage is applied to the oscillator is extremely short. The trailing edge of the pulse must be sharp, to allow fast switching from transmit to receive.

6-179. The next problem is that of power, as related to pulse dimensions. The distance a radar is able to detect a target depends, in part, on peak power and average power.

6-180. Just what is peak power and what is average power? Peak power is the maximum power which a set radiates during a pulse of RF energy. Average power is the power averaged over the entire pulse repetition period.

6-181. To determine average power, we must know peak power, pulse width, and pulse recurrence frequency. The amplitude of the pulse determines peak power, which is limited by the ability of circuit elements to withstand the stress of high voltage. Remember that PRF is a factor of maximum range.

6-182. Once the PRF is set, PW is the remaining factor which can be adjusted to allow for a proper level of average power.

$$\text{Average power} = \frac{\text{Peak power x pulse width}}{\text{PRT}}$$

$$\text{or} \quad P_{av} = \frac{P_{pk} \times PW}{PRT}$$

Since PRT = 1/PRF, average power can be written as

$$P_{av} = P_{pk} \times PW \times PRF$$

The modulator power supply must be capable of supplying the peak and average power transmitted.

6-183. The pulse used to control the generation of PRF power in the transmitter is developed in the modulator. Figure 6-30 is a block diagram of a radar transmitter using a line-pulsing modulator. This type modulator stores energy and determines the output pulse width.

6-184. In the pulsing modulator the power supply supplies the voltage for the Pulse Forming Network (PFN). The pulse forming network is a reactive device that stores the energy (voltage) and determines the pulse width. The charging choke and diode are used to allow the PFN to charge to nearly twice the power supply voltage. The PFN storing the energy is connected to a switch. This switch is usually a gas triode (thyratron) and is activated by a pulse from the timer which establishes the PRF. When the switch is closed, the PFN supplies energy thru the pulse transformer to the transmitting tube. The duration of this voltage pulse is determined by the PFN. The pulse transformer must be specially designed because there are very high frequency components present in a rectangular pulse of short duration. In general, a good pulse transformer must have low leakage inductance, low interwinding capacitance, and high primary inductance. The transmitter tube is a high frequency, high power oscillator. This oscillator circuit in most radar sets has a special microwave oscillator tube designed to operate at very high frequncies and to

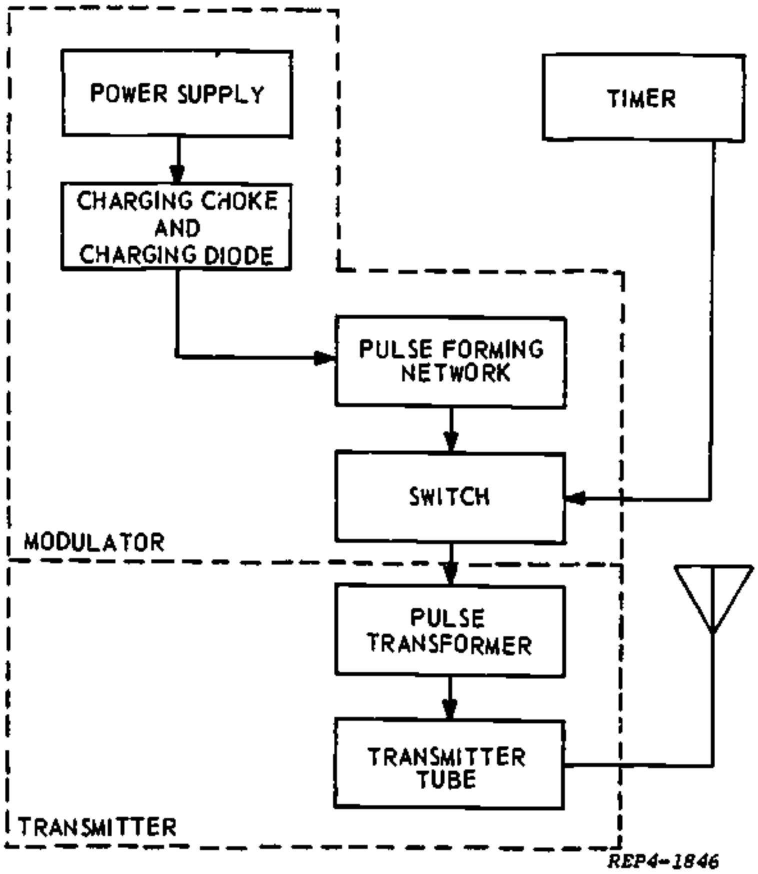



Figure 6-30. Typical Pulsed Radar Transmitter

produce large amounts of power. Regardless of the particular type oscillator circuit used, the oscillator will only produce oscillations in the output during the time the PFN supplies it with energy. The pulse of oscillations produced are coupled from the power oscillator to the antenna which converts it into an electromagnetic field which radiates into space. This electromagnetic field contains the oscillator frequency and all of the sidebands caused by pulse modulation. Thus the antenna and transmission lines used must be wideband devices.

6-185. Circuit Operation.

6-186. Figure 6-31* is the schematic diagram of a pulse modulated transmitter. This transmitter has two power supplies; one to furnish a positive charging voltage for the PFN and also the screen voltage for the oscillator. The other power supply develops a negative voltage for bias on the thyratron. Let us establish the direct current loop in each stage and trace a signal from input to output. Direct current flows from ground through the cathode to screen grid of V106, through RFC101; all of this is in parallel with R102. The current then flows through R101 to the positive power supply. This network develops the screen potential for the oscillator. Direct current flows from ground through the secondary of T102 through V103, L102, R103 and R104 to ground, to establish bias on V105. There is another direct current loop, but it is a little more complex. This is the charging and discharging of the PFN. The PFN is a reactive device consisting of L104, L105, C107 and C108. The inductive values of L104 and L105 are

*Figure 4 in KEP-GP-71

very small when compared with the inductive value of L103, the charging choke. Because of this small inductance of the PFN when compared to L103, they will be assumed to be a short. Thus, the two capacitors are in parallel, and capacitance ($C_t$) is equal to the sum of both. L103 and $C_t$ form a series LC circuit that is resonant at a frequency equal to one-half the PRF. For example, if the PRF is 2000 pps, the resonant frequency of L103 and $C_t$ is 1000 Hz. The reason for using a resonant frequency that is equal to one-half the PFR is to insure that the pulse forming network is fully charged. The time required for the voltage across $C_t$ to reach its maximum value is equal to or less than the time between pulses. If the PRF is 2000 pps, the time between pulses is 500 microseconds. The direct current to charge the PFN is from ground through the primary of T103 to C107 and C108. Electrons leave the top plates, flow through L104 and L105, V104 and L103 to B+, through the power supply to ground. As capacitors C107 and C108 are charging, and current is flowing through L103 a large field is built up. As the capacitors charge to the power supply voltage, the amount of current flow decreases. This allows the field around L103 to collapse, causing current to continue to flow in the same direction continuing to cnarge C107 and C108 to nearly twice the power supply voltage. When the field around L103 has collapsed, C107 and C108 being charged to nearly twice the power supply voltage would try to discharge, however they are prevented from doing so by V104 the charging diode. Thus the PFN is now charged to approximately twice the power supply voltage and will hold this charge until a trigger is applied to the switch, V105.

6-187. During the time the PFN is charging V105 is cut off. When a positive trigger is applied to the grid, coupled through C106 and developed across R104, the tube conducts (switch closed) and provides a discharge path for the PFN. The capacitors C107 and C108 start discharging through T103, V105, L104 and L105. As they discharge a field is built up around L104 and L105, and as C107 and C108 discharge, the amount of current flow starts to diminish. The field of L104 and L105 collapses keeping the current flow nearly constant until the capacitors and inductors are discharged, then the current falls to zero. A rectangular pulse is thus developed across the primary of T103, the duration of which is equal to 2 LC. When the PFN has discharged, V105 will cut off, and the PFN will recharge. The impedance of the PFN and the primary of T103 are matched to develop maximum power transfer. This results in one half the voltage of the PFN being developed across the transformer T103, which is transformer coupled to the plate of V106, the oscillator. Note that during the slow charge of the PFN through T103, a voltage was induced on the plate of V106 but it was negative. This will not produce oscillations in the output. When the PFN discharges, a positive voltage pulse is induced in the secondary of T103. This causes current to flow from ground through V106, the primary of T104, secondary of T103 to ground. V106 is an oscillator with the screen grid acting as the plate circuit and developing the necessary feedback through C112. Thus the oscillator is oscillating whenever screen voltage is present, but the oscillations are not developed in the plate circuit until the plate becomes positive. The plate becomes positive during the discharge of the PFN, so during that time the oscillations are developed in the primary of T104 and transformer coupled to the antenna.

6-188. Pulse Receiver.

6-189. The energy that a target reflects back to the antenna in a pulsed radar system is a very small fraction of the transmitted energy. These reflected signals contain the same frequencies as were transmitted - the carrier frequency and the sidebands associated with it. Information about the position of the target may be presented by the movement or appearance of a spot of light on a cathode-ray tube. The cathode-ray tube requires signals on the order of several volts for its operation, and will not respond to the high frequencies received. Therefore, amplifiers and a demodulator must be used to obtain a visible indication on the cathode-ray tube. Keep in mind, the input signal to

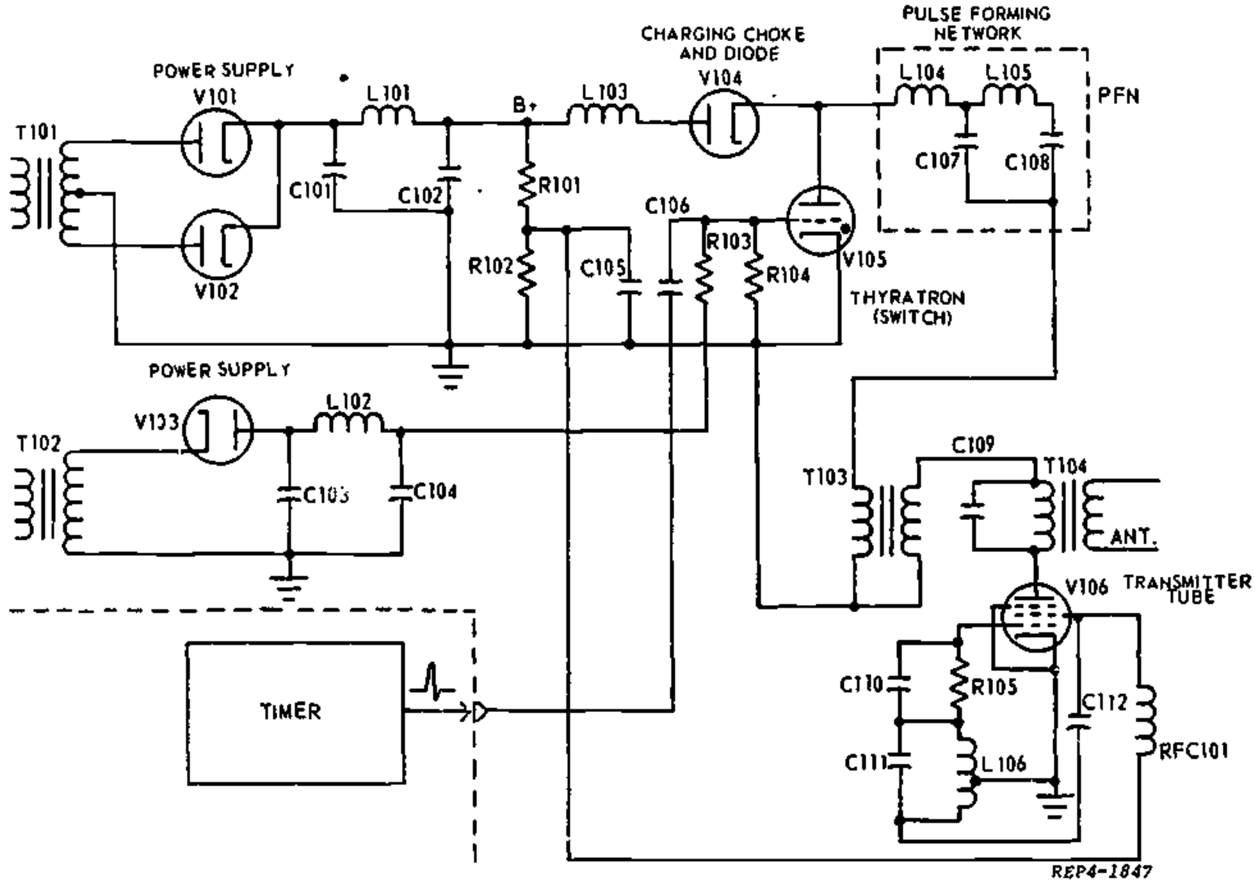



Figure 6-31. Pulse Modulated Transmitter

the amplifier is a pulse of extremely high-frequency, very low voltage, and very short duration.

6-190. The amplifiers and demodulator are in the receiver block of figure 6-29. An arrangement of the receiver components is shown in figure 6-32. The system shown is a superheterodyne type, similar to a conventional AM receiver, see paragraph 6-46 through 6-77. One difference between a conventional AM receiver and one used for a pulsed radar system is the bandwidth requirement.

6-191. Recall that a rectangular pulse is composed of a fundamental frequency plus a number of even and odd harmonics. The narrower the rectangular pulse, the greater the number of important harmonics. Thus, in a pulse radar system receiver, the narrower the pulse the greater the bandwidth requirement.

6-192. The bandwidth capability is needed for fidelity of pulse reproduction. For the best signal-to-noise ratio, however, there is a certain optimum IF bandwidth. To illustrate this optimum value, imagine a pulse radar system (pulses of fixed duration) having an IF amplifier with a controllable bandwidth.

6-193. As the bandwidth is increased from zero, in small increments, the peak amplitude of the pulse will increase at a linear rate. RMS noise voltage will also increase, but at a rate which is proportional to the square root of the bandwidth. As a result, signal-to-noise ratio will show a steady increase. This increase will continue, but at a decreased rate as the optimum bandwidth is approached. Increasing the bandwidth beyond the optimum value results in a decrease in the signal-to-noise ratio. This action is illustrated in figure 6-33. The curve of the signal-to-noise ratio makes it apparent that the optimum bandwidth is not extremely critical. It is approximately twice the reciprocal of pulsed width. Simply, the narrower the transmitted pulse, the wider the bandwidth requirement.

6-194. Another difference, due to bandwidth requirements, between the two types of receivers applies to the final amplifiers; these are audio amplifiers in a voice system and video amplifiers in radar. The video amplifiers are wideband amplifiers.

6-195. Circuit Operation.

6-196. Figure 6-34* illustrates the schematic diagram of a superheterodyne receiver used in a pulse modulated system. The direct current flow and the signal paths are the same as AM. Refer to paragraphs 6-86 through 6-103. As stated in paragraph 6-189, the signal is a pulse of energy and is usually displayed on a cathode-ray tube, it is therefore called video instead of audio. The output video signal is coupled from the secondary of T104 to the indicator system.

*Figure 6 in KEP-GP-71

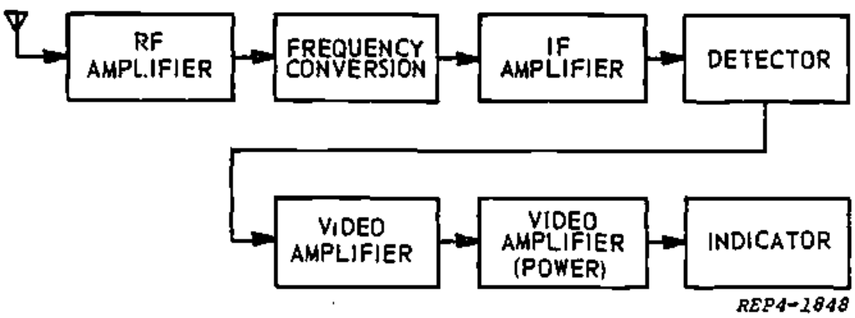



Figure 6-32. Block Diagram of Pulsed Receiver

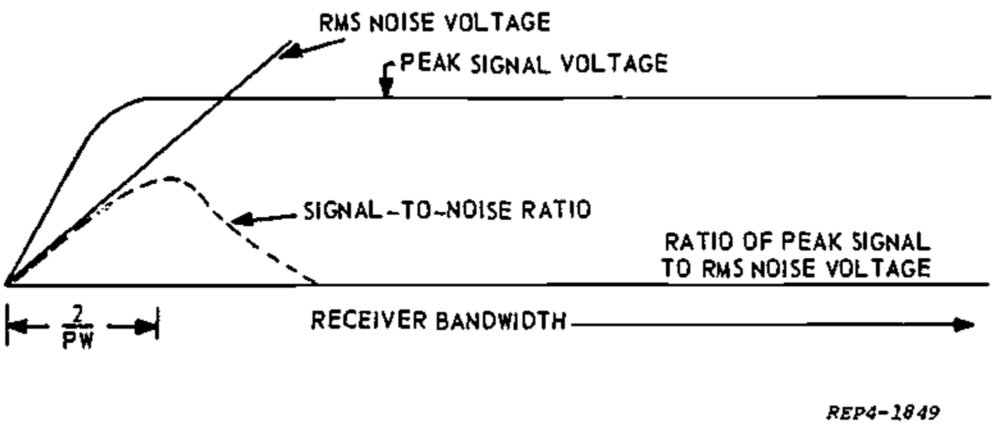



Figure 6-33. Optimum Receiver Bandwidth

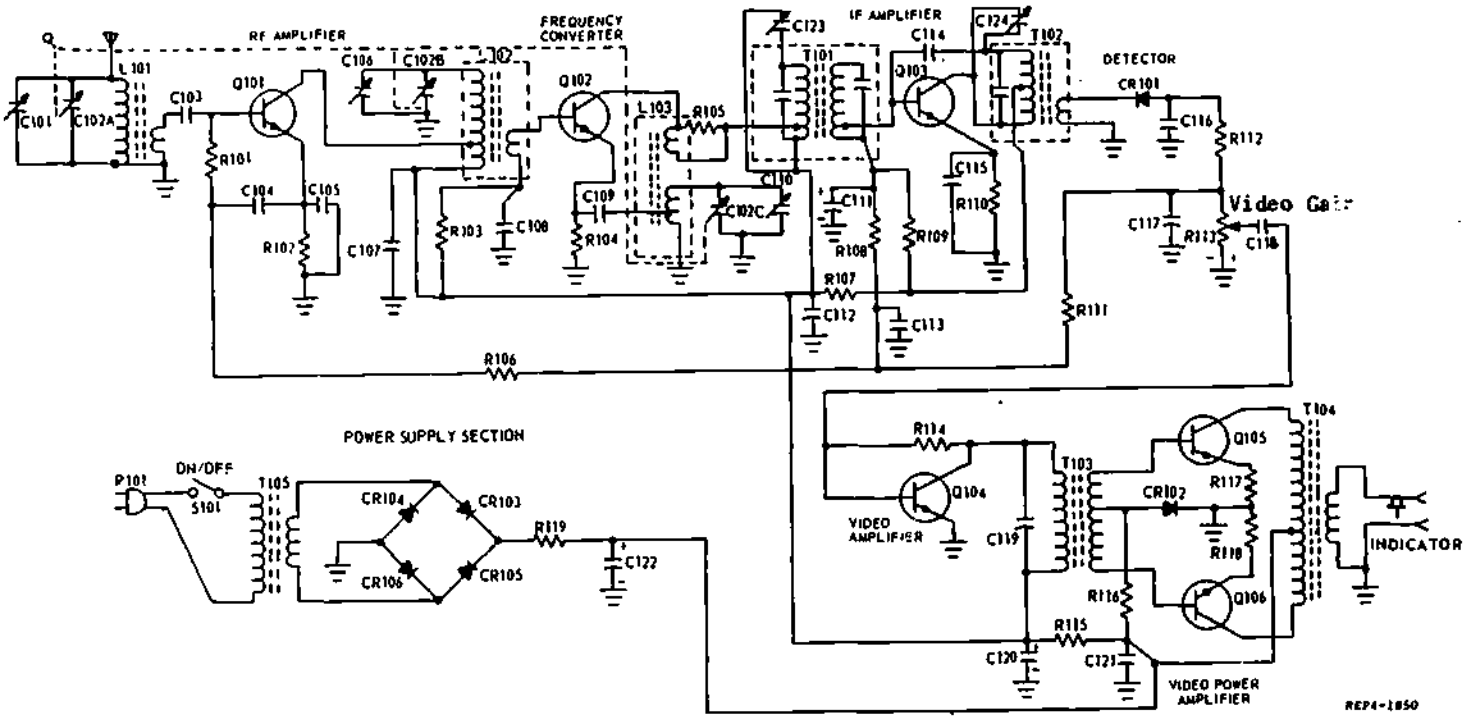



Figure 6-34. Pulse Receiver

Chapter 7

# SCHEMATIC INTERPRETATION AND TROUBLESHOOTING TECHNIQUES

## 7-1. Schematic Diagram Analysis.

7-2. Your ability to interpret schematic or block diagrams is vital when you are troubleshooting electronic equipment. As you go into maintenance work you will see many types of electronic diagrams, such as wiring diagrams, logic diagrams, signal flow charts, and voltage and resistance charts. All of these will aid you in your work, but you will find that the schematic and block diagrams will be used most often.

7-3. You can often arrive at the solution of a trouble by proper interpretation of the symptoms, with the aid of a schematic and/or block diagram.

7-4. SCHEMATIC MEANS THAT SOMETHING HAS BEEN DIAGRAMMED (LAID OUT) ACCORDING TO A SCHEME OR PLAN. In our work, a schematic is the diagram of an electronic circuit. Standard symbols are used to represent the component parts.

7-5. The plan for a schematic is to diagram the set in stages (such as RF amplifiers, IF amplifiers, converter, etc.). The signal source or input is usually shown on the left side of the diagram, then progresses through the stages toward the right and reaches the final output on the extreme right of the diagram.

7-6. Component parts (such as capacitors, resistors, coils, etc.), are numbered for identification. The part numbers usually progress from left to right, with the lowest number on the left. C1 or R1 is normally found on the left side of the diagram. If a set has 50 capacitors, C50 will be located in or near the output stage. You may see refinements, such as colored lines to make signal flow easier to follow, but most electronic equipment is laid out according to the basic plan that has just been covered.

7-7. Student Handout SH-IX-1 at the end of this chapter contains the schematic and block diagram of a typical AM receiver. This receiver is used in this chapter to cover proper troubleshooting techniques.

7-8. Notice how both diagrams in SH-IX-1 are arranged. The antenna is on the left, and you can follow the received signal as it progresses through the receiver. The speaker or output device is shown on the far right. The power supply is shown as a seperate section and the Automatic Volume Control (A. V. C.) circuit is shown as a dotted line with arrows (on the block diagram).

7-9. Most electronic equipment (such as radio transmitters and receivers) can be divided into sections such as, RF, IF Video, etc.).

7-10. In SH-IX-1, notice that the diagrams have been divided into sections with dashed lines. These sections are the RF, IF, and AF sections. The RF section receives the modulated RF signal, amplifies it and converts it to the modulated IF signal. The IF section amplifies the modulated IF signal and applies it to the AF section. The AF section extracts the AF signal from the IF signal and amplifies the AF signal enough to drive the speaker or output device.

7-11. Many of the electronic systems you will be working with in the Air Force will have more than one IF section. Each IF section will have a different frequency. When this occurs each IF SECTION will be numbered (such as 1st IF, 2nd IF, etc.).

7-12. In the schematic in SH-IX-1, the converter local oscillator tuning capacitor is gang tuned with the input tank circuit tuning capacitor. When the station selector dial is turned, the input tank circuit is tuned to a new frequency (station). The converter oscillator tank circuit is also tuned to a new frequency which is 455 kHz above the received frequency. For instance, if the input tank circuit is tuned to 690 kHz, the converter oscillator frequency will be tuned to 1145 kHz. If the input tank circuit is tuned to 1490 kHz, the converter oscillator frequency will be 1945 kHz. By keeping the converter oscillator at a frequency 455 kHz above the input tank frequency, the IF section can be tuned to 455 kHz. This increases the selectivity of the receiver.

7-13. The 455 kHz signal has the same AM variations that are present on the original RF input signal. The IF amplifier amplifies this modulated IF signal and applies it to the AF section.

7-14. The detector circuit in the AF section extracts the AF signal from the IF signal and applies it to the AF amplifier, which is a voltage amplifier. The AF signal is then applied to the AF power amplifier which provides current amplification to drive the speaker and produce sound.

7-15. The AVC circuit is shown in the block diagram as a dotted line with arrows to indicate the direction of the AVC voltage. On the schematic diagram the AVC circuit is composed of R113, C117, R111, R108, R106, and R101. The purpose of this circuit is to prevent the receiver from being overdriven if it receives a very strong signal. To accomplish this, a DC degenerative feedback voltage from the detector circuit is applied to the base of Q101 and Q103. As the input signal increases in amplitude, the degenerative DC voltage applied to the base of Q101 and Q103 decreases the forward bias of these two stages to keep the receiver from being overdriven. If this circuit was not in the receiver, you would hear the changes in input signal strength as changes in volume at the speaker. It would have the same effect as varying the volume control. The AVC circuit may also be called the Automatic Gain Control (AGC) circuit.

7-16. Troubleshooting Procedures.

7-17. Troubleshooting requires a combination of knowledge, skill, and a logical approach. Since your entry into this course, you have been concerned with acquiring the knowledge of electronics to enable you to maintain electronic equipment. The lab exercises that you have completed have started you toward developing the necessary skills for troubleshooting. A logical approach involves the development of a step by step procedure. We are about to outline a GENERAL procedure to follow, which works with most electronic equipment. You may find some differences when you get into the equipment covered by your AFSC, but these differences are mainly a mater of sequence.

7-18. The procedures are:

(1) Operational Check.

(2) Visual Check.

(3) Half-Split Method.

(4) Stage-By-Stage.

(5) Component Isolation.

7-19. Operational Check.

7-20. This is done by turning the equipment on and checking its operation against predetermined MINIMUM STANDARDS OF OPERATION. The standards for AF equipment are outlined in the Technical Manual for each unit. The operational check will usually isolate the trouble to a particular unit, such as a receiver, transmitter, modulator, or control unit. In addition to locating the unit where the trouble exists, an operational check will also help determine what particular function is not being performed within the defective system, by the symptoms the trouble causes. For example, in a receiver, the symtpom might be weak or no audio output. In a transmitter, the symptom might be low output power or the output frequency is unstable. Examples of other checks that could be made during an operational check to help determine the symptoms are:

(1) Front panel meter readings from built-in metering circuits in the equipment.

(2) Observation of oscilloscope patterns from built-in oscilloscope.

(3) Transmitter power and frequency checks.

(4) Receiver signal-to-noise and sensitivity checks.

(5) Modulator audio distortion and percent of modulation checks.

7-21. Half-Split Method.

7-22. The name here implies that you divide a system or unit into two equal parts for troubleshooting. Each part then would be divided into two more equal parts. Actually, this is not the case. It does mean that the unit should be divided into major sections, if possible. Whether or not it is possible to divide the unit into major sections is determined by the type of equipment you are troubleshooting. For example, the typical receiver that has already been discussed was divided into RF, IF, and AF sections according to their purpose and frequency.

7-23. A logical way to troubleshoot is to start with the section nearest the output, since the output is where you usually notice a symptom, and work toward the input until you have located the section the trouble is in.

7-24. Lets assume, through an operational check, you find that the receiver in SH X-1 has no output (sound) from its speaker. Using the half-split method, you will check one section at a time until you find the section that the trouble is in.

7-25. You can isolate the trouble to one section by using one of these two methods:

(1) Apply the output of an AF generator to the AF section and if you have an output (sound) at the speaker, you will know the AF section and the power supply are okay. Next, apply the output from an RF generator to the IF section and listen for an output from the speaker. If you get an output from the speaker, you will know that the IF section is okay and the trouble is located in the RF section. To confirm the trouble is in the RF section you will apply the modulated output of an RF generator to the RF section and listen for an output from the speaker.

(2) Using an RF generator, apply a modulated RF signal to the input of the RF section. The receiver tuning dial must be set to the same frequency as the RF generator frequency. An oscilloscope can now be used to check the inputs to each section. The section that has the proper input signal and an improper output signal is the section where the trouble is located.

7-26. Since the use of the oscilloscope is very important for you, the examples and the theoretical troubleshooting in this chapter will be done according to the second method discussed.

7-27. Stage-By-Stage Method.

7-28. Once the trouble has been isolated to one section of the equipment (example; receiver-RF section), it is logical to check each stage within a section, until you find the stage where the trouble is located. Again, you should start at the stage nearest the output of the section and work toward the input to the section. For example, using SH-IX-1, the modulated RF generator output is applied to the input to the RF section. If you check the input to the detector section with the oscilloscope and find the proper signal is present, you will then check the input to the AF amplifier. If the proper signal is not present at the input to the AF amplifier, you will know the trouble is in the detector stage. Since a stage is also called a circuit, this method may be called the circuit-by-circuit method of troubleshooting.

7-29. Component Isolation.

7-30. Now that the trouble is isolated to one stage (circuit), the next step is to find the component or components that caused the trouble. In this step you are looking for such things as, shorted or open transistors, shorted or leaking capacitors, resistors that have opened or changed ohmic value, open or shorted coil, etc.

7-31. This step is performed by making voltage and resistance checks of the individual components within a stage (circuit). The voltage checks are made with the equipment power ON and resistance checks must be made with the equipment power OFF. A multimeter may be damaged if resistance checks are made while the equipment is turned ON.

7-32. Before any actual measurements are made, a list or chart of the normal voltage and resistance measurements in each circuit should be obtained. For Air Force systems this chart can be found in the appropriate Technical Manual provided with the equipment. These manuals also contain explanations, diagrams, and other data needed for troubleshooting.

7-33. A portion of a voltage-resistance chart for a tube circuit is shown in figure 7-1.

7-34. Visual Check.

7-35. The visual check can be performed before, during, or after any of the other checks. For example, if you are performing an operational check and you see smoke coming from a unit, you should look to see where in the unit the smoke is coming from.

7-36. This is called a VISUAL check, but it actually includes the other senses too. Your sense of vision would be used by looking for broken wires, frayed or stripped insulation, burned parts, evidence of shorts, origins of smoke or arcing, or oil leaking from oil filled transformers, capacitors, or pulse forming networks. When resistors, transformers, coils, or capacitors overheat, they give off a distinctive odor and your sense of smell would be used to help locate the trouble. Since a component that has overheated will stay hot for quite a while, your sense of touch can be used. Any defective component that is found in the visual check must be replaced, even if that component is not the one that caused the original trouble.

7-37. After the component has been changed, another operational check should be performed to make sure there are no more troubles.

7-38. Adjustments and Alignment.

7-39. Adjustments necessary for troubleshooting are considered to be part of the troubleshooting procedure itself. The adjustments are made during troubleshooting to make sure an adjustment is not causing the problem.

7-40. Equipment alignments may be necessary after a repair has been made. Whether or not an alignment is necessary depends on the type of equipment and the type of repair performed.

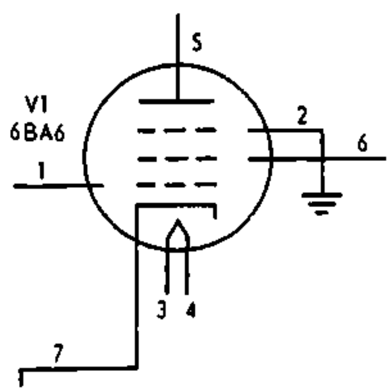
7-41. A schematic diagram for illustrating alignment is shown in student handout, SH-IX-1. This receiver is typical of the type used for standard broadcast band reception which means that the RF input frequencies will be in the range of 535 to 1605 kHz, (Broadcast Band). The local oscillator frequency is 455 kHz above the incoming radio frequency, and the intermediate frequency is 455 kHz.

7-42. At least two pieces of test equipment will be required to align the receiver illustrated in SH-IX-1. First, some type of output indicator is needed and second, an RF signal generator with AF amplitude modulation capability is required.

7-43. To indicate the receiver output there are several devices that may be used. Some examples are the VTVM, oscilloscope, and speaker. When using a VTVM it will be connected to the AVC line and maximum AVC voltage will indicate maximum output from the receiver. If using an oscilloscope it will be connected across the output of the audio section. Normally a speaker is included in the receiver circuitry. When it is used as an output indicator the volume of the audio tone is an indication of the receiver output.

7-44. There are several types of RF signal generators. The one used for this alignment must be capable of producing the IF (455 kHz) and RF (535 to 1605 kHz). 400 Hz and 1000 Hz are the audio tones most frequently used to amplitude modulate the RF signal.

| STAGE | TUBE | PIN NO. | VOLTAGE | RESISTANCE |
|---|---|---|---|---|
| V1 | 6BA6 | 1 | -2.5V | 5 MEG |
| | | 2 | 0 | 0 |
| | | 3 | 3.15 VAC | 0 |
| | | 4 | 3.15 VAC | 0 |
| | | 5 | +230V | 48K |
| | | 6 | +126V | 48K |
| | | 7 | +1.7V | 180 |
| | | | | |
| V2 | 6BE6 | 1 | -6.5V | 80K |
| | | 2 | 0 | 0 |
| | | 3 | 3.15 VAC | 0 |
| | | 4 | 3.15 VAC | 0 |
| | | 5 | +230V | 101K |
| | | 6 | | |




REP4-1851

Figure 7-1. Voltage Resistance Chart

7-45. Before discussing a step by step alignment procedure for the receiver, notice that all tuning components SH-IX-1 are located in the RF and IF sections. This means that there are four circuits that require alignment, the IF, the local oscillator, the antenna input and the RF amplifier.

7-46. Alignment procedures vary tremendously, depending on the receiver's complexity and its intended use. A general alignment procedure for the broadcast band receiver illustrated in SH-IX-1 is given below in four steps.

STEP #1. Set the output of the RF signal generator to 455 kHz (modulated with 400 Hz or 1000 Hz). Apply this signal to the input of the IF circuit (TP105) and adjust the tuning component (C124) in the IF stage for maximum output as shown on the output indicator that you have elected to use.

STEP #2. Disconnect the modulated 455 kHz signal from the IF amplifier and insert it at the input of the converter stage (TP103). Adjust the tuning component (C123) in the output of the converter circuit until there is maximum output from the receiver as shown by the indicator.

STEP #3. Set the output of the RF signal generator to a known frequency near the high end of the broadcast band (modulated with 400 Hz or 1000 Hz). Insert this signal at the antenna input and turn the tuning knob of the receiver until maximum output is indicated, and then adjust the trimmer capacitors in the RF output circuit (C106) and the antenna input circuit (C101) for maximum receiver output. At this point check to see if the tuning dial reading corresponds to the output frequency of the signal generator. If it does not, then adjust the dial until it indicates the same frequency as the generator output.

STEP #4. Leave the signal generator connected at the antenna input and adjust the local oscillator trimmer capacitor (C110) for maximum output from the receiver.

7-47. Theoretical Troubleshooting.

7-48. Now that the operation of the receiver and basic troubleshooting techniques have been completed, we can analyze trouble symptoms versus possible causes using the receiver schematic in SH X-1. The abnormal symptoms will be given first and then a list of some of the components that could cause the symptom or symptoms. Assume the half-split method has been used to narrow the trouble to one section, which is indicated in parenthesis.

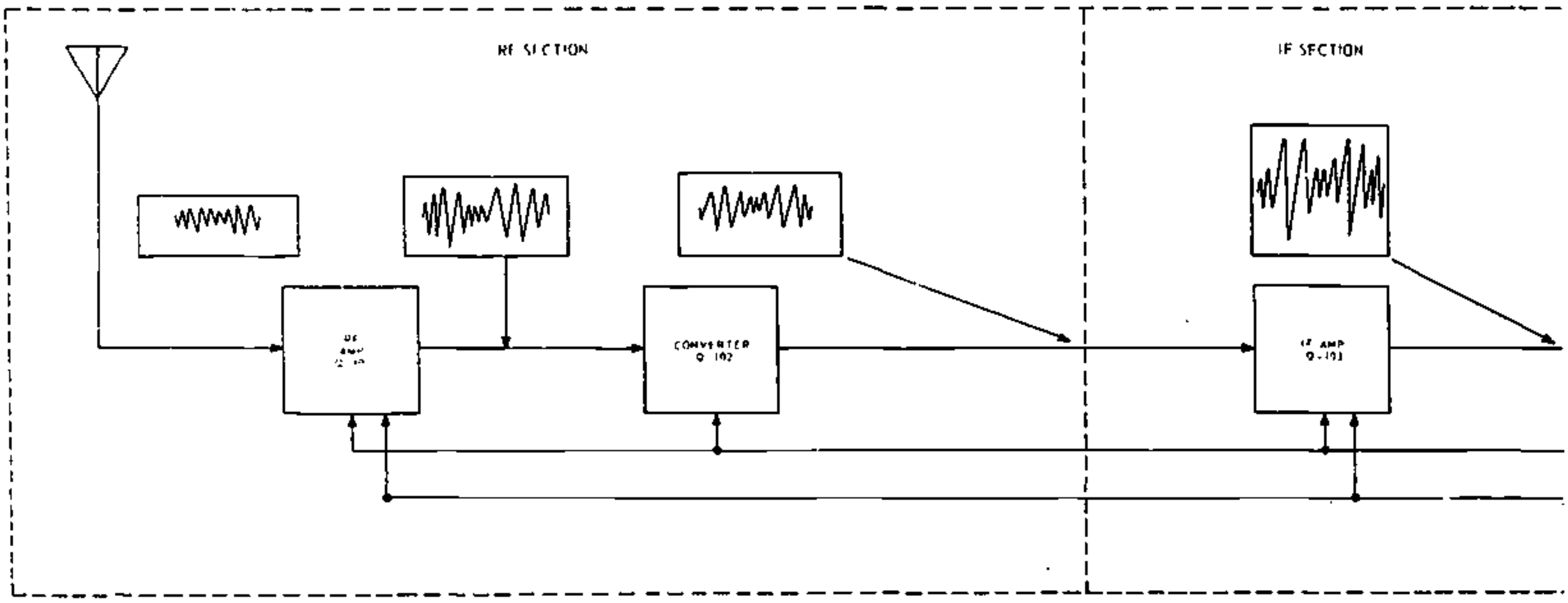
| SYMPTOMS | POSSIBLE TROUBLE |
|---|---|
| No output (sound) from the speaker.<br>(RF section) all DC voltages are normal. | C103 open.<br>L101 primary shorted.<br>C101 shorted. |
| No output from the speaker.<br>(AF section) all DC voltages normal. | CR101 open.<br>C118 open.<br>Speaker coil open. |
| Output from the speaker is weak, volume control-maximum (IF section) | C115 open.<br>C111 open. |
| No output from speaker.<br>(RF section) Emitter voltage and collector voltage of Q101 high. | R102 open. |
| No output from speaker.<br>(AF section) Emitter and collector voltage of Q104 low. | Q104 shorted. |

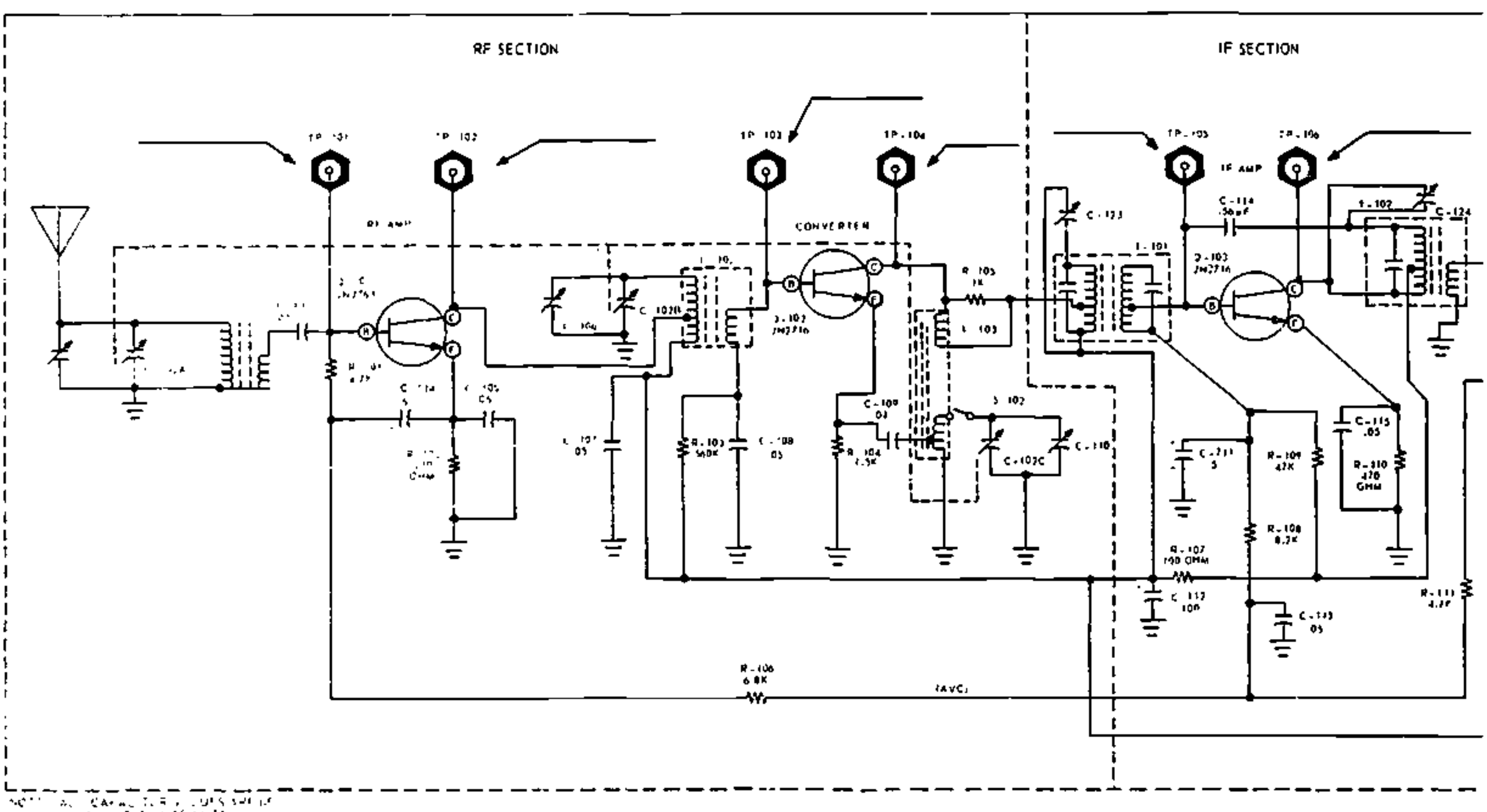
# NOTES

NOTES

Transistor Receiver

RECEIVER
BLOCK DIAGRAM




RECEIVER
SCHEMATIC DIAGRAM

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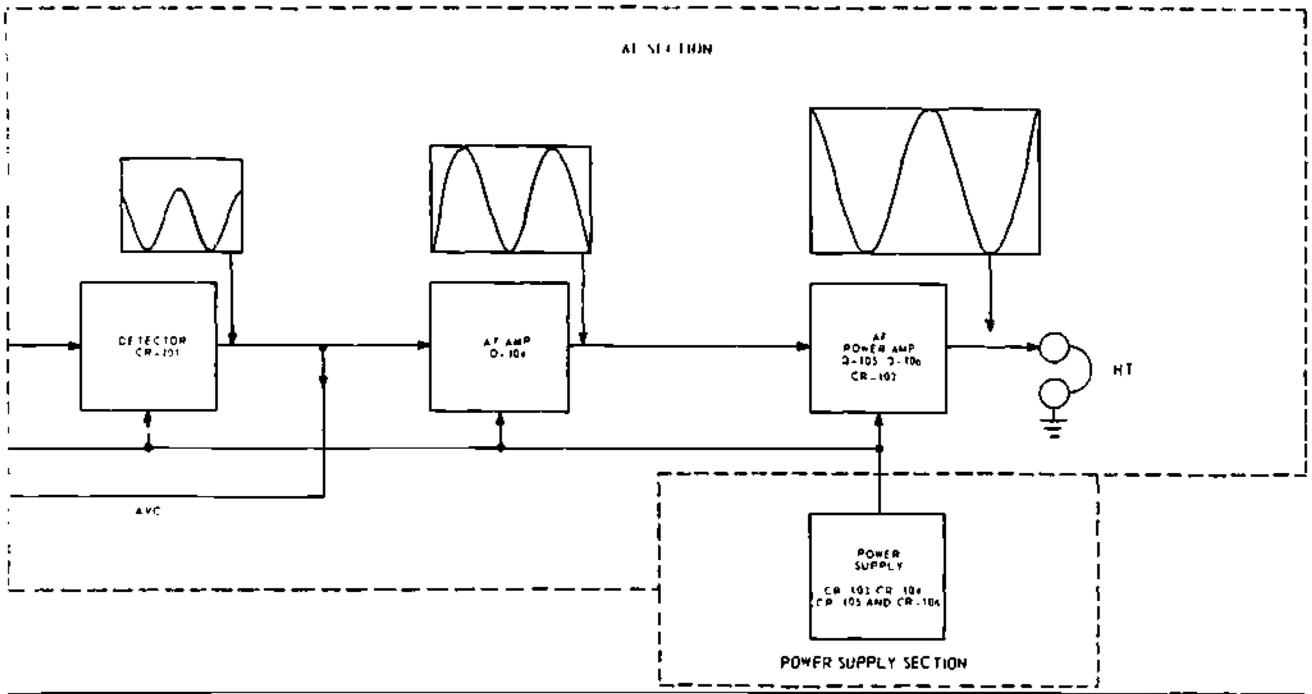


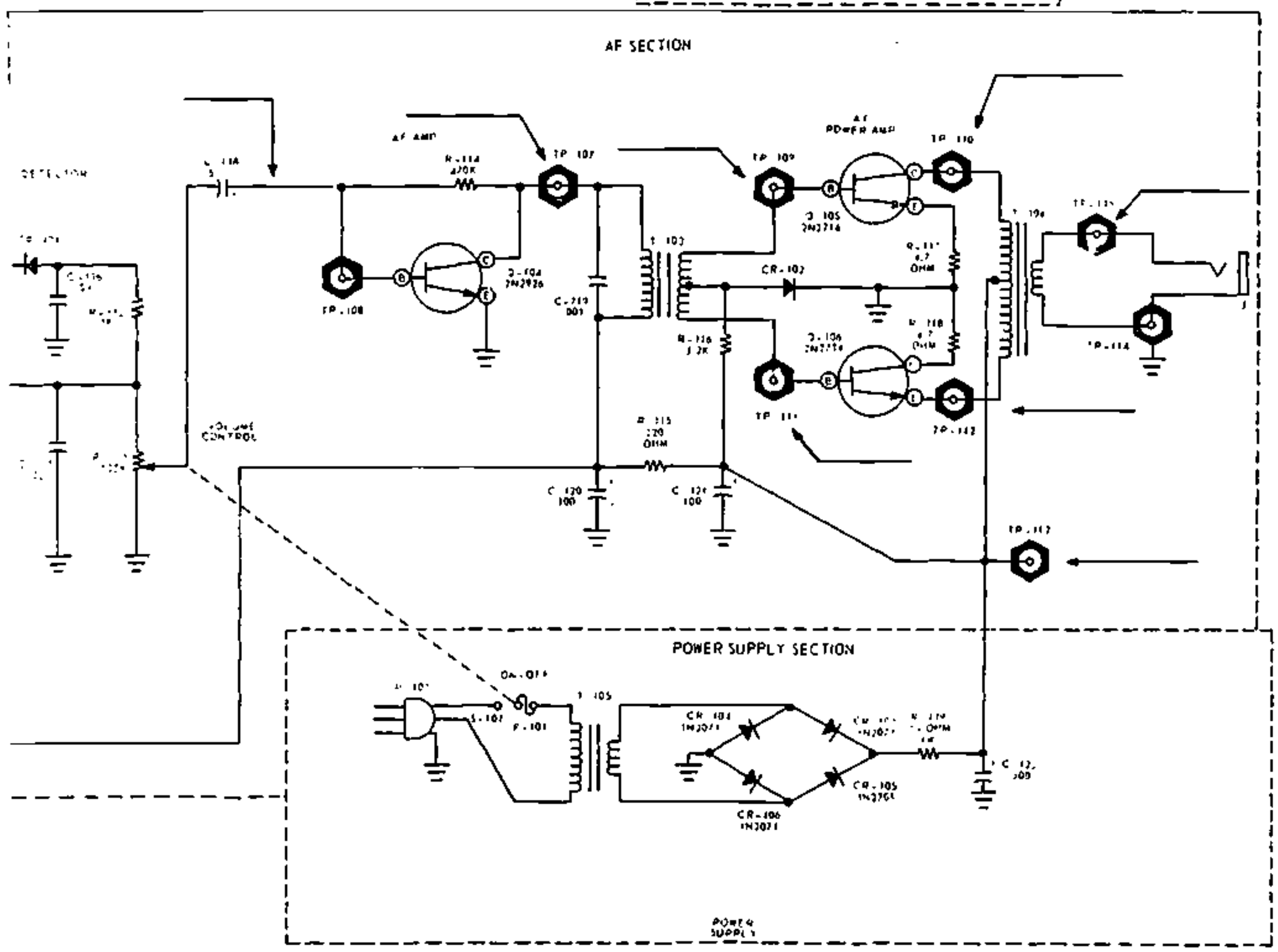


ATC Kessler 6-0897

Errata 1 for KEP-HO-IX-1, Transistor Receiver, 1 September 1975

In the AF Section, Q-106, exchange the Emitter and the Collector.

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PREPARE THE MAN

ATC ST 3AQR3X020-X
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Technical Training

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULES 63-73

## TRANSMIT AND RECEIVE SYSTEMS

1 May 1975

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Module 63

# HETERODYNING

Heterodyning is the process of combining or beating two signal frequencies in a non-linear device resulting in the production of additional frequencies equal to the sum and difference of the two originals. This process is necessary for circuit operations involving mixing, frequency conversion, amplitude modulation, and amplitude detection.

A non-linear device is any electronic component which passes a current flow NOT proportional to its applied voltage. Tubes and transistors are examples of nonlinear devices. A graph of voltage/current for these devices shows that an increase of current is not proportional to the increase of applied voltage.

Certain conditions must be met in a circuit in order for heterodyning to occur. They are: there must be at least two unlike frequencies and the frequencies must be applied to a non-linear device. If two pure sine waves of different frequency are combined, they will be in and out of phase at various times. As a result, algebraic addition will occur at the rate of the difference between the two frequencies. As this situation stands, without a non-linear device, the average signal from such a combination of signals would be zero. However, the non-linear device creates an imbalance which results in an average other than zero and thus an output exists. This output will include the two original frequencies, the sum and the difference frequencies. In practical applications, such as a radio receiver mixer or converter circuit, all of the heterodyning frequencies are not needed, only the difference frequency is required. The original and sum frequencies are filtered out. This filtering action is usually accomplished with a tuned tank circuit. The circuit is tuned to pass only the difference frequency, all other frequencies are bypassed to ground.

Receiver heterodyning, or conversion, is the process of beating the incoming RF signal with an internally generated RF oscillator frequency. This internal frequency is called the local oscillator frequency. If a local oscillator is used, then an additional stage called a mixer is required to combine the RF and local oscillator signals. Sometimes a stage called a converter is utilized. The converter combines the functions of generating the local oscillator frequency and combining it with the RF. In either case, the purpose is to convert the incoming RF signal to a lower frequency called the intermediate frequency (IF). The requirements for conversion are the same as given for heterodyning with the addition of an output frequency selecting circuit (filter). The frequency selected is the IF. Any incoming RF signal may be converted to the IF by tuning the local oscillator. The local oscillator frequency must be different than the desired incoming RF signal by an amount equal to the desired IF.

Module 64

# MODULATION

This module is concerned with how the electrical intelligence signal is converted into RF waveforms by four basic forms of modulation: amplitude, frequency, pulse and phase. Each type has certain advantages and disadvantages depending upon the intended use of the system.

Three terms are used frequently in this discussion of modulation: intelligence signal, carrier wave, and sidebands. The intelligence signal is the information we wish to transmit. The carrier wave is the reference signal for the modulating process. Sidebands are the frequencies generated by modulation in the frequency spectrum above and below the carrier frequency.

In amplitude modulation, the amplitude of the carrier is varied while the frequency remains constant. An analysis of the modulated carrier when modulated with a single tone shows that it contains the carrier frequency plus two new frequencies, the sum of the carrier frequency and the modulation frequency - the upper sideband, and the difference between the carrier and modulation frequency - the lower sideband. The amplitude of the modulated carrier is the algebraic sum of the unmodulated carrier and the sideband frequencies. In actual operation most signals used to modulate an RF carrier are complex waveforms made up of many frequencies. Each of these frequencies will produce an upper and lower frequency so that many sideband frequencies will be produced.

The bandwidth (BW) of an AM signal refers to the space the transmitted signal will occupy in the frequency spectrum. The BW is the distance between the upper and lower sidebands. If a 4 kHz signal were used to modulate a carrier, then the sidebands would be 4 kHz above and 4 kHz below the carrier frequency. The BW for this transmission would be 8 kHz. This rule holds true only if the modulation does not exceed 100 percent.

Modulation factor is used to determine the percent of modulation. Modulation factor in AM is the ratio of the difference between maximum and minimum peak-to-peak variations of the modulated carrier and the sum of the maximum and minimum peak-to-peak variations of the modulated carrier. Multiplying the modulation factor by 100 gives the percent of modulation. Percent of modulation can also be calculated by using the oscilloscope presentation of the modulated waveform and the formula as shown in figure 64-1.

Regardless of the unmodulated carrier amplitude, the 100 percent modulated carrier amplitude will be doubled at $E_{max}$ and zero at $E_{min}$. A percent of modulation less than 100 percent is under-modulation and greater than 100 percent is over-modulation. Over modulation produces severe distortion as well as new sidebands and increased bandwidth.

The total power radiated in the modulated carrier is equal to the sum of the powers contained in the separate components of the

$$\frac{E_{max} - E_{min}}{E_{max} + E_{min}} \times 100 = \text{percent of modulation}$$

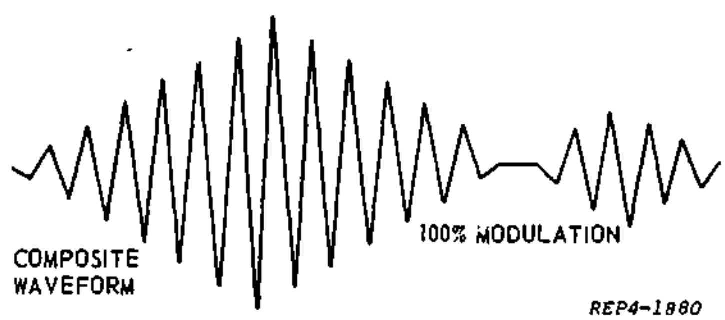


Figure 64-1

modulated wave. If the resistance of the transmitter load is known, the power distribution in the sidebands can be calculated. At 100 percent modulation the sideband peak voltage will be one-half that of the carrier. This value and the same load impedance will give the power in the sidebands. The total power in the transmitted signal will be the sum of the carrier, and upper and lower sideband power. Under modulation reduces total power by reducing the power in the sidebands while the carrier power remains the same. The following observations can be made of AM at 100 percent modulation; total sideband power is one-half the carrier power: total sideband power is one-third of the total transmitted power; the sideband power is distributed equally in the sidebands; each sideband contains one-sixth of the total power; the carrier contains two-thirds of the total power. Reducing modulation to less than 100 percent (under modulation) gives: no reduction in carrier power; less power in the sidebands; less total power.

A typical AM RF amplifier stage will have the modulating signal applied to the collector circuit. The circuit is biased class B so that the necessary non-linear operation is present for heterodyning. The amplitude of the modulating signal determines the percent of modulation. In this circuit, when the modulating signal amplitude equals the RF signal level, 100 percent modulation will be achieved.

Single-sideband (SSB) is a type of AM transmission where the carrier is suppressed and one sideband is eliminated. An advantage of SSB is that approximately one-half of the usual AM BW is required. During SSB modulation: the carrier is modulated with an intelligence signal; the carrier is suppressed; and one of the resulting two sidebands is eliminated. The special circuits necessary to generate SSB signals are the balanced modulator and the sideband filter. The balanced modulator is a diode bridge circuit connected such that the electrical potential from the RF carrier is always equal and thus no carrier potential is developed in the output. Sideband filters can be LC, crystal, or mechanical. The mechanical filter is a resonant device which converts electrical energy into mechanical energy, selects and passes only a certain mechanical frequency and converts the passed mechanical frequency back into electrical energy. The basic elements of the filter are the input and output transducers which convert the energy, metal disks which resonate at only one mechanical frequency, and coupling rods to transfer the mechanical energy between mechanical resonant disks.

Pulse modulation (P-M) is the modulation of a carrier by a pulse train. Pulse modulation has many applications in telegraphy, radar and telemetry. A pulse can be compared to a square wave which has an infinite number of odd harmonics. Each harmonic of the wave will heterodyne with the RF carrier to produce a set of sideband frequencies. The bandwidth requirements for pulse modulation are somewhat greater than AM or SSB.

Frequency modulation (FM) varies the frequency of the carrier above and below a center reference by an amount proportional to the amplitude of the modulating signal. When a single sine wave is used to modulate an FM system we will observe the following facts during a complete cycle of the signal. The center frequency of the carrier will be present only during the time that the modulating signal is at zero potential, when the modulating signal is either positive or negative the modulated carrier frequency will be either above or below the center frequency, the amplitude of the modulated RF carrier will not change throughout the modulating process.

Frequency deviation is the difference between the instantaneous frequency of the modulated wave and the carrier center frequency. The amplitude of the modulating signal will determine the amount of deviation. The frequency of the modulating signal determines the rate at which the oscillator deviates above and below the center frequency.

The FM waveform contains an infinite number of sidebands. However, the sidebands must contain at least one percent of the total transmitted power to be considered significant. The number of significant sidebands determines the BW of the transmitted signal. The number of significant sidebands is determined by the Modulation Index (MI). MI is a ratio of the frequency deviation to the modulating signal frequency. The frequency of deviation and frequency of the modulating signal are directly proportional. The MI is used to locate the number of significant sidebands on a chart. The space between the sidebands is equal to the modulating signal frequency. The BW will increase by increasing the amplitude of the modulating signal.

A reactance tube modulator is one means of generating an FM signal. The phase shifting network is the heart of the modulator. The network develops a phase shift of 90 degrees which appears capacitive or inductive (depending upon the construction of the circuit). The modulating signal varies the amount of this reactive effect. The network is electrically parallel to an oscillator tank circuit whose frequency will change because of the effects of the network.

Another FM modulator which is widely used in transistorized circuitry employs a voltage variable capacitor, called a varactor. The varactor is a simple solid state diode designed to have a certain amount of capacitance across the junction. The depletion region in the varactor determines the dielectric between the P and N elements. Reverse bias is applied and varied in accordance with the modulating signal. The depletion region varies the effective capacitance which in turn varies the oscillator frequency.

Phase modulation (PM) has similarities with FM. The amplitude is held constant and the wave, observed on a scope, appears to vary in frequency. However, the oscillator frequency is not changed during modulation. In PM the phase angle of the carrier is varied in accordance with the modulating signal, whereas the current amplitude of the resulting phase modulated wave is maintained constant. The rate at which a phase-modulated wave shifts from one phase value to another is proportional to the frequency of the modulating signal. The number of degrees through which the phase of the carrier is shifted is proportional to the amplitude of the modulating signal. The amplitude of the modulating signal determines the number of significant sidebands.

# DEMODULATION

One of the functions of a radio receiver is to demodulate the radio wave picked up by the receiving antenna. Demodulation is the process of extracting the signal intelligence from a modulated carrier wave. The requirements for demodulation are: non-linearity must be present to cause heterodyning; the original RF carrier signal must be present at the input of the demodulator to heterodyne with the sideband signals to reproduce the original intelligence signal; filtering is required to eliminate the unwanted RF after the intelligence is produced. The filter circuit is made up of components which shunt the RF to ground while retaining the desired frequencies.

AM demodulation is the process of extracting the signal intelligence from an AM carrier. An AM RF signal can be demodulated by several types of demodulators. The circuit for demodulating an AM signal is called a detector. Covered in this module are the diode, grid-leak, plate, infinite impedance, single sideband, and pulse detectors.

The diode detector is the simplest circuit. Current flows through the diode when the plate is positive with respect to the cathode. The non-linearity of the diode causes a heterodyne action between the RF carrier and the sidebands. The resulting frequencies will include the sum of the carrier and lower sideband, the sum of the carrier and upper sideband, and the difference between the carrier and sideband signals.

The grid-leak detector functions like the diode detector combined with a triode tube. The grid of the tube will function as the detector plate. The triode section then provides amplification of the detected signal. The grid-leak bias provides the non-linearity for heterodyne action. Input impedance is low because grid current must flow to perform the heterodyning.

The plate detector has a high input impedance because grid current does not flow during the entire cycle of RF variations of the input. Detection occurs within the triode tube because the cathode self-bias resistor is large enough to insure the stage will be biased at approximately cutoff.

The infinite impedance detector resembles the plate detector with the exception that the load resistor is located in the cathode. This arrangement makes the infinite-impedance detector essentially a cathode follower. Input impedance is extremely high.

The single sideband demodulator introduces a frequency to replace the suppressed carrier so that heterodyning may take place. The carrier signal must be at least ten times the amplitude of the sidebands to prevent distortion.

A pulse demodulator is essentially an amplitude detector with a very wide bandwidth.

FM demodulators studied in this module are Foster-Seeley discriminator, ratio detector, and quadrature detector. In order to demodulate the FM signal the demodulator stage must be a circuit which can sense frequency variations and convert them to voltage changes. The requirements for FM demodulation are: the input circuit to the demodulator must change frequency variations into amplitude variations; a non-linear impedance is necessary to heterodyne the carrier and sidebands.

The Foster-Seeley is a phase-shift type discriminator because demodulation depends on the phase-shift obtained across 2 transformer secondaries. A tuned circuit acts resistively as long as it is resonant. If the input signal is shifted above or below the resonant frequency of the tank circuit the circuit will be inductive or capacitive and the secondary will no longer be in phase. The resulting output voltage will either increase or decrease. Thus the frequency variations are changed into amplitude variations. A limitation of the Foster-Seeley is that any amplitude variations at the input result in noise or distortion in the output. For this reason the circuit must have an amplitude limiter stage preceding it.

The ratio detector is similar to the Foster-Seeley, but has the advantage of not requiring a limiter stage.

An FM demodulator employing a completely different principle is the quadrature detector. This demodulator is self-limiting and does not require a separate limiter. A gated beam tube is used in which the limiter grid and the quadrature grid must both be positive for plate current to flow. The incoming RF signal is connected to the limiter grid and the quadrature grid is connected to a high Q tank circuit which is resonant to the incoming center frequency. The tank circuit will determine the phase of the quadrature grid voltage. Since both grids must be positive for plate current to flow, the amount of plate conduction will depend upon the phase relationship between the signal on the limiter grid and the frequency applied to the quadrature grid. When the incoming signal frequency increases and decreases around the center frequency the average current will vary proportionally. Thus frequency variations are converted to amplitude variations.

Phase demodulation is the process of extracting the signal intelligence from a phase modulated RF waveform. An FM discriminator can sometimes be used for phase demodulation. However, a true reproduction can be obtained only with added processing of the signal. A phase demodulator is similar to the quadrature demodulator except that the reference is not provided by the tuned circuit, but from a separate reference signal.

## Module 66

## TRANSMISSION LINES

Transmission lines carry electromagnetic energy from a source to a load. All transmission lines have electrical characteristics of inductance and capacitance. These values of inductance and capacitance determine the characteristic impedance and cutoff frequency of the line. CHARACTERISTIC IMPEDANCE is the opposition to an AC signal while CUTOFF FREQUENCY is the highest frequency that will travel down the line without being attenuated. Five basic types of transmission lines are twisted pair, twin lead, open two-wire, flexible coaxial cable, and rigid coaxial cable. Physical length of a transmission line is measured in meters, centimeters, inches, feet, etc., and electrical length is measured in wavelengths. WAVELENGTH is defined as being the distance energy travels down the line in one cycle of the input frequency. Nonresonant lines have a maximum transfer of power, and all the energy is absorbed by the load. When there is a mismatch of impedance, some of the energy is reflected back to the source. The sum of the reflected waves and incident waves are standing waves. The minimum points of the standing waves are called NODES and the maximum points are LOOPS. The greater the voltage difference between the loops and nodes, the greater the standing wave ratio. A line that has standing waves is called a RESONANT LINE. There is a standing wave of voltage and one of current. The impedance of a transmission line increases as the leads are separated. DELTA MATCHING is a form of impedance matching by spreading the leads. STUB MATCHING is connecting a load to some portion of a quarter-wave matching stub. The quarter-wave matching stub is used to match the line impedance to the load impedance. It acts like a transformer to match two unlike impedances.

## ANTENNAS

An antenna is an electronic device that is used either for radiating electromagnetic energy into space or for collecting electromagnetic energy from space. In a radio transmitter the oscillator generates the high frequency signal, but the antenna is needed to change this signal into electromagnetic fields which are suitable for propagation into space. The radio receiver will amplify signals applied to its input, but an antenna is needed to intercept the electromagnetic fields that are in space and to change these fields into voltages and currents to which the receiver can respond. The half wave dipole is the fundamental element of an antenna. It can be used as a starting point for discussing the radiation of electromagnetic energy into space. Electrically, you can think of the dipole as a quarter wave section of transmission line opened out so the conductors are in line, not parallel. This is a resonant section of line; therefore, standing waves are present. These standing waves give the dipole its tuned or frequency sensitivity characteristics. The current flow in the conductor of the dipole produces electrostatic fields of force and electromagnetic fields of force in space that do not collapse back into the dipole but radiate out into space. This energy is called the radiation field. The electrostatic field is parallel to the length of the dipole while the electromagnetic field is around the conductor or perpendicular to the dipole. Antenna polarization is a method of orienting the antenna with respect to a known plane. An antenna that is horizontally polarized means that the E field is parallel to the surface of the earth, if it is vertically polarized, the E field is perpendicular to the surface of the earth. Another form of polarization is circular polarization; in this type the E field rotates around an axis in a 360 degree motion. The basic antenna is a half wave length long, but for low frequencies this will require a very long antenna. The lower the frequency the longer the antenna. One method of constructing a vertical antenna that has the tuned characteristics of the half wave antenna is the quarter wave, which uses the ground as the other quarter wave.

There are times when a directional antenna is required. Directivity is accomplished by adding either driven or parasitic elements to the antenna. This is known as an antenna array. The driven array consists of two or more elements with all elements connected to the generator. They may be divided into four basic types, the broadside array, the end fire array, the collinear array and the cardioid array. For the broadside array two half wave elements are placed one half wave apart and parallel to each other and excited in phase, most of the radiation takes place in a direction perpendicular to a plane through the elements. For the end fire array the two elements are spaced one half wave apart and excited 180 degrees out of phase, most of the radiation is directional in the plane of the array and perpendicular to the elements. For the cardioid array the two elements are spaced one fourth wave apart and excited 90 degrees out of phase. A unidirectional pattern is obtained that is in the direction of the plane of the array and perpendicular to the elements. A collinear array is formed when two half wave elements are placed end to end and excited in phase. In a collinear array there is no directivity in the plane perpendicular to the antenna, but there is a sharp pattern in the plane of the antenna.

A parasitic array is an antenna array which consists of two or more elements in which only one of the elements is driven. The other elements are excited by induction. There are two basic elements of this type; one a director, the other the reflector. The reflector is placed in back of the driven element and causes the energy to be reflected back towards the driven element. The director is placed in front of the driven element and reinforces the radiation of energy in the forward direction. This produces a unidirectional pattern.

Module 68

# AM SYSTEMS

The transmission of electromagnetic energy through space is a fundamental property of radio, radar and Nav-aids systems. Each of these systems are comprised of two major parts, a transmitter and a receiver. The transmitter produces the electromagnetic wave, modulated to contain information. The receiver intercepts the electromagnetic wave and reproduces the information.

A very common form of communications is the commercial standard broadcast system. This is an amplitude modulated (AM) system, where the information to be conveyed is in the form of amplitude changes in the transmitted RF signal. There are other uses of AM, in fact most ground to ground stations and air to ground stations used by the Air Force are AM systems.

A block diagram of an AM system is illustrated in figure 68-1. The RF oscillator produces an RF carrier which is modulated in the RF power amplifier by the audio signal. The audio signal is produced in the microphone, amplified by the audio amplifier, further amplified by the modulator so the proper power levels can be obtained. The RF amplifier is used as a buffer, frequency multiplier or voltage amplifier. The signals from the RF power amplifier are the carrier and sidebands. The antenna converts these signals into an electromagnetic wave.

The RF oscillator must have good frequency stability, or in other words, stay on the assigned frequency. If it does not have good frequency stability it can drift into the spectrum of another radio station and cause interference.

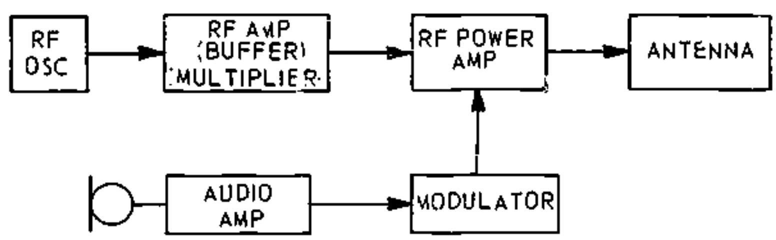


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Figure 68-1. AM Transmitter

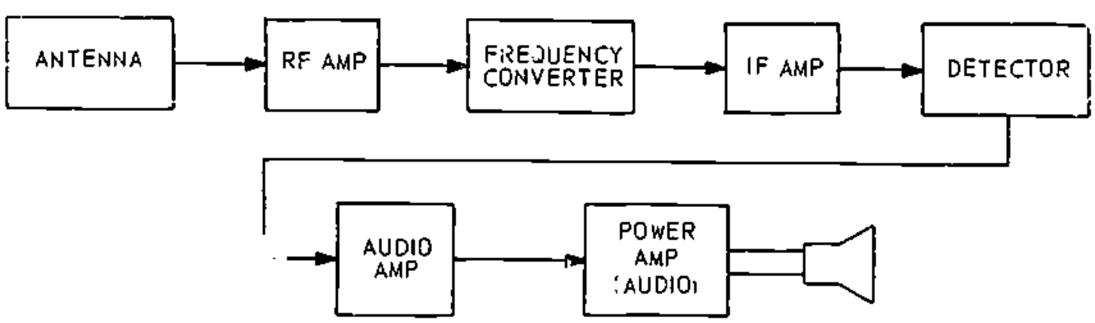


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Figure 68-2. AM Receiver

The block diagram of an AM radio receiver is illustrated in figure 68-2. The antenna intercepts the electromagnetic wave and converts it into RF currents. The RF amplifier selects the desired RF signals from the antenna, amplifies them and couples them to the frequency conversion stage which converts it to the Intermediate Frequency (IF). The modulated IF signal is selected and amplified by the IF amplifier and coupled to the detector. The detector reproduces the audio from the IF. The audio is amplified by the audio amplifier and audio power amplifier and reproduced as sound in the speaker.

The receiver should have good sensitivity. Sensitivity is the ability to reproduce the intelligence from a very weak RF signal. It should also have good selectivity, which is the ability to select one station. Distortion occurs in a receiver if the detector is operated in such a manner as to produce harmonics. Distortion also occurs if any of the important sidebands are not passed through to the detector. There is a form of interference called co-channel interference that may occur. This results from the receiver, receiving signals from two transmitters operating at the same frequency.

The schematic diagram of an AM transmitter is illustrated in figure 68-3. The RF oscillator V1 produces the RF carrier signal which is amplified by V2

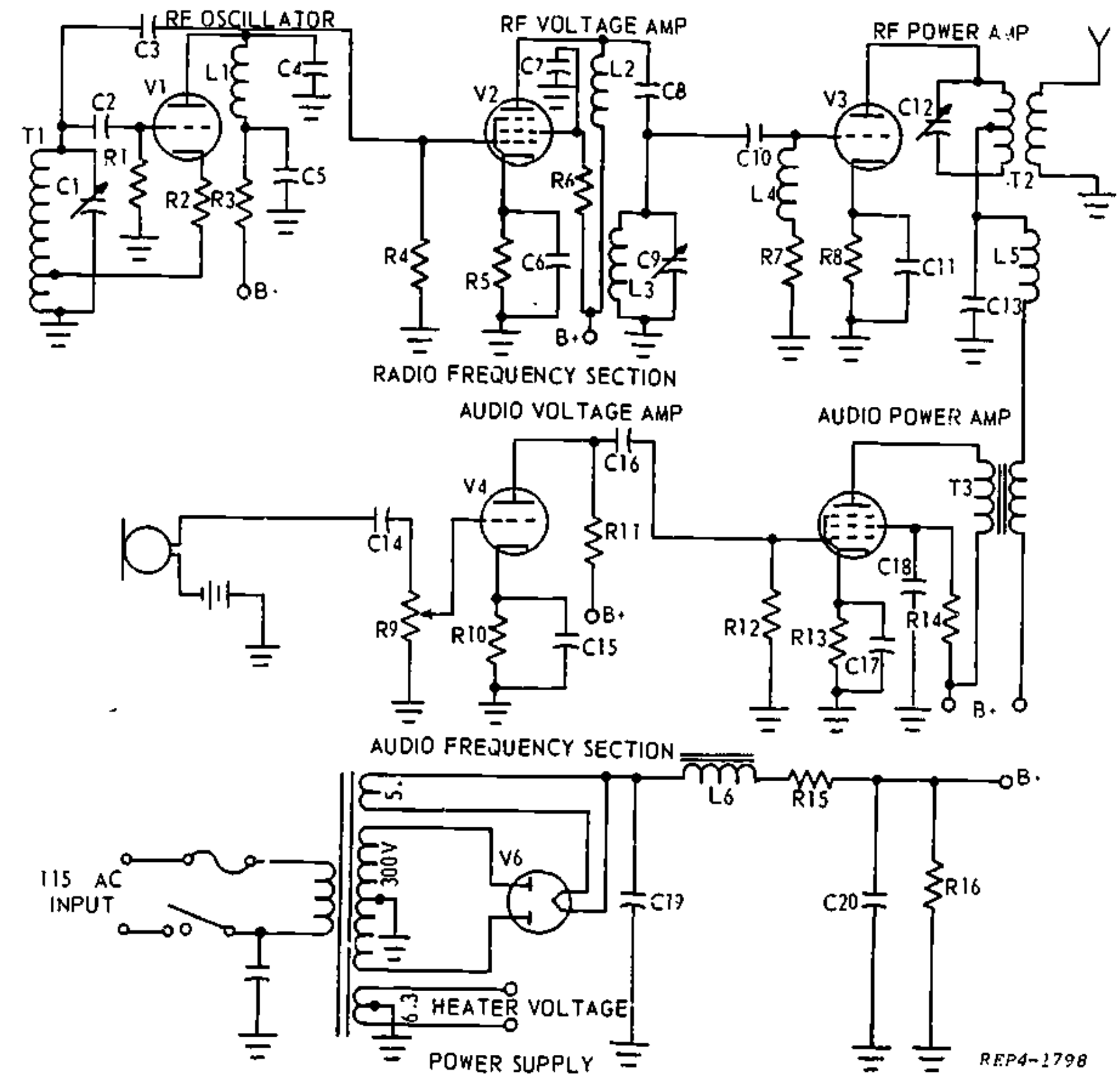


Figure 68-3

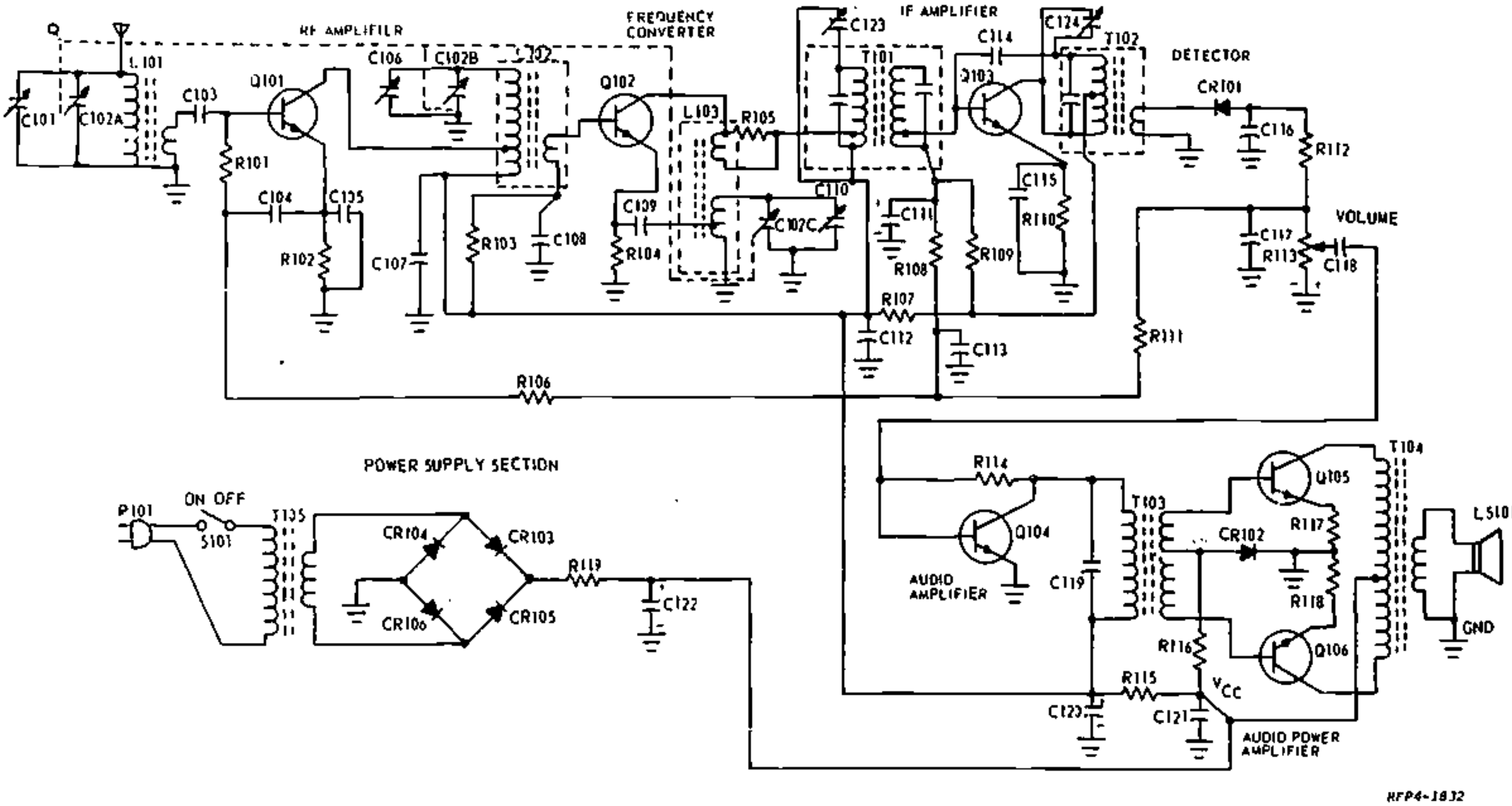
RF AMPLIFIER
FREQUENCY CONVERTER
IF AMPLIFIER
DETECTOR
VOLUME
POWER SUPPLY SECTION
ON OFF
AUDIO AMPLIFIER
AUDIO POWER AMPLIFIER
GND
RFP4-1832

Figure 68-4

)

)

and coupled to V3. The audio signal is produced in the microphone, amplified by V4 and coupled to the modulator, V5. The output of V5 is coupled into the plate circuit of V3, this causes modulation of the carrier, resulting in sideband frequencies being produced. The signals are coupled through T2 to the antenna for radiation into space. The DC paths in each of these stages is from ground through the stage to B+. In the power supply the current is from ground, through the power supply to B+.

The schematic diagram of an AM receiver is illustrated in figure 68-4. The RF oscillations are produced in the antenna by the electromagnetic waves. The RF amplifier Q101 selects the desired RF signals, amplifies them and couples them to Q102, the frequency converter. In Q102 the RF is converted by heterodyning action, to the IF frequency which is coupled to Q103 the IF amplifier. The IF is amplified and coupled to CR101 for demodulation. The audio is then amplified by Q104, Q105 and Q106 to drive the speaker. The speaker then converts the audio signal to sound. The DC paths of current in each stage is from ground through each stage to $V_{CC}$.

## Module 69

## FM SYSTEMS

In an FM communications system, the intelligence is conveyed by varying the frequency of a constant amplitude RF carrier. The modulating signal varies the carrier frequency to develop the transmitted signal. The amount of frequency deviation depends on the amplitude of the modulating signal while the rate of deviation depends upon the frequency of the modulating signal. A very important characteristic of FM when compared to AM is that FM is comparatively noise free. Noise randomly adds to the amplitude of the RF signal, and in an FM receiver these amplitude variations are clipped off and only the changes in frequency are demodulated.

In FM transmitters, there are various ways of modulating the carrier. One of the most common is a reactance modulated oscillator. Audio signals are converted into changes of reactance, which are part of the carrier oscillator circuit. These changes of reactance cause the oscillator frequency to deviate at the modulation rate. The deviations are usually not enough to produce a good FM signal so frequency multipliers are used. The frequency multipliers will multiply the deviation and increase the frequency of the carrier. The last stages in the transmitter produce the power desired to be transmitted. The antenna radiates the energy into space.

The FM receiver is usually a superheterodyne receiver with an RF amplifier, a frequency conversion stage, and an IF amplifier, an amplitude limiter, a frequency demodulator, audio amplifiers, and sound reproducers.

Module 70

# SINGLE SIDEBAND SYSTEMS

In single sideband (SSB) and conventional AM communication systems the intelligence to be conveyed is contained in the frequency difference between the carrier and the sidebands. In AM the carrier the upper and lower sidebands are transmitted, then in the receiver the sidebands are heterodyned against the carrier and the intelligence reproduced. In single sideband we want to convey the same signal, but only transmitting one of the sidebands, either the upper or lower. The purpose for doing this is simple, all of the power a transmitter can produce can be concentrated in the one sideband rather than being distributed in a carrier and two sidebands as in AM. There are other reasons for SSB, one is the reduction in bandwidth, SSB has one half the bandwidth of AM; less bandwidth, less noise. Another important characteristic is reduction of selective fading. Selective fading occurs in AM when the relationships of the carrier and sidebands are altered during transmission which results in loss of signal. In SSB we only transmit one sideband, the relationship can not be altered.

A block diagram of an SSB transmitter is illustrated in figure 70-1. The carrier oscillator produces the RF carrier which is modulated in the balanced modulator by the audio signal. The audio signal is produced in the microphone and amplified by the audio amplifier. Sidebands are produced in the balanced modulator and coupled to the filter, the carrier is not coupled to the filter. Only one set of sidebands, (upper or lower) pass thru the filter, heterodynes in the mixer

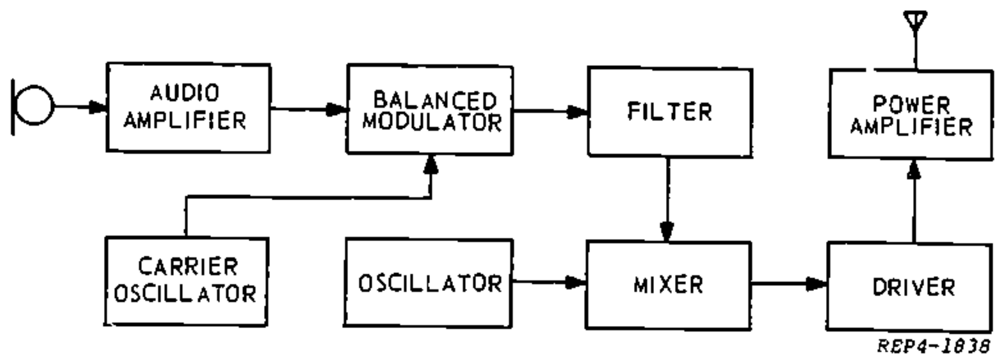


Figure 70-1. SSB Transmitter

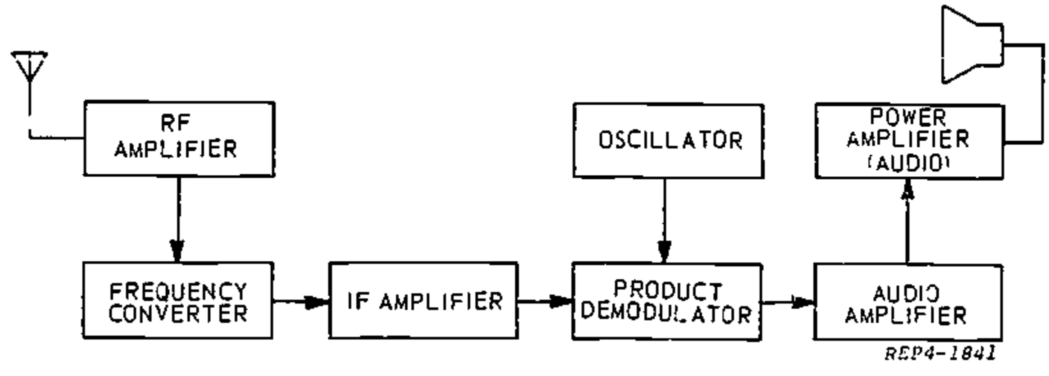


Figure 70-2. SSB Receiver

with the ouput of an oscillator, the sum frequency is amplified by the driver and power amplifier and delivered to the antenna for radiation.

The block diagram of a SSB receiver is illustrated in figure 70-2. The antenna intercepts the electromagnetic wave and converts it into RF current. The RF amplifier selects and amplifies the desired RF signal from the antenna. This signal is then coupled to the frequency conversion stage which converts it to the IF. The IF is selected and amplified by the IF amplifier and coupled to the product demodulator. The oscillator sends an RF signal (the carrier) to the product demodulator. The IF signal (sideband) and RF signal (carrier) from the oscillator are heterodyned in the demodulator and the audio signal is produced. The audio is amplified by the audio amplifier and power audio amplifier and reproduced as sound by the speaker.

The schematic diagram of a SSB transmitter is illustrated in figure 70-3. The carrier oscillator Q102 produces the carrier which is coupled to the balanced modulator CR101. The audio is amplified by Q101 and coupled to CR101. In CR101 the sidebands are produced and coupled to the filter. Only one set of sidebands is passed. The sidebands are coupled to the mixer Q104. The oscillator signal from Q103 is coupled to Q104 and the sum frequency is selected and coupled through T106 to the driver V101 then to the power amplifier V102. The signal is coupled thru T107 to the antenna for radiation into space. The DC paths in Q101, Q102, Q103 and Q104 are from ground thru each stage to $V_{CC}$. The DC paths in V101 and V102 are from ground thru the stages to B+.

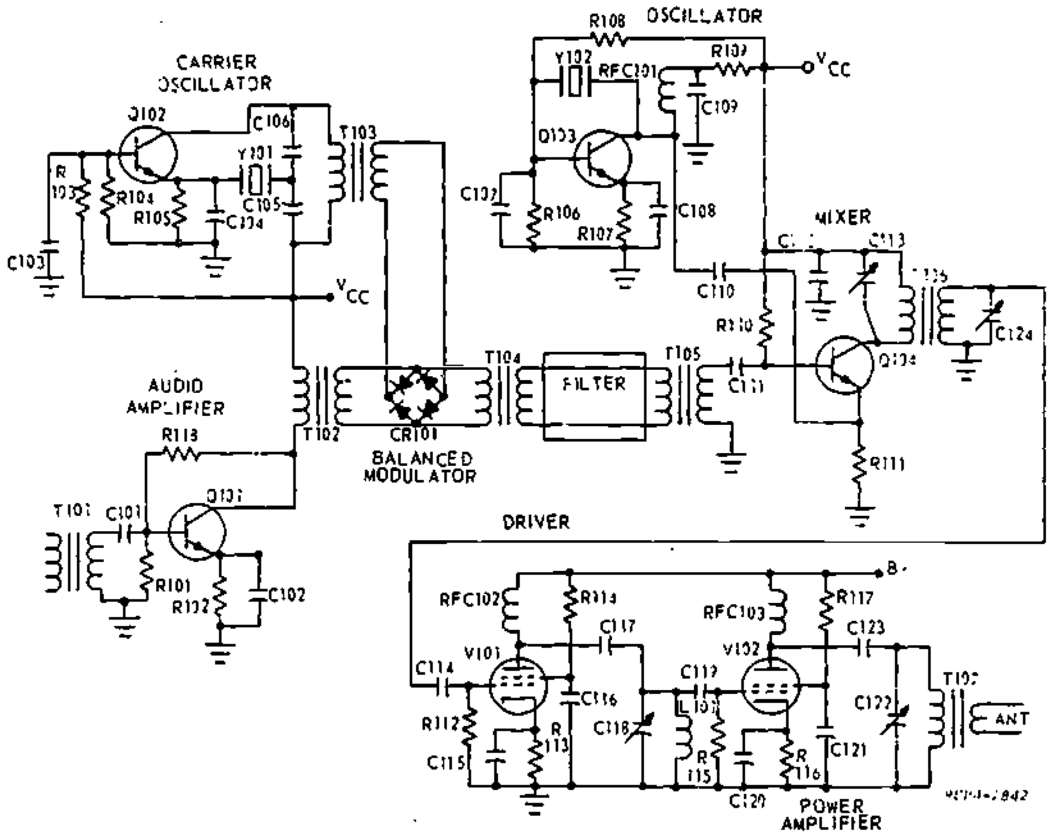


Figure 70-3. SSB Transmitter

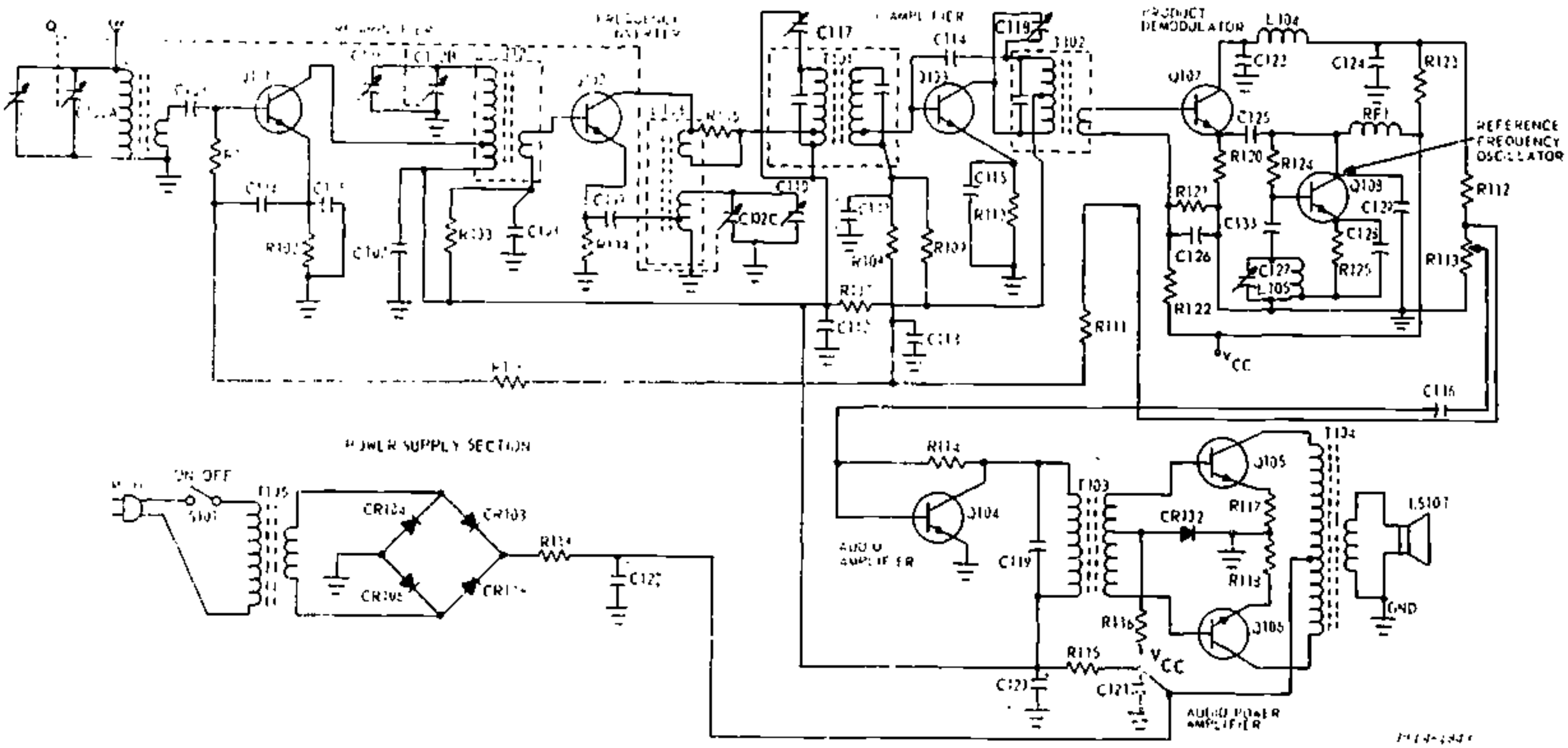


Figure 70-4. SSB Receiver

The schematic diagram of a SSB receiver is illustrated in figure 70-4. The RF oscillations are produced in the antenna by the electromagnetic waves. The RF amplifier Q101 selects the desired RF signals, amplifies them and couples them to Q102 the frequency converter. In Q102 the RF frequency is converted by heterodyning action to the frequency which is coupled to Q103, the IF amplifier. The IF is amplified and coupled to Q107. Oscillations produced by Q108 (carrier) are also coupled to Q107. The two signals are heterodyned in Q107 and the audio signal is produced. The audio is then amplified by Q104, Q105 and Q106. The speaker then converts the audio signal to sound. The DC paths of current in each stage is from ground thru the stage to $V_{CC}$.

## Module 71

## PULSE MODULATION SYSTEMS

Pulse modulation is the process of modulating an RF carrier by a pulse train. Pulse modulation has many uses, such as telemetry and time division multiplexing, but its main use is in pulse radar. Radar transmitters usually operate on the principle of producing a pulse of RF energy at certain intervals and for certain time durations. The pulse of energy produced by the transmitter travels through space away from the transmitter at about the speed of light, strikes an object, and is reflected back towards the transmitter. A receiver located near the transmitter receives the returned energy and produces a video signal. A cathode ray tube is usually used to measure the time required for the energy to travel from the transmitter to the target and back to the receiver. However, we are mainly concerned with how the transmitter produces the pulse of RF energy and how the receiver converts the returned signal to video. A block diagram of a pulse-modulated transmitter system is illustrated in figure 71-1. The power supply furnishes the power to charge the pulse forming network (PFN). The charging choke and diode

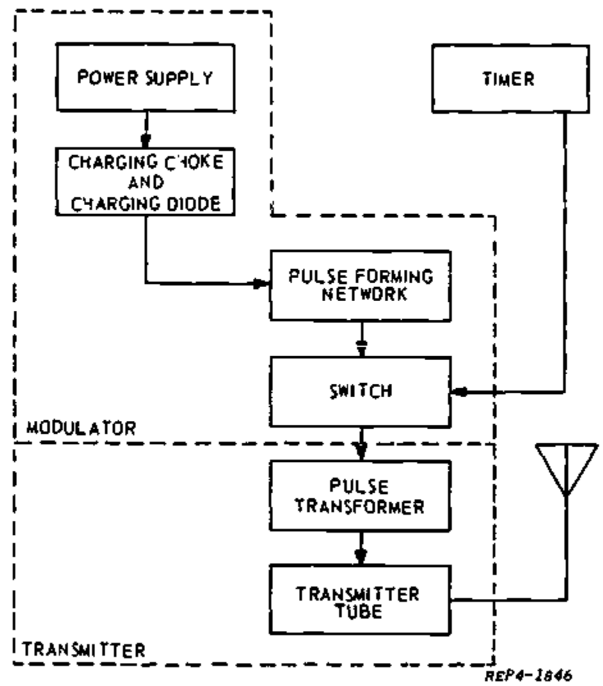


Figure 71-1. Pulse Modulated Transmitter

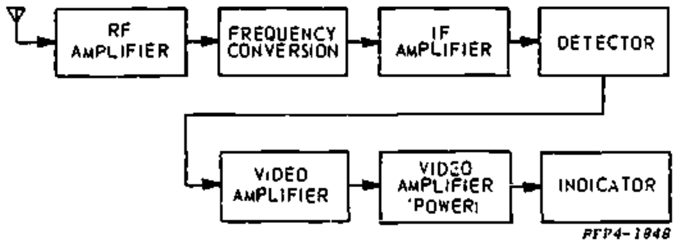


Figure 71-2

will charge the PFN to nearly twice the power supply voltage. The PFN stores the energy and will determine the duration of the pulse of energy supplied to the oscillator. The timer produces trigger pulses that cause the switch to operate and allows the PFN to discharge. The switch is a gas thyratron. When the PFN discharges through the pulse transformer it couples the energy to the transmitter tube. The transmitter tube produces output RF oscillations during the time of the pulse.

The block diagram of a pulse modulated receiver is illustrated in figure 71-2. The antenna intercepts the electromagnetic waves and converts them into RF currents. The RF amplifier selects the desired RF signals from the antenna, amplifies them, and couples them to the frequency converter, which converts them to the IF frequency. The IF is selected and amplified by the IF amplifier and coupled to the detector. The detector reproduces the video from the IF. The video is amplified by the video amplifier,

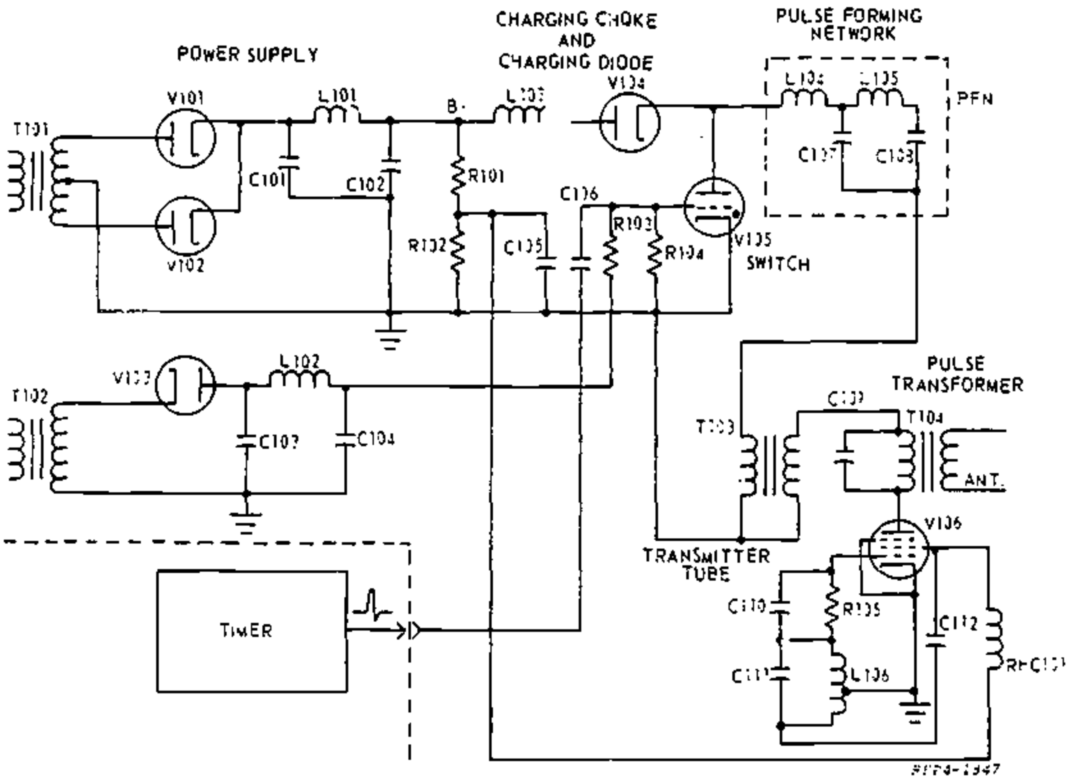


Figure 71-3. Pulse Modulated Transmitter

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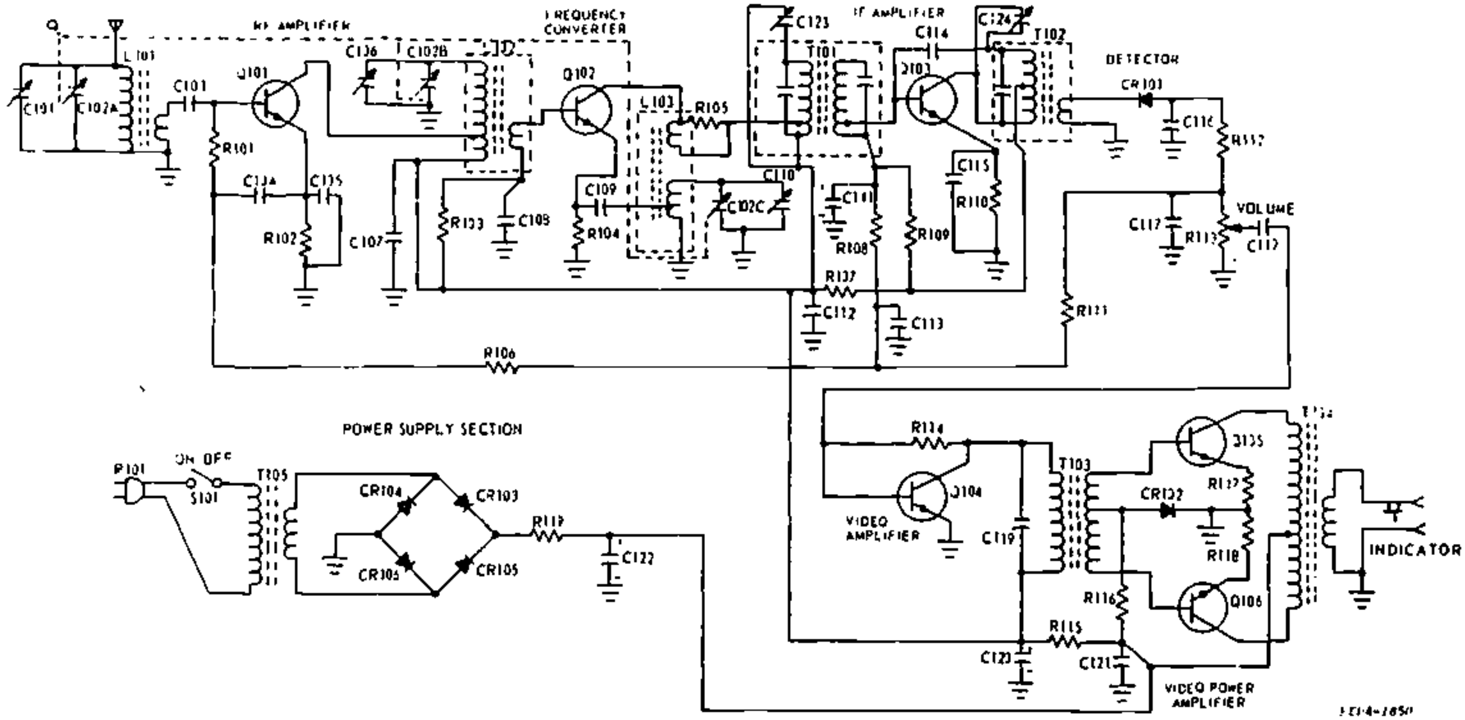
RF AMPLIFIER
FREQUENCY CONVERTER
IF AMPLIFIER
DETECTOR
VOLUME
POWER SUPPLY SECTION
ON OFF
VIDEO AMPLIFIER
VIDEO POWER AMPLIFIER
INDICATOR
L101
C101
C102A
Q101
R101
R102
C136
C102B
C107
R103
C108
Q102
L103
R105
C109
R104
C102C
C110
C123
T101
C114
Q103
C124
T102
C115
R110
C111
R108
R109
R107
C112
C113
CR101
C116
C117
R106
P101
S101
T105
CR104
CR103
CR105
R119
C122
R114
Q104
T103
C119
CR102
Q105
Q106
R116
R115
C120
C121
R118

Figure 71-4

power video amplifier, and reproduced by the indicator.

The schematic diagram of a pulse modulated transmitter is illustrated in figure 71-3. The PFN charges to nearly twice the power supply voltage (V101 and V102) and holds that charge. A positive trigger is applied to the grid of V105 which ionizes and allows the PFN to discharge through T103 and couples a pulse of energy to the plate of the RF oscillator, V106. The oscillations are produced during the pulse and coupled to the antenna by T104. The DC paths in each stage are from ground through the stage to B+. The bias for V105 is from the negative power supply V103 through R103 and R104 to ground.

The schematic diagram of a pulsed modulated receiver is illustrated in figure 71-4. The RF oscillations are produced in the antenna by the electromagnetic waves. The RF amplifier, Q101, selects the desired RF signals, amplifies them, and couples them to the frequency converter, Q102. In Q102 the RF is converted by heterodyning action down to the IF frequency which is coupled to the IF amplifier, Q103. The IF is amplified and coupled to CR101 for demodulation. The video is then amplified by Q104, Q105, and Q106. The indicator then displays the video. The DC paths of current in each stage is from ground through each stage to $V_{CC}$.

## Module 72

## TROUBLESHOOTING TECHNIQUES

A schematic diagram is a plan or diagram of an electronic circuit using standard symbols. Student Handout KEP-SH-IX -1, contains a block diagram and a schematic diagram of a typical superheterodyne radio receiver. Both diagrams are divided by dotted lines to show the RF, IF, and Audio sections.

Troubleshooting requires a logical step-by-step procedure to isolate a problem. Basically, these steps are:

1. An Operational Check
2. Visual Check
3. The Half-Split Method
4. The Stage-by-Stage Method
5. Component Isolation

The operational check is used to determine the section or stage of the system that is not operating properly. Some of these checks may consist of meter readings, oscilloscope readings; or power, frequency, signal to noise ratio, and percent of modulation checks.

The half-split method is used by dividing a complex system in half and determining which half contains the malfunction. This process is repeated until the fault is isolated to a stage.

The stage-by-stage method is a process where each stage is checked in turn, starting at the output and working toward the input. An RF signal generator may be used to inject a signal into the various stages while an oscilloscope may be used to monitor the output. When injecting the signal into the RF section of the receiver in SH-IX-1, a modulated 535 kHz to 1605 kHz is used. In the IF section, modulated 455 kHz is used. When injecting a signal into the audio section it is most common to use a 400 Hz or 1000 Hz signal.

The component isolation step occurs when the trouble has been isolated to a stage. Voltage and resistance checks are then used to determine the faulty component.

The visual check is made during any of the steps. Some of the things that can be determined by this check are frayed insulation, burnt components, evidence of arcing, broken leads or smoke from overheated components.

Once the bad component is replaced, another operational check is needed. This insures that all the troubles are cleared and the equipment is operating at peak performance.

Theoretical troubleshooting is also important. During the half-split or stage-by-stage methods, it is necessary to consult the block diagram. Here a knowledge of the purpose and operation of each stage is required. When the trouble is isolated to a stage, the schematic diagram must be used. When voltage and resistance checks are made within the stage, a knowledge of the purpose of each circuit component and its relationship to other components is necessary.

For example, if a good signal were found on the base of amplifier Q105 and there was no output from the collector, the trouble would be isolated to that stage. The first step in locating the defective component would be a voltage check. For example, the collector was found to be at $V_{CC}$ and zero volts on the emitter there are two possible troubles. The transistor could be bad or resistor R117 could be open, further resistance checks would locate the bad component.

PREPARE THE MAN

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-63

Technical Training

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 63

## HETERODYNING

1 July 1975

AIR TRAINING COMMAND

7-13

Designed For ATC Course Use

ATC Keesler 5-4415

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Electronic Principles Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-63
1 July 1975

# ELECTRONIC PRINCIPLES

## MODULE 63

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS



## OVERVIEW

1. SCOPE. This module presents material on the process of heterodyning. It discusses the need for heterodyning, how new frequencies equal to the sum and difference of two signals are produced. the requirements and some actual circuits used as heterodyning stages.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given a list of statements, select the one that describes heterodyning.

b. Given a list of statements concerning heterodyning match each with the terms:

(1) Nonlinearity
(2) Mixing
(3) Filtering

## LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following

READING MATERIALS:

Digest
Adjunct Guide with Student Text IX

AUDIO-VISUAL AIDS

TVK-30-652 Heterodyning

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK. CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

Supersedes Guidance Package, KEP-GP-63, 1 June 1974. 192

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the back of this guide.

If you experience any difficulty, contact your instructor.

Begin the program.

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Heterodyning is necessary for the transmission and detection of modulated radio waves. This guide will assist you in studying and understanding the basic facts about heterodyning.

A. Turn to Student Text Volume IX and read paragraphs 1-1 through 1-7.

1. Heterodyning is the process of:

_____ a. producing sum and difference frequencies by using one original frequency.

_____ b. beating two original frequencies in a linear device to produce sum and difference frequencies.

_____ c. combining two frequencies in a nonlinear device to produce frequencies equal to the sum and difference frequencies.

_____ d. beating a signal in a liner device and extracting sum and difference originals.

2. What is a nonlinear device?

_____ a. A device which allows current flow equally in both directions and thus can be used as a heterodyne element.

_____ b. Any component which passes all frequencies.

_____ c. An element, such as a transistor, operated in the straight portion of its operating curve.

_____ d. A device not allowing a current flow proportional to its applied voltage.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDE.

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B. Turn to Student Text Volume IX and read paragraphs 1-8 through 1-13. Return to this page and answer the following questions.

1. A condition for heterodyning to occur is:

_____ a. each voltage must be changing at a different frequency.

_____ b. each voltage must be changing at a different ampliutde, but at the same frequency.

_____ c. only one voltage must be present.

_____ d. an AC and a DC voltage are required in a nonlinear device.

2. Heterodyning produces:

_____ a. harmonics of the two original frequencies.

_____ b. the sum frequency of the two originals.

_____ c. the difference frequency of the two original frequencies.

_____ d. all of the above.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDE.

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C. Turn to Student Text Volume IX and read paragraphs 1-14 through 1-16. Return to this page and answer the following questions.

1. Filtering as used in heterodyning circuits refers to:

_____ a. the injection of usable harmonic frequencies.

_____ b. the selection of a frequency and rejection of all others.

_____ c. the rejection of all frequencies.

_____ d. the rejection of one frequency and passing of all others.

2. A filter for heterodyne purposes is made up of:

_____ a. a capacitor.

_____ b. an inductor.

_____ c. a tank circuit

_____ d. a diode with variable capacitor

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDE.

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D. Turn to Student Text Volume IX and read paragraphs 1-17 through 1-23. Return to this page and answer the following questions.

1. In a radio receiver, the resulting lower frequency from heterodyning the RF signal with the local oscillator signal is called:

_____ a. audio frequency.

_____ b. radio frequency.

_____ c. secondary frequency.

_____ d. intermediate frequency.

2. The difference between a mixer circuit and a converter circuit is:

_____ a. the mixer uses one transistor and a converter uses two transistors.

_____ b. the mixer passes higher frequencies than the converter.

_____ c. the converter is less efficient.

_____ d. the converter requires one tube or transistor.

3. What is required in a receiver in order to have frequency conversion?

_____ a. Two different signal frequencies, a filter circuit, and a nonlinear device.

_____ b. One high level signal frequency, a non-linear device, and a filter circuit.

_____ c. A non-linear device and two equal frequencies.

_____ d. An output frequency selection device so that new conversion frequencies can be selected.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDE.

---

E. Turn to Student Text Volume IX and read paragraphs 1-24 through 1-26. Return to this page and answer the following question.

1. Why will the difference frequency out of the converter circuit in the text illustration always be the same?

_____ a. The local oscillator frequency is always the same.

_____ b. The input tank circuit is gang-tuned with the local oscillator so that the difference frequency always remains the same.

_____ c. The radio frequency does not change even though the local oscillator is varied.

_____ d. The transistor prevents a change in the frequency.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDE.

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YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

---

## MODULE SELF-CHECK

QUESTIONS:

1. The conditions necessary for heterodyning to occur are:

_____ a. two like frequencies and a resistive device.

_____ b. two unlike frequencies and a nonlinear device.

_____ c. one frequency and linear device.

_____ d. two unlike frequencies and a liner device.

2. Heterodyne filtering results in the selection of one frequency through:

_____ a. the recombination of all the originals into one frequency.

_____ b. a resistive load.

_____ c. the rejection of all other frequencies by the diode which results in their return to the input circuit.

_____ d. a tuned circuit which offers a high impedance to the desired frequency while passing all others to ground.

3. Which of the following set of frequencies could be correctly found in a frequency conversion circuit of a receiver.

_____ a. 1490 kHz, 1945 kHz, 2525 kHz, 455 kHz.

_____ b. 1490 kHz, 455 kHz, 3435 kHz, 1035 kHz.

_____ c. 1490 kHz, 1945 kHz, 3435 kHz, 455 kHz.

_____ d. 1490 kHz, 1035 kHz, 2525 kHz, 1945 kHz.

4. A receiver tuning dial is tuned from a high to a lower frequency, which of the following actions would be necessary to produce the necessary conversion frequency within the receiver?

_____ a. Raise the local oscillator frequency by an equal amount.

_____ b. Lower the local oscillator frequency by an equal amount.

_____ c. Lower the local oscillator frequency by an amount proportional to the frequency being used.

_____ d. Raise the local oscillator frequency by an amount proportional to the frequency being used.

5. What are the two possible oscillator frequencies required, if the incoming RF signal is 1800 kHz and the desired output is 455 kHz?

a. _____________________________

b. _____________________________

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDE.

**ANSWERS TO A - ADJUNCT GUIDE**

1. c.    2. d.

If you missed ANY questions, review the material before you continue.

**ANSWERS TO B - ADJUNCT GUIDE**

1. a    2. d

If you missed ANY questions, review the material before you continue.

**ANSWERS TO C - ADJUNCT GUIDE**

1. b    2. c

If you missed ANY questions, review the material before you continue.

**ANSWERS TO D - ADJUNCT GUIDE**

1. d    2. d    3. a

If you missed ANY questions, reveiw the material before you continue.

**ANSWERS TO E - ADJUNCT GUIDE**

1. b

If you missed ANY questions, review the material before you continue.

**ANSWERS TO MODULE SELF-CHECK**

1. b
2. d
3. c
4. b
5. a. 1345 kHz
   b. 2255 kHz

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

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PREPARE THE MAN

ATC GP 3AQR3X020-X
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KEP-GP-64

Technical Training

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 64

## MODULATION

1 September 1975

AIR TRAINING COMMAND

7-13

Designed For ATC Course Use

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Radar Principles Branch
Keesler AFB, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-64
August 1975

# ELECTRONIC PRINCIPLES

## MODULE 64

## MODULATION

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS



### OVERVIEW

1. SCOPE: The material presented in this module covers the purpose of modulation and the various forms of modulation to include amplitude, frequency, phase, pulse and single sideband modulation. It brings out the relationships between the modulating signal, the carrier signal and the resulting sidebands.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given a list of statements about modulation, select the one which describes

(1) amplitude.
(2) frequency.
(3) phase.
(4) pulse.
(5) single sideband.

b. Given a list of statements about modulation, identify the one which describes

(1) intelligence signal.
(2) carrier wave.
(3) sidebands.

c. Given a formula and an oscilloscope representation of a carrier modulated waveform showing E maximum and E minimum, compute the percent of amplitude modulation.

d. Given a list of statements about frequency modulators, match each with the:

(1) reactance tube modulator.
(2) varactor modulator.

e. Given a list of statements about frequency modulation, select one that describes

(1) frequency deviation.
(2) modulating signal.
(3) rate of frequency change.

Supersedes KEP-GP-64, 1 May 1974.

## LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text, Volume IX

AUDIO VISUALS:

TV Lesson, Varicap Modulation, TVK-30-607
TV Lesson, Reactance Tube Modulator, TVK-30-606

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

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## ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the back of this Guidance Package.

Contact your instructor if you experience any difficulty.

Begin the program.

An understanding of modulation is necessary in order to study transmitter and receiver principles.

---

A. Turn to Student Text, Volume IX and read paragraphs 2-1 through 2-9. Return to this page and answer the following questions.

1. The characteristics of a sine wave which can be altered by the modulation process are ______________, ______________ and ______________.

2. Three basic methods of modulation are

_____ a. phase, velocity, amplitude.

_____ b. amplitude, frequency, and phase.

_____ c. amplitude, intensity, and frequency.

_____ d. frequency, amplitude, and velocity.

3. Match the following terms with the statements on the right:

_____ a. Intelligence signal

_____ b. Carrier wave

_____ c. Sidebands

(1) frequencies produced by modulation

(2) the modulating information

(3) reference signal

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

---

B. Turn to Student Text, Volume IX and read paragraphs 2-10 through 2-29. Return to this page and answer the following questions.

1. The modulated AM wave contains the carrier frequency plus

_____ a. at least two new frequencies.

_____ b. the modulating signal frequency.

_____ c. the reference frequency.

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2. The amplitude modulated carrier is the ____________________ sum of the carrier and new frequencies.

3. Indicate true or false for the following statements:

_____ a. The original modulating frequency will be transmitted.

_____ b. The complex modulation waveform contains many frequencies.

_____ c. The frequency of the carrier waveform will not change during the amplitude modulation process.

4. The bandwidth of an AM signal refers to the ____________________ the transmitted signal will occupy in the frequency spectrum.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

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C. Turn to Student Text, Volume IX and read paragraphs 2-30 through 2-38. Return to this page and answer the following questions.

1. Modulation factor is

_____ a. always 100 percent

_____ b. equal to the amplitude variations times the transmitted power.

_____ c. a ratio of the difference and sum of maximum and minimum peak-to-peak variations of the modulated carrier.

_____ d. a factor of the fundamental carrier reference to the original modulating signal.

2. Using figure 1 and the following formula, calculate the percent of modulation.

$$\frac{E_{max} - E_{min}}{E_{max} + E_{min}} \times 100$$

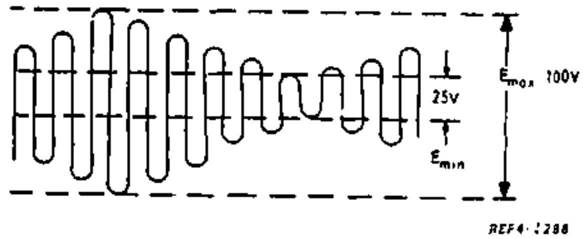


Figure 1

3. Using figure 1, what would the minimum value be in order to achieve 100 percent modulation?

4. What would be the result of over-modulation?

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D. Turn to Student Text, Volume IX and read paragraphs 2-39 through 2-44. Return to this page and answer the following questions.

1. Total transmitted power is equal to the sum of the carrier power plus the ______________ and the ______________ power.

2. What will be the total sideband power at 100 percent modulation if the carrier power is 50 watts?

3. Indicate true or false for the following statements assuming that modulation is 100%:

_____ a. Total sideband power is one-half the carrier power.

_____ b. Sideband power is distributed equally in two sidebands.

_____ c. Each sideband contains one-third of the total power.

_____ d. The carrier contains two-thirds of the total power.

4. What would be the result if the modulating frequency, which was causing 100 percent modulation, was reduced in amplitude?

_____ a. The carrier power would increase and sideband power would decrease.

_____ b. Total power would remain the same although the sideband power would be reduced.

_____ c. Both carrier power and sideband power would decrease.

_____ d. Carrier power would remain the same while sideband power would decrease.

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E. Turn to Student Text, Volume IX and read paragraphs 2-45 through 2-73. Return to this page and answer the following questions.

1. What principle is involved in the production of the modulated output from an AM transmitter?

2. Which of the following items are required to generate a single sideband signal:

_____ a. An intelligence signal, a balanced modulator, a sideband generator, and an audio wave.

_____ b. An unbalanced modulator, a sideband filter, and an intelligence signal.

_____ c. A sideband filter, an intelligence signal, an amplitude generator, and a carrier signal.

_____ d. A carrier, an intelligence signal, a balanced modulator, and sideband filter.

3. In single sideband transmission, the carrier is _______________ and one sideband is _______________.

4. The carrier is suppressed in the balanced modulator circuit because the _______________ in the modulator remains balanced.

5. Indicate true or false for the following statements concerning sideband filters:

_____ a. A sideband filter can be either electrical or mechanical.

_____ b. The mechanical filter is an electrically resonant device.

_____ c. The mechanical filter converts electrical energy into mechanical energy, then converts mechanical energy back to electrical energy.

_____ d. The transducer of a mechanical filter operates on the principle of magnetostriction.

_____ e. The transducer of a mechanical filter passes only the two sideband frequencies.

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F. Turn to Student Text, Volume IX and read paragraphs 2-74 through 2-103. Return to this page and answer the following questions.

1. The BW of the SSB signal is approximately _______________ the BW of the AM signal.

2. Just as in AM, when the peak voltage amplitude of the SSB modulating signal equals the carrier, we have _______________ percent modulation.

3. The output from an FM modulator will be at the center frequency

_____ a. when the modulating signal has zero amplitude.

_____ b. when the modulating signal has maximum amplitude.

_____ c. only when the modulator is first put into operation.

_____ d. every time the modulating signal is at its maximumum positive peak.

4. The amplitude of a frequency modulated RF wave

_____ a. will vary at the rate of the modulating signal.

_____ b. will vary at the rate of the audio frequency.

_____ c. will remain constant.

_____ d. varies only when the modulation drops to a very low level.

5. Maximum deviation of the FM oscillator will occur at the ____________________ voltage of the modulating signal.

6. Answer the following statements true or false:

_____ a. The frequency of the audio signal determines the rate of carrier frequency deviation.

_____ b. The FM wave contains an infinite number of sidebands.

_____ c. The number of significant sidebands is determined by the modulation index.

_____ d. A significant sideband must contain at least one percent of the total transmitted power.

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G. Turn to Student Text, Volume IX and read paragraphs 2-104 through 2-120. Return to this page and answer the following questions.

1. The formula for modulation index (MI) is MI = Fd/Fm. What will happen to modulation index if the amplitude of the modulating signal is increased?

_____ a. It will not change since the modulating signal amplitude is not a factor of modulation index.

_____ b. It will increase.

_____ c. It will decrease.

_____ d. It can not be determined because increasing the modulation amplitude changes other factors which are related to both elements of the formula.

2. The heart of the reactance tube modulator circuit is the ____________________ ______________________________ network.

3. The basic principle of the reactance tube modulator is

_____ a. The shunt effect of the tube causes a resistive imbalance of the tank circuit which varies the output frequency.

_____ b. A resistive network produces a bridge effect in parallel with a varying output tank circuit.

_____ c. An input signal causes the tube plate load resistor to vary the tank voltage and thus the output frequency varies.

_____ d. A change in tube current causes a change in reactance which is in parallel with the oscillator tank circuit. This causes a change in the oscillator frequency.

4. Indicate true or false for the following statements:

_____ a. A varactor modulator utilizes a diode which acts as a variable capacitor.

_____ b. The depletion region of a varactor diode varies with forward bias just as if the dielectric thickness of a capacitor were varied.

_____ c. The varactor is designed so that its operation varies nonlinearly such that the output frequency is directly related to the input.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

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H. Turn to Student Text, Volume IX and read paragraphs 2-121 through 2-137.

1. The difference between phase modulation and frequency modulation is:

_____ a. Phase modulation wave has varying power.

_____ b. Phase modulation utilizes amplitude modulation principles.

_____ c. Phase modulation does not vary the oscillator frequency.

2. The number of degrees through which the phase of a PM carrier is shifted is

proportional to the _______________ of the modulating signal.

3. The number of significant sidebands will (increase/decrease/remain the same) if the frequency of the modulating signal is increased while the amplitude remains the same.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

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MODULE SELF-CHECK

1. Answer the following questions true or false:

_____ a. The intelligence signal can be a single tone (one frequency) or a complex waveform.

_____ b. A carrier wave is the RF output of the transmitter.

_____ c. Sidebands are a product of the modulating process.

_____ d. Amplitude modulation varies the amplitude of the RF signal while the frequency ramains constant.

_____ e. In frequency modulation the rate of deviation depends upon the frequency of the modulating signal.

_____ f. Single sideband transmission is achieved with a filter to eliminate the carrier and a balanced modulator to allow transmission of only one sideband.

_____ g. Pulse modulation circuits require a somewhat narrower bandwidth because the transmissions are not as complex as amplitude modulation.

_____ h. The number of significant sidebands in FM is determined by the modulation index.

2. What will be the transmitted frequencies if a 1 MHz signal is amplitude modulated with 1 kHz?

_____ a. 1 kHz, 999 kHz, 1 MHz

_____ b. 1 MHz, 1.001 MHz, 999 kHz

_____ c. 1 kHz, 1.001 MHz, 1000 kHz

_____ d. 900 kHz, 1000 kHz, 1100 kHz

3. The bandwidth of the transmitted wave in question number 2 above would be:

_____ a. 1 kHz

_____ b. 4 kHz

_____ c. 2 kHz

_____ d. 2 Hz

4. Modulation factor in AM is

_____ a. a ratio of the difference and sum of the maximum and minimum peak-to-peak variations of the modulated carrier.

_____ b. a measure of distortion at 100 percent modulation.

_____ c. equal to carrier power times modulation signal power.

_____ d. a type of amplitude modulation where the factor of the carrier level causes a ratio of limited distortion.

5. An oscilloscope shows an AM envelope to have a maximum voltage of 50 volts and a minimum of 20 volts. What is the percent of modulation?

_____ a. 23%  _____ c. 43%

_____ b. 10%  _____ d. 33%

6. A 100 percent modulated AM wave has 150 watts of power. Match the following elements of the wave with its respective power

| | |
|---|---|
| _____ a. One sideband | (1) 150 watts |
| | (2) 100 watts |
| _____ b. Both sidebands | (3) 50 watts |
| | (4) 25 watts |
| _____ c. Carrier | (5) 66 watts |

7. An AM carrier is modulated 100%. If the amplitude of the modulating signal for this wave were increased, the result would

be ______________________ modulation.

9. A transducer in a sideband filter

_____ a. is mechanically resonant to one frequency.

_____ b. couples an electrical impulse from the input to the output internally.

_____ c. converts high frequency mechanical energy to low frequency.

_____ d. converts either electrical energy to mechanical energy or mechanical energy to electrical energy.

10. Pulse modulation is a kind of ________________ modulation.

11. The BW of a pulse modulated wave is ____________________ times the highest modulating signal frequency.

12. In frequency modulation, the unmodulated carrier frequency is designated the ________________ frequency.

13. Frequency deviation is defined as

_____ a. the amount the modulating signal increases from zero.

_____ b. the difference between the carrier center frequency and the frequency of the modulating signal.

_____ c. the difference between the instantaneous frequency of the modulated wave from the carrier center frequency.

_____ d. the sum of the instantaneous frequency of the modulated wave and carrier center frequency.

---

8. Match the following terms with their function in a single sideband modulator:

| | |
|---|---|
| _____ a. Intelligence signal | (1) Eliminates the carrier frequency |
| _____ b. Balanced modulator | (2) Produces the radio frequency |
| _____ c. Carrier generator | (3) Used to amplitude modulate the radio frequency |
| _____ d. Sideband filter | (4) Causes the bandwidth to be halved |

14. The ______________ of the modulating signal controls the rate of FM frequency change.

15. Modulation index

_____ a. is the ratio of frequency deviation of the carrier to the modulating signal frequency.

_____ b. is inversely proportional to the number of significant sidebands.

_____ c. is a ratio of the carrier center frequency to the modulating signal amplitude.

_____ d. depends upon the amplitude of the sidebands.

16. In a capacitive reactance tube modulator circuit, a positive voltage from the intelligence source will cause the output frequency to (increase/decrease/remain the same).

17. The depletion region of a varactor in a varactor modulator circuit serves as

_____ a. the bias for the oscillator

_____ b. the plates of the variable capacitor.

_____ c. the dielectric of a capacitor.

_____ d. a shunt to ground for the oscillator control circuit.

18. In a phase modulator circuit

_____ a. the phase angle of the carrier is varied in accordance with the modulating audio voltage.

_____ b. the phase of the carrier is maintained constant while the current amplitude of the resulting wave varies.

_____ c. the phase of the modulating signal is varied in accordance with the intelligence.

_____ d. the phase of the center frequency element of the carrier is shifted 90 degrees at the maximum audio amplitude.

19. If only the frequency used to modulate a carrier in a phase modulator is increased, the number of significant sidebands will (increase/decrease/remain the same).

20. A difference between FM and PM is:

_____ a. PM utilizes AM principles while FM does not.

_____ b. FM varies the oscillator frequency while PM does not.

_____ c. P' is amplitude sensitive while FM is not.

_____ d. FM changes frequency in accordance with the modulating signal amplitude while PM varies because of the modulating signal frequency.

CONFRIM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

ANSWERS TO A - ADJUNCT GUIDE

1. amplitude, frequency, phase
2. b
3. a. (2)
   b. (3)
   c. (1)

If you missed ANY questions, review the material before you continue.

ANSWERS TO B - ADJUNCT GUIDE

1. a
2. algebraic
3. a. False
   b. True
   c. True
4. space

If you missed ANY questions, review the material before you continue.

ANSWERS TO C - ADJUNCT GUIDE

1. c
2. 60 percent
3. 0 volts
4. distortion

If you missed ANY questions, review the material before you continue.

ANSWERS TO D - ADJUNCT GUIDE

1. upper sideband, lower sideband
2. 25 watts
3. a. True
   b. True
   c. False
   d. True
4. d

If you missed ANY questions, review the material before you continue.

ANSWERS TO E - ADJUNCT GUIDE

1. Heterodyning
2. d
3. suppressed, eliminated
4. bridge
5. a. True
   b. False
   c. True
   d. True
   e. False

If you missed ANY questions review the material before you continue.

ANSWERS TO F - ADJUNCT GUIDE

1. one-half
2. 100
3. a
4. c
5. Maximum
6. a. True
   b. True
   c. True
   d. True

If you missed ANY questions review the material before you continue.

ANSWERS TO G - ADJUNCT GUIDE

1. b
2. phase shifting
3. d
4. a. True
   b. False
   c. False

If you missed ANY questions, review the material before you continue.

ANSWERS TO H - ADJUNCT GUIDE

1. c
2. amplitude
3. remain the same

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK

1. a. T
   b. T
   c. T
   d. T
   e. T
   f. F
   g. F
   h. T

2. b

3. c

4. a

5. c

6. a. 4
   b. 3
   c. 2

7. over

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

9. d

10. amplitude

11. two

12. center

13. c

14. frequency

15. a

16. decrease

17. c

18. a

19. remain the same

20. b

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER INSTRUCTION.

PREPARE THE MAN

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ATC PT 3AQR3X020-X
Prepared by Keesler TTC
KEP-PT-64

TECHNICAL TRAINING

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 64

## MODULATION

1 July 1975

AIR TRAINING COMMAND

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Designed For ATC Course Use

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Electronic Principles Branch
Keesler Air Force Base, Mississippi

Programmed Text 3AQR3X020-X
KEP-PT-64
1 July 1975

# Electronic Principles

## Module 64

## MODULATION

This programmed text was prepared at Keesler Technical Training Center. It consists of one volume which analyzes the subject of Modulation.

The program was designed for use in the Basic Airman Electronic Principles Course, 3AQR3X020-X. The material contained herein has been validated using airman students who met the course input criteria. Eighty percent of the students scored at least eighty percent on the master validation examination. The average student required five hours to complete the program.

CONTENTS



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PROGRAMMED TEXT

# MODULATION MODULE 64

Instructions:

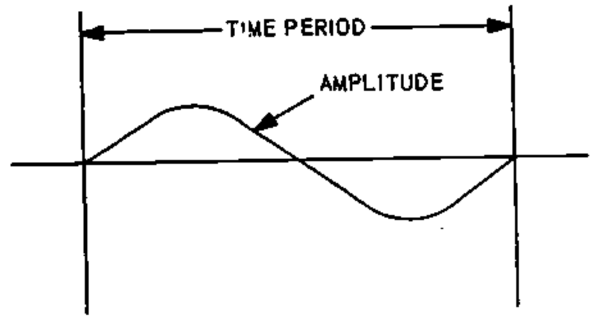
This text is designed to teach you the subject material in step-by-step sequence. You will be given small bits of information, each followed by a short quiz. At the end of each major area you will find a summary quiz. The answers for each quiz will be found on top of the next even numbered page.

Read the text carefully and answer the questions with care. Then turn to the correct answers and check before proceeding to the next section of text. If you require assistance consult your instructor.

## MODULATION

When a radio announcer speaks into a microphone his voice is heard on a radio receiver many miles away. In this text we will discuss how sound is converted into the RF wave that is transmitted into space.

Let's take a look at a common sine wave as shown in figure 1. This shows that the two characteristics of a sine wave are amplitude and time. We can change this sine wave by increasing or decreasing its amplitude or frequency. There is one other characteristic of this sine wave that can be changed. This is done by starting it at a later time. This results in the changing of the phase of the signal.



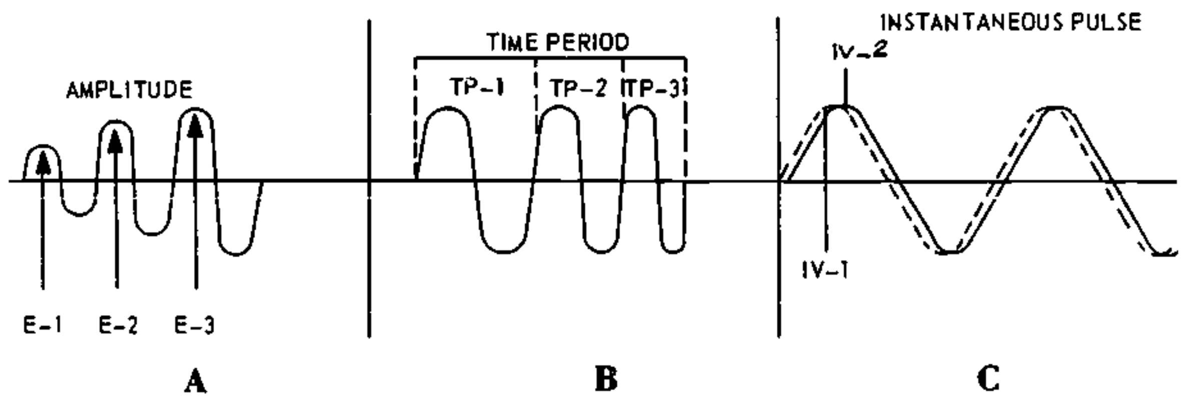

REP4-1280

Figure 1. Two Characteristics of a RF Sine Wave.

Figure 2A shows an amplitude change on each succeeding cycle of the RF waveform. As you can see, a great increase in amplitude has been made from E-1 to E-3.

Figure 2B shows the frequency changing with each cycle. The time period for TP-1 is much longer than that for TP-3. This means that the frequency has increased from TP-1 to TP-3.

Two waveforms of the same frequency are shown in figure 2C. Although they are the same frequency, note that they are not in phase. The peak of IV-1 occurs before the peak of IV-2.




REP4-1287

Figure 2. Variations in a Sine Wave's Characteristics

There are three ways the sine wave can be changed. We can change the amplitude or change the angle. When either frequency or phase of the waveshape is changed its angle is changed. We can now say that frequency and phase changes fall into a general category called angle variations.

QUICK QUIZ 1

1. The three ways to change a basic sine wave are to change its __________,

__________, or __________.

2. Frequency and phase changes fall under

a general heading called __________ variations.

Before we go any further, let's learn the meaning of some new terms.

CARRIER: an assigned reference frequency. It is a constant frequency signal that is assigned by the Federal Communications Commission (FCC) to each radio, television, radar, or other transmitter used in this country. Very little drift from this frequency is permitted. This prevents interference by the overlapping of stations and makes full use of the radio frequency spectrum.

INTELLIGENCE: an electrical wave or impulse that conveys an idea or expression. This could be an audio frequency such as voice or music.

MODULATION: the process in which the amplitude, frequency, or phase of an RF carrier wave is varied with time in accordance with the waveform of the superimposed intelligence. This means that an intelligence signal will be used to either change the amplitude, frequency, or phase of a basic sine wave.

Now with these definitions in mind let's look at the meaning of the following terms:

AMPLITUDE MODULATION (AM): the process of using intelligence to modify the amplitude of an RF carrier.

FREQUENCY MODULATION (FM): the process of using intelligence to modify the frequency of an RF carrier.

PHASE MODULATION (PM): the process of using intelligence to modify the phase of an RF carrier.

QUICK QUIZ 2

1. The term modulation means that an intelligence signal is used to vary the

________, ________, or ________ of an RF carrier.

2. A carrier wave is defined as an assigned

__________ __________.

3. Intelligence signal means, an electrical wave or impulse that conveys an

__________ or __________.

4. Three types of modulation are ________

modulation, ________ modulation, and

________ modulation.

When studying the process of HETERODYNING, we found that when two or more frequencies are applied to a non-linear impedance, new frequencies are generated. These new frequencies are the sum and the difference of the two originals.

Now we are going to use the heterodyning process to modulate an RF carrier. One frequency will be the RF carrier and the other frequency will be the intelligence signal. The two will be applied to a nonlinear impedance and the sum and difference frequencies will be generated.

Before proceeding further, let's look at another new term.

REP4-1293

Figure 3. Complex Waveshape of Intelligence Signal

SIDEBANDS: frequency bands on either side of the carrier which contain the frequencies produced by modulation.

When a single frequency is heterodyned with the carrier, one upper and one lower frequency are produced. These are the sum and difference of the two original frequencies. When voice communication is used, the intelligence signal is a wave made up of many frequencies as shown in figure 3.

When this wave is heterodyned with the carrier, many lower and upper sideband frequencies are generated. There is one lower and one upper frequency for each of the frequencies found in the complex audio wave.

There are two requirements which must be met for modulation to occur. First, we must have a non-linear impedance. This produces the sum and difference frequencies known as sidebands. Second, we must have a frequency selection device. Its purpose is to pass the carrier frequency and its sidebands and get rid of the original intelligence frequency, the harmonics of the intelligence and the harmonics of the carrier and sideband frequencies. The frequency selection device may be a parallel tank circuit. This circuit will have a center frequency tuned to the carrier frequency. The bandwidth of the tank circuit should be wide enough to pass the lowest and highest sideband frequencies. Anything below or above the bandwidth of the tank will not be passed.

QUICK QUIZ 3

1. In the process of modulation the intelligence is __________ with the carrier.

2. The resulting sum and difference frequencies are called upper and lower ________.

3. Two requirements for modulation are a ____________ impedance and a frequency ____________ device.

SUMMARY QUIZ 1

1. Three types of modulation are ________, ________ and ________ modulation.

2. A reference frequency assigned by the Federal Communications Commission is called a ____________ frequency.

3. Intelligence signal is an electrical impulse or wave that conveys an idea or expression. True/False

4. In the modulation process, intelligence is used to modify either the ________, __________, or ________ of the carrier.

5. During modulation the signals heterodyned together are the ________ and ________ waves.

6. Heterodyning two signals together produces ________ and ________ frequencies.

7. As a result of modulation, the sum and difference frequencies are called ________ and __________ sideband frequencies.

8. When heterodyning two signals, they are applied to a linear impedance. True/False

ANSWERS TO QUICK QUIZ 1

1. amplitude, frequency, phase
2. angle

ANSWERS TO QUICK QUIZ 2

1. amplitude, frequency, phase
2. reference frequency
3. idea, expression
4. amplitude, frequency, phase

ANSWERS TO QUICK QUIZ 3

1. heterodyned
2. sidebands
3. nonlinear, selection

ANSWERS TO SUMMARY QUIZ 1

1. amplitude, frequency, phase
2. carrier
3. true
4. amplitude, frequency, phase
5. intelligence, carrier
6. sum and difference frequencies
7. lower, upper
8. false

## AMPLITUDE MODULATION

Now that we have discussed the basic terms, let's take a close look at (AM) Amplitude Modulation.

Figure 4 shows a single steady audio tone used to modulate an RF carrier. In commercial radio the modulating audio intelligence is made up of many amplitudes and frequencies. In this explanation we will use only a single audio tone in presenting the principles of amplitude modulation.

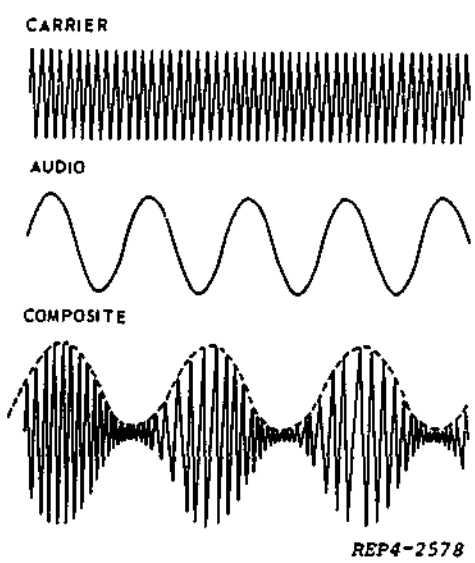



Figure 4. Resemblance of Composite AM Wave and Modulation

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Amplitude modulation alters the amplitude of the carrier in accordance with the frequency and amplitude of the modulating signal. Both of these factors affect the amplitude of the modulated wave, but in different ways. To illustrate this, let's compare the composite waveform in figure 4 with the waveshape of the modulating tone.

A dotted line connecting the peaks of the composite waveform has the frequency and shape of the audio waveform. Both audio and carrier are sine waves, but the composite waveform is a complex wave.

Now, vary the amplitude of each cycle of the modulating signal as we have done in figure 5. The smaller amplitude in the audio wave causes smaller amplitude variations in the composite wave.

Now let's see what happens when the modulating frequency changes. In figure 6 we have caused the audio frequency to increase and then decrease again. The composite wave changes as the audio frequency changes.

Look over all of the diagrams in this section once again and firmly establish them in your mind. From what we have seen thus far we can draw two firm conclusions concerning amplitude modulation:

1. The frequency of amplitude variations of the modulated waveform is proportional to the frequency of the modulating signal.

2. The amount of amplitude of the modulated waveform is proportional to the amplitude of the modulating signal.

---

QUICK QUIZ 4

1. The modulated wave is a complex wave made up of the carrier, audio, and sideband frequencies. True/False

2. Amplitude modulation causes the composite waveform to vary both in frequency and amplitude. True/False.

3. The frequency of the amplitude changes in the modulated waveform are in proportion to the ______________ of the audio signal.

4. The higher the amplitude of the modulating signal the ______________ (Higher/Lower) the amplitude of the modulated waveform.

---

Since the carrier and intelligence signals were heterodyned together during the modulation process, the composite wave contains new frequencies.

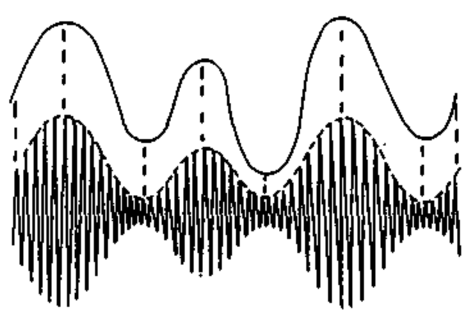


Figure 5. AM When Modulating Signal Amplitude Changes

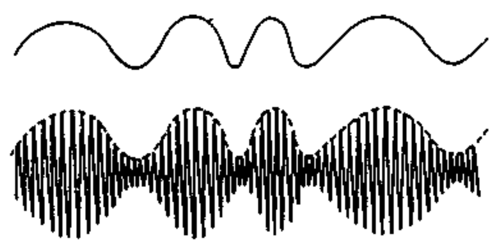


Figure 6. AM When Modulating Frequency Varies

ANSWERS TO QUICK QUIZ 4

1. False
2. True
3. frequency
4. higher

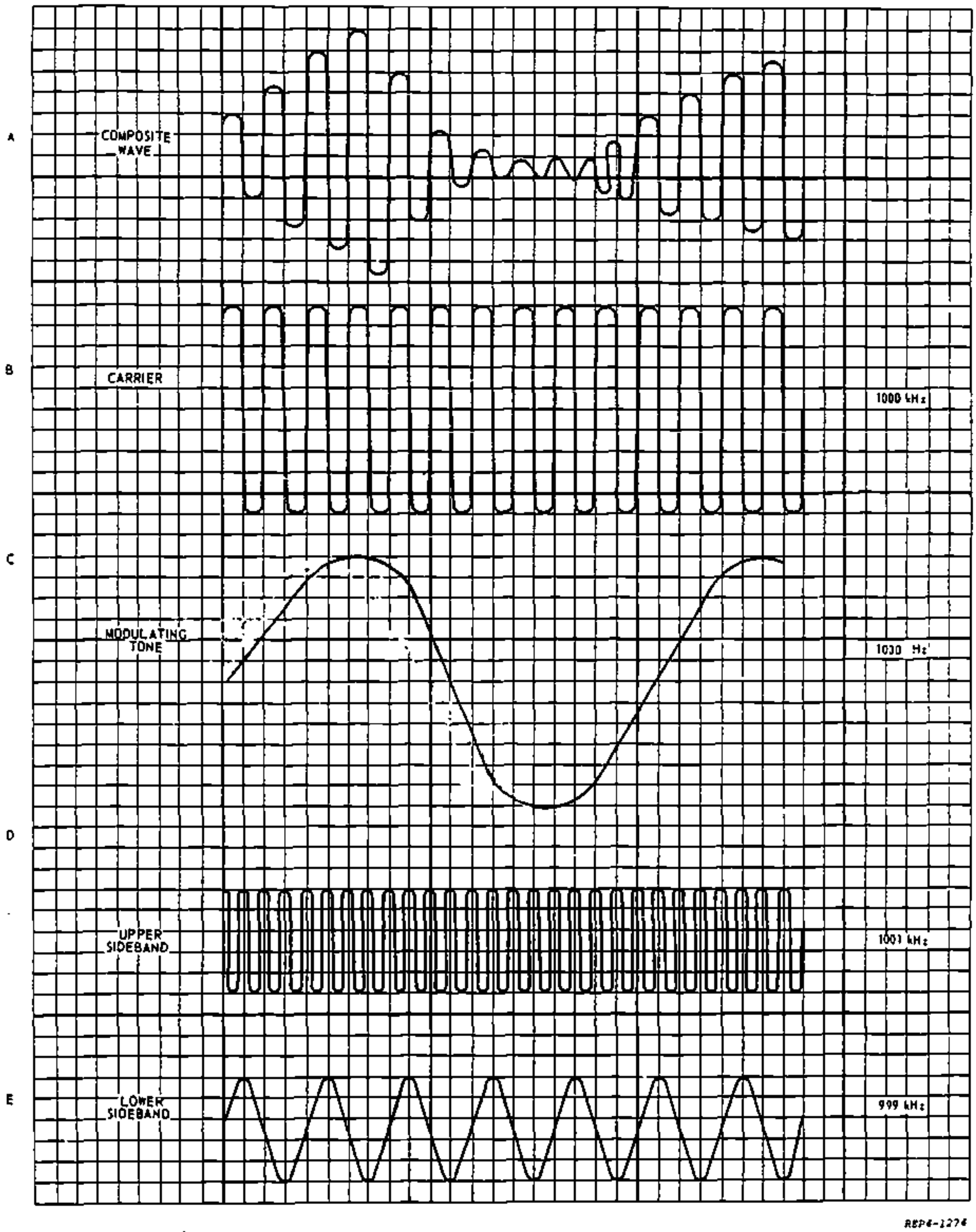


Figure 7. Components of an AM Wave

The parts of the modulated carrier wave are shown in figure 7. This breakdown shows that the modulated carrier (figure 7A) contains the carrier frequency (figure 7B) plus two new frequencies (figure 7D and figure 7E). The unmodulated carrier shown in figure 7B has a frequency of 1000 kHz with a constant amplitude, (figure 7C).

The upper frequency of 1001 kHz is equal to the carrier frequency plus the modulating frequency.

The lower frequency of 999 kHz is equal to the carrier frequency minus the modulating frequency. The amplitude of both new frequencies are equal.

QUICK QUIZ 5

1. If the carrier frequency is 1000 kHz and the intelligence frequency is 10 kHz,

the difference frequency will be ________

and the sum frequency will be ________

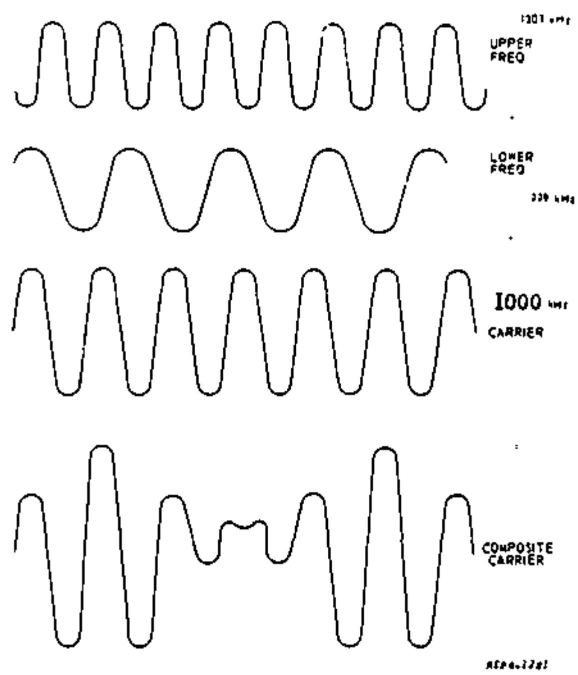


Figure 8. Algebraic Addition of Components in an AM Waveform

2. The wave to be transmitted contains several frequencies. True/False

3. The carrier is the result of heterodyning. True/False

The amplitude modulated waveform is the algebraic sum of the instantaneous amplitudes of the carrier and the upper side frequency and the lower side frequency signals. These waveforms are drawn using a common scale with respect to time in figure 8. The modulated wave then contains three distinct frequencies when modulated with a single tone, the carrier wave, the upper side frequency, and the lower side frequency.

QUICK QUIZ 6

1. The modulated wave consists of the carrier only. True/False

2. During modulation the lower side frequency, upper side frequency and carrier are algebraically added. True/False

3. The wave to be transmitted contains three frequencies. True/False

Figure 9 shows the Spectrum Analysis of an AM wave, this graph shows the amplitude of the signal versus frequency. The left side of the graph is the lowest frequency and the right side is the highest frequency. In figure 9 the modulating signal is 1000 Hz and the carrier is 1000 kHz. When heterodyned a composite wave is originated that

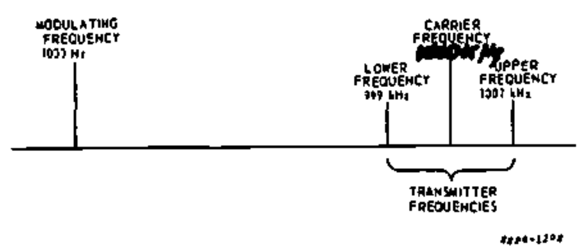


Figure 9. Spectrum Analysis of an AM Waveform

ANSWERS TO QUICK QUIZ 5

1. 990 kHz, 1010 kHz
2. true
3. false

ANSWERS TO QUICK QUIZ 6

1. false
2. true
3. true

contains the carrier, lower side frequency, and upper side frequency. All of the frequencies shown in figure 9 are present, but a filter circuit is used to pass only the three frequencies in the composite wave, the modulating frequency is eliminated. At this point, it is important for you to see that the original intelligence is not a part of the transmitted wave.

QUICK QUIZ 7

1. The spectrum graph has frequency plotted vertically and amplitude horizontally. True/False

2. The composite wave that is transmitted contains the ____________, the upper, and ____________ sideband frequencies.

3. The intelligence signal is not a part of the transmitted signal. True/False

In actual operation most waveforms used to modulate an RF carrier are complex waveforms.

Figure 10A shows a complex waveform. This waveform is made up of four frequencies: 1 kHz, 2 kHz, 3 kHz, and 4 kHz. When this signal is used to modulate a 600 kHz carrier, four upper and four lower frequencies are developed. These signals and the carrier are shown in figure 10B.

The upper frequencies are 601 kHz, 602 kHz, 603 kHz, and 604 kHz, and are called the upper sideband (USB) signals. The lower frequencies are 596 kHz, 597 kHz, 598 kHz, and 599 kHz and are called the lower sideband (LSB) signals.

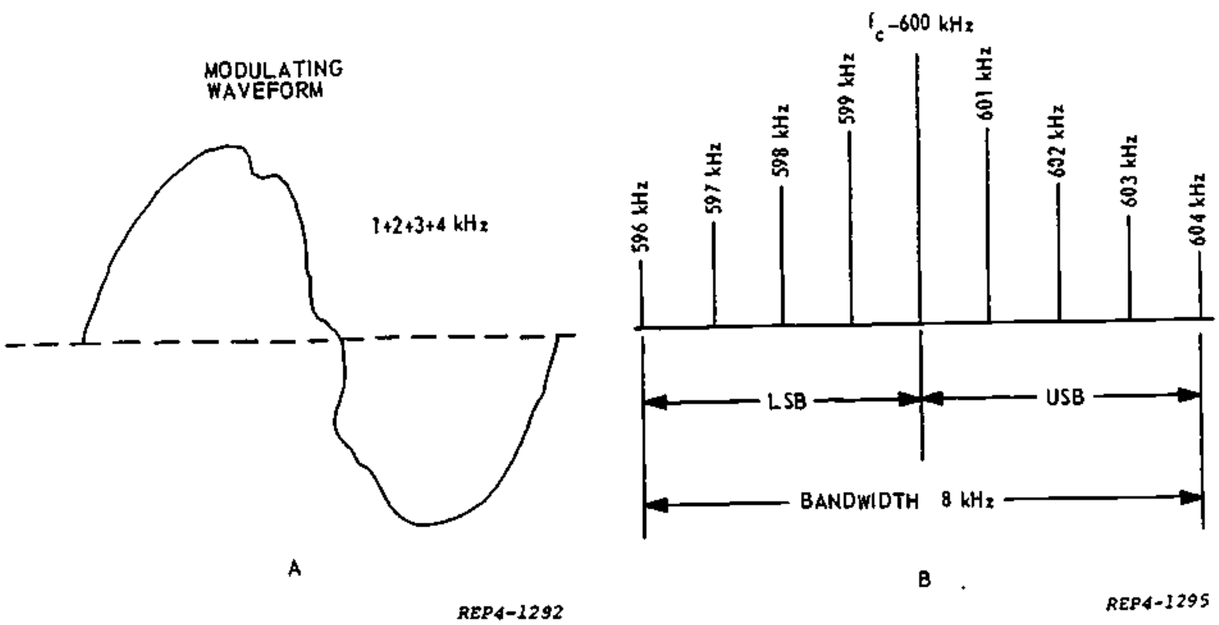


Figure 10. Development of Sidebands

The bandwidth (BW) of an AM signal refers to the space the transmitted frequencies will occupy in the frequency spectrum. Recall the transmitted frequencies in AM are the carrier signal, and the upper and lower sidebands. Look at figure 10 and see that the USB and LSB are each 4 kHz wide. This means that the BW of the transmitted signal is 8 kHz. If a 1000 kHz carrier is modulated with a 10 kHz signal, the upper side frequency will be 1010 kHz and the lower side frequency will be 990 kHz. The bandwidth in this case will be 20 kHz. Based on these facts we can say that the BW is equal to the distance from the lowest side frequency to the highest side frequency.

---

1. If a 1000 kHz carrier were modulated with a complex wave made up of 2 kHz, 4 kHz, and 6 kHz signals, what would be the lower sideband frequencies?

2. In question 1 above, what would be the bandwidth?

3. BW is equal to the distance between carrier and the highest upper side frequency. True/False

4. Many upper and lower side frequencies are usually generated because we usually modulate with a complex waveform. True/False

---

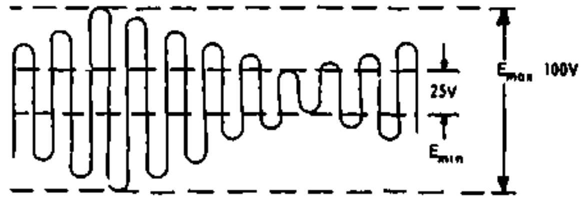


Figure 11. AM Composite Waveform Showing 60 Percent Modulation

Modulation factor in AM is the ratio of the maximum to minimum voltage of the modulated waveform. The modulation factor times 100 gives the percent of modulation.

Percentage of modulation can be found by suing an oscilloscope presentation of the modulated waveform, & the following formula:

$$\text{Percent of modulation} = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \times 100$$

where

$E_{max}$ = maximum amplitude of the modulated carrier wave.

$E_{min}$ = minimum amplitude of the modulated carrier wave.

An AM waveform is shown in fgure 11. Using the formula, and the voltages given, let's calculate the percent of modulation:

$$\% \text{ of modulation} = \frac{100 - 25}{100 + 25} \times 100 = \frac{75}{125}$$

$$\times 100 = .6 \times 100 = 60\%$$

Now use the formula and the oscilloscope presentation in figure 12 to find the percent of modulation.

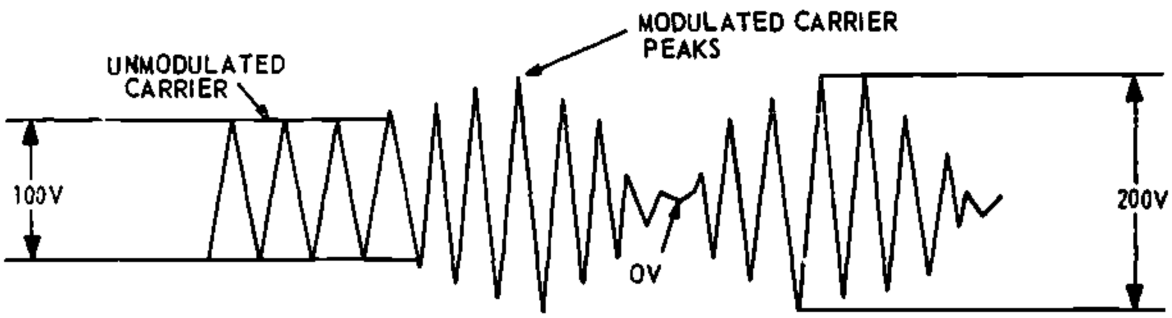


Figure 12. AM Composite Waveform Showing 100% Modulatio n

ANSWERS TO QUICK QUIZ 7

1. false
2. carrier, lower
3. true

ANSWERS TO QUICK QUIZ 8

1. 998 kHz, 996 kHz, and 994 kHz
2. 12 kHz
3. false
4. true

$$\% \text{ of modulation} = \frac{200 - 0}{200 + 0} \times 100 = 1 \times 100$$

$$= 100\%$$

A percent of modulation of less than 100% is "under modulation", and the output will be less than maximum power output. A percent of modulation greater than 100% is "over modulation". Over modulation causes severe distortion due to the sidebands heterodyning together creating harmonics.

A close look at the waveform in figure 12 shows the unmodulated carrier to be 100V peak-to-peak, while the maximum peak-to-peak carrier voltage after modulation is 200 V. The minimum carrier voltage after modulation is 0V. In the composite waveform there are two new frequencies produced during the modulation process, these two frequencies are equal in amplitude. If the unmodulated carrier in figure 12 is 100 V peak-to-peak and the modulated carrier is 200 V peak-to-peak, then the sum of the sidebands must be 100 V peak-to-peak. Since these two signals are equal then each side frequency must be 50 V peak-to-peak.

With over modulation, the BW of an AM signal will be increased due to the distortion produced. This distortion produces new upper and lower side frequencies which increase the bandwidth of the transmitted signal.

Figure 13 A shows a modulating signal that is 150 V peak-to-peak. This signal is

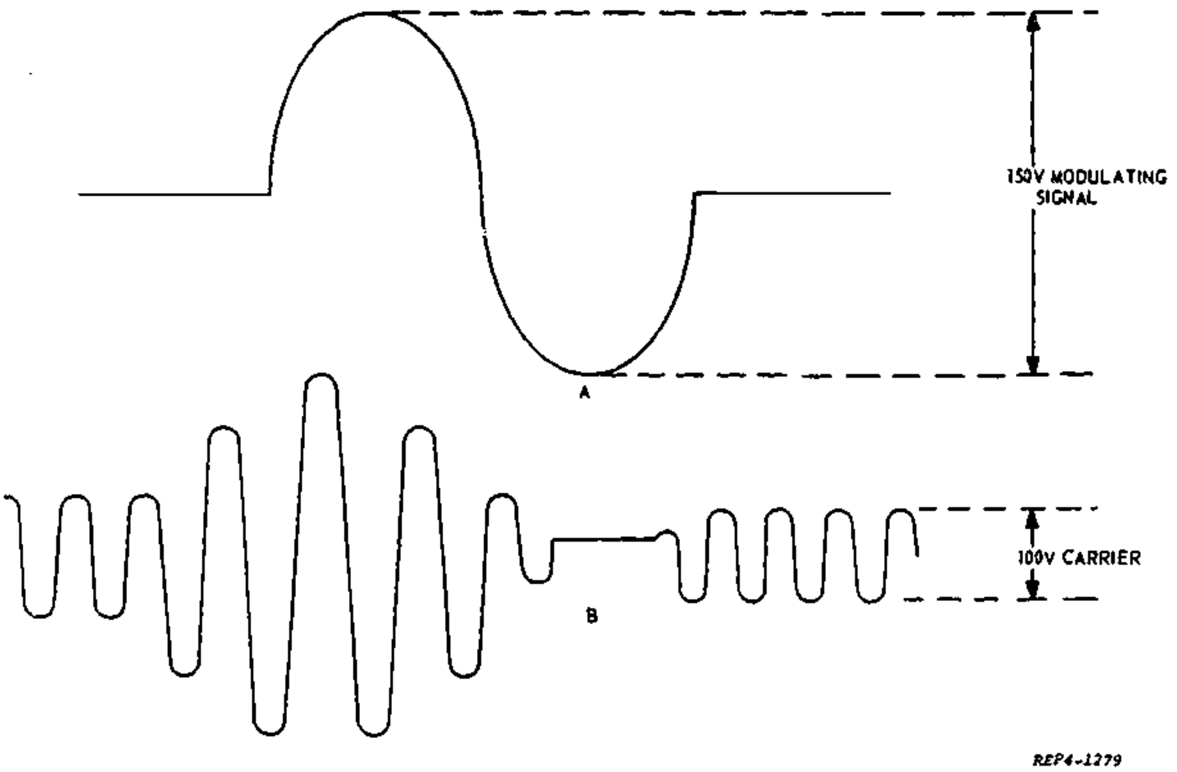


Figure 13. Over Modulating an AM Carrier

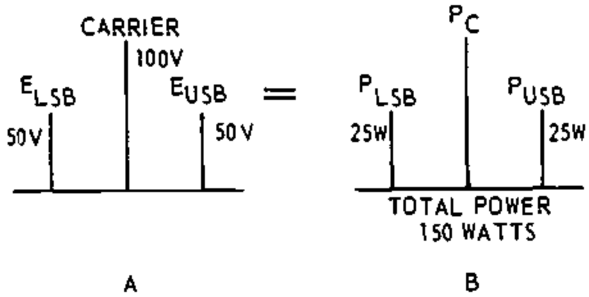


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Figure 14. Power and Voltage aw 100% Modulation

used to modulate a carrier that is 100 V peak-to-peak as in figure 13B. Note that during much of the negative half-cycle of the modulating signal, the amplitude of the modulated wave (figure 13B) is zero. Thus, the negative half-cycle of modulating signal has been clipped. This then would cause unwanted harmonics of the modulating signal to be genørated during the modulating process. These harmonics would appear as unwanted frequencies in the transmitted spectrum, thus increasing the BW of the transmitted signal.

---

QUICK QUIZ 9

1. The ratio between the peak variations of a modulated wave and its reference is expressed at % of modulation. True/False

2. Use the formula $\frac{E_{max} - E_{min}}{E_{max} + E_{min}} \times 100 = \%$

Find % when:

a. Max = 80V Min = 20V % = ________

b. Max = 70V Min = 30V % = ________

---

The total power in the modulated wave is equal to the sum of the carrier and SB powers found in that modulated wave.

In figure 14 we can find the total power transmitted for a 100 percent modulated carrier wave. Figure 14 shows the peak voltage contained in the carrier and in each sideband. The resistance of the load is assumed to be 100 ohms. We know from earlier studies that to find power we use this formula:

$$P = \frac{E^2}{R}$$

Use the voltage given for the carrier in figure 14A, and find carrier power:

$$P_c = \frac{(100)^2}{100} = \frac{10000}{100} = 100 \text{ watts}$$

Peak carrier power is equal to 100 watts and is shown in figure 14B. The peak sideband power then would be found by using the same formula and the peak amplitude of one sideband.

$$P_{LSB} = \frac{(50)^2}{100} = 25 \text{ watts}$$

The power of the other sideband is the same or 25 watts. Total sideband power is the sum of the USB and LSB powers. We find the peak sideband power is equal to 50 watts. Total peak transmitted power then is found by adding carrier power to sideband power. Using the power given for the carrier and sidebands in figure 14B, the total transmitted power equals 100 + 50 or 150 watts.

Under modulation reduces total power by reducing the power in the sidebands.

Figure 15 shows the power distribution of an AM waveform modulated 50%. Using the power formula with the voltage given for the carrier in figure 15A, we find:

$$P_c = \frac{(100)^2}{100} = \frac{10000}{100} = 100 \text{ watts}$$

The power in the carrier is still 100 watts. When you find the power for each sideband using the values given in figure 15B you will have 6.25 watts for each sideband or the

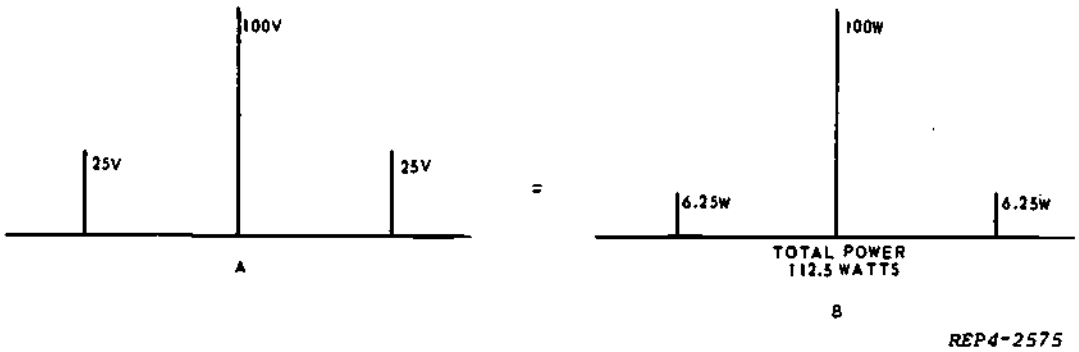


Figure 15. Voltage and Power Distribution at Fifty Percent Modulation. The Resistance of the Load is 100 Ohms

---

ANSWERS TO QUICK QUIZ 9

1. true
2. a. 60
   b. 40

---

total sideband power of 12.5 watts. Total power in the modulated waveform then is found by adding carrier power to sideband power. Total power is 112.5 watts.

From the preceding analysis of power distribution we find at 100 percent modulation:

a. total sideband power is one half the carrier power.

b. the carrier contains two thirds of the total power.

c. total sideband power is one third of the total transmitted power.

d. the total sideband power is distributed equally in two sidebands.

e. each sidehand comtwpmyhone sixth of the total power.

Reducing modulation to less than 100% (under modulation) gives:

a. no reduction in carrier power.

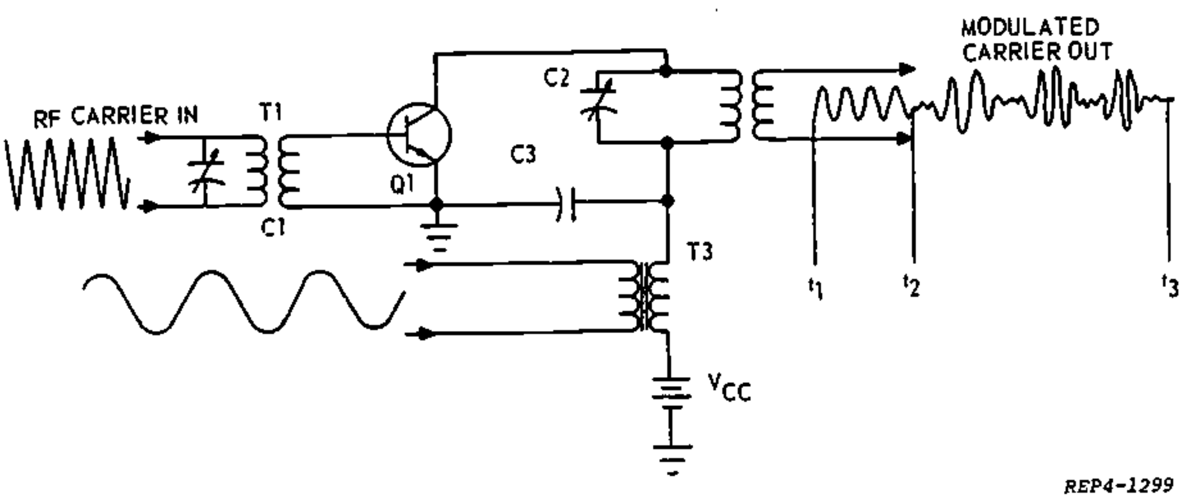


Figure 16. Simplified Circuit Using Amplitude Modulation

b. less power in the sidebands.

c. less total power.

---

QUICK QUIZ 10

1. If the carrier power were 50 watts at 100% modulation, the total SB power would be __________ watts.

2. If the total power were 300 watts at 100% modulation, the carrier power would be __________ watts.

3. If the carrier power were 200 watts at 100% modulation the upper SB power would be __________ watts.

---

Figure 16 shows an RF amplifier stage with an audio modulating signal fed to the collector circuit. In this circuit, the carrier is applied to the base, and the collector voltage is varied at the modulating (audio) rate.

Let's say there is a carrier signal fed through T1 to the base circuit of Q1, and there is no audio signal applied to T3. Since the stage is biased class B, transistor Q1 will conduct only on the positive alternation of the carrier input signal. The amplified output carrier pulses at the collector of Q1 then will cause the tank circuit, C2 and primary of T2, to oscillate at the carrier frequency. This unmodulated carrier signal is shown on the output waveform from $t_1$ to $t_2$.

When an audio modulating signal is applied through T3 to the collector circut, the modulating voltage across the secondary of transformer T3 is in series with the collector battery voltage $V_{CC}$. The positive half cycle of the audio signal voltage series aids the battery voltage, $V_{CC}$, increasing the emitter-collector voltage. The negative half cycle of the audio voltage series-opposes battery voltage $V_{CC}$, decreasing the emitter-collector voltage. When the emitter to collector voltage increases, the output of the RF amplifier increases, and when the emitter to collector voltage decreases, the output decreases. If you look at the waveforms from $t_2$ to $t_3$ (figure 16) you will see that the output of the amplifier increased on the positive half cycle of the modulating signal and decreased on the negative half cycle. Now look at the output RF waveform at $t_2$ to $t_3$ and note the amplitude variations resulting from the output of the amplifier increasing and decreasing.

The amplifier in figure 16 is being modulated 100%. Decreasing the amplitude of the modulating signal causes under modulation. Increasing the amplitude of the modulating signal would cause over modulation. The output modulated waveform at T2 is made up of the carrier frequency, the USB, and LSB.

---

QUICK QUIZ 11, REFER TO FIGURE 16

1. The circuit uses the intelligence signal to vary the ______________ amplitude.

2. When there is no modulating signal input there will be no output. True/False

3. The parallel resonant tank in the collectoe circuit is tuned to the modulating frequency. True/False

4. The modulating signal increases and decreases the collector voltage. True/False

5. If the amplitude of the modulating signal is decreased the total output power will decrease. True/False

---

## SINGLE-SIDEBAND

Single-Sideband (SSB) is a term used to describe the process of single-sideband communications operation, and the equipment required for this type of operation. Within the transmitter, the carrier is suppressed and later restored at the receiver. In single-sideband operation, only one sideband is transmitted.

ANSWERS TO QUICK QUIZ 10

1. 25 watts
2. 200 watts
3. 50 watts

ANSWERS TO QUICK QUIZ 11

1. carrier
2. false
3. false
4. true
5. true

From these statements we can say that during SSB modulation:

a. a carrier is modulated with an intelligence signal.

b. the carrier is suppressed.

c. one of the two sidebands is eliminated.

In conventional AM, the transmitter output is made up of the carrier frequency, a USB, and an LSB. If we place a filter at the output of the transmitter to take out the carrier and one sideband, we will have SSB transmission.

This is not the best way to obtain a SSB signal. A more practical method is to modulate the RF carrier signal at some low power stage in the transmitter, suppress the carrier, get rid of one of the sidebands and use the power amplifiers to amplify the remaining sideband. This will let us use all of the available power the transmitter can produce. This process is called SSB generation.

SSB type transmission is only used for voice communications. The ability to reproduce a wide range of frequencies such as those found in music is very poor. This is called low fidelity. Some of the advantages of SSB are:

a. More effective power

b. Increased range

c. Narrower BW allowing more stations in a small section of the frequency spectrum.

QUICK QUIZ 12

1. In SSB transmission, only the carrier frequency is transmitted. True/False

2. The bandwidth of SSB is ____________ that of conventional AM

3. After modulation takes place in SSB the ________________ is suppressed and one ______________ is filtered out.

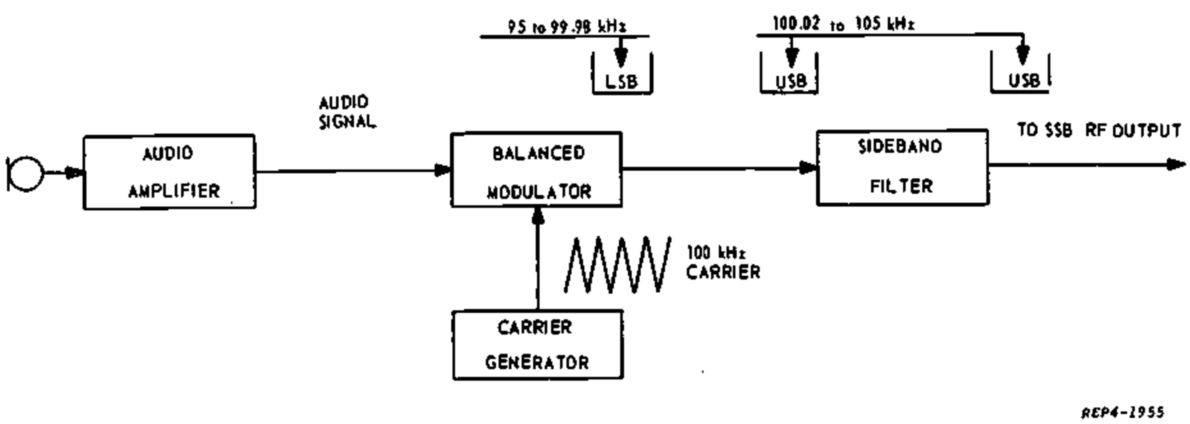


Figure 17. Circuits Used to Generate a Single-Sideband Signal

In order to generate a single-sideband signal we need:

a. an intelligence signal.

b. a carrier signal.

c. a balanced modulator.

d. a sideband filter.

When these are properly connected, they will produce a single-sideband signal. Figure 17 is a block diagram that shows a circuit that will convert the intelligence signal to a SSB RF signal. The intelligence signal is a composite waveform containing frequencies from 20 Hz to 5 kHz.

The audio amplifier amplifies the audio signal from the microphone. This signal is coupled to the balanced modulator where it will modulate the 100 kHz carrier signal from the carrier generator. The audio and RF signals are then heterodyned in the balanced modulator to produce the LSB signal, 95 to 99.98 kHz, and a USB signal, 100.02 to 105 kHz. This double-sideband signal is applied to the sideband filter. The carrier signal is not applied to the sideband filter. The sideband filter will select the desired sideband signal. In this example, the USB was selected and the LSB was eliminated.

---

QUICK QUIZ 13

1. What is the input to the balanced modulator?

2. What is the output of the balanced modulator?

3. The carrier signal is eliminated by the SB Filter. True/False

4. The carrier is of no use after the signal leaves the balanced modulator. True/False

5. When there is no modulating signal input, there is no output from the transmitter. True/False

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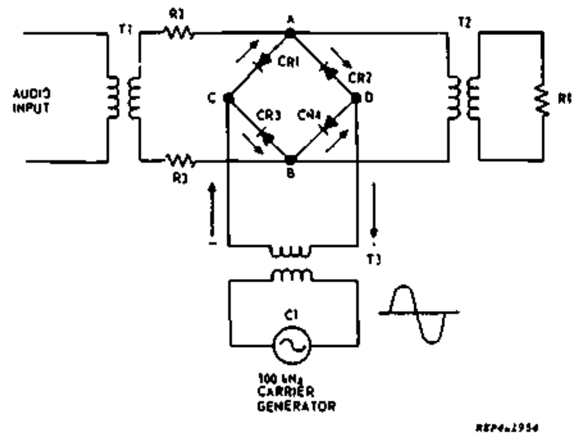


Figure 18. Modulator Circuit of a Single Sideband Generator

The balanced modulator circuit is shown in figure 18. Transformer T1 is used to couple the audio signal to points A and B. Transformer T2 couples both the USB and LSB outputs to R1. T3 couples the 100 kHz carrier signal to points C and D. Diodes CR1 through CR4 have matched forward and reverse resistances. G1 generates the carrier signal.

We can use figure 18 to see how the carrier is eliminated in the balanced modulator. The primary of T2 is connected across the bridge circuit at point A and B. Assume there is no modulating signal applied across T1, and the 100 kHz carrier signal is applied to T3 with the polarity shown in figure 18. The carrier signal fed to points C and D of the diode bridge will forward bias the diodes. The diodes conduct equally as shown by the arrows. There is also no difference in potential between points A and B. The conducting diodes represent a very low resistance effectively placing a short across the primary of T2. At this time there is no current flow thru the primary of T2. When the carrier signal at the secondary of T3 reverses, point C on the bridge is positive and point D is negative, the diodes are reverse biased. Again, there is no difference in potential between points A and B, and carrier current does not flow thru the primary of T2. The carrier signal was not coupled thru T2 and R1 because the bridge in the modulator remained balanced. The carrier was suppressed.

ANSWERS TO QUICK QUIZ 12

1. false
2. 1/2 or half
3. carrier - SB

ANSWERS TO QUICK QUIZ 13

1. Audio intelligence and the carrier
2. USB and LSB
3. false
4. true
5. true

Within the balanced modulator the carrier signal causes the diodes to switch on and off at the rate of the carrier frequency.

Figure 19 shows the action that takes place when the balanced modulator has both an audio signal and an RF carrier signal fed in at the same time. R2 and R3 are used to keep the two signals from acting on one another.

The waveforms (figure 19) show one cycle of the audio signal with many cycles of the RF carrier signal on the same time axis,

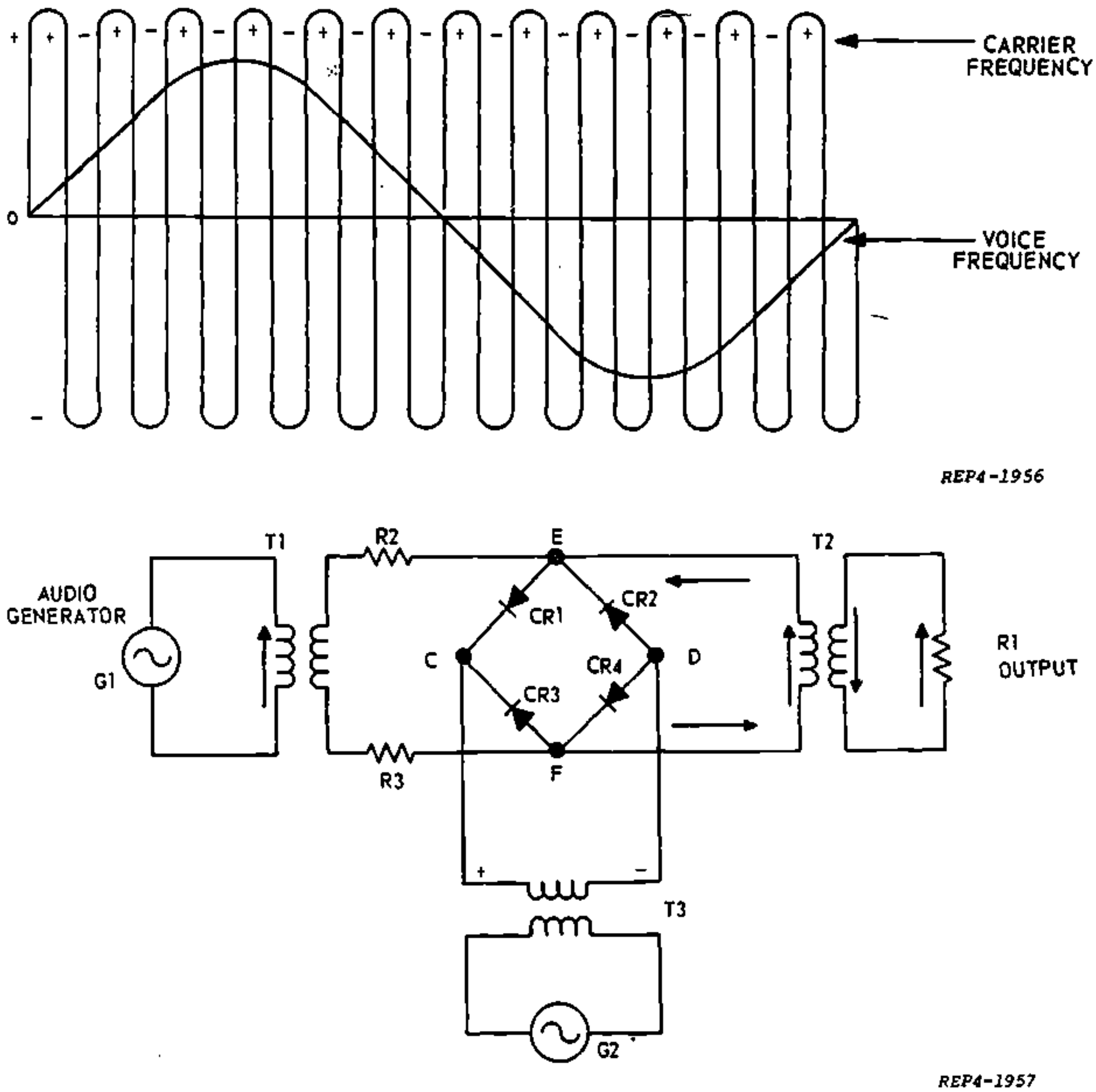


Figure 19. Modulator Circuit of a Single Sideband Generator with Waveforms

but not combined in the modulator. The positive and negative signals show the carrier polarity. Note that the peak value of the carrier is slightly greater than that of the voice signal; in actual operation the carrier signal is much greater.

When both waveforms (figure 19) are fed to the modulator, the diodes CR1, CR2 and CR3 and CR4 will be reverse biased when the polarity of the carrier signal is as shown on T3. This polarity is shown as positive on the RF waveforms. Now the audio signal applied thru T1 makes point E positive, and point F negative. Current flows in the circuit as shown by the arrows for the duration of the positive half cycle of the carrier shown on the waveforms. On the next half cycle of the carrier, the polarity of the secondary voltage at T3 becomes negative. The diodes are forward biased and the low forward resistance acts like a short across the primary of T2 and keeps the signal from coupling through to the other winding of T2. This is repeated for each carrier cycle.

The shaded areas on the waveform in figure 20 show when the diodes are reverse biased and there is an output from the modulator.

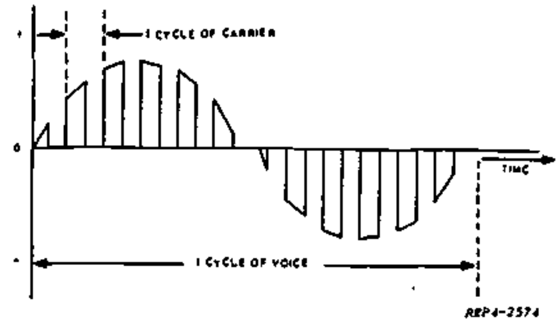


Figure 21. Modulator Output

The unshaded areas show when the diodes are forward biased and there is no output from the modulator. The shaded areas also show the polarity of the modulator output across R1 (figure 19).

The signal at the modulator output is shown in figure 21. The waveform contains the upper and lower sidebands. The carrier frequency is not in the output because carrier current does not flow in the primary of T2 (figure 19) at any time.

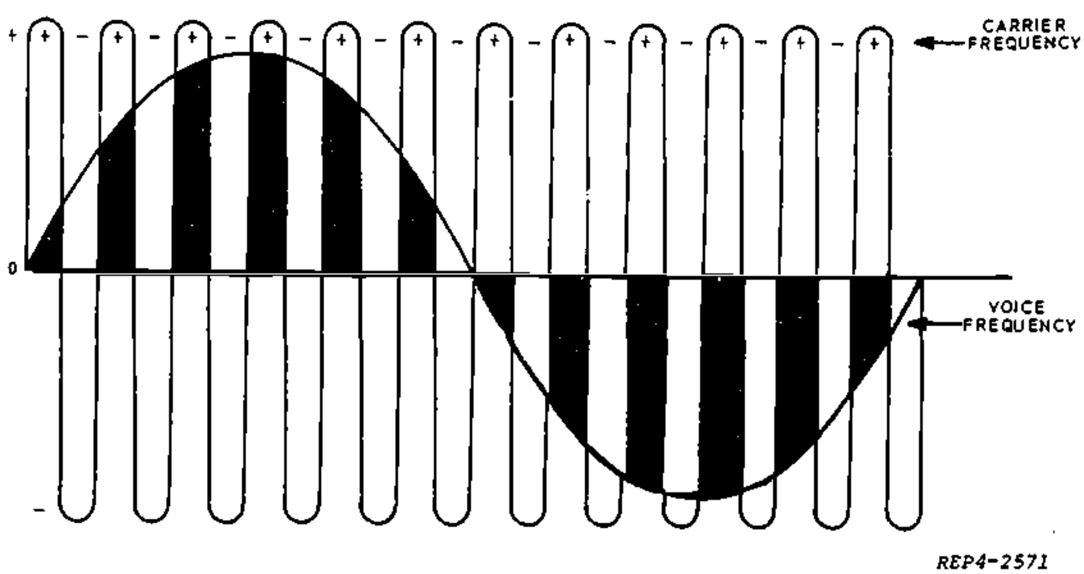


Figure 20. Waveforms of a Balanced Bridge Modulator

QUICK QUIZ 14, REFER TO FIGURES 18 & 19

1. When there is no audio input to T1 there is no current flow through R1. True/False

2. When an audio signal is present across T1, the current in R1 flows on one half alternation of the carrier generator. True/False

3. When point D on the bridge is negative in respect to point C, current flows from point A to B. True/False

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Sideband filters are bandpass filters. A bandpass filter allows only a selected band of frequencies to pass.

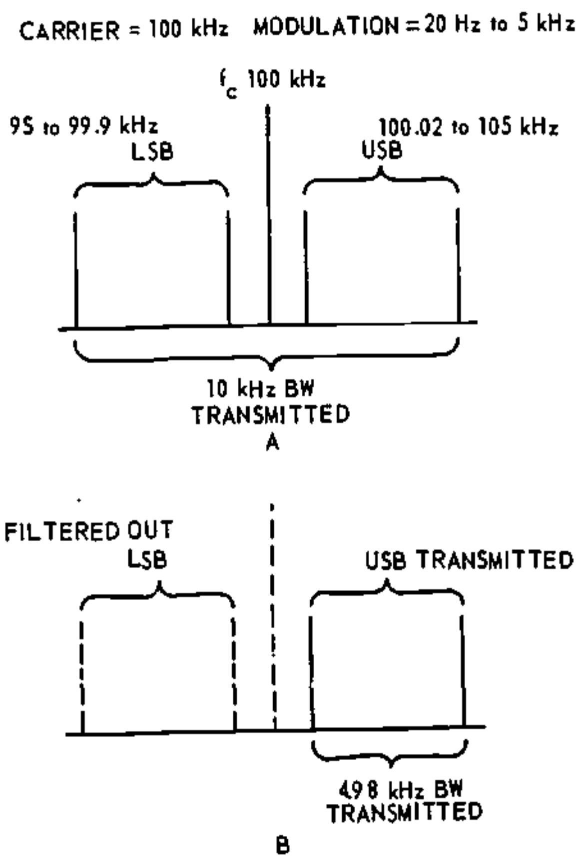


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Figure 22. Bandwidth Comparison of Conventional AM and SSB Signals

The BW of the SSB signal is approximately one half the BW of the conventional AM signal.

Figure 22A shows the transmitted spectrum of a conventional AM signal. Figure 22B shows the transmitted spectrum of a SSB signal. When the 100 kHz carrier signal of the conventional AM transmitter is modulated with the 5 kHz signal, the composite wave that is transmitted consists of the 100 kHz carrier, the LSB 95 kHz, and the USB 105 kHz. The BW required in the frequency spectrum is 10 kHz. When the 100 kHz carrier signal in the SSB transmitter is modulated with the same audio signal, only one sideband is transmitted. Thus, the BW required in the spectrum is 5 kHz.

---

QUICK QUIZ 15

1. The BW of a SSB transmitter is approximately ________ ________ the BW of the conventional AM transmitter signal.

2. Use a carrier of 100 kHz and a modulating frequency of 15 kHz and calculate the following:

a. BW of a conventional AM transmitter. ____________

b. BW of a SSB transmitter.

____________

3. If the modulating signal frequency decreases what happens to BW?

a. increases
b. decreases
c. remains the same
d. doubles

---

PULSE MODULATION

Another type of amplitude modulation is Pulse Modulation (P-M). Pulse modulation is defined as the modulation of a carrier by a pulse train. Pulse modulation is used for many things; from telegraphy to radar and telemetry to multiplexing. There are far too many applications of pulse modulation to tell about each of them. In this chapter we will cover the basic principles of pulse modulation.

In figure 23, observe the modulating square wave. You know that it contains an infinite number of odd harmonics as well as its fundamental frequency. Let us say that the square wave has a fundamental frequency of 1 kHz, and will be used to modulate an RF carrier signal of 1 MHz. When these signals heterodyne, two frequencies will be produced - a sum frequency (1.001 MHz), and a difference frequency (.999 kHz). Not only will the fundamental frequency of the square wave heterodyne with the carrier, but each of the harmonics contained in the square wave will also heterodyne with the carrier, and sum and difference frequencies associated with those harmonics are produced. For example, the third harmonic of the modulating square wave (3 kHz) when heterodyned with the carrier will produce an upper frequency of 1.003 MHz, and a lower frequency of .997 kHz. Another set of sum and difference frequencies are produced for the fifth harmonic of the square wave, and so on to infinity.

Now look at figure 23 and see the relative amplitude of the sidebands as they relate to the amplitudes of the harmonics found in the square wave. Note the first set of sum and difference signals, these are directly associated with the amplitude of the square wave. The second set of sum and difference signals are related to the third harmonic content within the modulating square wave. The third set is associated with the fifth harmonic and is only one-fifth the amplitude of the first set of sum and difference signals. This rule will apply for each sum and difference signal to infinity. Notice that the upper and lower sidebands (figure 23) are made up of the sum and difference signals produced during the modulation process.

---

QUICK QUIZ 16

1. When a square wave is used to modulate the carrier, one pair of SB frequencies are produced for the fundamental frequency and one pair for each of the odd harmonics. True/False

2. Refer to figure 23. If the frequency of the carrier is 1 MHz, and the 5th harmonic is 5 kHz, what would be the two side frequencies developed by this harmonic?

---

In AM when a carrier is modulated, the resultant complex waveform as viewed on an oscilloscope appears to change in amplitude. Figure 24A shows a carrier modulated with a square wave. The peak voltage of the

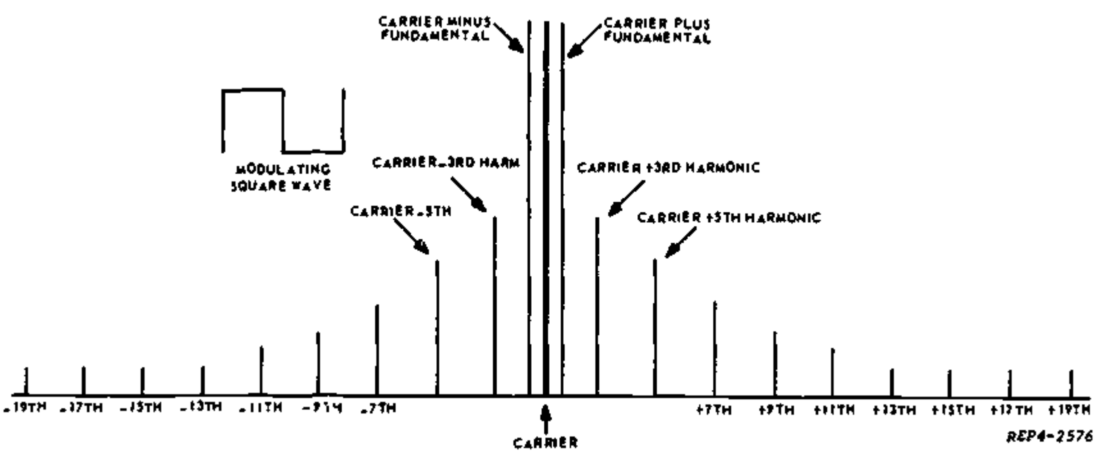


Figure 23. Spectrum Distribution when Modulating with a Square Wave

ANSWERS TO QUICK QUIZ 14
1. true
2. true
3. false

ANSWERS TO QUICK QUIZ 15
1. one half
2. a. 30 kHz
   b. 15 kHz
3. b

ANSWERS TO QUICK QUIZ 16
1. True
2. LSB = .995 MHz USB = 1.005 MHz

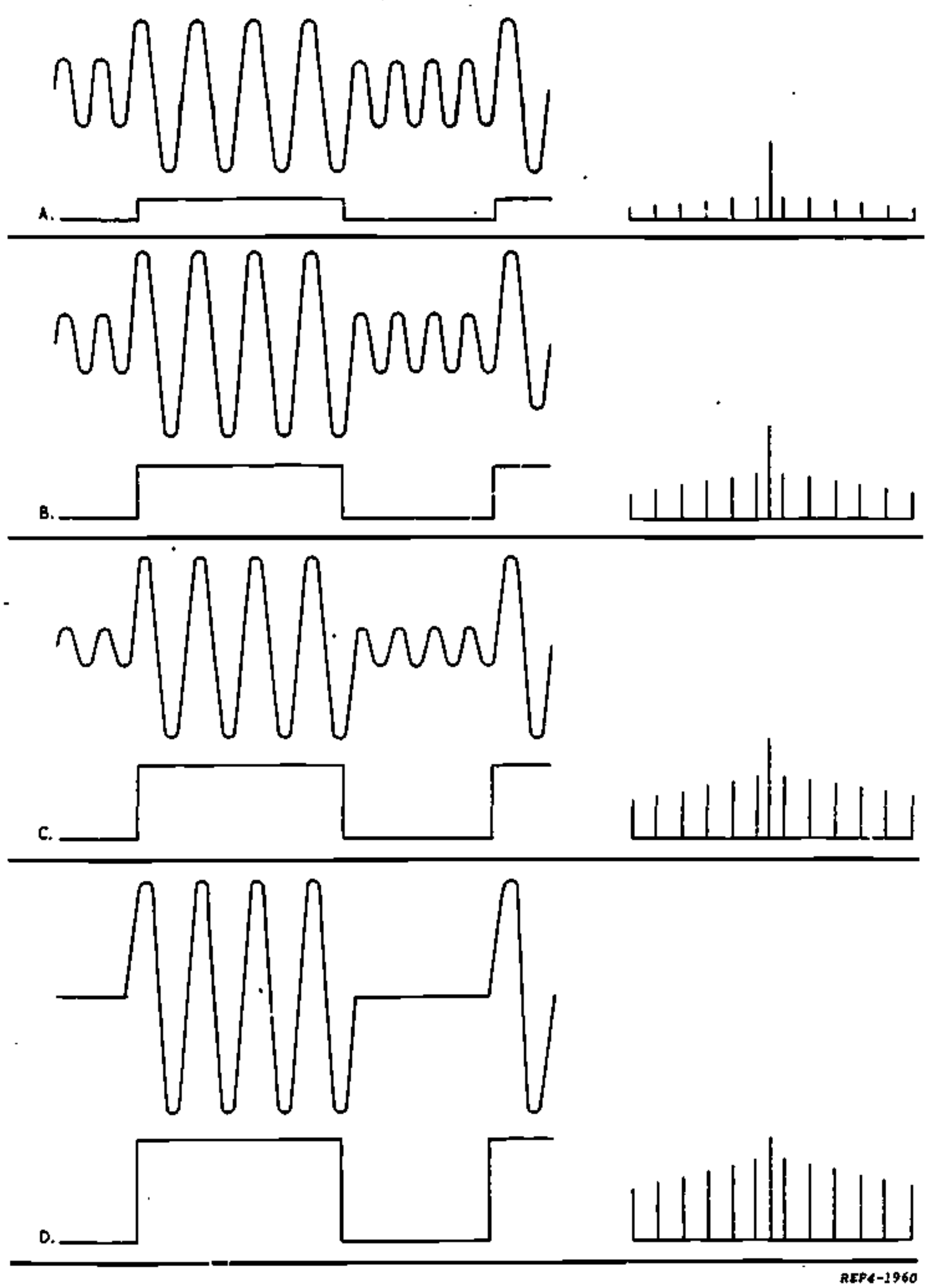


Figure 24. Various Square Wave Modulation Levels

square wave signal is less than the peak voltage of the unmodulated carrier signal. The resultant amplitude modulated carrier signal above the modulating square wave (figure 24A) increases in amplitude when the square wave is positive. Note that when the square wave is negative, the resultant modulated carrier wave decreases in amplitude. In figure 24B the modulating square wave is increased in amplitude, the RF peaks increase as the complex waveform increases during the positive alternation of the square wave and decreases during the negative half of the square wave. In figure 24C the amplitude of the square wave is further increased, until it is almost equal to the unmodulated carrier voltage. The modulated wave is almost zero during the negative alternation of the square wave. Now look at figure 24D where we increase the square wave modulating voltage so that it is greater in amplitude than the carrier. Now during the negative alternation of the square wave the modulated wave is not present.

In the frequency spectrum associated with each of these conditions, note the carrier amplitudes stay constant in figure 24A, B, and C but the sidebands are increasing in amplitude as the amplitude of the modulating square wave increases. In figure 24D; however, we increase the square wave modulating voltage so that it is greater in amplitude than the carrier. Note that the sideband power distribution does not change, but as the sidebands take on more of the transmitted power, so will the carrier.

So far in pulse modulation the same general rules apply as in AM. In figure 24C where the peak amplitude of the square wave is about equal to the peak amplitude of the unmodulated carrier, we have about 100% modulation.

In AM the bandwidth of the transmitted waveform is always two times the highest modulating signal frequency contained in the modulating waveform. The same holds true for PM.

Thus far, we have established a carrier, and then we caused its peaks to increase and decrease as the square wave is applied. Some pulse modulation systems modulate a carrier in this manner. Other systems produce no RF carrier until pulsed, and RF occurs during the pulse. As an example, look at figure 25 and establish a carrier

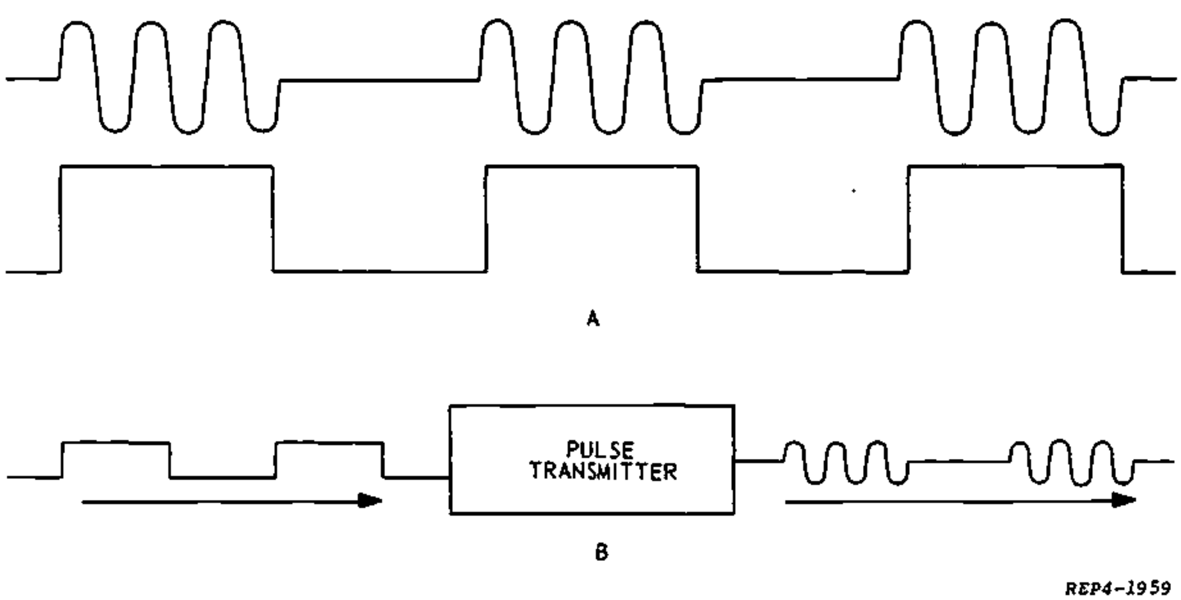


Figure 25. Pulse Transmission

frequency of 1 MHz. Each cycle of the RF energy requires a certain amount of the time; if we allow oscillations to occur for a given period of time, only during selected intervals as shown in figure 25A, we are PULSING the system as shown in figure 25B.

SUMMARY QUIZ 2

1. Match the following terms with their definitions:

a. ______ modulation
b. ______ carrier
c. ______ intelligence signal
d. ______ amplitude modulation
e. ______ sidebands

1. An electrical wave or impulse that conveys an idea or expression.

2. The process of using intelligence to modify the amplitude of an RF carrier.

3. Frequency bands on either side of the carrier which contain frequencies produced by modulation.

4. The process by which the amplitude, frequency, or phase is varied in accordance with an intelligence signal.

5. A reference frequency assigned by the Federal Communications Commission.

2. In AM, the modulated wave is a result of both the frequency and amplitude of the intelligence signal. True/False

3. When modulation takes place, which signals are heterodyned?

a. Intelligence and carrier

b. Intelligence and sidebands

c. Carrier and sidebands

d. Sum and difference

4. The conventional AM wave that is transmitted contains the ______________ and sideband frequencies.

5. Over modulation is caused by excessive carrier amplitude. True/False

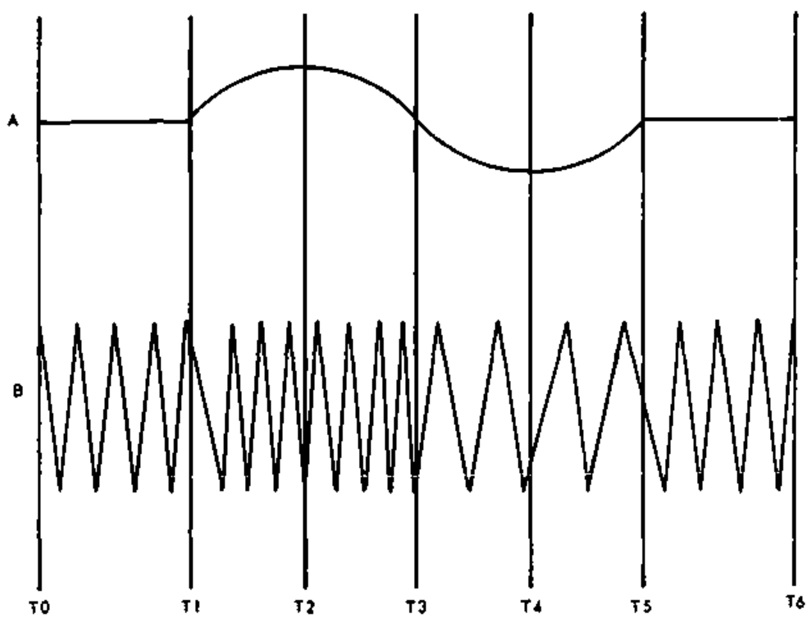


Figure 26. FM with a Modulating Signal

6. At 100% modulation the power in the modulated wave is divided:

a. 2/3 in the carrier and 1/3 in the sidebands.
b. 50% in the carrier and 50% in the sidebands.
c. 1/3 in the carrier and 2/3 in the sidebands.
d. 75% in the carrier and 25% in the sidebands.

7. In AM, the BW is equal to twice the highest modulating frequency. True/False

8. In SSB, the balanced modulator

a. eliminates the undesired SB
b. suppresses the carrier
c. heterodynes the sidebands
d. isolates the mechanical filter

9. What is the relationship between the BW of the conventional AM and that of SSB transmissions?

10. In pulse modulation using a square wave, the fundamental and each odd harmonic will produce a pair of sideband frequencies. True/False

---

## FREQUENCY MODULATION

Technically, Frequency Modulation (FM) is defined as angle modulation of a sinusoidal carrier in which the instantaneous frequency of the modulated wave differs from the carrier frequency by an amount proportional to the instantaneous amplitude of the modulating wave. This means that an intelligence signal is used to modify the frequency of the RF carrier.

When a frequency modulated wave is viewed on an oscilloscope, the frequency of the modulated wave can be seen to constantly change as the amplitude of the intelligence signal changes, however, the amplitude of the modulated wave will remain constant.

In frequency modulation the unmodulated carrier frequency is designated the center frequency.

Figure 26A shows a single sinewave of audio signal. This signal will be used to frequency modulate an RF carrier signal. Figure 26B shows the resulting frequency modulated waveform. Both waveforms have been drawn on a common scale with respect to time. From T0 to T1, there is no modulation of the RF carrier wave by the modulating signal. Thus, the carrier wave remains on the center frequency. During the T1 to T2 interval, the modulating signal increases from zero toward a maximum positive peak amplitude. The RF carrier wave departs from center frequency, and increases toward a higher frequency. From T2 to T3, as the modulating waveform decreases back to zero, the RF carrier wave decreases in frequency toward the center frequency. At time T3, the modulated carrier will have the same frequency as the unmodulated carrier signal. From T3 to T4, as the modulating waveform increases from zero to a maximum negative peak amplitude, the carrier wave will depart from center frequency and decrease to a lower frequency. From T4 to T5, as the modulating signal will decrease from its maximum egative peak amplitude toward zero, the carrier wave will increase in frequency back toward the center frequency. From T5 to T6 there is no modulation, thus, the carrier frequency remains on the center frequency.

During the complete modulation cycle of the RF waveform in figure 26, we find that:

a. The center frequency was present only when there was no modulation applied, or the modulating signal has zero amplitude.

b. When the modulating waveform has a positive amplitude the frequency of the modulated waveform was higher than the center frequency.

c. When the modulating waveform has a negative amplitude the frequency of the modulated waveform was lower than the center frequency.

d. The amplitude of the modulated RF carrier did not change throughout the modulation process.

ANSWERS TO SUMMARY QUIZ 2

1. a. 4 b. 5 c. 1 d. 2 e. 3
2. true
3. a
4. carrier
5. false
6. a
7. true
8. b
9. SSB is half that of AM
10. true

FREQUENCY DEVIATION is defined as the difference between the instantaneous frequency of the modulated wave and the carrier frequencq. Sometimes this is called amount of deviation. We can say it is how far the carrier is caused to deviate or change either above or below its center frequency.

In the FM transmitter the oscillator oscillates at the center frequency when there is no modulating signal from the modulator. An intelligence signal from the modulator will cause the oscillator to change frequency and swing above and below the center frequency. Maximum deviation of the oscillator frequency will take place at the voltage peak of the modulating signal.

The amount of deviation of the oscillator is determined by the amplitude of the modulating signal as shown in figure 27. The

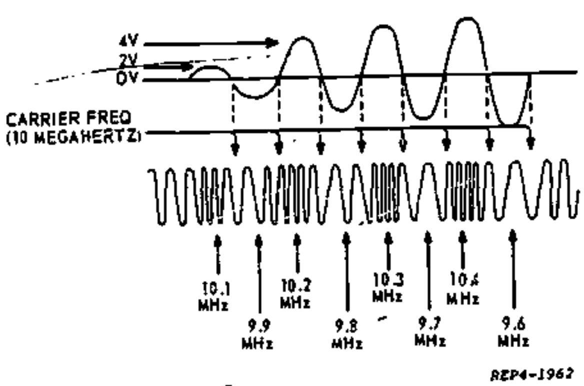


Figure 27. Deviation with Respect to Modulating Amplitude

modulating signal with a 2 V peak amplitude is used to modulate a carrier signal of 10 MHz. As the modulating signal increases its peak amplitude, the carrier oscillator frequency deviates from its center frequency to a maximum frequency of 10.1 MHz. As the modulating signal decreases in amplitude back to zero, the oscillator deviation becomes zero. As the modulating signal changes to its maximum peak negative amplitude, the oscillator frequency deviates below its center frequency to 9.9 MHz. As the modulating signal goes from its maximum peak negative amplitude back to zero, the oscillator signal deviation decreases to zero. A 4V peak amplitude modulating signal causes the carrier to deviate as previously explained, however, the oscillator deviates from its center frequency to 10.2 MHz and back to the center frequency during the positive half cycle of the modulating signal. During the negative half cycle of the modulating signal, the oscillator will deviate from the center frequency to 9.8 MHz and back to its center frequency.

Look once more at figure 27 and see that the maximum amount the oscillator deviated from its center frequency using the 2V peak amplitude signal was 100 kHz.

| | |
|---|---|
| Maximum oscillator frequency | 10.1 MHz |
| Oscillator center frequency | 10 MHz |
| Maximum deviation | .1 MHz (100 kHz) |

When the 4V peak amplitude signal is used, the maximum amount of deviation from center frequency is 200 kHz. From this analysis we can conclude that maximum frequency deviation of the oscillator signal from its center frequency is determined by the peak amplitude of the modulating signal.

The frequency of the modulating signal determines the frequency deviation of the oscillator above and below the center frequency.

In figure 28 the frequency of the audio signal determines the rate of carrier frequency deviation. Figure 28A shows a high frequency audio signal used to modulate the RF carrier and figure 28B shows the same carrier modulated with a low frequency audio signal.

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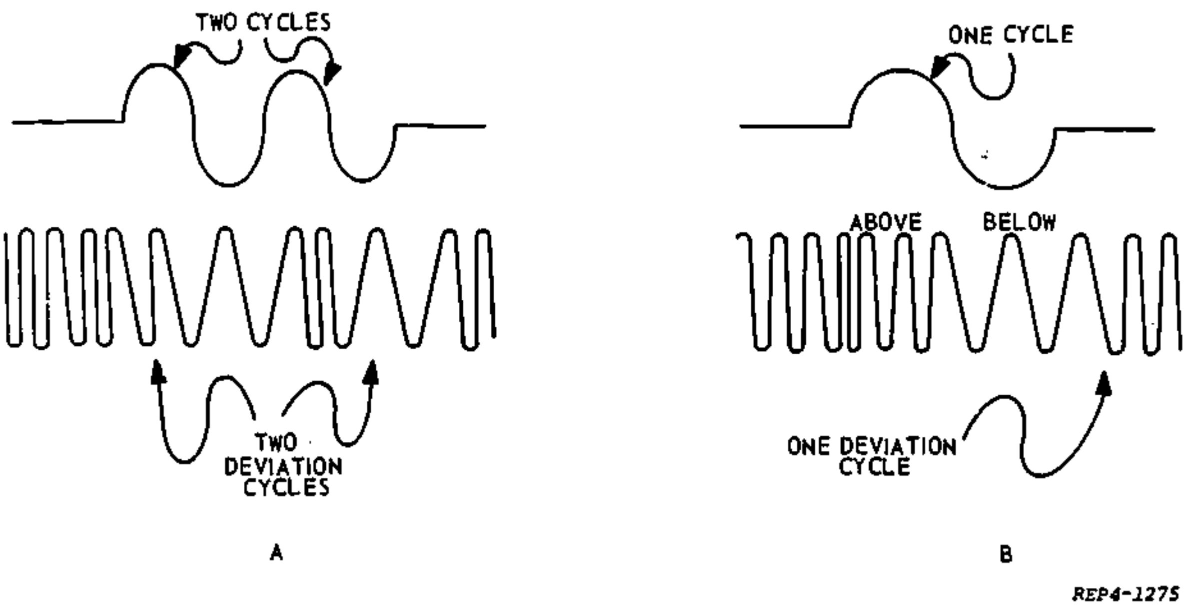


Figure 28. Rate of Frequency Deviation

You can now see that the modulating signal in figure 28A is twice the frequency of 28B. Also note that the frequency of deviation is directly proportional to the frequency of the modulating signal. As the frequency of the modulating signal is increased the rate of deviation will also increase. From this we can state that the rate of frequency deviation is directly proportional to the frequency of the modulating signal.

---

QUICK QUIZ 17

1. In FM when the amplitude of the modulating signal increases:

   a. the amount of deviation increases
   b. the rate of deviation increases
   c. the amount of deviation decreases
   d. the rate of deviation decreases

2. In FM when the frequency of the modulating signal increases:

   a. the amount of deviation increases
   b. the rate of deviation increases
   c. the amount of deviation decreases
   d. the rate of deviation decreases

---

When modulation takes place in FM an infinite number of sidebands are generated, however, all of them are not important. In FM a sideband must contain at least one percent of the total transmitted power to be classified as a significant sideband. The number of significant sidebands determines the bandwidth of the transmitted signal. The number of significant sidebands is determined by the modulation index (MI).

The modulation index is a ratio of the frequency deviation (amount) to the modulating signal frequency (rte) causing the deviation. The formula for modulation index is:

$$MI = \frac{f_d}{f_m}$$

where:

$f_d$ = frequency deviation (amount)
$f_m$ = frequency of the modulating signal (rate)

For example, let's say we are using the 1 V modulating signal and the frequency of the signal is 15 kHz. The 1 V modulating signal caused the oscillator frequency to deviate

ANSWERS TO QUICK QUIZ 17

1. a 2. b

30 kHz from the oscillator center frequency.

$$MI = \frac{30\text{ kHz}}{15\text{ kHz}} = 2$$

We see the MI is 2

A question now is how do we use the modulation index to determine the number of significant sidebands? The chart in figure 29 lists the number of significant sidebands contained in the modulated waveform when the modulation index is known. For modulation index of 2, there would be 8 significant sidebands, 4 USB and 4 LSB signals, in the transmitted spectrum.

Now, let's take a look at our transmitted spectrum. Figure 30 illustrates the frequency-modulated output spectrum for a modulation index of 2. The center frequency is the same frequency as the unmodulated carrier. The frequency of the first sideband pair is respectively higher and lower than the center frequency by the amount of the modulating frequency. The second set of sidebands have frequencies respec: vely higher and lower than the center frequency by an amount of two times the modulating frequency. The third set is three times and the fourth set is four times the modulating frequency.

| MODULATION INDEX | SIGNIFICANT SIDEBANDS |
|---|---|
| .01 | 2 |
| .4 | 2 |
| .5 | 4 |
| 1.0 | 6 |
| 2.0 | 8 |
| 3.0 | 12 |
| 4.0 | 14 |
| 5.0 | 16 |
| 6.0 | 18 |
| 7.0 | 22 |
| 8.0 | 24 |
| 9.0 | 26 |
| 10.0 | 28 |
| 11.0 | 32 |
| 12.0 | 32 |
| 13.0 | 36 |
| 14.0 | 38 |
| 15.0 | 38 |

REP4-1963

Figure 29. Modulation Index Chart

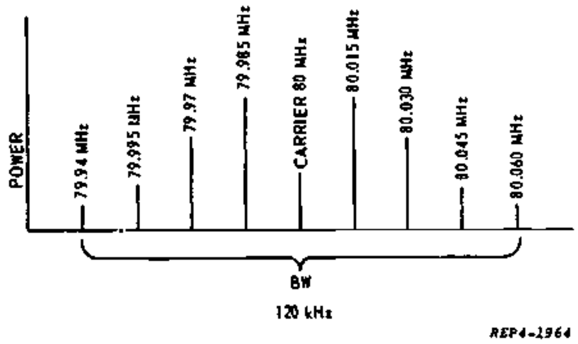


Figure 30. Spectrum Distribution for a Modulation Index of "2"

Look again at figure 30, and note that the BW of the transmitted FM signal is 120 kHz. In FM, increasing the frequency or amplitude of the modulating signal increases the BW of the transmitted signal. Another way of determining BW is by this formula: BW = Number of significant sidebands X rate of modulation. In the previous example there are 8 significant sidebands and the rate of modulation is 15 kHz. Therefore, 8 X 15 kHz = BW of 120 kHz.

QUICK QUIZ 18

1. Define significant sideband.

2. The amount of deviation is 75 kHz and the rate of deviation is 15 kHz. What is the BW? ________________ (Use figure 29, Modulation Index Chart)

3. In FM, what determines the amount of space between the sidebands? ________________

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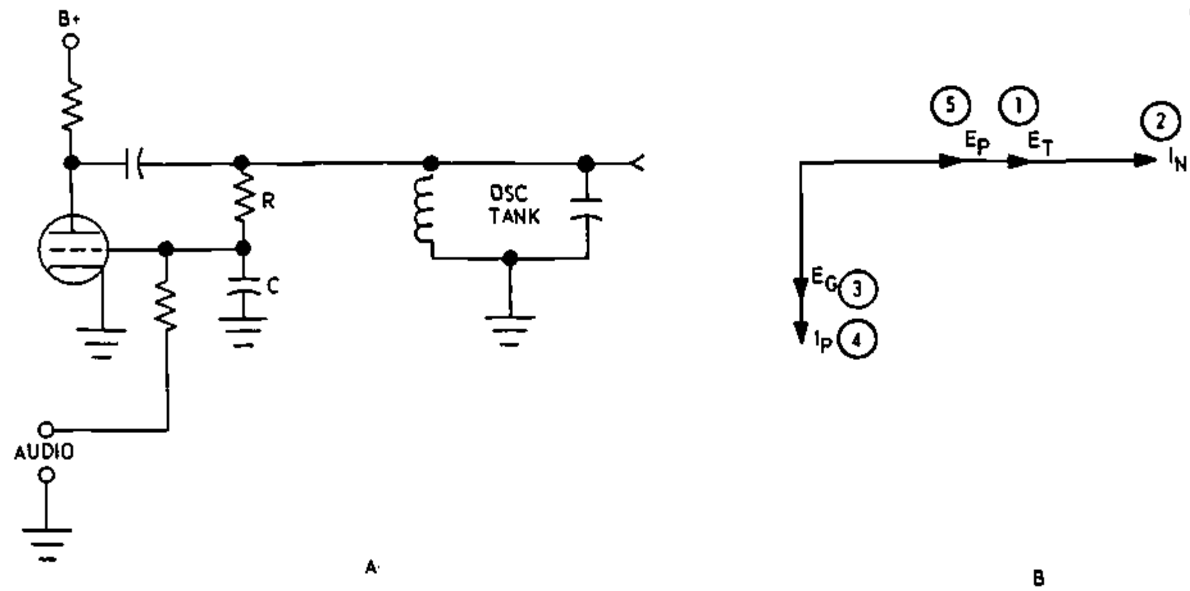



REP4-1965

Figure 31. Reactance Tube Modulator (Inductive Reactance)

A common circuit used in frequency modulation is the reactance tube modulator. Look at the basic circuit (figure 31A), and notice the arrangement of R and C in the circuit. This is a phase shifting network and the heart of the reactance tube circuit. The resistance of R is much larger than the capacitive reactance of C. This causes the circuit to act resistively to the oscillator tank circuit.

Now let's examine the effects of this arrangement:

a. The tank voltage ($E_t$) will be the reference vector as shown in figure 31B.

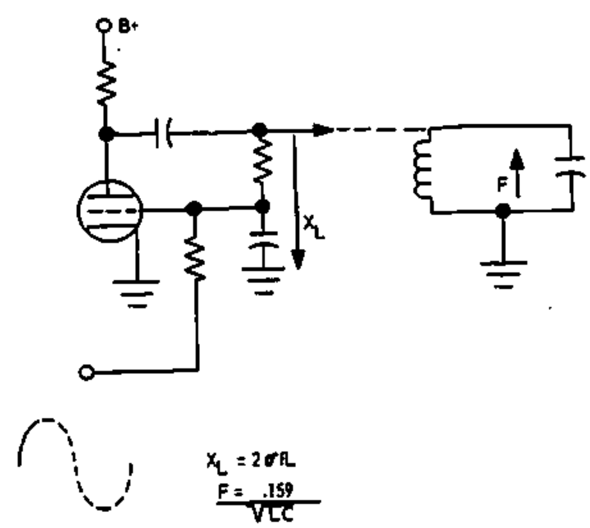
b. Since the tank is in parallel with the RC network, the current in the network ($I_n$) will be nearly in phase with the tank voltage. (Remember that the network is primarily resistive.)

c. Network current ($I_n$) will develop a voltage across C that lags the current $I_n$ by 90°. The voltage developed across C is the grid voltage (Eg) for the reactance tube.

d. Grid voltage ($E_g$) and plate current ($I_p$) are in phase, and both lag $E_t$ by 90°.

e. Since the tube is in parallel with the tank, the plate voltage, $E_p$, of the tube is in phase with the tank voltage, $E_t$. Since $I_p$ lags $E_p$ by 90°, the tank sees the reactance tube circuit as an inductor placed in parallel with the tank.

Now, let's see what happens when an audio signal voltage is fed to the input jack. On the positive alternation, the reactance tube current will increase, and the inductive reactance reflected to the tank decreases (figure 32). When the inductive reactance decreases the resonant frequency of the tank increases.




REP4-1966

Figure 32. Reactance Tube Modulator With Positive-Going Input

ANSWERS TO QUICK QUIZ 18

1. A SB that contains 1% or more of the total power.

2. 240 kHz

3. The modulating frequency.

When the audio input goes negative, current decreases. The inductive reactance then increases and the tank frequency decreases (figure 33).

Now, let's take a look at a circuit that serves as a capacitive reactance instead of an inductive reactance. To do this the phase shifting network is changed, as shown in figure 34. Note that the capacitor has been placed between the plate and grid and the resistor is between grid and ground. Another change has been made to the circuit that does not show in the diagram -- the capacitive reactance is now much greater than the resistance. The circuit will now act in the following manner.

a. Tank voltage will again be the reference vector.

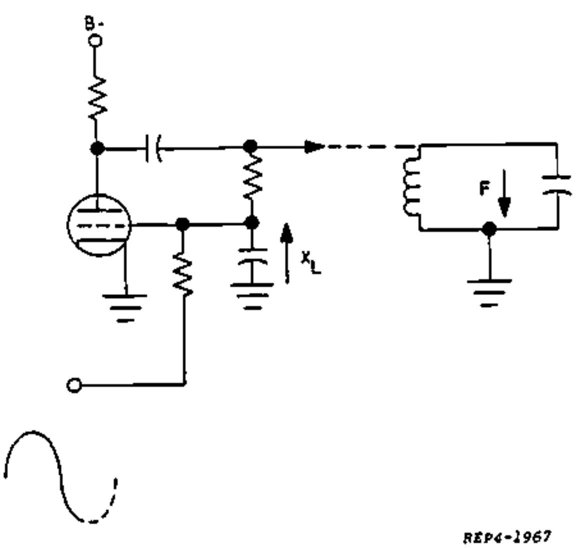



Figure 33. Reactance Tube Modulator with Negative-Going Input

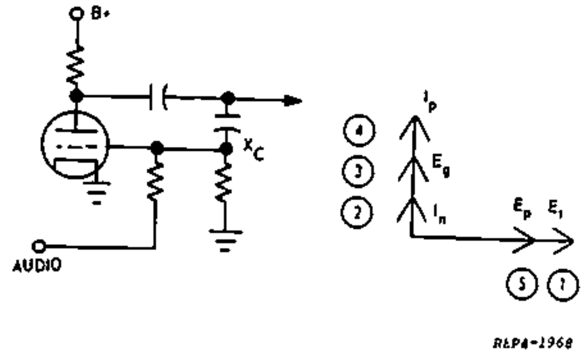



Figure 34. Reactance Tube Modulator (Capacitive Reactance)

b. Since the RC network is now capacitive, the network current will lead tank voltage by nearly 90°.

c. Voltage across the resistor will be in phase with network current and lead tank voltage by nearly 90°. This voltage is felt on the grid ($E_g$). (Tand voltage is the voltage across the capacitor which lags network current by 90°.)

d. Since plate current and grid voltage are in phase, plate current will lead plate voltage by 90°.

e. Plate voltage ($E_p$) will be in phase with tank voltage since the tank and tube are connected in parallel.

You can see by this vectorial analysis that $I_p$ leads $E_p$ by 90°. The circuit is therefore, acting capacitively, and reflects a capacitive reactance to the tank. This circuit does not act the same as the inductive circuit, because inductive and capacitive reactances differ:

$$X_L = 2\pi fL$$

and

$$X_C = \frac{1}{2\pi fC}$$

In the capacitive circuit, a positive voltage from the intelligence source will cause the output frequency to decrease, while a negative voltage will increase output frequency.

QUICK QUIZ 19

1. The reactance tube modulator is a circuit where the modulating signal varies the reactance of an oscillator tank circuit. True/False

2. The output frequency of the reactance tube modulator varies at a rate determined by the ________ of the audio output.

3. The output frequency deviates from center to one extreme depending upon the ____________ of the audio input signal.

Another FM modulator that is widely used in transistorized circuitry employs a voltage variable capacitor, called a VARACTOR. The varactor is simply a diode, or PN junction, designed to have a certain amount of capacitance across the junction. Figure 35 shows the schematic symbol and a diagram of a varactor in a simple oscillator circuit. (This is not a working circuit, but merely a simplified illustration.) The capacitance of a varactor, as with all capacitors, is determined by the area of the capacitor plates and the distance between the plates. The depletion region in the varactor determines the distance (dielectric) between the P and N elements (plates).

In all PN junctions when reverse bias is varied, we change the thickness of the depletion region, and therefore, the capacitance changes. The varactor is designed so the change in capacitance is linear with a change in the applied voltage. Proper circuit design prevents the application of forward bias.

Notice the simplicity of operation of the circuit in figure 36. An audio signal applied to the input results in the fllowing action:

a. On the positive alternation, reverse bias increases and the dielectric (depeltion retion) width increases. This decreases capacitance, which increases the frequency of the oscillator.

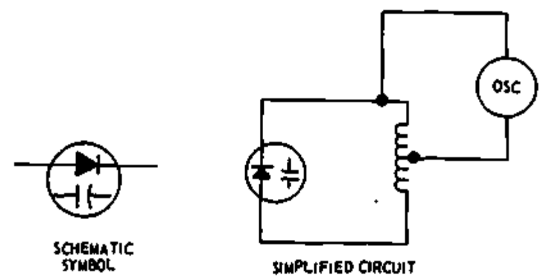



Figure 35. Varactor Symbol and Schematic

b. On the negative alternation of the audio signal, the reverse bias decreases, resulting in an oscillator frequency decrease.

QUICK QUIZ 20

1. In the varactor FM modulator, the intelligence signal causes the oscillator frequency to vary by changing the ____________ on the varactor.

2. The output frequency of the varactor FM modulator varies at a rate determined by the ________ of the audio input.

3. The amount of deviation in the varactor FM modulator is determined by the ______________ of the audio.

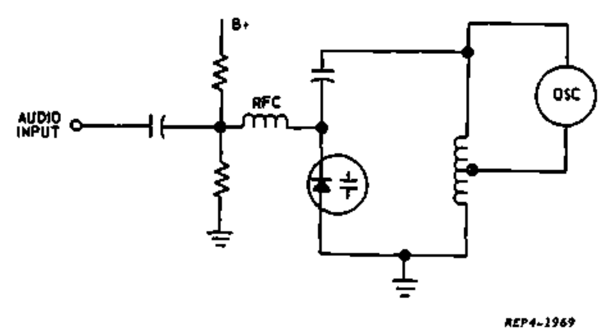



Figure 36. Varactor FM Modulator

ANSWERS TO QUICK QUIZ 19

1. true
2. frequency
3. amplitude

ANSWERS TO QUICK QUIZ 20

1. bias
2. frequency
3. amplitude

## PHASE MODULATION

In FM, the transmitter oscillator changes frequency above and below the center frequency as the modulating signal is applied. In phase modulation (PM), the transmitter oscillator frequency s not changed during the modulation process. In fact the PM system usually employs a crystal oscillator and the phase of the output is caused to change.

Phase modulation implies that the phase angle of a carrier is varied in accordance with the modulating audio voltage, whereas the current amplitude of the resulting phase modulated wave is maintained constant.

When a phase-modulated wave is seen on an oscilloscope, it looks like a frequency-modulated wave; that is, the phase-modulated wave varies in frequency and has a constant current amplitude. Thus, as in a frequency-modulated wave the power in the phase-modulated wave does not change.

A PM wave is produced by shifting the phase of the carrier with respect to the modulating voltage while keeping the amplitude of the carrier constant. A transmitter utilizing phase modulation uses phase-shifting circuits following the oscillator that slows down or speeds up the frequency of the carrier.

Figure 37A illustrates the unmodulated RF carrier. The amplitude and frequency of the carrier are constant.

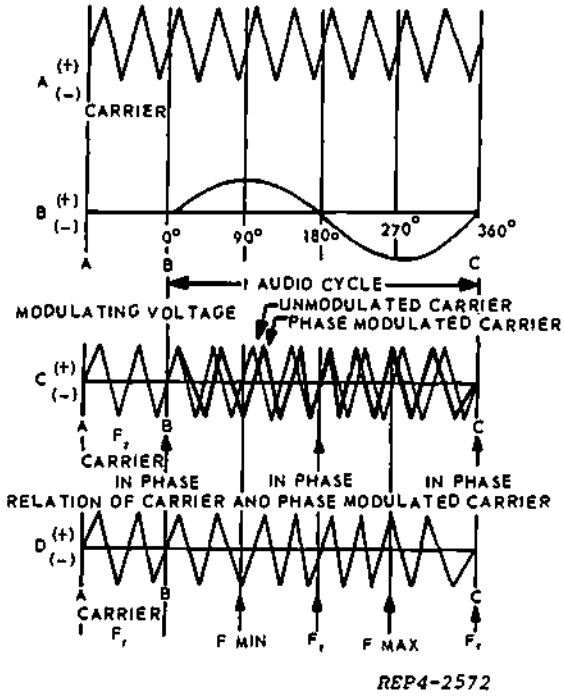



Figure 37. The Phase-Modulated Wave

Figure 37B illustrates a sine-wave audio voltage which modulates the carrier. During time interval A to B no modulating voltage is applied to the carrier. During time interval B to C the single sine-wave of audio voltage modulates the carrier.

Figure 37C shows the phase shifting of the carrier to the resulting phase-modulated wave. The unmodulated carrier is shown as a thin-line. The thin line wave is used as the reference wave to show the phase shifting of the carrier to the resulting phase-modulated wave. The resulting phase-modulated wave is represented by the heavy-line wave in figure 37.

In figure 37D we see the resulting phase modulated waveform. This waveform is the output waveform of the phase modulator. Note that in the time interval from A to B, when the carrier is not modulated, the output of the modulator is the carrier frequency ($F_c$). In the time interval from B to C, the carrier is modulated and the resulting output waveform of the modulator is seen to be varying in frequency.

Note that when the carrier is modulated by the positive half cycle o the modulating signal in figure 37B (0° to 180°), the phase of the modulated wave in figure 37C leads the phase of the original reference carrier. Likewise, when the carrier is modulated by the negative half cycle of the modulating voltage in figure 37B (180° to 360°) the phase of the modulated wave in figure 37C lags the phase of the original reference carrier.

The rate at which a phase-modulated wave shifts from one phase to another is proportional to the frequency of the modulating voltage. The higher the frequency, the more rapidly the phase of the modulated wave shifts.

The number of degrees through which the phase of the carrier is shifted is proportional to the amplitude of the modulating voltage. The greater the amplitude of the modulating voltage, the greater the number of degrees through which the phase-modulated carrier is shifted during modulation.

When an RF carrier is phase modulated, we generate sidebands. The sidebands produced in phase-modulation are spaced on either side of the carrier signal by an amount equal to the modulating signal frequency. The amplitude of the modulating signal determines the number of significant sidebands in phase-modulation. Increasing the amplitude of the modulating signal increases the number of significant sidebands.

Increasing the frequency of the modulating signal while leaving the amplitude constant will not increase the number of significant sidebands.

Figure 38A shows the spectrum for a carrier modulated with a 10 kHz signal. Figure 38B shows the spectrum for a carrier modulated with a 5 kHz signal. Both modulating signals had the same amplitude. Note that there are 10 significant sidebands in each spectrum. Also note that only the BW of the transmitted spectrum changes as the frequency changes. In PM, increasing the frequency or amplitude of the modulating signal increases the BW of the transmitted signal.

---

QUICK QUIZ 21

1. In phase modulation the phase of the carrier is varied in accordance with amplitude and frequency of the intelligence signal. True/False

2. In phase modulation the frequency of the carrier oscillator is caused to shift, resulting in a phase shifted signal. True/False

3. What determines the spacing of the sidebands in phase modulation?

---


SPECTRUM FOR CARRIER MODULATED WITH A 10 kHz SIGNAL

SPECTRUM FOR CARRIER MODULATED WITH A 5 kHz SIGNAL

REP4-1298

Figure 38. PM Spectrum

ANSWERS TO QUICK QUIZ 21

1. true
2. false
3. The frequency of the intelligence signal.

SUMMARY QUIZ 3

1. Two types of angle modulation are:

   a. frequency and phase modulation
   b. frequency and amplitude modulation
   c. amplitude and phase
   d. heterodyning and frequency modulation

2. Match the terms and definitions:

   a. ______ carrier

   b. ______ heterodyne

   c. ______ modulation

   d. ______ intelligence signal

   e. ______ sidebands

- - - - - - - - - - - - - - - - - - - - - - -

1. An electrical wave or impulse that conveys an idea or expression.

2. An assigned reference frequency.

3. Frequency bands on either side of the carrier containing the frequencies produced by modulation.

4. The process of mixing two or more frequencies in a non-linear impedance resulting in the production of new frequencies.

5. An intelligence signal changing either the amplitude, frequency, or phase of a basic sine wave.

3. In an amplitude modulation spectrum, the spacing of the sidebands is determined by:

   a. the amplitude of the modulating frequency.

   b. the frequency of the modulating frequency.

   c. The Bessel Function.

   d. the amplitude and frequency of the carrier.

4. When a carrier is amplitude modulated with a composite wave consisting of five frequencies, the spectrum will contain ______ LSB frequencies and ______ USB frequencies.

5. In AM, when the amplitude of the modulating signal equals the amplitude of the carrier, the % of modulation is:

   a. zero
   b. 100%
   c. 50%
   d. fine

6. In single sideband transmission, the output of the transmitter contains

   a. the carrier and the USB frequencies.

   b. the carrier, modulating signal and sideband frequencies.

   c. either USB or LSB frequencies only but not both.

   d. both USB and LSB frequencies.

7. In SSB, the output of the balanced modulator contains the:

   a. USB and LSB frequencies only.

   b. Carrier and LSB frequencies.

   c. Carrier and USB frequencies.

   d. One SB frequency.

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## ANSWERS TO QUICK QUIZ 19

1. true
2. frequency
3. amplitude

## ANSWERS TO QUICK QUIZ 20

1. bias
2. frequency
3. amplitude

## PHASE MODULATION

In FM, the transmitter oscillator changes frequency above and below the center frequency as the modulating signal is applied. In phase modulation (PM), the transmitter oscillator frequency s not changed during the modulation process. In fact the PM system usually employs a crystal oscillator and the phase of the output is caused to change.

Phase modulation implies that the phase angle of a carrier is varied in accordance with the modulating audio voltage, whereas the current amplitude of the resulting phase modulated wave is maintained constant.

When a phase-modulated wave is seen on an oscilloscope, it looks like a frequency-modulated wave; that is, the phase-modulated wave varies in frequency and has a constant current amplitude. Thus, as in a frequency-modulated wave the power in the phase-modulated wave does not change.

A PM wave is produced by shifting the phase of the carrier with respect to the modulating voltage while keeping the amplitude of the carrier constant. A transmitter utilizing phase modulation uses phase-shifting circuits following the oscillator that slows down or speeds up the frequency of the carrier.

Figure 37A illustrates the unmodulated RF carrier. The amplitude and frequency of the carrier are constant.

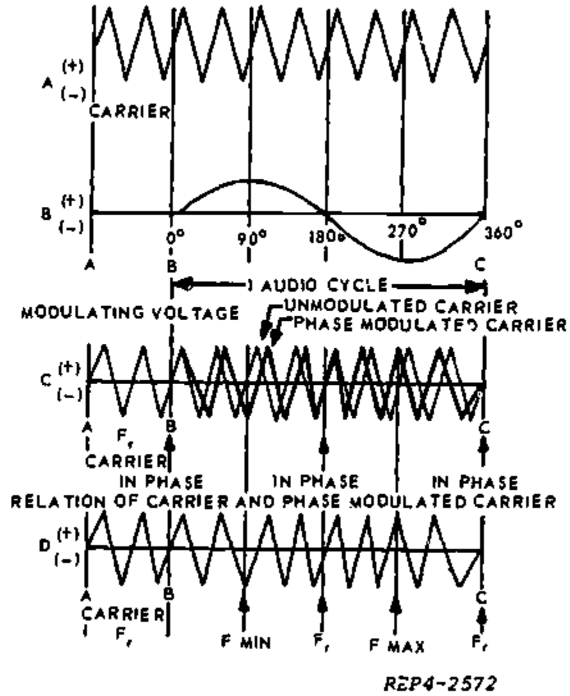


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Figure 37B illustrates a sine-wave audio voltage which modulates the carrier. During time interval A to B no modulating voltage is applied to the carrier. During time interval B to C the single sine-wave of audio voltage modulates the carrier.

Figure 37C shows the phase shifting of the carrier to the resulting phase-modulated wave. The unmodulated carrier is shown as a thin-line. The thin line wave is used as the reference wave to show the phase shifting of the carrier to the resulting phase-modulated wave. The resulting phase-modulated wave is represented by the heavy-line wave in figure 37.

In figure 37D we see the resulting phase modulated waveform. This waveform is the output waveform of the phase modulator. Note that in the time interval from A to B, when the carrier is not modulated, the output of the modulator is the carrier frequency ($F_C$). In the time interval from B to C, the carrier is modulated and the resulting output waveform of the modulator is seen to be varying in frequency.



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ANSWERS TO QUICK QUIZ 21

1. true
2. false
3. The frequency of the intelligence signal.

SUMMARY QUIZ 3

1. Two types of angle modulation are:

   a. frequency and phase modulation
   b. frequency and amplitude modulation
   c. amplitude and phase
   d. heterodyning and frequency modulation

2. Match the terms and definitions:

   a. ______ carrier

   b. ______ heterodyne

   c. ______ modulation

   d. ______ intelligence signal

   e. ______ sidebands

---

1. An electrical wave or impulse that conveys an idea or expression.

2. An assigned reference frequency.

3. Frequency bands on either side of the carrier containing the frequencies produced by modulation.

4. The process of mixing two or more frequencies in a non-linear impedance resulting in the production of new frequencies.

5. An intelligence signal changing either the amplitude, frequency, or phase of a basic sine wave.

3. In an amplitude modulation spectrum, the spacing of the sidebands is determined by:

   a. the amplitude of the modulating frequency.

   b. the frequency of the modulating frequency.

   c. The Bessel Function.

   d. the amplitude and frequency of the carrier.

4. When a carrier is amplitude modulated with a composite wave consisting of five frequencies, the spectrum will contain ______ LSB frequencies and ______ USB frequencies.

5. In AM, when the amplitude of the modulating signal equals the amplitude of the carrier, the % of modulation is:

   a. zero
   b. 100%
   c. 50%
   d. fine

6. In single sideband transmission, the output of the transmitter contains

   a. the carrier and the USB frequencies.

   b. the carrier, modulating signal and sideband frequencies.

   c. either USB or LSB frequencies only but not both.

   d. both USB and LSB frequencies.

7. In SSB, the output of the balanced modulator contains the:

   a. USB and LSB frequencies only.

   b. Carrier and LSB frequencies.

   c. Carrier and USB frequencies.

   d. One SB frequency.

8. In pulse modulation, when a carrier is modulated by a square wave, sidebands are generated that correspond to:

a. The odd and even harmonics.

b. The fundamental frequency and each odd harmonic.

c. The fundamental frequency and each even harmonic.

d. The fundamental frequency only.

9. In FM, rate of modulation is determined by the amplitude of the modulating signal. True/False

10. In FM, how many sidebands are generated when modulation occurs?

11. In FM, the amount of frequency deviation is determined by the ________ of the modulating frequency.

12. In the FM oscillator, the frequency of the oscillator is caused to shift in accordance with the rate and amount of the ________ signal.

13. In phase modulation, the phase of the carrier is caused to shift after it leaves the oscillator. True/False

14. In phase modulation, the amount of shift is determined by the frequency of the intelligence signal. True/False

15. In amplitude, frequency and phase modulation; the sideband spacing is determined by:

a. Rate and amount of the modulating signal.

b. Frequency of the modulating signal only.

c. Amplitude of the modulating signal only.

d. None of the above.

ANSWERS TO SUMMARY QUIZ 3

1. a
2. a-2 c-5 e-3
   b-4 d-1
3. b
4. five, five
5. b
6. c
7. a
8. b
9. false
10. infinite number
11. amplitude
12. intelligence or audio
13. true
14. false
15. b

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Basic and Applied Electronics Dept.
Keesler Air Force Base, Mississippi

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This programmed text was prepared at Keesler Technical Training Center. It consists of one module which analyzes the principles of demodulation.

The program was designed for use in the basic airman electronic principles course, 3AQR3X020-X. The material contained herein has been validated using airman students who met the course input criteria. Eighty percent of the students scored at least eighty percent on the master validation examination. The average student required 4 hours to complete the program.

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# PROGRAMMED INSTRUCTION PACKAGE

## MODULE 65 - DEMODULATION

This program will take you through the subject one step at a time. Each area will teach you a small bit of information. At the end of each short area, there are questions to be answered. The answers to the questions are on the top of the next even numbered page.

Read the text carefully, answer the Quick Quiz and then check your work. Do not move on until you are sure you know the subject completely. If you need help, consult your instructor.

OBJECTIVES:

1. Given a list of statements about demodulation, select the one that describes:
   a. AM
   b. sideband
   c. pulse
   d. phase
   e. FM
2. Given schematic diagrams of AM demodulators, match each with:
   a. diode detector.
   b. grid leak detector.
   c. plate detector.
   d. infinite-impedance detector.
3. Given a list of statements, match each with the schematic of:
   a. Foster-Seeley discriminator.
   b. ratio detector.
   c. quadrature detector.

## DEMODULATION

One of the many things that take place in a radio receiver is the demodulation of the radio wave that has been picked up by the antenna. Actually, demodulation is the process of reproducing the intelligence from the modulated wave. You recently found that the modulated wave leaving the transmitter did not contain the original intelligence signal as a separate frequency. The intelligence was represented by the spacing between the carrier and the sideband frequencies. In order to reproduce the intelligence in the receiver, the carrier and sideband frequencies must be heterodyned together. The difference frequency developed by this action will be a reproduction of the original intelligence.

The requirements that must be met for demodulation to take place are as follows:

a. The demodulator input circuit must be sensitive to the type of modulation that was used in the transmitter. For example, if the frequency of the carrier was varied in the transmitter, then the demodulator input circuit must be sensitive to frequency changes.

b. Both the carrier and sideband frequencies must be present.

c. Nonlinearity must be present so that heterodyning can take place.

d. A filter must be used at the output of the demodulator to remove all of the unwanted frequencies.

QUICK QUIZ 1

1. The modulated wave leaving the transmitter does not contain the intelligence frequency. True/ False

2. The purpose of demodulation is to heterodyne the carrier and intelligence frequencies. True/False

3. If the carrier is absent, demodulation cannot take place. True/False

4. The purpose of the filter is to remove the intelligence frequency. True/False

Check your answers at the top of the next even numbered page.

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AM Demodulation

There are several types of AM demodulators that are used to reproduce the intelligence from an amplitude modulated wave. These circuits are often called AM Detectors.

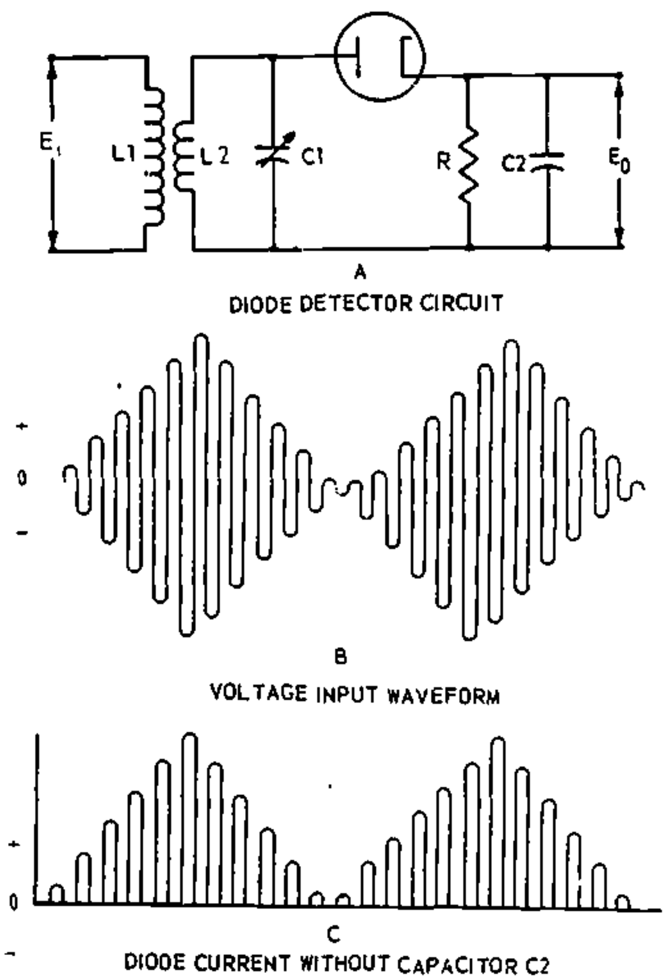


Figure 1. Diode Detector Circuit and Waveforms

The diode detector shown in figure 1A is one of the more common types. The input tank circuit is made up of L2 and C1 and is tuned to the carrier frequency. The bandwidth of this tank circuit is wide enough to pass all of the sideband frequencies. When these frequencies are applied to the nonlinear vacuum tube, heterodyning takes place. Capacitor C2 supplies the filtering action to take out all of the unwanted frequencies. Resistor, R, develops the low frequencies, which will be a reproduction of the intelligence. Assume that we have a 455 kHz carrier modulated with a 5 kHz signal. The composite wave coming in will consist of three frequencies, a 455 kHz carrier, a lower sideband of 450 kHz, and the upper sideband of 460 kHz. This composite waveform is fed to the detector input as shown in figure 1B. Current flows through the diode only when the plate is positive with respect to the cathode. As a result of this nonlinear action, the output waveform will be a series of RF pulses as shown in figure 1C. Since the carrier and sideband frequencies have been heterodyned together, the output waveform now contains other frequencies in addition to those found at the input. These are:

a. 905 kHz, the sum of the carrier (455 kHz) and the LSB (450 kHz).

b. 915 kHz, the sum of the carrier (455 kHz) and the USB (460 kHz).

c. 5 kHz, the difference between carrier (455 kHz) and the two sideband frequencies.

All of these frequencies are fed to the filter network consisting of R and C2. The filter is designed to offer a path of low impedance to high frequencies. This will cause the 450, 455, 460, 905, and 915 kHz signals to be passed to ground. This filter also offers a high impedance to low frequencies so the 5 kHz is reproduced across R and is present at the output.

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QUICK QUIZ 2

1. In figure 1, the vacuum tube serves as:

   a. an infinite impedance.
   b. a nonlinear impedance.
   c. a constant resistance.
   d. an AM Modulator.

2. If an AM wave is fed to a diode detector and consisted of a 455 kHz carrier, a LSB of 445 kHz and an USB of 465 kHz, what will the demodulated intelligence frequency be? _____

3. In figure 1, the tank circuit consisting of L2 and C1 is tuned to:

   a. the USB frequency.
   b. the LSB frequency.
   c. the carrier frequency.
   d. the intelligence frequency.

4. Another common name for an AM Demodulator is ____________________.

Check your answers at the top of the next even numbered page.

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Grid Leak Detector

Figure 2 shows another AM demodulator called the Grid Leak Detector. It functions in much the same way as the diode detector except that since we are using a triode, amplification will take place.

ANSWERS TO QUICK QUIZ 1

1. True
2. False
3. True
4. False

ANSWERS TO QUICK QUIZ 2

1. a nonlinear impedance.
2. 10 kHz
3. the carrier frequency.
4. AM Detector

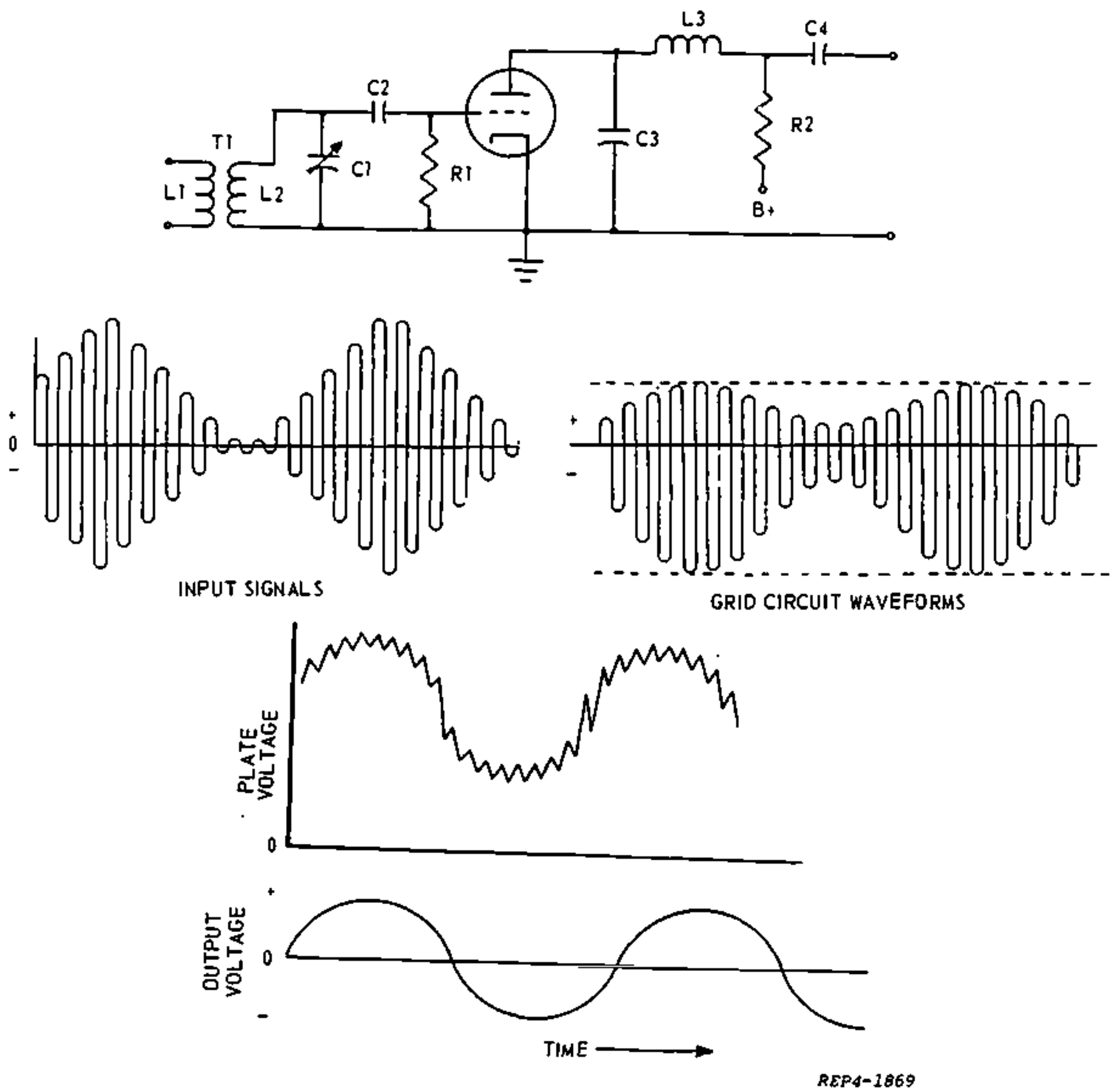


Figure 2. Grid-Leak Detector, Schematic and Waveforms

The input tank circuit is sensitive to amplitude changes the same as in the diode detector and is tuned to the carrier frequency. When an input wave appears across the tank circuit, the grid leak capacitor charges very fast through the tube from cathode to control grid on the positive half cycles. On the negative half cycles, the grid capacitor discharges very slowly through the large resistor R1. This forms the bias that develops the grid waveform as shown in figure 2. This grid waveform contains the carrier, USB and LSB frequencies as well as their sum and difference frequencies. This waveform is then amplified by the triode tube and filtered in the plate circuit. C3 and L3 filter out the high frequencies while the low frequencies are developed across the plate load resistor R2 and coupled through C4 to the next stage. In the grid leak detector, the impedance is low because grid current must flow to allow the heterodyning action to take place within the grid circuit.

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QUICK QUIZ 3

1. Heterodyning is not needed in the grid leak detector. True/False

2. When the input signal goes positive,

   a. current flows from cathode to control grid.

   b. current flows from R1 to the cathode.

   c. current flows from plate to cathode.

   d. the current stops flowing in the circuit.

3. In the grid leak detector, bias is developed by

   a. current from cathode to plate.

   b. capacitor discharge from grid to plate.

   c. capacitor discharge through the grid resistor.

   d. current flow from cathode to control grid.

4. The grid waveform contains only the demodulated waveform. True/ False

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Plate detector

The plate detector is shown in figure 3. This circuit has a high input impedance because the grid current does not flow during the entire input cycle of the RF signal.

The circuit made up of L2 and C, reacts to amplitude changes and takes care of the first of the requirements for demodulation. Heterodyning takes place in the triode tube because the cathode self bias resistor is large enough to insure that the stage is biased very close to cut off. The cathode by-pass capacitor C1 is large and holds the voltage across R1 steady even at the lowest audio frequencies. The filtering action is taken care of by the network of C2 and L3. Figure 3B shows the waveforms that are found in the plate detector. On the positive half cycle of the input RF signal, the plate voltage goes down due to the increase in the voltage drop across the plate load resistor R2 and filter choke L3. Filter capacitor C2 discharges through the conducting tube. The voltage drop across R2 and L3 is small so the drop in plate

ANSWERS TO QUICK QUIZ 3

1. False    2. a    3. c    4. False

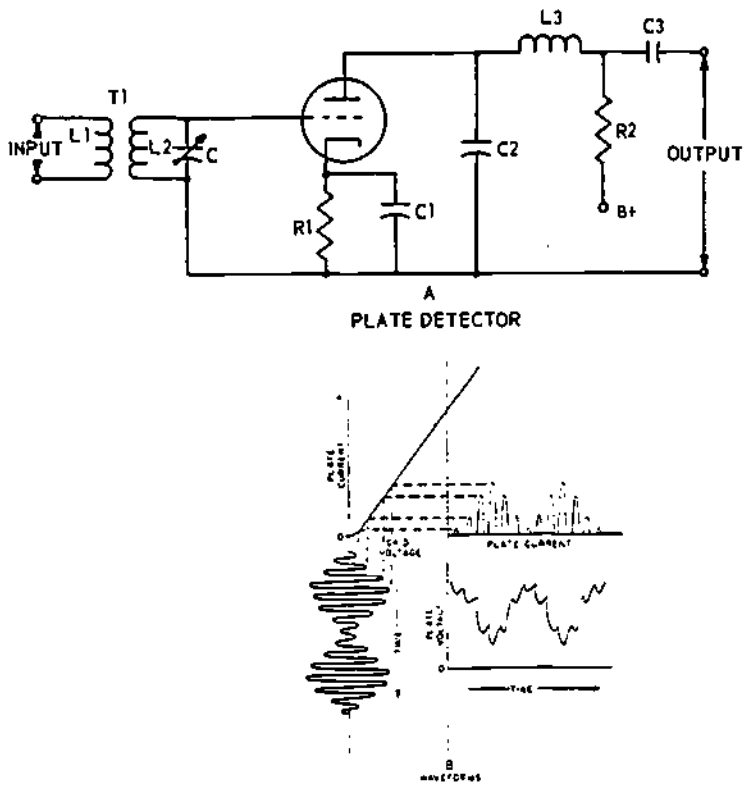


Figure 3. Plate Detector Schematic and Waveforms

voltage is very small. When the input RF signal goes negative, the plate current goes down and the plate voltage goes up. C2 now charges through L3 and R2. The quick voltage changes are resisted by R2 and L3. Therefore, the voltage change across the filter capacitor C2 which is felt at the output will be at an audio (intelligence) rate.

QUICK QUIZ 4

1. Filtering action that reproduces the intelligence is accomplished by

   a. R1 and C1
   b. C2 and L3
   c. L3 and R2
   d. L2 and C

2. Bias is formed by

   a. R1 and C1
   b. L2 and C
   c. cathode to grid resistance

3. In the plate detector, the input signal amplitude develops the tube bias. True/False

4. When the input signal goes negative, the plate voltage increases. True/False

Check your answers at the top of the next even numbered page.

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Infinite Impedance Detector

The Infinite Impedance Detector is shown in figure 4. It looks very much like the plate detector. However, you should notice that the output is now taken from the cathode. Essentially, the infinite impedance detector is a cathode follower with a cathode bypass capacitor to filter out the high frequencies and to develop the low frequencies.

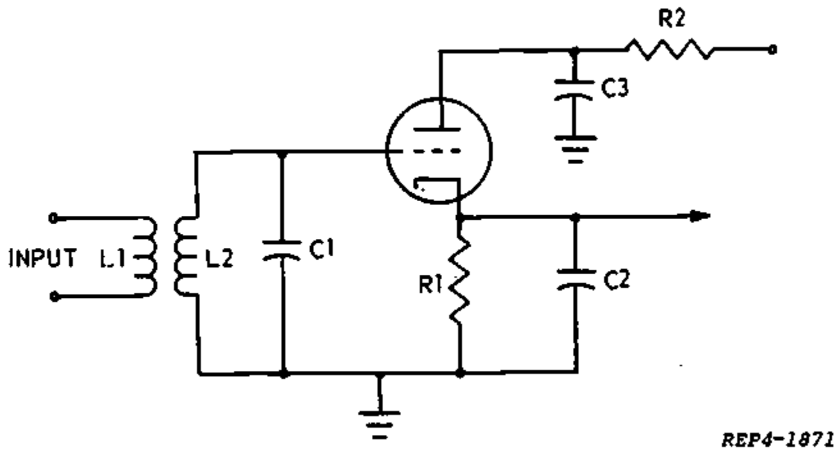


Figure 4. Infinite Impedance Detector.

The input tank circuit responds to input amplitude changes to fill the first demodulator requirement. The tube serves as the nonlinear impedance to produce heterodyning. R1 and C2 take care of the filtering. The input impedance for this circuit is very high. Therefore the grid voltage stays negative even when the input signal is very high. C3 and R2 in the plate circuit act as an RF bypass filter and prevent the RF changes from entering the B+ power supply.

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QUICK QUIZ 5

1. The infinite impedance detector is essentially

   a. an amplifier.
   b. a cathode follower.
   c. a low impedance circuit.
   d. a grid leak filter.

2. The grid is negative only when the input signal is negative. True/False

3. C2 develops the low frequencies and filters the high frequencies. True/False

4. C2 and R2 are required to develop the output signal. True/False

Check your answers at the top of the next even numbered page.

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ANSWERS TO QUICK QUIZ 4

1. b    2. a    3. True    4. True

ANSWERS TO QUICK QUIZ 5

1. b    2. False    3. True    4. False

Single Sideband

You will remember that when you studied single sideband transmission, the carrier and intelligence were heterodyned to develop the USB and LSB. Then the carrier was suppressed and one sideband was filtered out so that the only frequency that was transmitted was the remaining sideband. We also found previously, that the intelligence signal was not transmitted but was represented by the space between the carrier and sidebands in the transmitted wave. Since the reference (carrier) frequency is not transmitted, the signal arriving at the receiver is useless by itself. Therefore, we will re-establish the same carrier frequency within the receiver to heterodyne with the incoming sideband frequency.

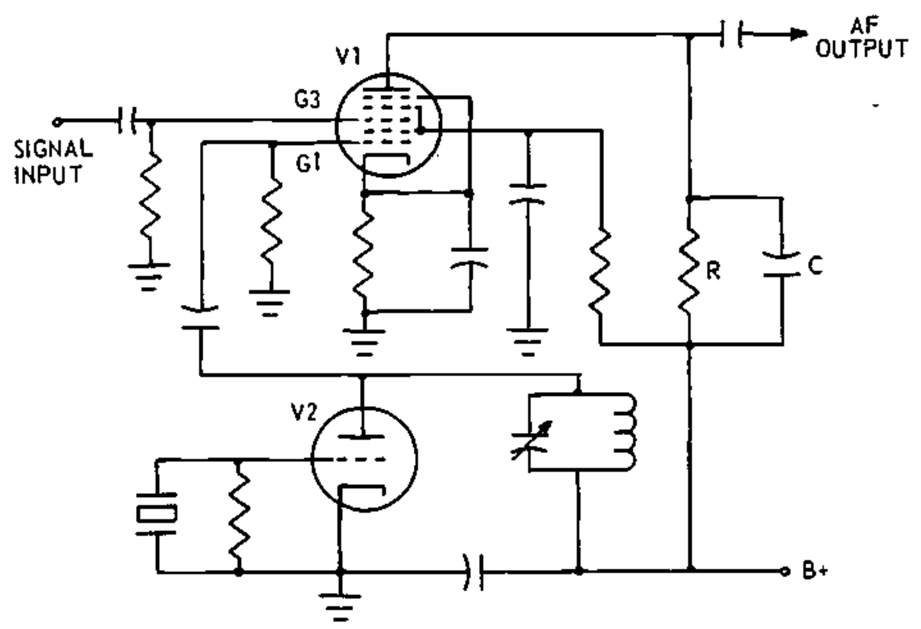


Figure 5. Product Detector Schematic

Figure 5 shows a product detector circuit used to demodulate single sideband waves. V1 is the demodulator that provides the nonlinearity for heterodyning and is sensitive to amplitude changes. V2 is a crystal controlled oscillator tuned to the same frequency as the transmitter carrier. The oscillator signal and input sideband frequencies are heterodyned in V1. In the plate circuit of V1 will be found the composite wave consisting of the oscillator signal, input signal, and their sum and difference frequencies. R and C filter out the high frequencies and develop the low frequencies which will be the audio intelligence.

QUICK QUIZ 6

1. The crystal controlled Oscillator V2 is used to

   a. heterodyne with the carrier frequency.

   b. tune the receiver.

   c. provide a reference frequency for demodulation.

   d. provide a modulated output.

2. Filtering is accomplished by

   a. the parallel tank in the plate circuit of V1.

   b. R and C

   c. the RC network at the input to V1.

3. The signal at the input to the demodulator consists of the carrier and only one sideband. True/False

4. V1 is sensitive to amplitude changes and provides nonlinearity. True/False

Check your answers at the top of the next even numbered page.

Pulse

Pulse demodulation is a process of reproducing a pulse from a pulse modulated RF waveform. A typical pulse detector is shown in figure 6. You may notice that the pulse demodulator is essentially a diode detector with a few modifications.

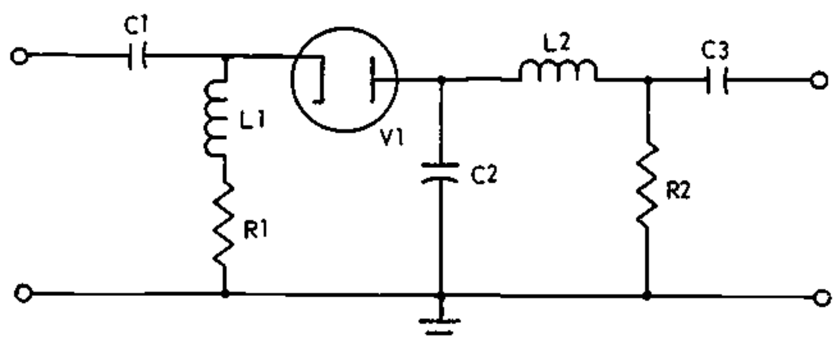


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Figure 6. Pulse Detector

You should recall that in a pulse modulated wave there were many upper and lower sideband frequencies. This caused the transmitted wave to have an extremely wide bandwidth. Therefore, in order to accurately reproduce the pulse, the input circuit to the demodulator must also have a very wide bandwidth. As in the diode detector, V1 is the required nonlinear device, L2 and C2 is the filter, and the pulse signal is developed across R2. C1, L1, and R1

ANSWERS TO QUICK QUIZ 6

1. c  2. b  3. False  4. True

have been added to widen the bandwidth of the circuit. This insures proper reproduction of the original pulse that was used in the modulation process.

QUICK QUIZ 7

1. A wide bandwidth is necessary to reproduce a pulse. True/False

2. The filter requirement is accomplished by

   a. C1 and L1

   b. C2 and L2

   c. Neither of the above, not required.

Check your answers at the top of the next even numbered page.

SUMMARY QUIZ 1

1. Name the four requirements for demodulation.

2. In an AM demodulator, if the input wave consisted of a 455 kHz carrier, a lower SB of 440 kHz and an upper SB of 470 kHz, what would be the intelligence frequency?

3. In an AM detector that uses an input tank circuit, the center frequency of the circuit will be tuned to

   a. the carrier frequency.
   b. the intelligence frequency.
   c. the sum frequency.
   d. the LSB frequency.

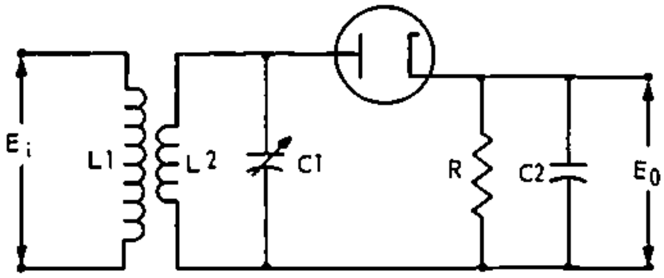
4. The output from a grid leak detector is from the plate circuit. True/False

5. An infinite impedance detector is essentially a

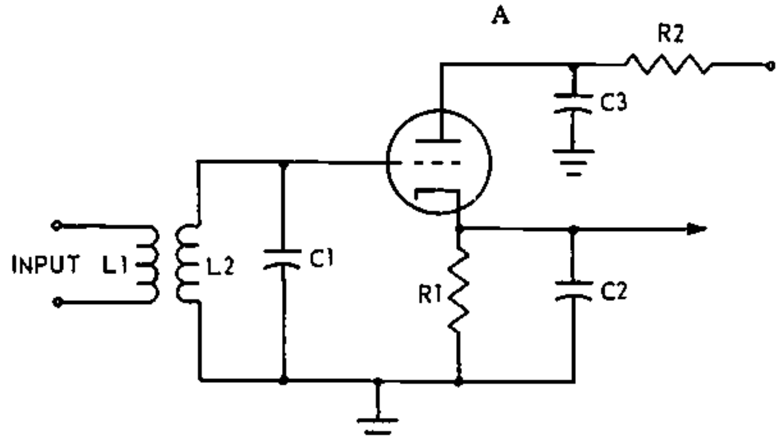
   a. low impedance device.
   b. filter input circuit.
   c. grid modulator.
   d. cathode follower.

6. Which of the following is a requirement for single sideband demodulation?

   a. An input filter.
   b. Reference frequency insertion.
   c. Frequency multipliers.
   d. An output from the cathode circuit.




A




B

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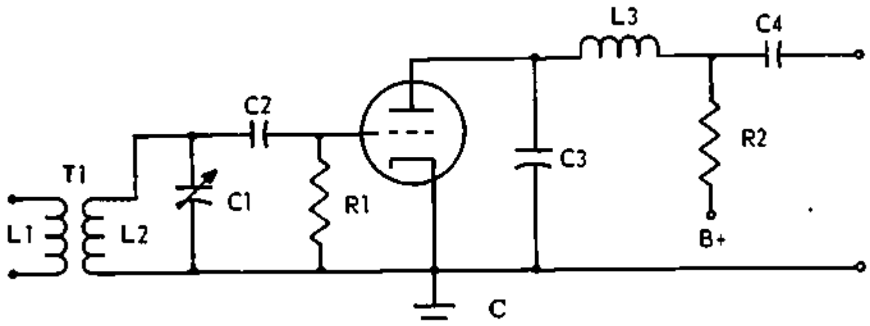
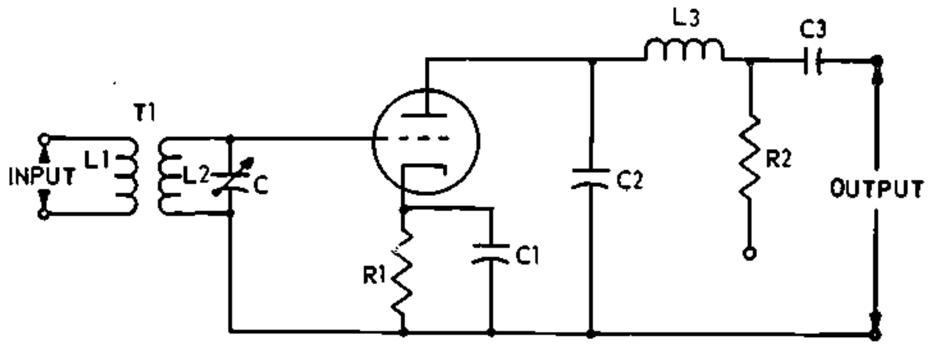



C




D

Match the four schematics of demodulators to the following:

7. __________ Grid leak detector.

8. __________ Diode detector.

9. __________ Infinite impedance detector

10. __________ Plate detector.

ANSWERS TO QUICK QUIZ 7

1. True  2. b

ANSWERS TO SUMMARY QUIZ 1

1. a. Circuit sensitive to type of modulation used.
   b. Nonlinearity
   c. Filtering
   d. Carrier and sideband frequencies must be present.
2. 15 kHz
3. a
4. True
5. d
6. b
7. c
8. a
9. b
10. d

FM Demodulation

In Frequency Modulation you learned that during the process of modulation the varying amplitude of the intelligence signal caused the carrier to shift above and below its center frequency. In order to demodulate the FM signal, the demodulator must contain a circuit that can sense these frequency changes and convert them into amplitude (voltage) changes. The circuit in the FM receiver that can reproduce the intelligence from the FM wave is called the Frequency Discriminator or FM Detector. The requirements for FM demodulation are:

a. an input circuit that converts frequency variations into amplitude variations.

b. a nonlinear impedance to be used in the heterodyning process.

c. a filter to remove the unwanted frequencies.

d. a load to develop the output signal.

QUICK QUIZ 8

1. Two commonly used names for an FM demodulator are:

   a. ____________________  b. ____________________

2. The first requirement for FM demodulation is that the input circuit must convert ____________________ variations into ____________________ variations.

3. The other three requirements for FM demodulation are:

   a. ____________________  c. ____________________

   b. ____________________

Check your answers at the top of the next even numbered page.

Foster-Seeley Discriminator

The Foster-Seeley discriminator shown in figure 7 has all of the requirements for FM demodulation. The input tank circuit, L2, L3, L4, and C1 converts frequency variations into voltage variations. Diodes V1 and V2 are the nonlinear impedances necessary for heterodyning. The RF filtering is taken care of by C2 and C3. Load resistors R1 and R2 develop the output intelligence signal.

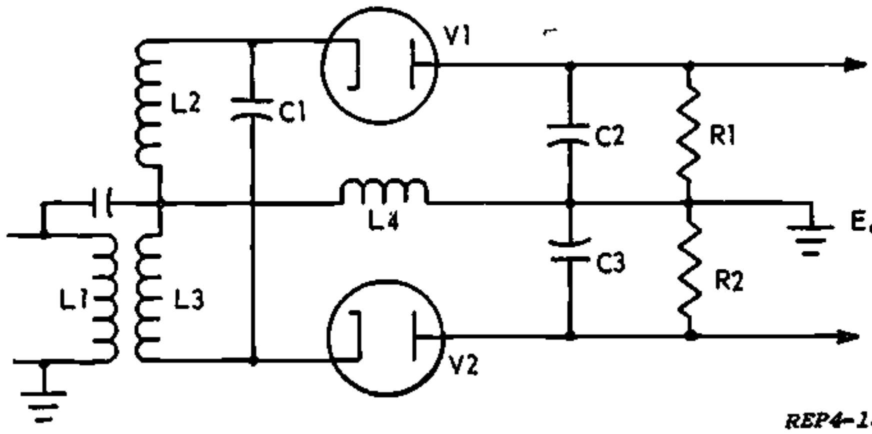



Figure 7. Foster-Seeley Discriminator

The Foster-Seeley discriminator is a phase shift circuit. When a varying frequency is applied to L1 the resulting phase shift across the transformer causes more or less voltage to be induced into the secondary windings consisting of L2 and L3. For example, when the carrier frequency is fed to L1, and equal amount of voltage is induced into L2 and L3. This causes V1 and V2 to conduct an equal amount. Current flows from the top of L2, through V1, R1, L4 and back to the bottom of L2. This drops a negative voltage across R1. At the same time current flows from the bottom of L3 through V2, R2, and L4 to the top of L3. This causes a positive voltage to be dropped across R2. Notice that the output is taken across both output resistors. If the same amount of current flows through both resistors and they are of equal value, they will drop the same amount of voltage. So, when the input signal is the carrier frequency, there is zero volts out. When the input frequency goes above the carrier frequency, more voltage is induced into L2 and less into L3. V1 now conducts harder and V2 conducts less. This results in a large negative voltage drop across R1 and a small positive voltage dropped across R2. The algebraic sum at the output is a negative DC. When the input frequency goes below the carrier frequency, more voltage is induced into L3 and less into L2. This causes V2 to conduct hard and V1 to conduct less. The algebraic sum at the output is now positive. As a summary of this action we could say, if the input frequency swings above the carrier reference, the DC output goes negative. When the input frequency swings below the carrier reference, the DC output goes positive, also the farther the input frequency swings above the carrier reference, the more current flows in the circuit and the higher the DC voltage that is dropped across the load resistors. In this manner the changing frequency is converted into a changing DC voltage which is a replica of the original intelligence.

There is one feature of the Foster-Seeley discriminator that must be considered. The design of the circuit will permit any amplitude changes at the input to cause amplitude changes in the output. This means that amplitude changes caused by noise will be heard in the output. This disadvantage can be eliminated by preceeding the discriminator with a limiter. This clips the noise amplitude variations and leaves the varying frequency.

ANSWERS TO QUICK QUIZ 8

1. a. Frequency discriminator. b. FM detector.

2. frequency, voltage

3. a. Nonlinear impedance b. Filter c. Load

QUICK QUIZ 9

1. If the input to the Foster-Seeley is the carrier frequency, what is the output?

2. Where is the output taken from the Foster-Seeley?

3. Which components filter out the unwanted frequencies?

4. When the input frequency goes above the carrier reference, what happens to the current through V2?

Check your answers at the top of the next even numbered page.

Ratio Detector

The ratio detector, shown in figure 8, is very similar to the Foster-Seeley discriminator. You should notice that the input circuit composed of L1, L2, L3, and C1 are exactly the same. You should also notice that diodes V1 and V2 are now connected in series. The output in this circuit is taken across only a part of the load giving it the name, ratio detector.

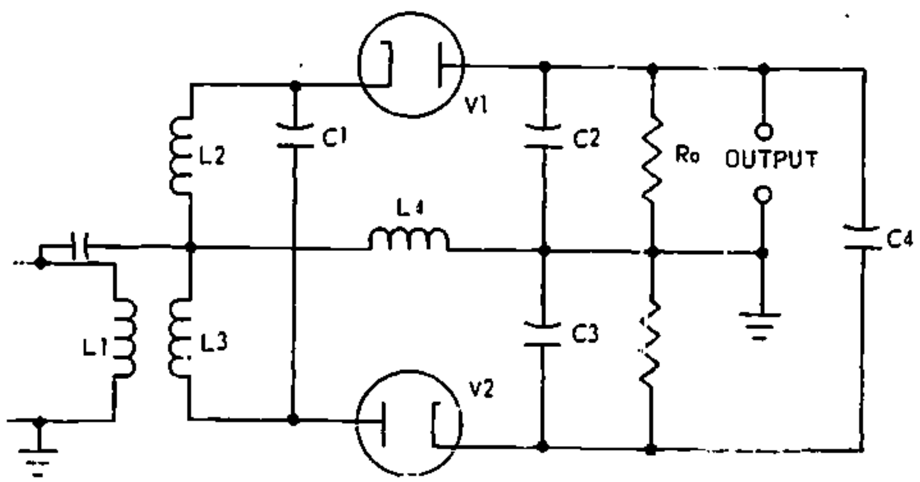



Figure 8. Ratio Detector

The input circuit operates the same as in the Foster-Seeley, converting frequency changes into voltage changes. The resulting voltages cause a voltage drop across the two load resistors at the output. When the input consists of the carrier frequency, there will be current through V1 and a voltage drop across the output resistor $R_o$. This will be the reference rather than zero volts as in the Foster-Seeley. As the input frequency increases and decreases, the voltage will vary across the output resistor. Sharp increases in amplitude such as that caused by noise, is compensated for by capacitor C4. Since C4 is a large capacitor, it works with $R_0$ to form a long time constant. Sharp increases are absorbed by the capacitor because it takes a long time to charge. since the circuit is not effected by sudden amplitude changes, it does not need to be proceeded by a limiter. The features that help in identifying the ratio detector are as follows:

a. The diodes are connected in series.

b. The output is taken across only half the load.

c. The circuit does not need to be preceeded by a limiter.

---

QUICK QUIZ 10

1. The input circuit to the Ratio Detector is the same as that in the Foster-Seeley. True/False

2. Which components remove the unwanted frequencies?

3. What is the function of V1 and V2?

4. What is the purpose of C4?

Check your answers at the top of the next even numbered page.

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Quadrature Detector

The Quadrature Detector is shown in figure 9. This detector uses a completely different principle that those just covered. The tube is self limiting and therefore it is not effected by sharp amplitude changes such as those made by noise. For this reason, it does not have to be preceeded by a limiter.

In this tube, a focusing device forms a shield around the cathode. The shield has a narrow slot that allows the electron beam to pass. This is indicated by the cross shaped cathode symbol. The limiter grid acts like a gate, when the gate is open the electrons will flow through it toward the screen grid. The screen grid refocuses the beam toward the quadrature grid. The quadrature grid also acts as a gate and can either pass or block the flow of electrons. In this tube either the limiter or quadrature grid is able to cut off the flow of plate current. Plate current will only flow when both gates are open. Now look at the circuit at the top of figure 9. Note that the screen grid has been removed since it is not needed in this explanation. The input signal will be like the one as shown in figure 9c.

When the current passes the limiter grid it has a waveshape as in figure 9d. Note that this is a square wave. The electron beam will induce a current into the quadrature grid that will develop a voltage across the high Q tank circuit. The tank now begins to oscillate but is shifted in phase by 90°. This is shown in figure 9E. Since the quadrature grid has the same conduction and cutoff levels as the limiter grid, the wave will be cut to a square wave. See figure 9F. Both grids must be positive at the same time in order to have plate current. You can see in figure 9G, where the current waves are overlapped, how much time current actually flows for each cycle of the input signal. The time plate current actually flows is shown in figure 9H.

ANSWERS TO QUICK QUIZ 9

1. Zero volts
2. Across load resistors R1 and R2
3. C2 and C3
4. Decreases

ANSWERS TO QUICK QUIZ 10

1. True
2. C2 and C3
3. Nonlinear impedances to provide heterodyning of the sidebands and carrier.
4. A large capacitance used to absorb sharp increases in amplitude such as noise.

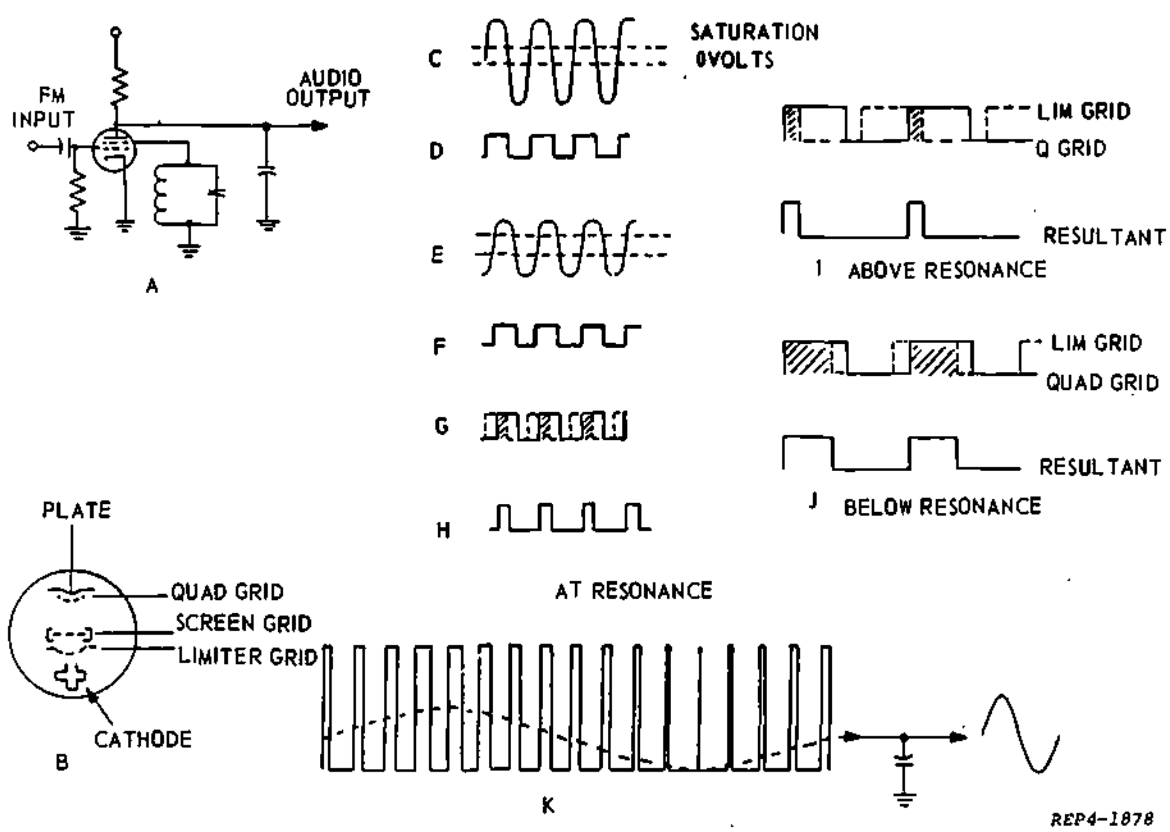


Figure 9. Quadrature Detector

The frequency of this pulse is the same as that found at the input to the limiter grid. Now lets see what happens when there is a change in frequency at the input. If the frequency goes down, the voltage across the quadrature tank also goes down in frequency. This allows both gates to be open for a longer time so plate current will flow longer. Note the overlap of the two signals and wide plate current wave shape in figure 9J. When the input frequency goes up, just the opposite will take place. The two grid signals move more out of phase, the time the two gates are open at the same time becomes shorter. Now plate current will flow for a less time. This can be seen in figure 9I. The filter capacitor in the output plate circuit will eliminate the unwanted frequencies. The charge on the capacitor will follow the varying plate current which is a reproduction of the original intelligence. This can be seen by the dotted line in figure 9K.

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QUICK QUIZ 11

1. The limiter and quadrature grids must be positive at the same time in order to have plate current. True/False

2. When the input frequency goes up, the time that plate current flows will go down. True/False

3. At the carrier frequency, the quadrature tank oscillates 90° out of phase with the input signal. True/False

4. The quadrature detector must be proceeded by a limiter to clip the noise pulses. True/False

Check your answers at the top of the next even numbered page.

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Phase Demodulation

Phase demodulation is the process of reproducing the intelligence from a phase modulated wave. You will recall that when the carrier was phase modulated we caused its phase to be shifted. How far it was shifted was determined by the voltage amplitude of the intelligence signal. Now we must change the shifting phase back into voltage amplitude changes. Figure 10 shows a modified quadrature detector that is used as a phase detector. The first thing we must do in this process is to know what the phase of the original signal was before it was shifted. We can do this by using a frequency from a master oscillator that is set to the same frequency as the carrier in the transmitter. The new carrier is fed to one grid and the phase modulated input signal to the other grid. The circuit now operates as before with the two grids acting as gates to control current flow. In figure 10 it is shown that when the phase of the two signals are farther apart, the two gates are open at the same time for a lesser period and the plate current pulse is narrow. When the two signals are close to, or of the same phase, the two gates are open longer at the same time and the plate current pulse is wider. The capacitor in the plate circuit filters out the unwanted frequencies and the varying change is a replica of the original intelligence signal.

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QUICK QUIZ 12

1. Phase demodulation means to reproduce the original intelligence from the phase modulated wave. True/False

2. It is not necessary to know the original carrier frequency during phase demodulation. True/False

3. When the input and reference frequencies are of the same phase, the plate wave shape is wide. True/False

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ANSWERS TO QUICK QUIZ 11

1. True 2. True 3. True 4. False

ANSWERS TO QUICK QUIZ 12

1. True 2. False 3. True

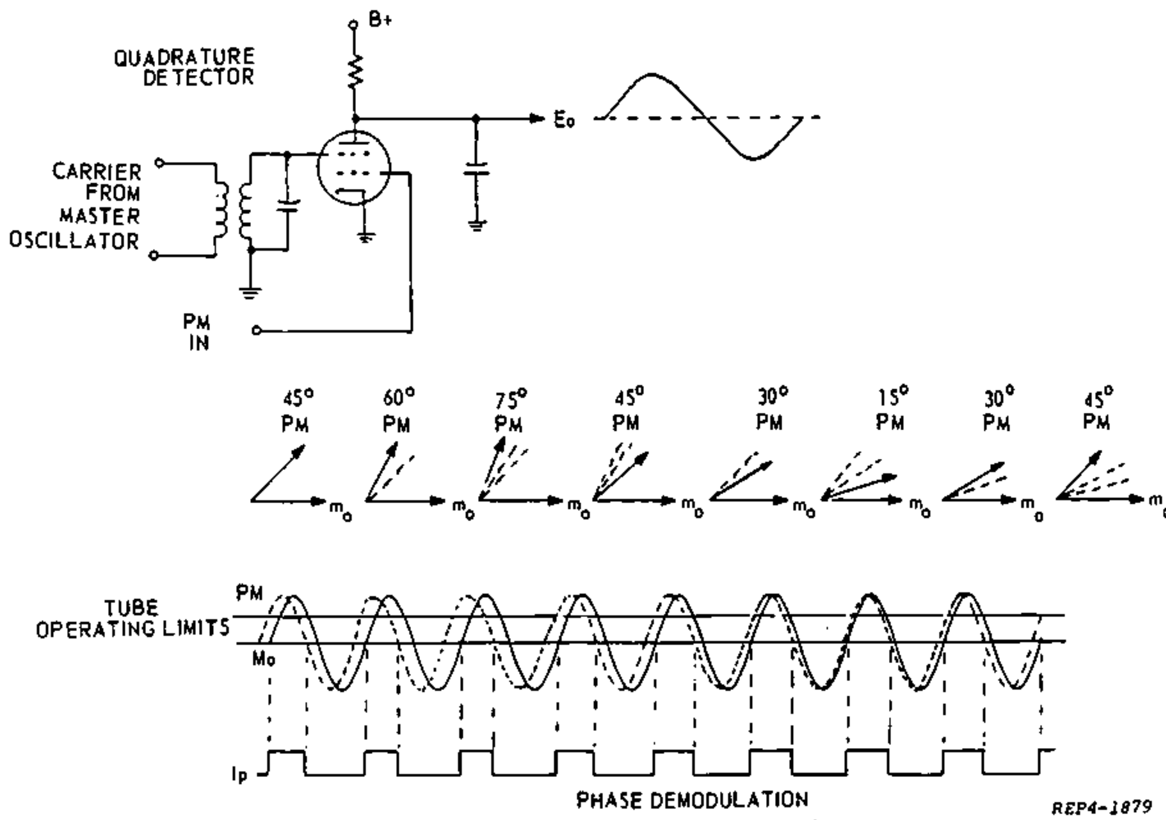



Figure 10. Phase (Quadrature) Detector

SUMMARY QUIZ 2

1. Name the four requirements for frequency demodulation.

a.

b.

c.

d.

2. Frequency demodulation can be described as:

   a. converting frequency changes into voltage amplitude changes.

   b. converting phase changes into frequency changes.

   c. converting voltage amplitude changes into frequency changes.

   d. converting voltage amplitude changes into phase changes.

3. During the demodulation process which of the following statements are true?

   a. The USBs are heterodyned with the LSBs.

   b. The carrier is heterodyned with the Sidebands.

   c. The USBs are added to the LSBs.

   d. The USBs are subtracted from the LSBs.

4. In the Foster-Seeley discriminator, changes in the amplitude of the input signal does not effect the output. True/False

MATCH THE STATEMENTS TO THE NAME OF THE CIRCUIT IN QUESTIONS 5, 6 and 7.

5. ______ Foster-Seeley Discriminator

6. ______ Ratio Detector

7. ______ Quadrature Detector

a. The tubes conduct in series.

b. Must be preceeded by a limiter to prevent noise in the output.

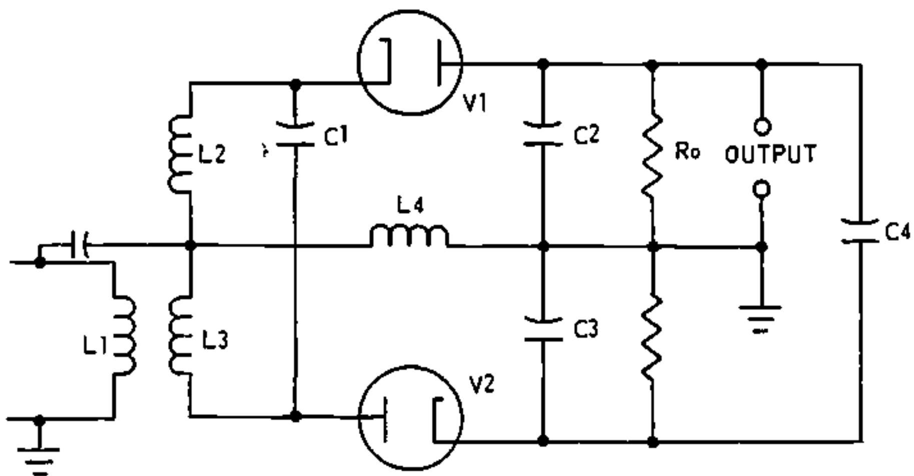
c. Operates as if it contained two gates which must be open at the same time to allow current flow.

MATCH THE SCHEMATIC DIAGRAMS OF DEMODULATORS WITH THE NAMES IN QUESTIONS 8, 9, and 10.

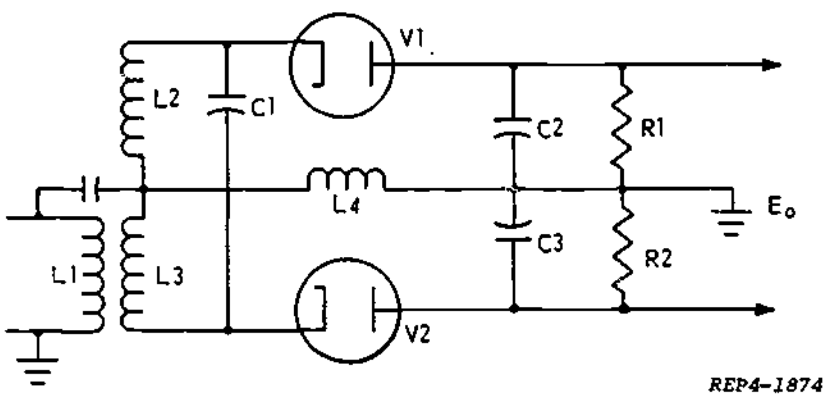
8. ______ Foster-Seeley

9. ______ Ratio Detector

10. ______ Quadrature Detector

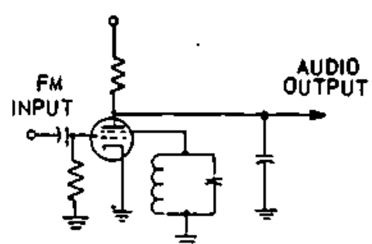



A




REP4-1874

B




C

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NOTES

ANSWERS FOR SUMMARY QUIZ 2

1. a. an input circuit that converts frequency changes to voltage amplitude changes.

   b. Nonlinearity

   c. Filter

   d. Load

2. a

3. b

4. False

5. b

6. a

7. c

8. b

9. a

10. c

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PREPARE THE MAN

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-65

Technical Training

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 65

## DEMODULATION

1 May 1974

7-13


Keesler Technical Training Center
Keesler Air Force Base, Mississippi


Designed For ATC Course Use

DO NOT USE ON THE JOB

Electronic Principles Department
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-65
1 May 1974

# ELECTRONIC PRINCIPLES

## MODULE 65

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS



Errata 1 For Guidance Package, KEP-GP-65, 1 May 1974 15 June 1974

| PAGE | LINE | CORRECTION |
|---|---|---|
| 12 | 7 | Place answer blanks before "a" thru "e" and delete blanks before options "1" thru "6". |

Supersedes KEP-GP-65, January 1974, which will be used until the stock is exhausted.

# DEMODULATION

1. SCOPE: The material presented in this module covers the purpose and methods of demodulation. You will study the various circuits used to demodulate; amplitude, single sideband, pulse, phase and frequency modulated signals.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given a list of statements about demodulation, select the one that describes:

(1) AM

(2) sideband

(3) pulse

(4) phase

(5) FM

b. Given schematic diagr' ms of AM demodulators, match each with:

(1) diode detector

(2) grid leak detector

(3) plate detector

(4) infinite-impedance detector

c. Given a list of statements match each with the schematic of:

(1) Foster-Seeley discriminator

(2) ratio detector

(3) quadrature detector

AT THIS POINT, YOU MAY TAKE THE MODULE SELF CHECK. IF YOU DECIDE NOT TO TAKE THE MODULE SELF CHECK, TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

LIST OF RESOURCES

## DEMODULATION

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest

Adjunct Guide with Student Text

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

# DEMODULATION

One of the functions of a radio receiver is to demodulate the radio wave picked up by the receiving antenna. Demodulation is the process of extracting the signal intelligence from a modulated carrier wave. The requirements for demodulation are: non-linearity must be present to cause heterodyning; the original RF carrier signal must be present at the input of the demodulator to heterodyne with the sideband signals to reproduce the original intelligence signal; filtering is required to eliminate the unwanted RF after the intelligence is produced. The filter circuit is made up of components which shunt the RF to ground while retaining the desired frequencies.

AM demodulation is the process of extracting the signal intelligence from an AM carrier. An AM RF signal can be demodulated by several types of demodulators. The circuit for demodulating an AM signal is called a detector. Covered in this module are the diode, grid-leak, infinite impedance, single sideband, and pulse detectors.

The diode detector is the simplest circuit. Current flows through the diode when the plate is positive with respect to the cathode. The non-linearity of the diode causes a heterodyne action between the RF carrier and the sidebands. The resulting frequencies will include the sum of the carrier and lower sideband, sum of the carrier and upper sideband, and the difference between the carrier and sideband signals.

The grid-leak detector functions like the diode detector combined with a triode tube. The grid of the tube will function as the detector plate. The triode section then provides amplification of the detected signal. The grid-leak bias provides the non-linearity for heterodyne action. Input impedance is low because grid current must flow to perform the heterodyning.

The plate detector has a high input impedance because grid current does not flow during the entire input cycle of RF variations of the input. Detection occurs within the triode tube because the cathode self-bias resistor is large enough to insure the stage will be biased at approximately cutoff.

The infinite impedance detector resembles the plate detector with the exception that the load resistor is located in the cathode. This arrangement makes the infinite-impedance detector essentially a cathode follower. Input impedance is extremely high.

The signle sideband demodulator introduces a frequency to replace the suppressed carrier so that heterodyning may take place. The carrier signal must be at least ten times the amplitude of the sidebands to prevent distortion.

A pulse demodulator is essentially an amplitude detector with a very wide bandwidth.

FM demodulators studied in this module are Foster-Seeley discriminator, ratio detector, and quadrature detector. In order to demodulate the FM signal the demodulator stage must be a circuit which can sense frequency variations and convert these to voltage changes. The requirements for FM demodulation are: the input circuit to the demodulator must change frequency variations into amplitude variations; a non-linear impedance is necessary to heterodyne the carrier and sidebands.

The Foster-Seeley is a phase-shift type discriminator because demodulation depends on the phase-shift obtained across 2 transformer secondaries. A tuned circuit acts resistively as long as it is resonant. If the input signal is shifted above or below the resonant frequency of the tank circuit the circuit will be inductive or capacitive and the secondary will no longer be in phase. The resulting output voltage will either increase or decrease. Thus the frequency variations are changed into amplitude variations. A limitation of the Foster-Seeley is that any amplitude variations at the input result in noise or distortion in the output. For this reason the circuit must have an amplitude limiter stage preceding it.

The ratio detector is similar to the Foster-Seeley, but has the advantage of not requiring a limiter stage.

An FM demodulator employing a completely different principle is the quadrature detector. This demodulator is self-limiting and does not require a separate limiter. A gated beam tube is used in which the limiter grid and the quadrature grid must both be positive for plate current to flow. The incoming RF signal is connected to the limiter grid and the quadrature grid is connected to a high Q tank circuit which is resonant to the incoming center frequency. The tank circuit will determine the phase of the quadrature grid voltage. Since both grids must be positive for plate current to flow, the amount of plate conduction will depend upon the phase relationship of the signal on the limiter grid to the resonant frequency applied to the quadrature grid. When the incoming signal frequency increases and decreases around the center frequency the average current will vary proportionally. Thus frequency variations are converted to amplitude variations.

Phase demodulation is the process of extracting the signal intelligence from a phase modulated waveform. An FM discriminator can sometimes be used for phase demodulation. However, a true reproduction can be obtained only with added processing of the signal. A phase demodulator is similar to the quadrature demodulator except that the reference is not provided by the tuned circuit, but from a separate reference signal.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

# DEMODULATION

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the top of the next even numbered page following the questions.

If you experience any difficulty, contact your instructor.

Begin the program.

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A. Turn to Student Text, Volume IX, Chapter 3 and read paragraphs 3-1 through 3-8. Return to this page and answer the following questions.

1. The modulated waveform at the transmitter does not contain the ____________ signal.

2. Filtering is required at the output of an AM demodulator to reject the:

   ______ a. intermediate frequencies.

   ______ b. audio frequencies.

   ______ c. unwanted radio frequencies.

   ______ d. noise frequencies.

3. The original RF carrier signal must be present at the input of the demodulator to:

   ______ a. present a linear load for the detector.

   ______ b. develop the signal for detection.

   ______ c. heterodyne with the sidebands and develop the intelligence signal.

   ______ d. heterodyne with the original intelligence signal and sidebands in order to separate the intelligence.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

---

B. Turn to Student Text, Volume IX, Chapter 3 and read paragraphs 3-9 thru 3-33. Return to this page and answer the following questions.

ANSWERS TO A:

1. original intelligence

2. c

3. c

If you missed ANY questions, review the material before you continue.

1. Match the following detectors with the statements.

| | |
|---|---|
| a. Diode detector | 1. Input impedance is high because grid current does not flow during the entire cycle. |
| b. Grid-leak detector | 2. Current flows during the half cycle the plate is positive with respect to cathode. |
| c. Plate detector | 3. The capacitor in the output detects the RF. |
| d. Infinite-impedance detector | 4. Input impedance is low because grid current must flow to perform the heterodyne action. |
| | 5. The circuit is essentially a cathode follower. |

2. Because the capacitor and resistor in the output of the diode detector have a ________ ________________ time constant, the voltage across the capacitor will vary at the ________ frequency.

3. The triode section of a grid leak detector:

   a. detects the RF signal

   b. detects the audio signal

   c. amplifies the detected signal

   d. acts as the cathode of the detector

4. Before detection of a SSB signal can take place, the ______________________ signal must be restored in the receiver.

5. The detector used in pulse demodulation is essentially a/an ______________________ detector.

6. The bandwidth of the pul: demodulator must be wide because:

______ a. of the high amplitude of the modulating signal.

______ b. of the large frequency deviation of the carrier.

______ c. of the many sidebands.

______ d. there is more intelligence information in the pulse wave system per unit of time.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

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C. Turn to Student Text, Volume IX, Chapter 3 and read paragraphs 3-34 thru 3-57. Return to this page and answer the following questions.

1. The FM receiver must be able to sense ______________________ variations and convert them into voltage changes.

2 The Foster-Sheeley discriminator depends upon the ________________ shift obtained across the transformer secondary.

3. Answer the following statements as True or False.

______ a. The Foster-Seeley discriminator is not amplitude sensitive.

______ b. The Foster-Seeley transformer voltages are both in-phase with $E_P$ at resonance.

______ c. The output voltage amplitude of the Foster-Seeley discriminator varies inversely with the input frequency deviation.

4. The __________________ detector is similar to the Foster-Seeley but does not require a limiter stage.

5. In the vector analysis of the ratio detector we are concerned with:

______ a. the primary voltage compared to the transformer secondary voltage.

______ b. the current in the transformer secondary.

______ c. the voltage phase on the primary.

______ d. amplitude variations applied to the diodes.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

---

ANSWERS TO B:

1. a. 2
   b. 4
   c. 1
   d. 5
2. long, audio
3. c
4. carrier
5. amplitude
6. c

If you missed ANY questions, review the material before you continue.

ANSWERS TO C:

1. frequency
2. phase
3. a. False
   b. False
   c. False
4. ratio
5. d

If you missed ANY questions, review the material before you continue.

D. Turn to Student Text, Volume IX, Chapter 3, and read paragraphs 3-58 thru 3-74. Return to this page and answer the following questions.

1. The quadrature detector is:

   ______ a. Self limiting

   ______ b. Self exciting

   ______ c. Self cancelling

   ______ d. Self generating

2. Plate current can flow in the quadrature detector when:

   ______ a. both the limiter and quadrature grids are open.

   ______ b. the limiter grid is open and the quadrature grid is closed.

   ______ c. the limiter grid is closed and the quadrature grid is open.

   ______ d. both the limiter and quadrature grids are closed.

3. The quadrature grid in a phase detector is excited by:

   ______ a. the plate supply voltage

   ______ b. a reterence signal from the transmitter.

   ______ c. grid return voltage.

   ______ d. self induction from the current returned to the screen.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

---

ANSWERS TO D:

1. a
2. a
3. b

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

DEMODULATION

QUESTIONS:

1. The requirements of AM demodulation are:

_____a. linearity and filtering.

_____b. non-linearity and resistance.

_____c. heterodyning and filtering.

_____d. linearity and heterodyning.

2. The input to an AM demodulator contains the following frequencies: 1490 kHz, 1488 kHz, 1492 kHz. What will be the frequency out from this demodulator?

_____a. 5000 Hz

_____b. 2000 Hz

_____c. 200 kHz

_____d. 1 kHz

3. Filtering is required in the AM demodulator output because:

_____a. high audio frequencies must be eliminated.

_____b. noise must be removed from the output.

_____c. RF must be removed from the audio signal.

_____d. the power ripple must be minimized.

4. The grid of the grid-leak detector tube will function as:

_____a. the detector plate.

_____b. part of the RF suppressor.

_____c. the detector cathode

_____d. part of the filter circuit.

5. For SSB demodulation to take place:

_____a. the transmitter must supply a reference signal.

_____b. the other sideband must be restored in the receiver.

_____c. the receiver restores the missing carrier frequency.

_____d. a balanced demodulator must be used.

MODULE SELF-CHECK

6. The bandwidth of the pulse demodulator must be wide because

_____ a. of the high amplitude of the modulating signal.

_____ b. of the large frequency deviation of the carrier.

_____ c. of many sidebands.

_____ d. there is more intelligence information in the pulse wave system per unit of time.

7. Select the statement which best describes the following terms:

a. AM

b. SSB

c. pulse

d. phase

e. FM

_____ 1. A demodulator essentially the same as an amplitude type but requires a very large bandwidth.

_____ 2. The original RF carrier signal must be present at the input of the demodulator to heterodyne with the sideband and signals to reproduce the original intelligence.

_____ 3. Demodulation is accomplished by a modified FM detector.

_____ 4. An oscillator must be used to furnish the carrier signal.

_____ 5. Amplitude demodulation is accomplished with a ratio detector.

_____ 6. Frequency variations must be changed into amplitude variations.

8. The requirements fo. FM demodulation are:

_____ a. linear impedance, frequency to amplitude conversion, filtering.

_____ b. frequency to amplitude conversion, non-linear impedance, filtering.

_____ c. amplitude to frequency conversion, filtering, resistive load.

_____ d. frequency variation to amplitude conversion, discrimination, and a load resistance.

9. The tank circuit of the Foster-Seeley acts in what manner at resonance?

_____ a. resistive.

_____ b. capacitive.

_____ c. inductive or capacitive, depending upon the construction of the circuit.

_____ d. can not be determined without knowing circuit values.

10. The quadrature tube consists of:

    a. Cathode, limiter grid, accelerator grid, quadrature grid, plate.

    b. cathode, accelerator grid, screen grid, quadrature grid, plate.

    c. cathode, screen grid, quadrature grid, selector grid, plate.

    d. cathode, limiter grid, screen grid, quadrature grid, plate.

11. The phase detector is excited by a reference from the ____________ .

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

MODULE SELF-CHECK

ANSWERS TO MODULE SELF-CHECK

1. c.
2. b.
3. c.
4. a.
5. c.
6. c.
7. a. 2
   b. 4
   c. 1
   d. 3
   e. 6
8. b.
9. a.
10. d.
11. transmitter.

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER INSTRUCTION.

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ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-66

Technical Training

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 66

## TRANSMISSION LINES

1 June 1974

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Electronic Principles Department
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-66
1 June 1974

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 66

## TRANSMISSION LINES

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS



Supersedes Guidance Package, KEP-GP-68, 1 January 1974, which may be used until supply is exhausted.

# TRANSMISSION LINES

1. SCOPE: The material discussed in this module will cover the theory of transmission lines, five types of lines, losses of energy on the lines, and the generation of standing waves and how they effect the lines operation. Some material will be presented on special line devices.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given a list of statements about transmission lines, match each with a diagram of

(1) open two wire.
(2) twisted pair.
(3) twin lead.
(4) flexible coaxial cable.
(5) rigid coaxial cable.

b. From a list of statements concerning transmission lines, match each with the terms

(1) traveling wave.
(2) incident wave.
(3) reflected wave.
(4) nonresonant line.
(5) resonant line.
(6) standing wave.
(7) standing wave ratio.
(8) voltage node.
(9) voltage loop.
(10) current node.
(11) current loop.

c. Given a list of statements about transmission lines, select the one which describes

(1) physical length.
(2) electrical length.
(3) characteristic impedance.
(4) cutoff frequency.

d. Given a group of terms concerning transmission lines, match each with the illustration of

(1) delta matching.
(2) stub matching.
(3) matching transformer.

AT THIS POINT, YOU MAY TAKE THE MODULE SELF-CHECK. IF YOU DECIDE NOT TO TAKE THE MODULE SELF-CHECK, TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

LIST OF RESOURCES

## TRANSMISSION LINES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest

Adjunct Guide with Student Text

AUDIO-VISUALS:

TV Lesson, Resonant Lines, TVK-30-614

TV Lesson, Transmission Lines, TVK-30-613

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

## TRANSMISSION LINES

Transmission lines carry electromagnetic energy from a source to a load. All transmission lines have electrical characteristics of inductance and capacitance. These values of inductance and capacitance determine the characteristic impedance and cutoff frequency of the line. CHARACTERISTIC IMPEDANCE is the opposition to an AC signal while CUTOFF FREQUENCY is the highest frequency that will travel down the line without being attenuated. Five basic types of transmission lines are twisted pair, twin lead, open two-wire, flexible coaxial cable, and rigid coaxial cable. Physical length of a transmission line is measured in meters, centimeters, inches, feet, etc., and electrical length is measured in wavelengths. WAVELENGTH is defined as being the distance energy travels down the line in one cycle of the input frequency. Nonresonant lines have a maximum transfer of power, and all the energy is absorbed by the load. When there is a mismatch of impedance, some of the energy is reflected back to the source. The sum of the reflected waves and incident waves are standing waves. The minimum points of the standing waves are called NODES and the maximum points are LOOPS. The greater the voltage difference between the loops and nodes, the greater the standing wave ratio. A line that has standing waves is called a RESONANT LINE. There is a standing wave of voltage and one of current. The impedance of a transmission line increases as the leads are separated. DELTA MATCHING is a form of impedance matching by spreading the leads. STUB MATCHING is connecting a load to some portion of a quarter-wave matching stub. The quarter-wave matching stub is used to match the line impedance to the load impedance. It acts like a transformer to match two unlike impedances.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

ADJUNCT GUIDE

# TRANSMISSION LINES

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the top of the next even numbered page following the questions.

If you experience any difficulty, contact your instructor.

Begin the program.

---

The reason for studying this material is to develop an understanding of the basic facts about transmission lines.

A. Turn to Student Text Volume IX and read paragraphs 4-1 through 4-18. Return to this page and answer the following questions.

1. What is a transmission line?

____a. A conductor or series of conductors used to develop an electromagnetic wave.

____b. A conductor or series of conductors used to carry energy from a source to a load.

____c. A line used to transfer mechanical energy from a source to a load.

____d. The line of sight transmission of an electromagnetic wave in space.

2. From the list of statements concerning transmission line losses, match each with the terms.

____a. Copper

____b. Skin effect

____c. Radiation

____d. Capacitive

(1) Electromagnetic energy not collapsing back into the conductor.
(2) Heat loss in the dielectric.
(3) Power loss due to the resistance of the line.
(4) High frequency currents tend to move only on the surface of the conductor.

3. Which TWO losses are resistive losses?

____a. Copper.

____b. Skin effect.

____c. Radiation.

____d. Capacitive.

4. As the frequency of the energy on a transmission line is increased, the radiation loss

____a. decreases.

____b. remains the same.

____c. increases.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

B. Turn to Student Text Volume IX and read paragraphs 4-19 through 4-32. Return to this page and answer the following questions.

1. Identify the following types of transmission lines by inserting the letter under the correct drawing.

____a. Open two-wire.

____b. Twisted pair.

____c. Rigid coaxial cable.

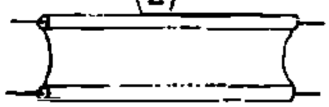
____d. Twin lead.

____e. Flexible coaxial cable.

(1)

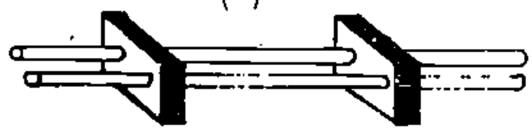
________

(2)



________

(3)

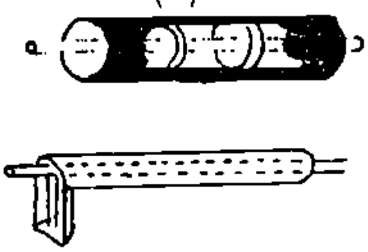


________

(4)

________

(5)



________

2. What is the major loss for twisted pair?

____a. Radiation.

____b. Copper.

____c. Skin effect.

____d. Dielectric.

3. What is the major loss for twin lead?

____a. Dielectric.

____b. Skin effect.

____c. Copper.

____d. Radiation.

4. What is the major loss for open two-wire?

____a. Dielectric.

____b. Skin effect.

____c. Copper.

____d. Radiation.

ADJUNCT GUIDE

ANSWERS TO A:

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

If you missed ANY questions, review the material before you continue.

B. (Continued)

5. Which transmission line has the smallest losses and is used for high frequency, high power applications?

____a. Open two-wire.
____b. Rigid coaxal cable.
____c. Twisted pair.
____d. Twin lead.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

C. Turn to Student Text Volume IX and read paragraphs 4-33 through 4-44. Return to this page and respond to the following statements/questions.

1. Characteristic impedance of a transmission line is determined by

____a. series inductance and series capacitance.
____b. series inductance and shunt capacitance.
____c. shunt inductance and shunt capacitance.
____d. shunt inductance and series capacitance.

2. What happens to the $Z_O$ of a line if the length of the line is doubled?

____a. Remains the same.
____b. Doubles.
____c. Reduces by one-half.
____d. Reduces by a square of the original value.

3. Compute the value of $Z_O$ if the unit of inductance is 4 millihenrys and capacitance is 5 picofarads. NOTE: $Z_o = \sqrt{L/C}$.

4. What happens to the value of $Z_O$ if the capacitive value increases?

____a. Increases.
____b. Decreases.
____c. Remains the same.

5. What happens to the value of $Z_O$ if the inductive value increases?

____a. Increases.
____b. Decreases.
____c. Remains the same.

6. Cutoff frequency is the ______________ frequency that will pass down a transmission line without attenuation.

7. What would be the relative values of $X_L$ and $X_C$ above cutoff frequency?

____a. $X_L$ small, $X_C$ small.

____b. $X_L$ small, $X_C$ large.

____c. $X_L$ large, $X_C$ small.

____d. $X_L$ large, $X_C$ large.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

---

D. Turn to Student Text Volume IX and read paragraphs 4-45 through 4-61. Return to this page and answer the following questions.

1. The physical length of a transmission line is measured in

____a. number of wavelengths on the line.

____b. linear measure.

____c. the distance energy travels in one cycle.

____d. even multiples of 1 lambda.

2. The electrical length of a transmission line is measured in

____a. number of wavelengths on the line.

____b. linear measure.

____c. the distance energy travels in one cycle.

____d. even multiples of 1 lambda.

3. What happens to the velocity of energy moving on the transmission line if the capacitive value of the line is increased?

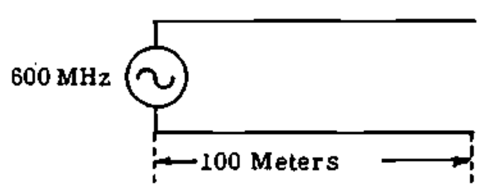
____a. Increases.

____b. Decreases.

____c. Remains the same.

4. If a 600 MHz signal is traveling down a transmission line at 300,000,000 meters per second, what is the wavelength? ______________

5. What is the electrical length of this line? ______________




6. What happens to electrical length if physical length remains the same but the frequency is increased?

____a. Increases.

____b. Decreases.

____c. Remains the same.

ADJUNCT GUIDE

ANSWERS TO B:

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

If you missed ANY questions, review the material before you continue.

ANSWERS TO C:

1. b  2. a  3. 28.28 k ohms  4. b  5. a  6. highest  7. c

If you missed ANY questions, review the material before you continue.

D. (Continued)

7. What happens to electrical length if the physical length is reduced?

____ a. Increases.

____ b. Decreases.

____ c. Remains the same.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

---

E. Turn to Student Text Volume IX and read paragraphs 4-62 through 4-94. Return to this page and answer the following questions.

1. A nonresonant transmission line is a transmission line with

____ a. standing waves.

____ b. reflected waves.

____ c. incident waves.

____ d. all of the above.

2. A resonant transmission line is a line with

____ a. standing waves.

____ b. reflected waves.

____ c. incident waves.

____ d. all of the above.

3. Energy moving on the line as incident or reflected waves are called ____________ waves.

4. List six types of terminations that will cause standing waves. (Sequence not important.)

a. ______________________

b. ______________________

c. ______________________

d. ______________________

e. ______________________

f. ______________________

5. Voltage is reflected (in phase, out of phase) from an open.

6. Voltage is reflected (in phase, out of phase) from a short.

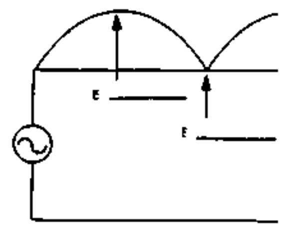
7. Current is reflected (in phase, out of phase) from an open.

8. Current is reflected (in phase, out of phase) from a short.

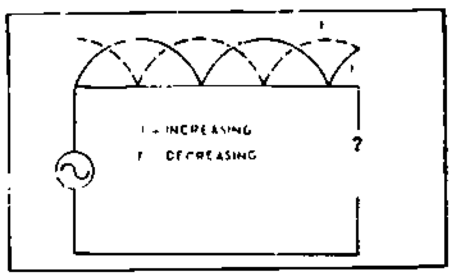
9. The standing wave of voltage is the result of incident wave of voltage and the

____________________________ of voltage.

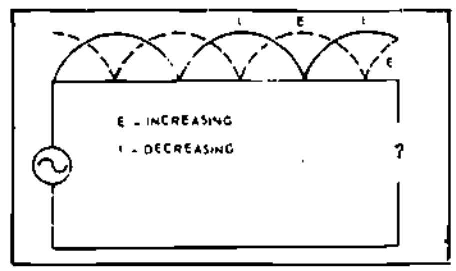
10. On the diagram, identify the points of a voltage LOOP and a voltage NODE.



11. What is the termination?




12. What is the termination?




13. What reactive properties occur 1/4 of a wavelength from an open termination?

____ a. Parallel resonance

____ b. Series resonance

____ c. Capacitive

____ d. Inductive

14. What reactive properties occur 3/8 of a wavelength from a shorted termination?

____ a. Parallel resonance

____ b. Series resonance

____ c. Capacitive

____ d. Inductive

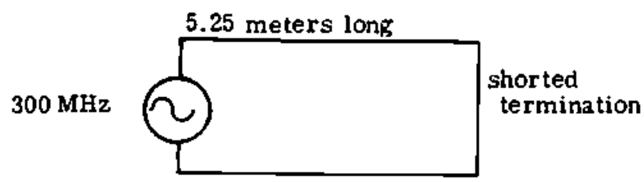
15. Using the diagram, determine what reactive properties will be reflected to the generator.

____ a. Open

____ b. Short

____ c. Inductive

____ d. Capacitive




16. If the transmission lines have a $Z_O$ of 1000 ohms and $R_L$ is 50 ohms, what is the SWR? ____________________

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

ADJUNCT GUIDE

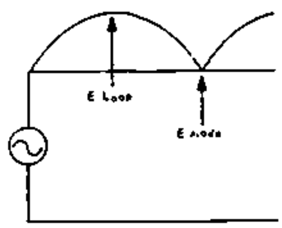
ANSWERS TO D:

1. b 2. a 3. b 4. .5 meters 5. 200 6. a 7. b

If you missed ANY questions, review the material before you continue.

ANSWERS TO E:

1. c 2. d 3. traveling
4. open, short, capacitive, inductive, $R_L$ greater than $Z_0$, $R_L$ smaller than $Z_0$
5. in phase 6. out of phase 7. out of phase 8. in phase 9. reflected
10.



11. inductive 12. capacitive 13. b 14. c 15. a 16. 20 to 1

If you missed ANY questions, review the material before you continue.

F. Turn to Student Text Volume IX and read paragraphs 4-95 through 4-106. Return to this page and answer the following questions.

1. How long physically is a quarter-wave transformer used at 300 MHz? ____________

2. What would be the $Z_t$ of a quarter-wave transformer used to match a 5000-ohm line with a 100-ohm load? $Z_t = \sqrt{Z_0 \times R_L}$

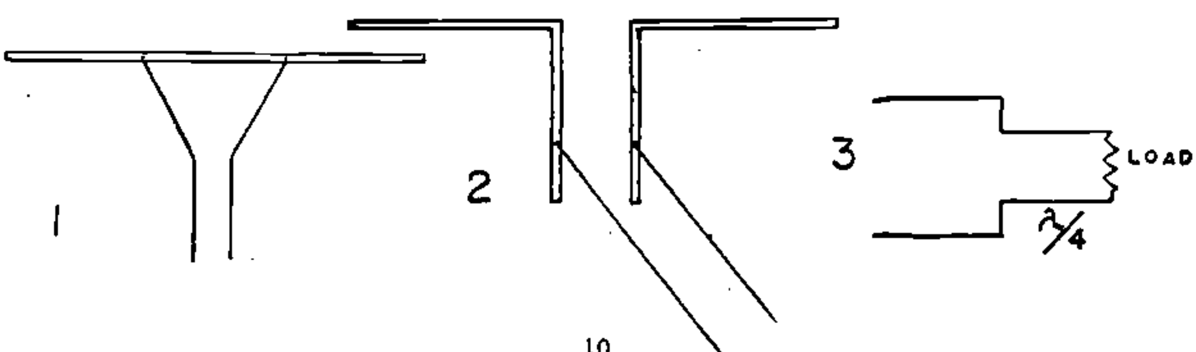
3. What is the purpose of using a delta match?

____a. Maximum reflections. ____c. Maximum transfer of power.

____b. Maximum standing waves. ____d. Maximum SWR.

4. From the list of terms, match each with the diagrams.

____a. Matching transformer ____b. Delta match ____c. Stub match



5. The stub match and the matching transformer match impedances because of ______________________ impedances.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

ADJUNCT GUIDE

ANSWERS TO F:

1. .25 meters
2. 707 ohms
3. c
4a. 3 b. 1 c. 2
5. reflected

If you missed ANY questions, review the material before you continue.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

## TRANSMISSION LINES

QUESTIONS:

1. From the list of statements about transmission lines, match the statement with the correct diagram.

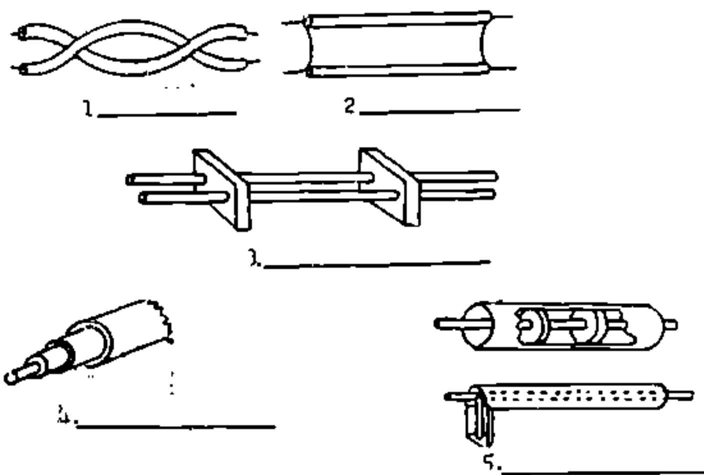
____ a. An inner conductor and an outer concentric conductor or braided wire separated by polyethlene plastic or similar insulation.

____ b. Two conductors separated by means of spacers or spreaders.

____ c. Two conductors molded into the edges of a polyethylene plastic ribbon.

____ d. Two insulated conductors twisted together to form a flexible line.

____ e. A center conductor placed inside of a rigid metal tube.




2. List the major loss by each type of line.

   a. Twisted pair ____________

   b. Twin lead ____________

   c. Open two-wire ____________

   d. Flexible coaxial ____________

   e. Rigid coaxial ____________

MODULE SELF-CHECK

3. From a list of statements about transmission lines, select the one which describes

____ a. physical length.

____ b. electrical length.

____ c. characteristic impedance.

____ d. cutoff frequency.

(1) The opposition to alternating current due to the inductance and capacitance of the line.

(2) The length of the line measured in a linear measure.

(3) The length of the line measured in feet or inches only.

(4) The opposition to direct current due to the resistance of the line.

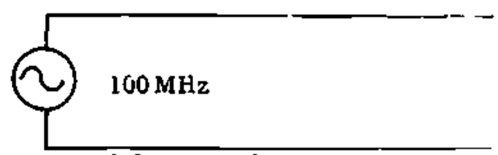
(5) The highest frequency that will pass down the line without attenuation.

(6) The lowest frequency that will pass down the line.

(7) The length of the line measured in number of wavelengths.

(8) The distance on the line that energy travels in one cycle.

4. Compute the electrical length of this line.




1.5 meters long

5. Compute $Z_0$, if the line has a unit of inductance of 2 millihenrys and a unit capacitance of 8 picofarads. $Z_0 = \sqrt{L/C}$.

6. What would be the physical length of a line in meters, if the signal applied is 100 MHz

and the electrical length is 5 wavelengths long? ____________________

7. From the list of statements concerning transmission lines, match the statement with the correct term.

____ a. Traveling wave

____ b. Incident wave

____ c. Reflected wave

____ d. Nonresonant line

(1) The resultant wave of the incident wave and the reflected wave.
(2) A transmission line with standing waves.
(3) The point on the standing wave that indicates maximum current.
(4) A line having only an incident wave.
(5) The point on the standing wave that indicates minimum voltage.

| | |
|---|---|
| ____e. Resonant line | (6) The point on the standing wave that indicates maximum voltage. |
| ____f. Standing wave | (7) The relationship of impedance of the line to the impedance of the load. |
| ____g. Standing wave ratio | (8) The energy moving on a transmission line. |
| ____h. Voltage node | (9) The energy moving from the load toward the source. |
| ____i. Voltage loop | (10) The point on the standing wave that indicates minimum current. |
| ____j. Current node | (11) The energy moving from the source to the load. |
| ____k. Current loop | |

8. Compute the SWR if the line impedance is 50 ohms and the load impedance is 300 ohms.

9. From a group of terms concerning transmission lines, match the term with the correct illustration.

a. Artificial line

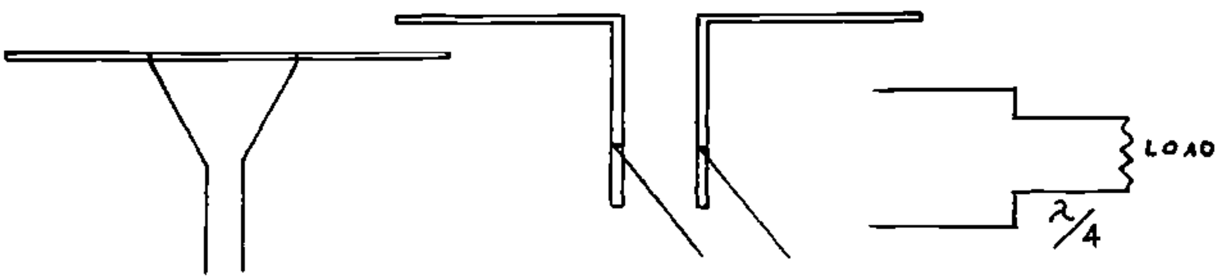
b. Delta matching

c. Infinite line

d. Matching transformer

e. Stub matching

f. Line balanced converter




(1) ________ (2) ________ (3) ________

10. The delta match is used to match the load impedance to the impedance of

____a. flexible coaxial cable.

____b. twisted pair.

____c. twin lead or open two-wire.

____d. rigid coaxial cable.

CONFIRM YOUR ANSWERS ON TH NEXT EVEN NUMBERED PAGE.

MODULE SELF-CHECK

ANSWERS TO MODULE SELF-CHECK:

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

2a. dielectric b. dielectric c. radiation d. dielectric e. copper

3a. 2 b. 7 c. 1 d. 5

4. 1/2 wavelength

5. 15.8114 k ohms

6. 15 meters

7a. 8 b. 11 c. 9 d. 4 e. 2 f. 1 g. 7 h. 5 i. 6 j. 10 k. 3

8. 6 to 1

9. (1) b (2) e (3) d

10. c

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

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ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-67

Technical Training

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 67

## ANTENNAS

October 1975

AIR TRAINING COMMAND

7-13

Designed For ATC Course Use

ATC Keesler 6-2043

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Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-67
October 1975

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 67

## ANTENNAS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS



### OVERVIEW

1. SCOPE: The purpose of this module is to develop your understanding of the principles of antenna operation. Various types of antenna arrays, their radiation patterns and polarization will be discussed.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. From a list of statements describing antenna polarization, select the one that describes

(1) circular polarization.
(2) horizontal polarization.
(3) vertical polarization.

b. From a list of statements on antenna wavelengths, select the one that describes:

(1) half-wave.
(2) quarter-wave.

c. From a list of statements about the elements of a directional antenna, select the one that describes the function of

(1) driven element.
(2) reflector.
(3) directors.

d. Given a list of statements concerning antenna arrays, match each with the following terms:

(1) Broadside array.
(2) End-fire array.
(3) Cardioid array.
(4) Collinear array.

### LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

Supersedes Guidance Package, KEP-GP-67, 1 July 1974.

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READING MATERIALS:

Digest
Adjunct Guide with Student Text, Volume IX

AUDIO VISUALS:

TVK 30-661, Antennas
VTF 1-5401A, Antenna Fundamentals - Propagation
VTF 1-5401B, Antenna Fundamentals - Directivity
VTF 1-5401C, Antenna Fundamentals - Bandwidth

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

## ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

Contact your instructor if you experience any difficulty.

Begin the program.

---

Studying this material will help to develop an understanding of how an antenna converts electrical energy into an electromagnetic field and how the antenna radiates energy.

A. Turn to Student Text, Volume IX and read paragraphs 5-1 through 5-13. Return to this page and answer the following questions.

1. An antenna is used to radiate or collect ________________ energy.

2. An electromagnetic wave moves through space at (approximately) ________________.

3. List two fields that are contained in an electromagnetic wave.

a. ________________

b. ________________

4. In figure 1, current flows toward point (A) (B).

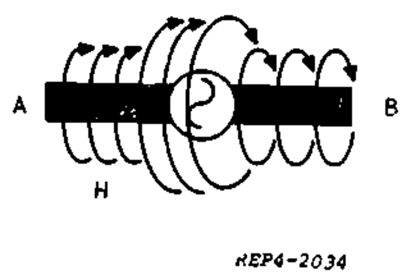


Figure 1

5. In figure 2, current will flow toward point (A) (B).

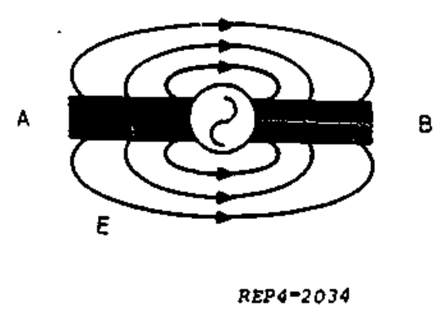


Figure 2

6. In figure 3, which of the following circuits does the source see:

_____ a. Inductive

_____ b. Capacitive

_____ c. Parallel resonant (resistive)

_____ d. Series resonant (resistive)

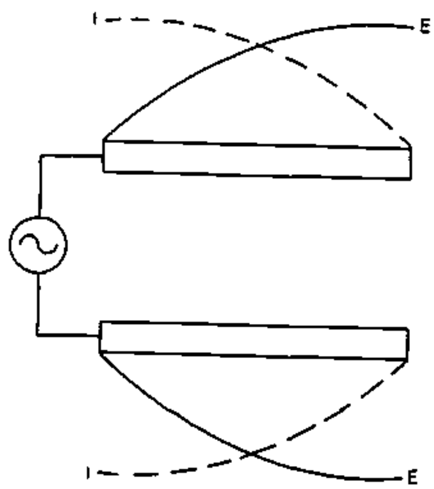


Figure 3

7. In figure 4, the standing waves are shown on a (quarter-wave) (half-wave) (fullwave) antenna.

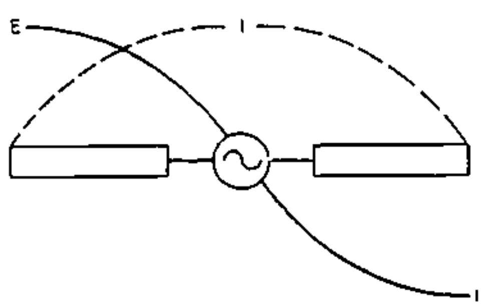


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Figure 4

CONFIRM YOUR ANSWERS

B. Turn to Student Text, Volume IX and read paragraphs 5-14 through 5-29. Return to this page and answer the following questions.

1. The portion of the electromagnetic field that completely collapses when the voltage and current reverse, is the

_____ a. radiation field.

_____ b. induction field.

2. The electric and magnetic fields on an antenna are (in-phase) (90° out-of-phase) (180° out-of-phase).

3. The field that varies inversely with the distance radiated from the antenna is the

_____ a. radiation field.

_____ b. induction

4. The ease with which radiation occurs from a transmitting antenna varies (directly, indirectly) with the frequency.

5. Which of the following fields is used as the reference in determining antenna polarization?

_____ a. H

_____ b. E

_____ c. Radiation

_____ d. Induction

6. If the E field is perpendicular to the surface of the earth, the antenna is:

_____ a. horizontally polarized.

_____ b. vertically polarized.

_____ c. circularly polarized.

7. For maximum transfer of energy the transmitting and receiving antenna should

_______________________________________________

8. When is circular polarization necessary?

CONFIRM YOUR ANSWERS

C. Turn to Student Text, Volume IX and read paragraphs 5-30 through 5-35. Return to this page and answer the following questions.

1. The basic dipole antenna is (1/4) (1/2) (1) wave length long.

2. To electrically shorten an antenna we can add series

_____ a. capacitance.

_____ b. inductance.

_____ c. resistance.

3. Which factor determines the physical length of a simple dipole antenna?

_____ a. Power

_____ b. Bandwidth

_____ c. Frequency

_____ d. Directivity

4. An antenna that uses an image as the other quarterwave section is the _____________ antenna.

CONFIRM YOUR ANSWERS

D. Turn to Student Text, Volume IX and read paragraphs 5-36 through 5-54. Return to this page and answer the following questions.

1. From the list of statements concerning antenna arrays, match each with the following terms:

_____ a. Broadside array

_____ b. End-Fire array

_____ c. Cardioid array

_____ d. Collinear array

1. Two or more half-wave elements placed one-half wavelength apart, parallel, and excited in phase at the centers.

2. Two half-wave elements placed end-to-end and excited in phase at the centers.

3. Two or more half-wave elements placed one-half wavelength apart, parallel, and excited 180° out of phase at the centers.

4. Two half-wave elements placed one-fourth wavelength apart, parallel, and excited 90° out of phase at the centers.

2. From the list of statements about the elements of a parasitic array, select the one that describes the function of the:

_____ a. Driven element.

_____ b. Reflector.

_____ c. Directors.

1. An element that causes maximum energy radiation in the direction toward the driven element.

2. An element placed so that it will produce maximum radiation from the driven element toward itself.

3. The element of the array that is connected to the source or load.

3. Adding more elements to an end-fire antenna will (increase)(decrease) directivity.

4. From the diagram, identify the array. ____________________

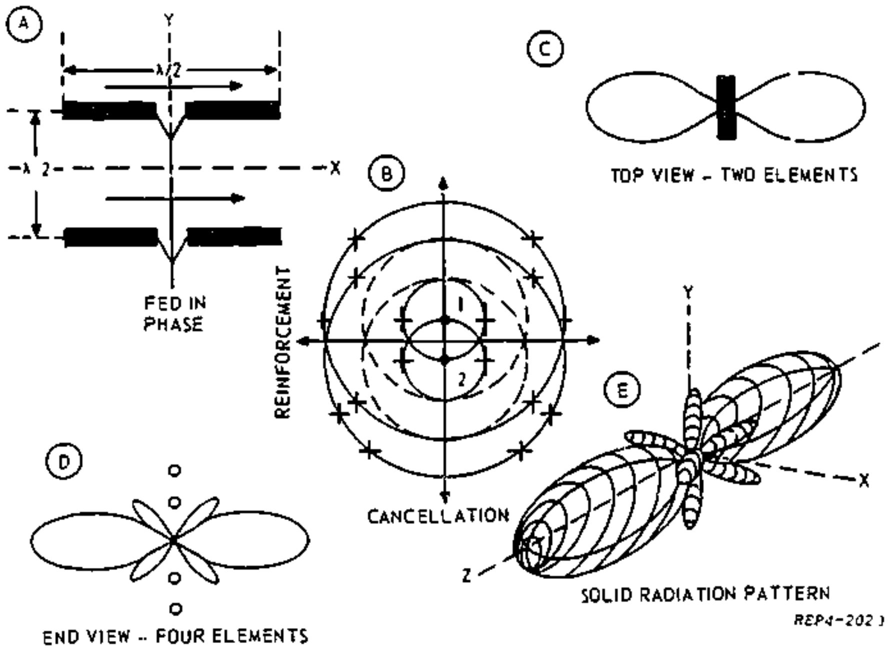


Figure 5

5. From the diagram identify the array. ____________________

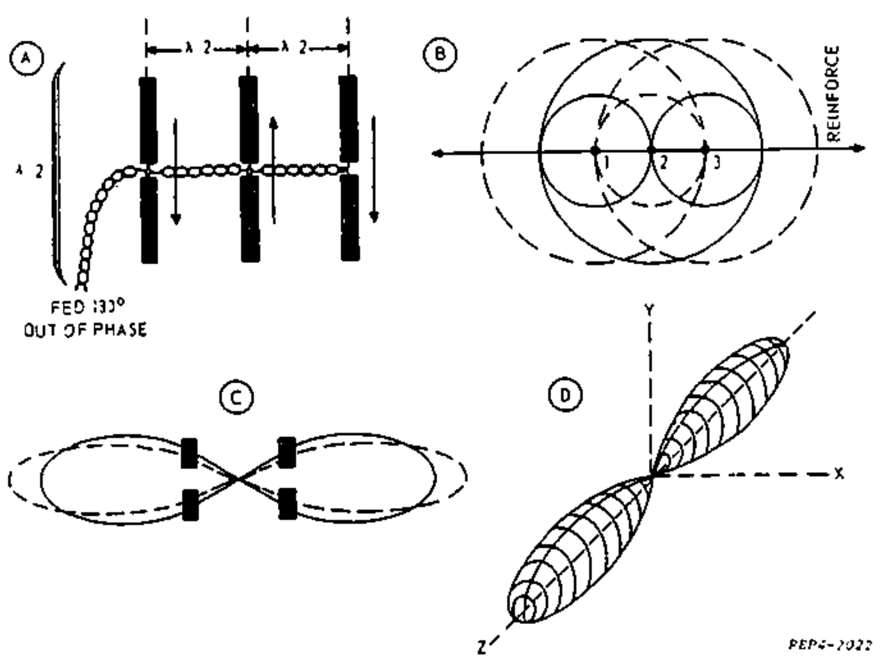


Figure 6

CONFIRM YOUR ANSWERS.

## MODULE SELF-CHECK

1. From the list of statements describing antenna polarization, select the one that describes:

_____ a. Circular polarization

_____ b. Horizontal polarization

_____ c. Vertical polarization

1. An electromagnetic wave whose E-field is parallel to the surface of the earth.

2. An electromagnetic wave that rotates through 360 degrees for each cycle of the RF signal.

3. An electromagnetic wave that has its E-field perpendicular to the surface of the earth.

2. What is the electrical length of a basic dipole antenna?

_______________________.

3. A grounded quarter-wave antenna is electrically _______________ wave length long.

4. To electrically lengthen an antenna _______________________ is added in series.

5. Which element is connected to the generator in a parasitic array?

_____ a. Driven.

_____ b. Reflector.

_____ c. Director.

6. In a cardiod array, the elements are fed

_____ a. in-phase.

_____ b. 180 degrees out of phase.

_____ c. 90 degrees out of phase

_____ d. 45 degrees ou of phase.

7. In a broadside array, the elements are fed

_____ a. in-phase.

_____ b. 180 degrees out of phase

_____ c. 90 degrees out of phase.

_____ d. 45 degrees out of phase.

8. In a end-fire array, the elements are fed

_____ in-phase.

_____ 180 degrees out of phase.

_____ 90 degrees out of phase.

_____ 45 degrees out of phase.

9. In a collinear array, the elements are fed

_____ a. in-phase.

_____ b. 180 degrees out of phase.

_____ c. 90 degrees out of phase.

_____ d. 45 degrees out of phase.

10. The antenna element that causes maximum radiation going from the driver toward the parasitic element is called the

_____ a. driver.

_____ b. director.

_____ c. reflector.

11. If a dipole has its elements perpendicular to the ground, what is the polarization?

_____ a. Circular.

_____ b. Horizontal.

_____ c. Vertical.

12. An antenna element that causes maximum energy radiation from itself toward the driven element is

_____ a. driver.

_____ b. director.

_____ c. reflector.

CONFIRM YOUR ANSWERS

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NOTES

ANSWERS TO A - ADJUNCT GUIDE

1. electromagnetic
2. the speed of light
3. E; H
4. B
5. A
6. d
7. half-wave

If you missed ANY questions, review the material before you continue.

ANSWERS TO B - ADJUNCT GUIDE

1. b
2. 90° out of phase
3. a
4. directly
5. b
6. b
7. have the same polarization or lie in the same plane.
8. when the plane of energy is not fixed and a resultant loss in energy transfer can occur.

If you missed ANY questions, review the material before you continue.

ANSWERS TO C - ADJUNCT GUIDE

1. 1/2
2. a
3. c
4. Marconi

If you missed ANY questions, review the material before you continue.

ANSWERS TO D - ADJUNCT GUIDE

1. a. 1
   b. 3
   c. 4
   d. 2
2. a. 3
   b. 1
   c. 2
3. increase
4. Broadside
5. End-fire

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK

1. a. 2
   b. 1
   c. 3
2. 1/2 wavelength
3. 1/2 wavelength
4. inductance or an inductor
5. a
6. c
7. a
8. b
9. a
10. b
11. c
12. c

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-68

Technical Training

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 68

## AM SYSTEMS

October 1975

AIR TRAINING COMMAND

7-13

Designed For ATC Course Use

ATC Keesler 6-2047

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Radar Principles Branch
Keesler AFB, Mississippi

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KEP-GP-68
October 1975

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 68

## AM SYSTEMS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS



### OVERVIEW

1. SCOPE: This module contains material on a basic AM communications system. It includes the requirements for transmitter frequency stability, receiver sensitivity and distortion, the block diagrams of a transmitter and receiver with a description of each block, and the schematic diagram of a transmitter and receiver with the description of signal and current paths.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given a list of statements of transmitter characteristics, select the statement that describes frequency stabilization.

b. Given a list of statements of the following receiver characteristics, select the statements which describe

(1) sensitivity.
(2) selectivity.

c. From a list of statements, select the statements that identify the causes of

(1) second harmonic distortion.

(2) bandpass distortion.

(3) cochannel interference.

d. Given a labeled block diagram of a list of statements that describe each block of an AM transmitter, match each block with the proper statements.

e. Given a labeled block diagram and a list of statements that describe each block of a single conversion AM receiver, match each block with the proper statement.

f. Given a schematic diagram of an AM transmitter, trace

(1) the RF and intelligence signal flow from origin to output.

(2) direct current paths through each stage in a closed loop.

Supersedes Guidance Package KEP-GP-68, 1 June 1974.

g. Given a schematic diagram of a superheterodyne AM receiver, trace

(1) the signal flow from origin to output.

(2) direct current path through each stage in a closed loop.

## LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text, Volume IX

AUDIO VISUALS:

TVK-30-609, Introduction to Receivers

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

## ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

Contact your instructor if you experience any difficulty.

Begin the program.

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Radio communications play a very important part in the mission of the United States Air Force. You may be involved in the operation and maintenance of some of these systems. The material presented in this module will assist in developing an understanding of the principles of an Amplitude Modulated System.

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A. Turn to Student Text, Volume IX and read paragraphs 6-1 through 6-16. Return to this page and answer the following questions.

1. An oscillator and an antenna can produce an electromagnetic wave which can be radiated into space. (TRUE)(FALSE)

2. Figure 1 illustrates a basic transmitter. What is the function of the buffer?

_____ a. Eliminate undesirable sideband frequencies.

_____ b. Increase the bandwidth of the transmitted signal.

_____ c. Prevent the antenna from affecting oscillator frequency.

_____ d. Produce new frequencies through the process of heterodyning.

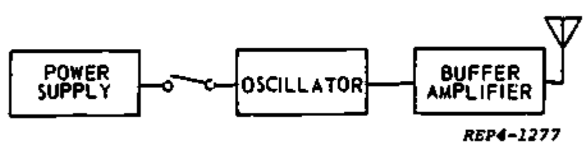


Figure 1

3. The ability of a receiver to reproduce the intelligence of a very weak signal is a function of receiver_____________.

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4. Name the function of each section of the receiver illustrated in figure 2.

a. ______________________________

b. ______________________________

c. ______________________________

d. ______________________________

e. ______________________________

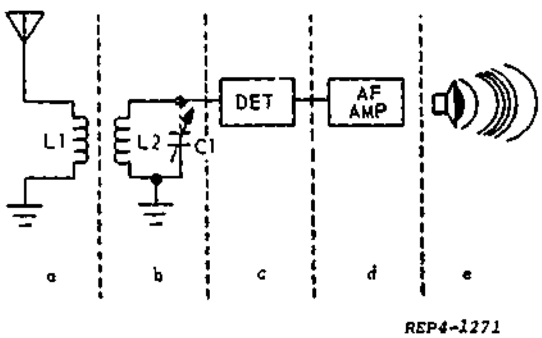


Figure 2

5. The ability of a receiver to select and reproduce a desired signal from several closely spaced stations or from interfering frequencies is determined by receiver

______________________________

CONFIRM YOUR ANSWERS

B. Turn to Student Text, Volume IX and read paragraphs 6-17 through 6-40. Return to this page and answer the following questions:

NOTE: In answering questions 1 through 6, refer to figure 3 of the Adjunct Guide or ST-IX, figure 6-5.

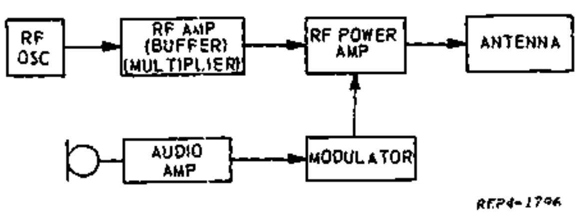


Figure 3. AM Transmitter

1. The RF OSC is used to produce the

______ a. modulated carrier.

______ b. unmodulated sidebands

______ c. modulated carrier and sidebands.

______ d. unmodulated carrier.

2. The MULTIPLIER is used to increase the

______ a. power level of the carrier.

______ b. frequency of the carrier in multiples of the carrier.

______ c. frequency of the carrier by any desired amount.

______ d. frequency of the carrier by heterodyning action.

3. The AUDIO AMP is used

______ a. to amplify the audio so that it is large enough to drive the MODULATOR to cut off and saturation.

______ b. as a very narrow band amplifier, to amplify the current from the microphone.

______ c. as an amplifier to increase the signal amplitude to a sufficient amplitude to drive the MODULATOR.

______ d. to convert the audio sounds into electromagnetic energy.

4. The MODULATOR is used to

______ a. provide the nonlinearity for modulation.

______ b. provide the power for the sidebands.

______ c. provide isolation for the oscillator.

______ d. produce the sidebands.

5. The RF POWER AMP is used to

_____ a. provide the nonlinearity for modulation.

_____ b. provide the power for the sidebands.

_____ c. produce changes in carrier frequency.

_____ d. amplify the audio signal.

6. The ANTENNA is used to convert

_____ a. RF signals into sound waves.

_____ b. RF signals into electromagnetic waves.

_____ c. electromagnetic waves into sound waves.

_____ d. RF signals into audio signals.

7. Figure 4 illustrates the modulating section of a transmitter. Determine the carrier power $P_c$ __________ and the sideband power $P_{sb}$ __________.

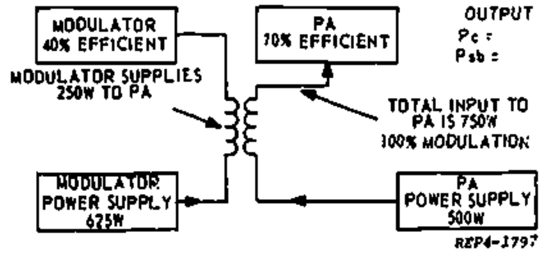


Figure 4

8. If amplification occurs after modulation, the sidebands receive more amplification than the carrier. (TRUE)(FALSE)

9. Changing the load on the carrier oscillator

_____ a. is desirable.

_____ b. is undesirable.

_____ c. cannot be avoided.

10. The stage in which modulation occurs is (linear)(nonlinear).

CONFIRM YOUR ANSWERS

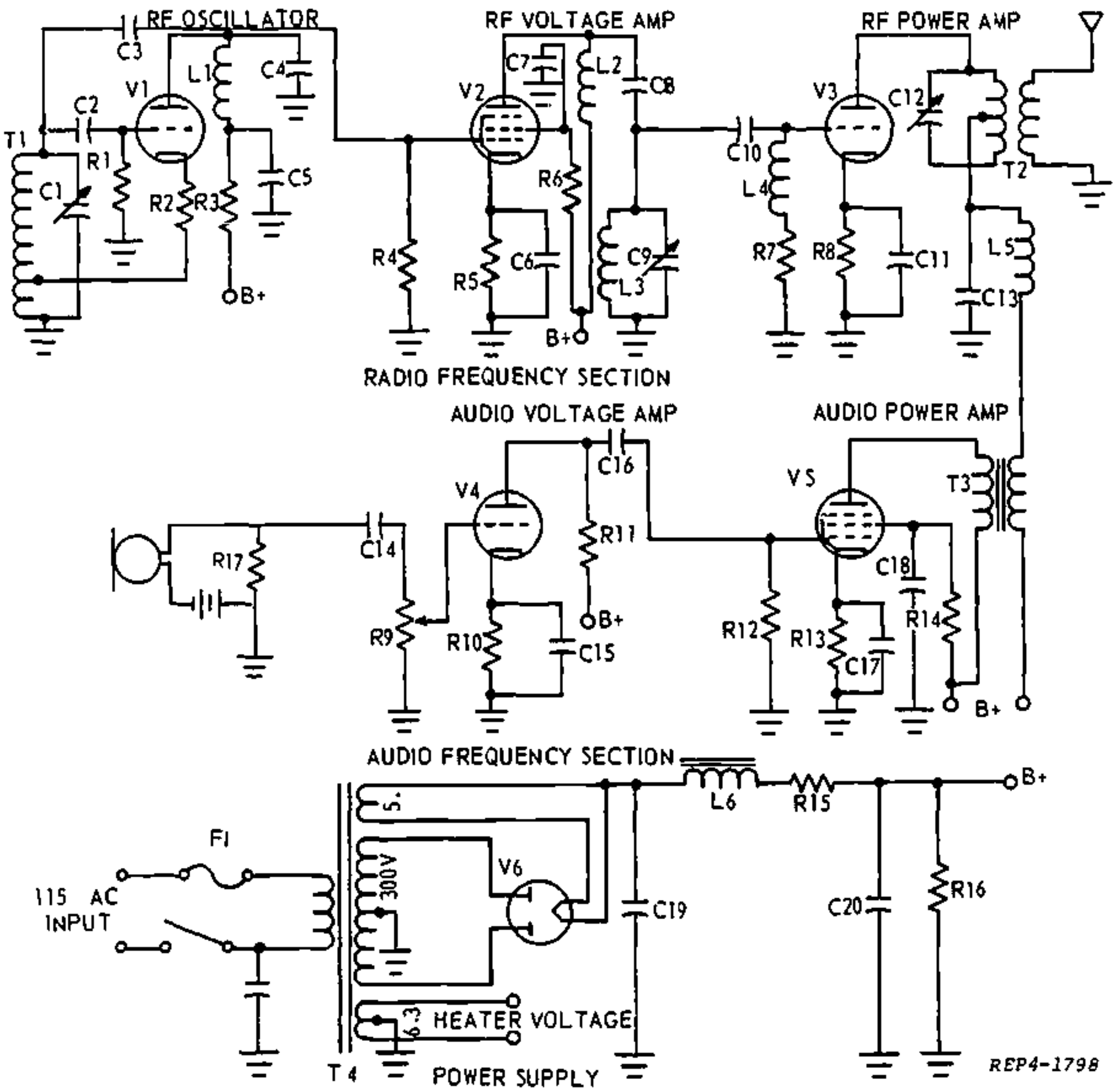


Figure 5

C. Turn to Student Text, Volume IX and read paragraphs 6-41 through 6-44. Return to this page and answer the following questions.

NOTE: Use figure 5 in answering questions 1 through 10.

1. A DC path of current through the RF oscillator is from ground through T1,

R ________, V1, L ________,

R ________, to B+.

2. RF oscillations are coupled from T1 and C1 through C ________ to the grid of V ________. RF is coupled from the plate of V2 through C ________ and C ________, amplified by V3 and developed in the tank circuit consisting of C ________ and T ________ (primary) and coupled to the antenna.

3. The DC path of current in the audio voltage amplifier is from ground through R ____, V ____, and R ____, to B+.

4. The DC path for current from the RF and AF stages is from B+ (top of R16), R ____, L____, V____ and T4 secondary to ground.

5. A path of DC in the RF power amplifier is from ____ through R ____, V____, T____(primary), L____ and T____ (secondary), to B+.

6. Two paths for DC in the RF voltage amplifier stage are from ground through R5 to: the plate of V2, L____, to B+; and the ____ ____ of V2, R____, to B+.

7. Two paths for DC in the audio power amplifier stage are from ground through R13; to the plate of V5, T____ ____, to B+; and to the screen grid of V5, R____, to B+.

8. The signal coupled to the antenna consists of a

____ a. sideband only.

____ b. modulated audio.

____ c. carrier and audio.

____ d. carrier and sidebands.

9. In figure 5, modulation is accomplished by varying the ____ ____ of V____.

10. The percent of modulation of the transmitter (figure 5) will (increase)(decrease) if the wiper arm of R9 is moved toward ground.

CONFIRM YOUR ANSWERS

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D. Turn to Student Text, Volume IX and read paragraphs 6-45 through 6-77. Return to this page and answer the following questions.

NOTE: Use figure 6 in answering questions 1 through 8.

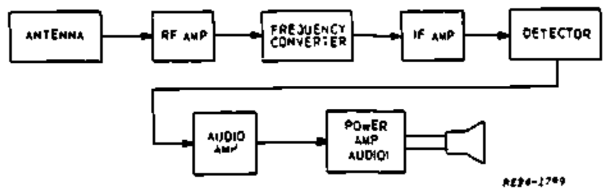


Figure 6

1. The RF AMP reduces interference caused by

____ a. mirror frequencies.

____ b. co-channel signals.

____ c. image frequencies.

2. Name the two basic types of frequency conversion stages used in a superheterodyne receiver.

____

____

3. An oscillator is part of the frequency conversion stage called a

____ ____

4. The local oscillator may be tuned above or below the desired incoming RF (TRUE) (FALSE)

5. What is the image frequency for 1500 kHz if the oscillator is tuned below the desired RF and the IF is 455 kHz?

6. All superheterodyne receivers use an intermediate frequency of 455 kHz. (TRUE) (FALSE)

7. The IF amplifier tank is adjusted to different stations. (TRUE)(FALSE)

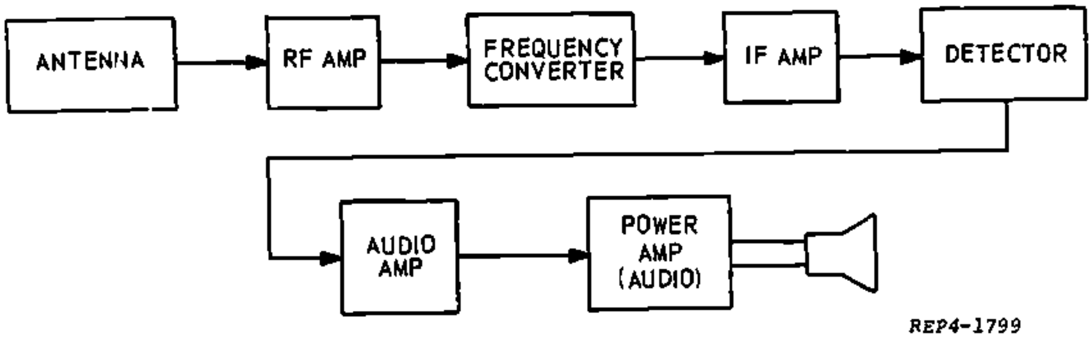


Figure 6. (Repeated)

8. From the labeled block diagram and the list of statements that describe each block of a single conversion AM receiver, match each block with the proper statement.

BLOCK

_____ a. IF AMP

_____ b. AUDIO AMP

_____ c. ANTENNA

_____ d. DETECTOR

_____ e. POWER AMP

_____ f. RF AMP

_____ g. FREQUENCY CONVERTER

STATEMENT

1. The stage that amplifies the small AC voltages induced into the antenna.

2. The stage that changes the incoming radio frequencies to intermediate frequencies.

3. The stage that primarily determines the selectivity of the receiver.

4. The stage that converts the electromagnetic waves into voltage and current.

5. The stage where the sidebands are heterodyned against the carrier.

6. The stage that produces the power to drive a speaker.

7. The stage that amplifies the audio signal from the detector.

CONFIRM YOUR ANSWERS

---

E. Turn to Student Text, Volume IX read paragraphs 6-78 through 6-85. Return to this page and answer the following questions.

1. Elimination of outer sidebands results in ____________________ distortion.

2. Distortion caused by heterodyning the sidebands against each other is __________ ____________________ distortion.

3. Reception of more than one signal of the same frequency is called ____________ ____________________

4. Square law distortion is a direct result of second harmonic distortion. (TRUE)(FALSE)

5. Adding second harmonics to a signal will alter its shape. (TRUE)(FALSE)

6. Cochannel interference may be reduced by using directional antennas. (TRUE) (FALSE)

7. Bandpass distortion may be reduced by reducing the bandwidth of the IF amplifier. (TRUE)(FALSE)

8. The fidelity of a square law detector is poor compared to a linear detector. (TRUE) (FALSE)

CONFIRM YOUR ANSWERS

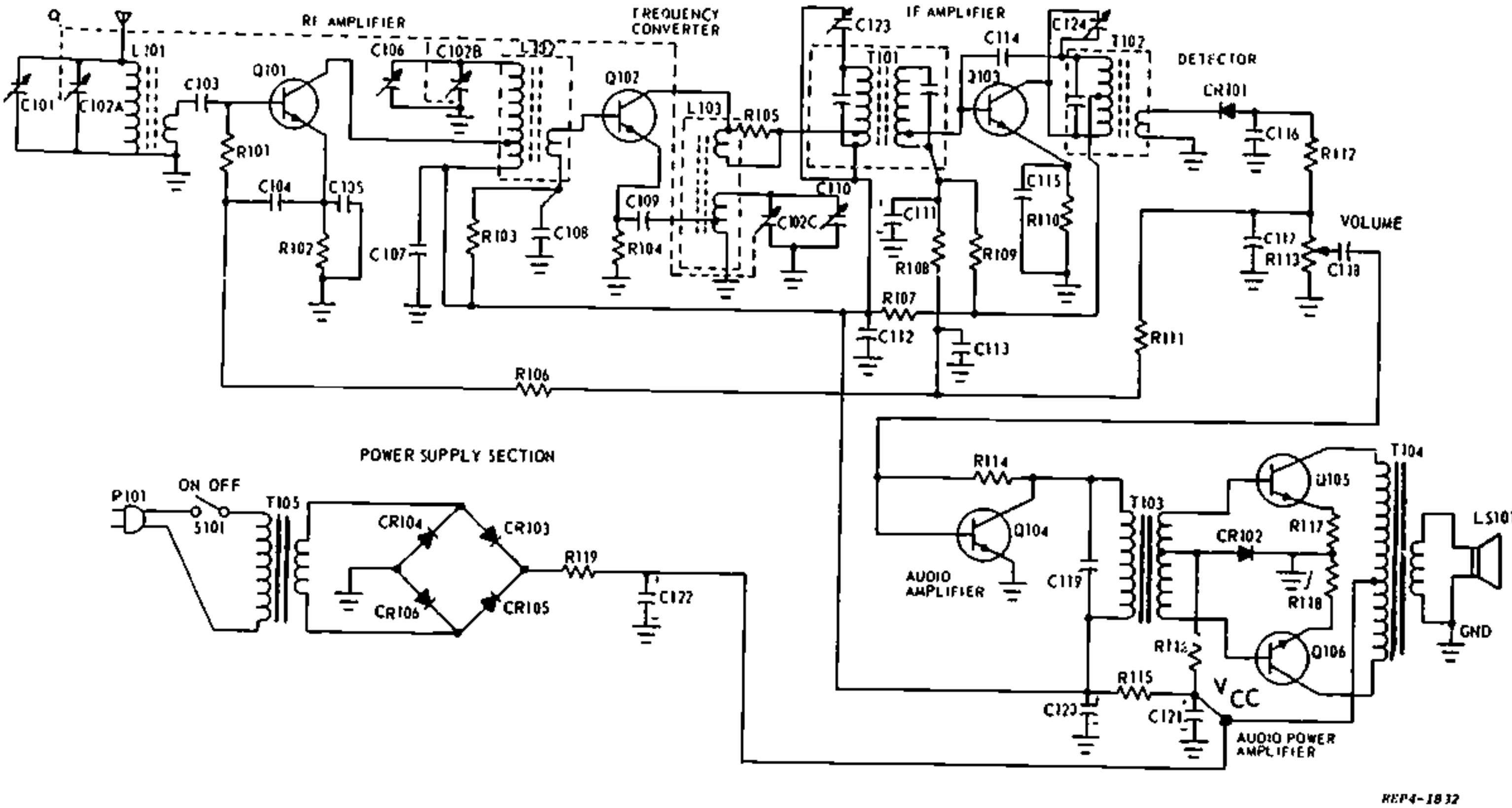
RF AMPLIFIER
FREQUENCY CONVERTER
IF AMPLIFIER
DETECTOR
VOLUME
POWER SUPPLY SECTION
ON OFF
AUDIO AMPLIFIER
AUDIO POWER AMPLIFIER
VCC
GND
C101
C102A
L101
C103
Q101
R101
C104
C105
R102
C106
C102B
L102
C107
R103
C108
Q102
L103
R105
C109
R104
C102C
C110
C123
T101
C114
Q103
C111
R108
R109
C115
R110
R107
C112
C113
C124
T102
CR101
C116
R112
C117
R113
C118
R111
R106
P101
S101
T105
CR104
CR103
CR106
CR105
R119
C122
R114
Q104
C119
T103
CR102
R117
R118
Q105
Q106
T104
LS101
R115
C120
C121
REP4-1832

FIGURE 7

F. Turn to Student Text, Volume IX and read paragraphs 6-86 through 6-103. Return to this page and answer the following questions.

NOTE: Use figure 7 in answering questions 1 through 20. (Figure 6-16 of ST-IX)

1. Which signal is present in the collector circuit of Q104?

_____ a. Modulated IF.

_____ b. RF.

_____ c. Audio.

_____ d. IF.

2. The amplified RF is coupled to the

_____ a. base of Q102 by L102.

_____ b. base of Q101 by C103.

_____ c. collector of Q102 by T101.

_____ d. collector of Q104 by C119.

3. Capacitors C101, C106 and C110 are

_____ a. main tuning capacitors.

_____ b. trimmer capacitors.

_____ c. padder capacitors.

4. Which signal is coupled from the antenna to Q101?

_____ a. Selected RF.

_____ b. IF.

_____ c. Modulated IF.

_____ d. Amplitude modulated audio.

5. The amplified IF is coupled to

_____ a. Q102 by T102.

_____ b. Q104 by T103.

_____ c. CR101 by T102.

_____ d. Q101 by R101.

6. The audio is first amplified by _____ and then, _____ and _____ in push pull.

7. Which signal is coupled from CR101 to the base of Q104?

_____ a. RF.

_____ b. IF.

_____ c. Modulated RF.

_____ d. Audio.

8. The signal developed in the tuned circuit of L103, C110 and C102C is

_____ a. modulated RF.

_____ b. modulated IF.

_____ c. unmodulated RF.

9. The amplified audio at the collector of Q104 is coupled to the base of Q105 and Q106 through

_____ a. R115 and R116.

_____ b. C119, R115 and R116.

_____ c. C119, C120 and CR102.

_____ d. T103.

10. The _______________ signal is developed across R113.

11. As the RF signal strength increases, the AVC voltage becomes (more) (less) positive.

12. Moving the wiper of R113 away from ground, increases the signal voltage applied to Q104 and increases the audio out. (TRUE) (FALSE)

13. The DC paths in the IF amplifier are from ground through R _______, emitter-base of Q _______, T101 secondary, R _______ and R _______ to $V_{CC}$; and from ground through R110, emitter-collector of Q 103, R _______, R _______, to $V_{CC}$.

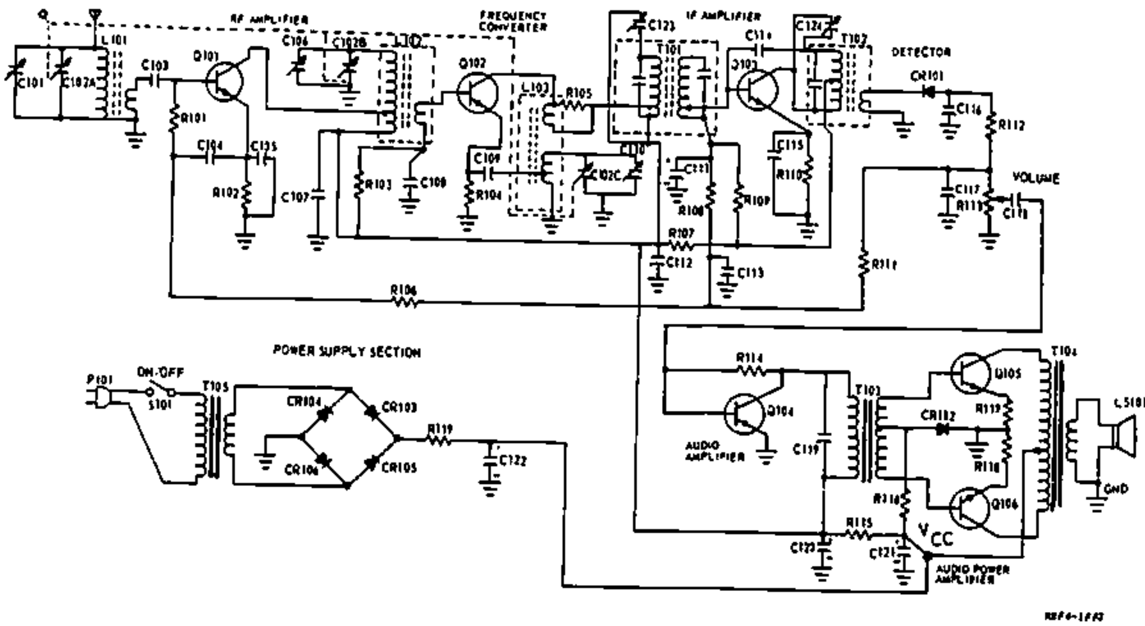


Figure 7. (Repeated)

14. The DC paths in the RF amplifier, Q101, are from ground through ________, emitter-base of Q101, and ________ to the AVC voltage; and from ground through R102, emitter-collector of Q101 and ______ and ________, to $V_{CC}$.

15. A path for current in the audio amplifier, Q104, is from ground, through emitter-collector of Q104, and ________ primary, ________, to $V_{CC}$.

16. The DC paths in the audio power amplifier stage, Q105, are from ________ through R ________, emitter-base of Q105, T ________ ______ and R ______ to $V_{CC}$, and from ground through R117, emitter-collector of Q105, T ________ to ________.

17. The DC paths in the power amplifier stage, Q106, are from ground through R ________, emitter-base of Q106, T ________ and R ________ to $V_{CC}$; and from ground through R118, emitter-collector of Q106, T ______ ______, to ______.

18. The DC paths in the frequency converter, Q102, are from ground through R ______, emitter-base of Q102, L ______ ______, R ________ and R115 to $V_{CC}$, and from ground through R104, emitter-collector of Q102, R ________ and L ______ (in parallel), through T ______ ______ and R ______ to $V_{CC}$.

19. The forward bias network for Q104 is from ground through the emitter-base junction of Q104, R ______, T ______ ______, R ______, to ______.

CONFIRM YOUR ANSWERS

________________________________

## MODULE SELF-CHECK

1. From the list of statements, select the statements that identify the causes of

_____ a. second harmonic distortion.

_____ b. bandpass distortion.

_____ c. cochannel interference.

1. Distortion caused by another station on the same channel as the one desired.

2. Distortion caused by heterodyning the sidebands.

3. Distortion caused by the elimination of some of the desired sidebands prior to demodulation.

2. From the list of statements of transmitter characteristics, select the statement that describes frequency STABILIZATION.

_____ a. reproduce the intelligence signal.

_____ b. maintain the operating frequency.

_____ c. produce the desired power out.

_____ d. convert audio signals into RF signals.

3. From the list of statements of receiver characteristics, select the statement that describes SENSITIVITY.

_____ a. The ability of a receiver to select and reproduce a desired signal from among several closely spaced stations.

_____ b. Ratio of the IF output voltage to the input signal voltage of the frequency converter.

_____ c. The ability of a receiver to reproduce the original modulating signal.

_____ d. The ability of a receiver to reproduce the intelligence of a very weak signal.

4. From the list of statements of receiver characteristics, select the statement that describes SELECTIVITY.

_____ a. The ability of a receiver to select and reproduce a desired signal from several closely spaced stations.

_____ b. Ratio of the IF output voltage to the input signal voltage of the frequency converter.

_____ c. The ability of a receiver to reproduce the original modulating signal.

_____ d. The ability of a receiver to reproduce the intelligence of a very weak signal.

5. Direct modulation of an oscillator usually causes frequency instability. (TRUE)(FALSE)

6. Variations in load impedance on an LC oscillator will not cause frequency changes. (TRUE)(FALSE)

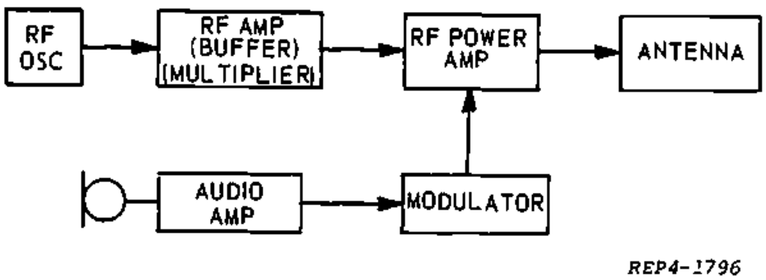


Figure 1

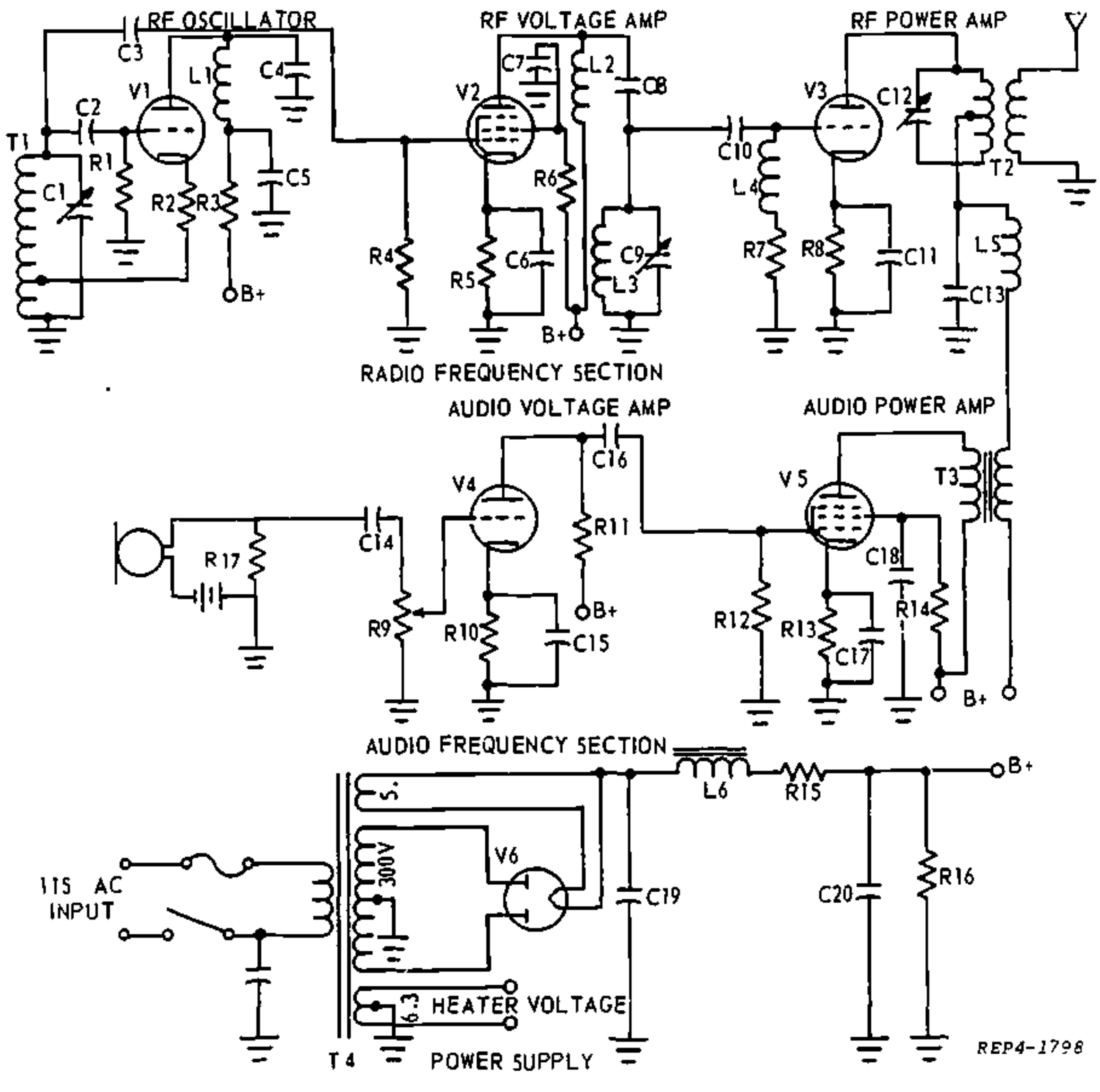


Figure 2

7. From the labeled block diagram and a list of statements that describe each block of an AM transmitter, match each block with the proper statements. Refer to figure 1 or ST-IX, figure 6-5.

| BLOCK | STATEMENT |
|---|---|
| _____ a. RF OSC | 1. The stage that converts RF currents into electromagnetic energy. |
| _____ b. RF AMP | 2. The stage that produces the carrier. |
| _____ c. RF POWER AMP | 3. The stage in which the sidebands are produced. |
| _____ d. AUDIO AMP | 4. The stage that amplifies the signal applied to the modulator. |
| _____ e. MODULATOR | 5. The stage that produces the power for the sidebands. |
| _____ f. ANTENNA | 6. The stage that is used as an isolator, frequency multiplier or amplifier. |

Refer to figure 2 for questions 8 and 9.

8. Trace the RF and intelligence signals from origin to output. For each stage, in turn, name the type of input and output signals and the next stage. (Figure 6-7 in ST-IX)

V 4 input audio
output _____
next stage _____

V5 input _____
output _____
next stage _____

V 1 input _____
output _____
next stage _____

V2 input _____
output _____
next stage _____

V 3 inputs _____
& _____
output _____
next stage Antenna

9. Trace the direct current paths from ground through each stage. Place the component number in the blanks, in turn.

V1. T _____, R _____
V _____, L _____ and
R _____, to B+.

V2. R _____, V _____, to
screen grid, R _____ to B+;
also through V _____, to plate,
and L _____, to B+.

V3. R _____, V _____,
T _____, L _____
and T _____, to B+.

V4. R _____, V _____
and R _____, to B+.

V5. R _____, V _____,
to screen grid, and R _____,
to B+; also through V _____
to plate and T _____, to B+.

V6. R _____, R _____,
L _____, V _____,
T _____ (power transformer-secondary) to ground.

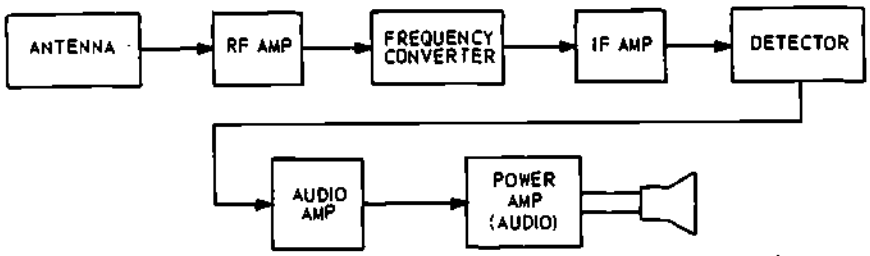


Figure 3

10. Use figure 3 or figure 6-8 in ST-IX and the list of statements that describe each block of an AM receiver, match each block with the proper statement.

BLOCK

_____ a. ANTENNA

_____ b. RF AMP

_____ c. FREQUENCY CONVERTER

_____ d. IF AMP

_____ e. Detector

_____ f. Audio AMP

_____ g. POWER AMP

STATEMENT

1. The stage that determines the receivers selectivity and major portion of the receivers gain prior to demodulation.

2. Intercepts the electromagnetc wave and converts it into RF currents.

3. The stage that produces the power to drive the final transmitter stage.

4. The stage that reproduces the intelligence signal from the modulated IF signal.

5. The stage that heterodynes a local signal with the RF to produce the IF.

6. The stage that amplifies the audio taken from the detector output.

7. The stage that selects and amplifies the desired RF signals.

11. Use figure 6-16 of KEP-ST-IX and trace the signal flow from origin to output. For each stage, in turn, name the type of input and output and the next stage.

Q101 — input RF; output _____; next stage _____

Q102 — input _____; output _____; next stage _____

Q103 — input _____; output _____; next stage _____

CR101 — input _____; output _____; next stage _____

Q104 — input _____; output _____; next stage _____

Q105 & Q106 input ________

output ________

next stage . Speaker .

12. Use figure 6-16 of KEP-ST-IX and trace the circuit current paths from ground through each stage. Place the component number in the blanks, in turn.

Q101. R ________, emitter-base of Q ________, R ________, R ________, R ________, R ________, R ________ and R ________, to $V_{CC}$; also, R ________, emitter-collector of Q ________, L ________, and R ________, to $V_{CC}$.

Q102. R ________, emitter-base of Q ________, L ________, R ________, and R ________ to, ________; also, R ________, emitter-collector of Q ________ L ________ and R ________ (in parallel), then T ________, R ________, to ________.

Q103. R ________, emitter-base of, Q ________, T ________, R ________, R ________, R ________ to ________; also, R ________, emitter-collector, Q ________, T ________, R ________, R ________, to ________

Q104. Emitter-base ground, of Q ________, R ________, T ________ primary, R ________, to $V_{CC}$; also, emitter-collector of Q ________ T ________, R ________, to $V_{CC}$.

Q105. R ________, emitter-base of Q ________, T ________, R ________, to ________; also, R ________, emitter-collector of Q ________, T ________, to ________.

Q106. R ________, emitter-base of Q ________, T ________, R ________, to $V_{CC}$; also, R ________, emitter-collector of Q ________, T ________, to $V_{CC}$.

CONFIRM YOUR ANSWERS

ANSWERS TO A - ADJUNCT GUIDE

1. True
2. c
3. sensitivity
4. a. Reception
   b. Selection
   c. Detection
   d. Amplification
   e. Reproduction
5. selectivity

If you missed ANY questions, review the material before you continue.

ANSWERS TO B - ADJUNCT GUIDE

1. d
2. b
3. c
4. b
5. a
6. b
7. $P_c = 350$ W
   $P_{sb} = 175$ W
8. False
9. b
10. nonlinear

If you missed ANY questions, review the material before you continue.

ANSWERS TO C - ADJUNCT GUIDE

1. R2, L1, R3
2. C3, V2, C8, C10, C12, T2
3. R10, V4, R11
4. R15, L6, V6
5. ground, R8, V3, T2 (primary), L5, T3 (secondary).
6. L2; screen grid, R6
7. T3; R14
8. d
9. plate voltage, V3
10. decrease

If you missed ANY questions, review the material before you continue.

ANSWERS TO D - ADJUNCT GUIDE

1. c
2. mixer
   converter (order not important)
3. converter
4. True
5. 590 kHz
6. False
7. False
8. a. 3 e. 6
   b. 7 f. 1
   c. 4 g. 2
   d. 5

If you missed ANY questions, review the material before you continue.

ANSWERS TO E - ADJUNCT GUIDE

1. bandpass
2. 2nd harmonic
3. cochannel interference
4. True
5. True
6. True
7. False
8. True

If you missed ANY questions, review the material before you continue.

ANSWERS TO F - ADJUNCT GUIDE

1. c
2. a
3. b
4. a
5. c
6. Q104; Q105 and Q106
7. d
8. c
9. d
10. audio
11. less
12. True
13. R110; Q103; R109; R107; R115 and T102; R107; R115
14. R102; R101; R106 and L102; R115

15. T103; R115
16. ground; R117; T103 secondary; R116 and T104 primary; $V_{CC}$
17. R118; T103 secondary; R116 and T104 primary; $V_{CC}$
18. R104, L102 secondary; R103 and R105; L103, T101 primary; R115
19. R114; T103 primary; R115, $V_{CC}$

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK

1. a. 2
   b. 3
   c. 1
2. b
3. d
4. a
5. True
6. False
7. a. 2
   b. 6
   c. 3
   d. 4
   e. 5
   f. 1
8. V4 input - audio output - amplified audio next stage - V5 (modulator)

   V5 input - audio output - amplfied audio next stage - V3 (RF power amplifier)

   V1 input - tank frequency output - amplified carrier next stage - V2 (RF voltage amplifier)

   V2 input - carrier output - amplified carrier next stage - V3 (RF power amplifier)

   V3 inputs - carrier & audio output - modulated RF wave next stage - antenna
9. V1 - T1, R2, V1, L1, and R3
   V2 - R5, V2, R6; also, V2, L2.
   V3 - R8, V3, T2, L5 and T3.
   V4 - R10, V4, and R11.
   V5 - R13, V5, R14; also, V5, T3.
   V6 - R16, R15, L6, V6, T4
10. a. 2
    b. 7
    c. 5
    d. 1
    e. 4
    f. 6
    g. 3
11. Q101 - input - RF output - RF next stage - Q102 (Frequency Converter)

    Q102 - input - RF output - IF next stage - Q103 (IF Amplifier)

    Q103 - input - IF output - amplified IF next stage - CR101 (Detector)

    CR101 - input - IF output - audio next stage - Q104 (Audio Amplifier)

    Q104 - input - audio output - amplified audio next stage - Q105 & Q106 (Audio Power Amplifier)

    Q105 & Q106 - input - audio output - amplified audio next stage - Speaker
12. Q101. R102, Q101, R101, R106, R108, R109, R107 and R115; also, R102, Q101, L102 and R115

    Q102. R104, Q102, L102, R103, R103, R115, to $V_{CC}$; also, R104, Q102, L103 and R105 then T101, R115, to $V_{CC}$.

    Q103. R110, Q103, T101, R109, R107, R115, to $V_{CC}$; also, R110, Q103, T102, R107, R115 to $V_{CC}$.

    Q104. Q104, R114, T103, R115; also, Q104, T103, R115.

    Q105. R117, Q105, T103, R116, to $V_{CC}$; also, R117, Q105, T104, to $V_{CC}$.

    Q106. R118, Q106, T103, R116, to $V_{CC}$; also, R118, Q106, T104

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER INSTRUCTION.

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ATC GP 3AQR3X020-X

Prepared by Keesler TTC

KEP-GP-70

Technical Training

# Electronic Principles (Modular Self-Paced)

## Module 70

## SINGLE SIDEBAND SYSTEMS

February 1976

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Designed For ATC Course Use

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Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-70
February 1976

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 70

## SINGLE SIDEBAND SYSTEMS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

### CONTENTS



### OVERVIEW

1. SCOPE: This module contains material on the basics of a single sideband communications system and includes the following: the block diagrams of a transmitter and receiver with a description of signal and current paths.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives.

a. Given a labeled block diagram and a list of statements that describes each block of a single sideband transmitter, match each block with the proper statement.

b. Given a labeled block diagram and a list of statements that describes each block of a single sideband receiver, match each block with the proper statement.

c. Given a schematic diagram of a single sideband transmitter, trace

(1) the RF and intelligence signal flow from origin to output.

(2) direct current path through each stage in a closed loop.

d. Given a schematic diagram of a single sideband receiver, trace

(1) the signal flow from origin to output.

(2) direct current path through each stage in a closed loop.

### LIST OF RESOURCES

To satisfy the objectives of this module you may choose, according to your training, experience, and preferences, any or all of the following.

READING MATERIALS:

Digest

Adjunct Guide with Student Text, Volume IX

AUDIOVISUAL AIDS:

TV Lesson, Introduction to Single Sideband, TVK-30-611

Supersedes Guidance Package KEP-GP-70, 1 August 1975; stock on hand will be used.

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

## ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Confirm your answers with the answers at the back of this Guidance Package.

Contact your instructor if you experience any difficulty.

Begin the program.

---

The material presented in this module will assist you in understanding the operation of a single sideband communication system.

A. Turn to Student Text, Volume IX, and read paragraphs 6-125 through 6-145. Return to this page and answer the following questions.

1. Single sideband transmitters suppress one set of sidebands and the carrier. (True) (False)

2. The bandwidth of a SSB system comparec to AM is

_____a. the same.

_____b. twice as wide.

_____c. one half.

_____d. much wider.

3. An AM transmitter is modulated with a tone at 100 percent modulation. Which of the following divisions of intelligence power are produced in one sideband?

_____a. 1/6 total power

_____b. 1/4 total power

_____c. 1/3 total power

_____d. 1/8 total power

4. SSB has better performance because of

_____a. wider bandwidth.

_____b. reduction in selective fading.

_____c. lower signal to noise ratio.

_____d. the simplicity of the demodulator.

5. SSB transmitters are more efficient due to elimination of the _______________.

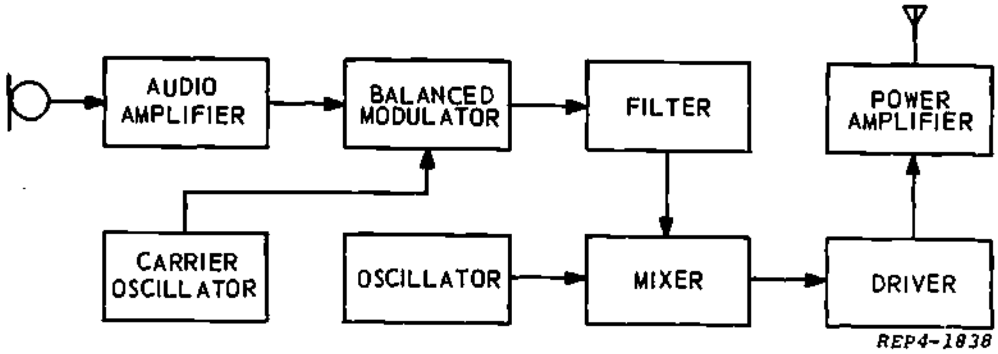


Figure 1. Single Sideband Transmitter Block Diagram

NOTE: Use figure 1 in answering questions 6 through 12.

6. Which stage eliminates the carrier in a SSB transmitter?

____a. Filter

____b. Mixer

____c. Balanced modulator

____d. Driver

7. The carrier oscillator in a SSB transmitter does not require a high degree of stability. (True) (False)

8. The input to the balanced modulator is

____a. audio and modulated carrier.

____b. audio and an unmodulated carrier.

____c. DC and a modulated carrier.

____d. DC and audio.

9. The output of the balanced modulator is the

____a. upper and lower sidebands and the carrier.

____b. upper sidebands and the carrier.

____c. lower sidebands and the carrier.

____d. upper and lower sidebands.

10. The filter eliminates

____a. both sets of sidebands.

____b. the carrier.

____c. one set of sidebands.

____d. power supply ripple.

11. What is the function of the mixer?

____a. Produce harmonics of the sideband.

____b. Raise the frequency of the sideband.

____c. Increase the frequency swing of the sidebands.

____d. Lower the frequency of the sideband.

12. From the labeled block diagram and the list of statements that describe each block of a single sideband transmitter, match each with the proper statement.

BLOCKS

_____a. Power Amplifier

_____b. Carrier Oscillator

_____c. Mixer

_____d. Audio Amplifier

_____e. Driver

_____f. Balanced Modulator

_____g. Filter

_____h. Oscillator

STATEMENTS

(1) The stage that develops the RF carrier.

(2) The stage that passes the desired sidebands.

(3) The stage where the sidebands are produced and the carrier eliminated.

(4) The stage that amplifies the audio.

(5) The stage that produces the power to be radiated.

(6) The stage that raises the frequency level of the sideband.

(7) The intermediate amplifier.

(8) The stage that produces an RF signal.

CONFIRM YOUR ANSWERS.

________________________________________

B. Turn to Student Text, Volume IX, and read paragraphs 6-146 through 6-149. Return to this page and answer the following questions.

1. A conventional AM broadcast receiver can receive and demodulate SSB. (True) (False)

2. The bandwidth of an SSB receiver compared to an AM receiver is

_____a. the same.

_____b. twice as wide.

_____c. half as wide.

3. The product demodulator has two signal inputs. They are the ____________________ and the ____________________.

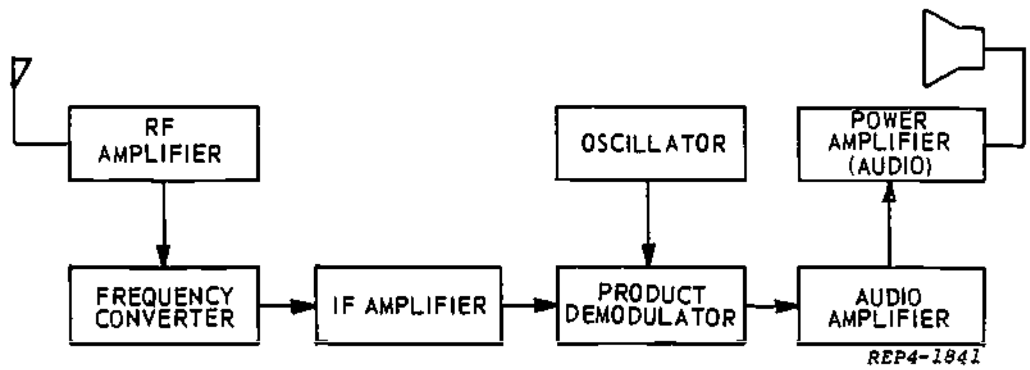


Figure 2. SSB Receiver Block Diagram

4. From the labeled block diagram (figure 2) of an SSB receiver, match each block with the proper statement.

____a. Frequency Converter

____b. Audio Amplifier

____c. RF Amplifier

____d. Product Demodulator or Detector

____e. Power Amplifier

____f. Oscillator

____g. IF Amplifier

(1) The stage that primarily determines receiver selectivity.

(2) The stage that produces the power to drive the speaker.

(3) The stage that produces audio.

(4) The stage that primarily determines the receiver sensitivity.

(5) The stage that produces a carrier signal.

(6) The stage that converts the incoming RF to IF.

(7) The stage that amplifies the signal from the demodulator.

CONFIRM YOUR ANSWERS.

---

C. Turn to Student Text, Volume IX, and read paragraphs 6-150 through 6-153. Return to this page and answer the following questions.

NOTE: Use figure 3 in answering questions 1 through 22 (figure 6-26 in KEP-ST-IX).

1. The paths of direct current in the mixer are from ground through R____, Q____, and R110 to $V_{CC}$. Also from ground through R____, Q____, and T106 to $V_{CC}$.

2. The paths of direct current in the audio amplifier are from ground through R102, Q____ in parallel with R____, then through R____ and T102 to $V_{CC}$. Also from ground through R102, Q____ and T____ to $V_{CC}$.

3. The direct current paths in the carrier oscillator are from ground through R105, emitter base of Q102 in parallel with R104, then through R103 to $V_{CC}$. Also from ground through R105, emitter collector of Q102, and primary of T103 to $V_{CC}$. (True) (False)

4. The direct current paths in Q103 are from $V_{CC}$ through R109, RFC101, collector emitter of Q103, C108 to ground. Also from $V_{CC}$ through R108, base emitter of Q103 and C108 to ground. (True) (False)

5. The direct current in the plate circuit of the driver is from ground through R113, V____, and RFC____ to B+.

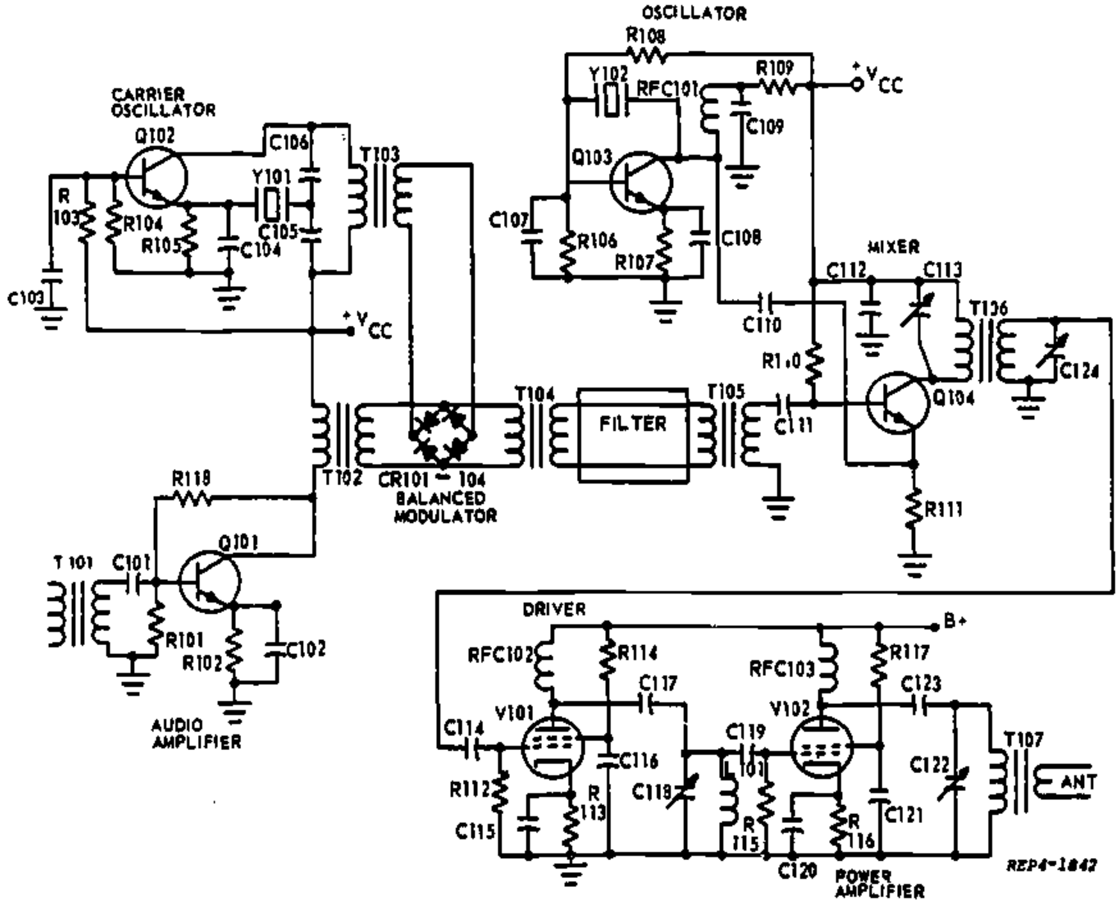


Figure 3. SSB Transmitter Schematic

6. The path of screen current in the power amplifier is from ground through R____, V102 and R____ to B+.

7. The direct current in the plate circuit of V102 is from _______ through R____, V102 and RFC____ to B+.

8. The screen current path for V101 is from ________ through R____, V101 and R____ to B+.

9. The audio signal is coupled through C101, developed across R101, and applied to the base of Q101. (True) (False)

10. The amplified audio is coupled to the base of Q102. (True) (False)

11. The carrier oscillations are coupled through T102 into CR101. (True) (False)

12. The carrier is coupled out of the balanced modulator through T104 to the filter. (True) (False)

13. The audio is coupled into the balanced modulator through T102. (True) (False)

14. The carrier oscillator signal is coupled into the balanced modulator through T103. (True) (False)

15. The only output through T104 is the upper and lower sidebands. (True) (False)

16. The filter passes the desired sidebands to T105. (True) (False)

17. The oscillations from the collector of Q103 are applied to the

____a. collector of Q104.

____b. emitter of Q104.

____c. base of Q104.

____d. control grid of V101.

18. The desired sideband from T105 is coupled to the

____a. base of Q103.

____b. collector of Q104.

____c. base of Q104.

____d. collector of Q103.

19. The output signal of the driver is coupled to the grid of the power amplifier. (True) (False)

20. The output of the mixer Q____ is coupled to the grid of V____.

21. The power amplifier receives its signal from the driver into its plate circuit by coupling through RFC102 and RFC103. (True) (False)

22. The output of V102 is coupled to the antenna. (True) (False)

CONFIRM YOUR ANSWERS.

---

D. Turn to Student Text, Volume IX, and read paragraphs 6-154 through 6-155. Return to this page and answer the following questions.

NOTE: Use figure 4 in answering questions 1 through 20 (figure 6-27 in KEP-ST-IX).

1. The RF signal is coupled to the base of Q101, the

____a. RF amplifier.

____b. frequency converter.

____c. IF amplifier.

____d. limiter.

2. The amplified RF from the RF amplifier is coupled to

____a. the base of Q102 by L102.

____b. the base of Q102 by R103.

____c. the collector of Q102 by T101 and R105.

____d. the collector of Q104 by C119.

3. What type signal is present in the collector circuit of Q104?

____a. Modulated IF

____b. RF

____c. Audio

____d. IF

4. What signal is coupled through C109 to the emitter of Q102?

____a. Modulated IF

____b. RF

____c. Unmodulated IF

____d. Local oscillator

5. What signals are coupled from the collector of Q102 to the base of Q103?

____a. RF

____b. IF

____c. Modulated RF

____d. Audio

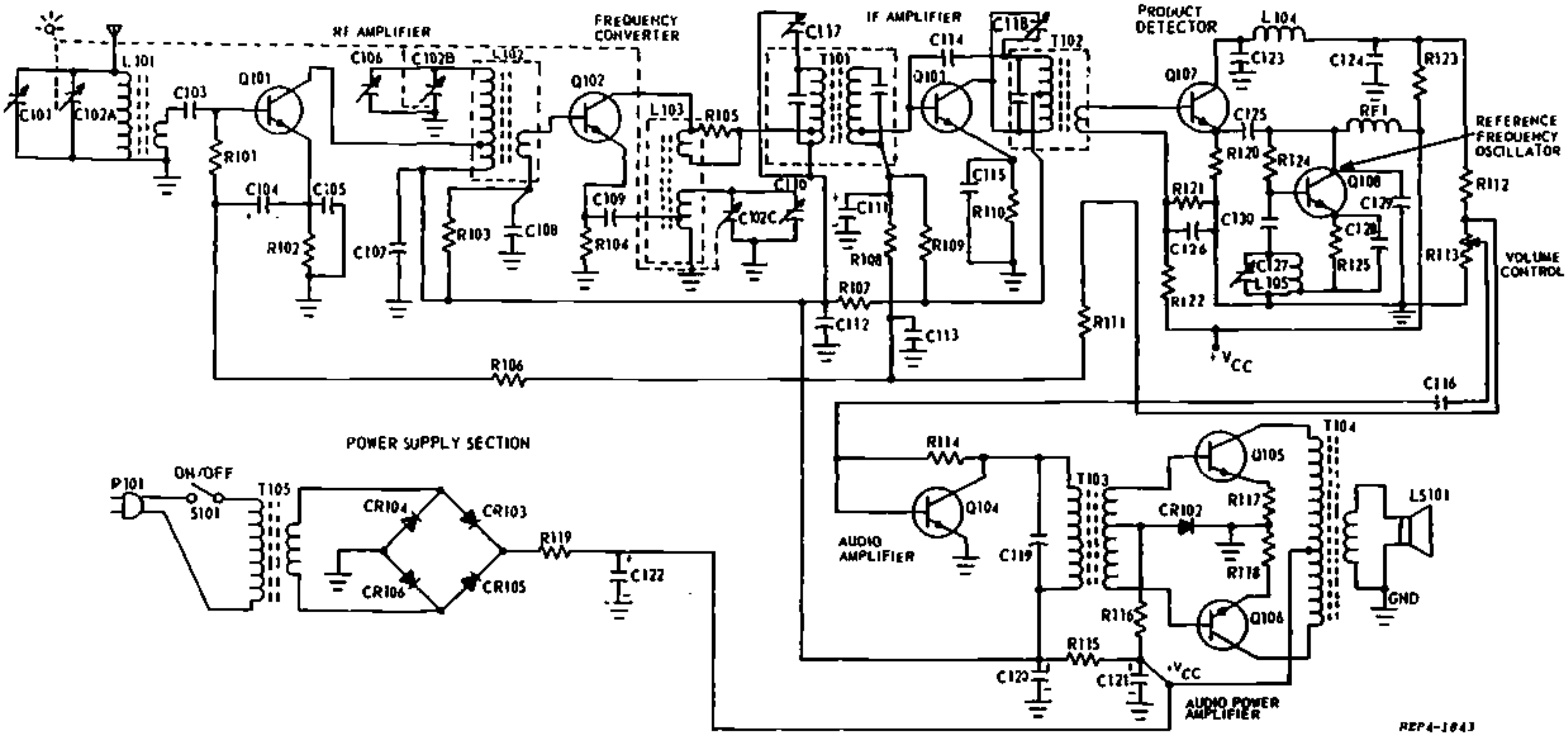


**Figure 4. SSB Receiver Schematic**

6. The signal coupled through C125 to the demodulator is the

_____a. upper sideband frequency.

_____b. lower sideband frequency.

_____c. carrier frequency.

_____d. audio signal.

7. The IF is applied to the base of Q107. (True) (False)

8. The signal developed across R113 is the

_____a. modulated IF.

_____b. carrier.

_____c. sideband.

_____d. audio.

9. The amplified audio in the collector of Q104 is coupled to the base of Q105 and Q106 through

_____a. R115 and R116.

_____b. C119, R115 and R116.

_____c. T103.

_____d. C119, C120 and CR102.

10. The DC paths in Q106 are from _______ _________ and R_____ through emitter base of Q106 through T_____ and R116 to $V_{CC}$. Also from _________ and R_____ through emitter collector of Q106 and T_____ to $V_{CC}$.

11. The DC paths in the IF amplifier are from ground through R_____, Q_____, T101, R_____, R_____, R_____, to $V_{CC}$, also from ground through R_____, Q_____, T102, and R_____, R_____, to $V_{CC}$.

12. The forward bias network for the carrier oscillator is from ground through L105, C130, R124, and RFC107 to $V_{CC}$. (True) (False)

13. The collector path of direct current in Q108 is from ground, part of L105, R125, emitter collector of Q108 and RFC107 to $V_{CC}$. (True) (False)

14. The DC paths for Q102 are from ground through R_____, emitter base of Q102, L_____, and R103 to $V_{CC}$, also from ground through R_____, emitter collector of Q102, R_____, and L_____ in parallel then T101 to $V_{CC}$.

15. The forward bias network for Q104 is from ground through the emitter base junction of Q104, C118, R113, R112, and R123 to $V_{CC}$. (True) (False)

16. The correct DC paths in the RF amplifier are from ground through R____, emitter base of Q____, R101 and R____ to a positive voltage, also from ground through R____, emitter collector of Q101 and L____ to $V_{CC}$.

17. The DC paths in the circuit of Q105 are from ground through R____, emitter base of Q105, T____ and R116 to $V_{CC}$, also from ground through R117, ________________ ________________ of Q105 and T104 to $V_{CC}$.

18. The collector load of Q104 is ________.

19. The DC paths for Q107 are from ground through R____, emitter base of Q107, secondary of T____ in parallel with R121, then through R____ to ____, also from ground through R____, emitter collector of Q107, L____ and R____ to $V_{CC}$.

20. A path of direct current in the carrier oscillator is from ground through L105, R125, emitter collector of Q108 and RFC101 to $V_{CC}$. (True) (False)

CONFIRM YOUR ANSWERS.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

## MODULE SELF-CHECK

QUESTIONS:

1. A SSB system is less subject to noise because it

____a. has a wider bandwidth.

____b. produces less noise in the transmitter.

____c. has a narrower bandwidth.

____d. is in a noise free spectrum.

2. A SSB system is less subject to selective fading. (True) (False)

3. The benefits of the SSB system arise primarily from the higher overall efficiency of generation and use of sideband power. (True) (False)

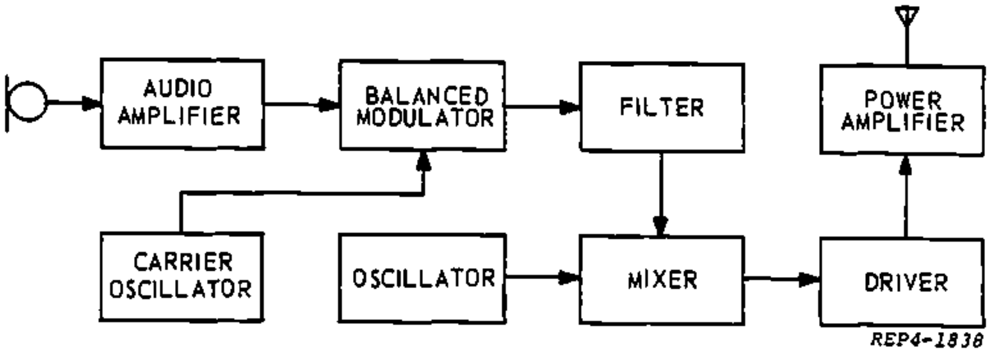


Figure 1. Single Sideband Transmitter

4. From the labeled block diagram in figure 1 and the list of statements that describe each block of a single sideband transmitter, match each with the proper statement.

BLOCKS

_____a. Carrier Oscillator

_____b. Filter

_____c. Driver

_____d. Oscillator

_____e. Balanced Modulator

_____f. Mixer

_____g. Power Amplifier

_____h. Audio Amplifier

STATEMENTS

(1) The stage that produces the sidebands and eliminates the carrier.

(2) The stage that amplifies the audio to the level necessary to drive the balanced modulator.

(3) The stage that produces the RF carrier.

(4) The stage that produces the power to be radiated by the antenna.

(5) The stage in which heterodyning occurs to raise the frequency level of the desired sideband.

(6) The stage that passes only the desired sideband.

(7) An intermediate amplifier used to develop a signal large enough to drive the power amplifier.

(8) The stage that produces the RF signal used to heterodyne with the sideband to produce the desired frequency level.

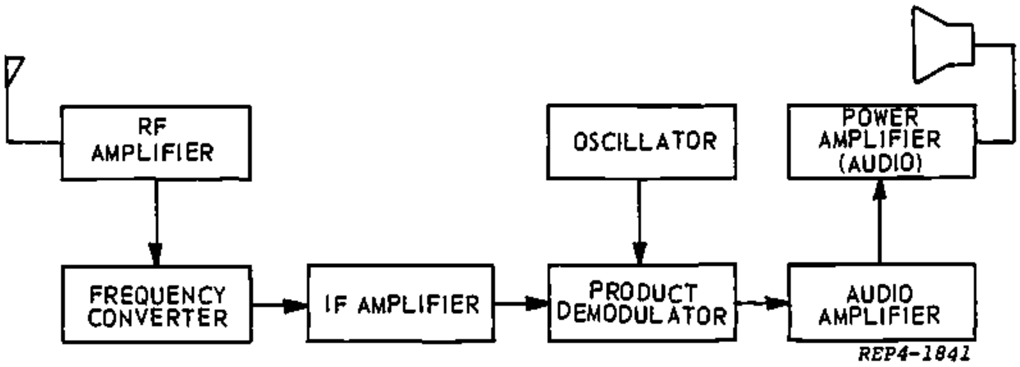


Figure 2. Block Diagram SSB Receiver

5. From the labeled block diagram shown in figure 2, and the list of statements that describe each block of a single sideband receiver, match each block with the proper statement.

BLOCKS

_____a. IF Amplifier

_____b. Power Amplifier (Audio)

_____c. Frequency Converter

_____d. Audio Amplifier

_____e. Oscillator

_____f. RF Amplifier

_____g. Product Demodulator or Detector

STATEMENTS

(1) The nonlinear stage that produces the audio.

(2) The stage that produces the signal to heterodyne with the sideband to produce the intelligence.

(3) The stage that amplifies the audio so that it is large enough to drive the power amplifier.

(4) The tuned amplifier that amplifies the desired signal from the frequency converter.

(5) The output stage.

(6) The stage that produces the IF.

(7) The stage that selects the desired incoming frequency, amplifies it, and couples it to the frequency converter.

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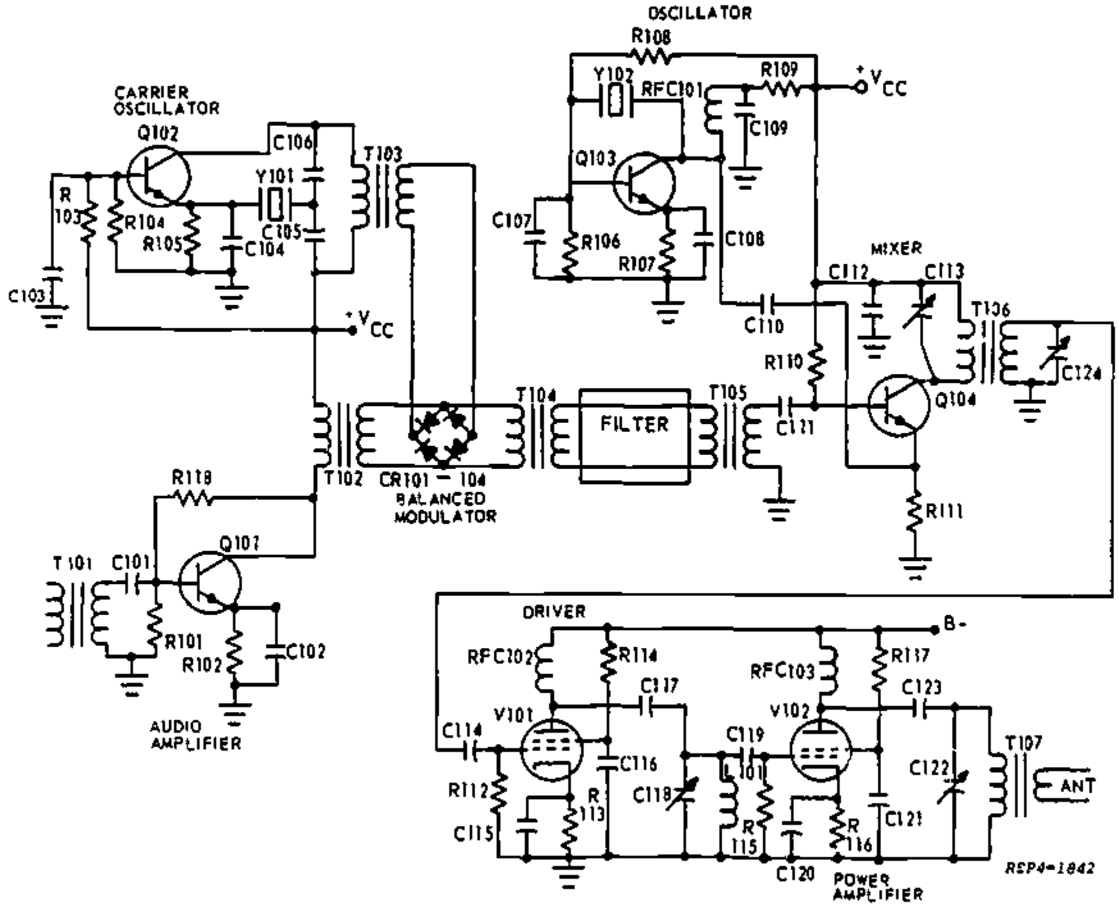


Figure 3. SSB Transmitter Schematic

6. Using figure 3, the schematic diagram of a single sideband transmitter, trace the RF and intelligence signals from origin to output. List each stage in turn, name the type of input and output signals, and the next stage.

Q_____ input ____________________

output ____________________

next stage ____________________

Q_____ output ____________________

next stage ____________________

CR_____ inputs __________ & __________

outputs __________ & __________

next stage ____________________

Filter_____ inputs __________ & __________

output ____________________

next stage ____________________

Q_____ output ____________________

next stage ____________________

Q_____ inputs __________ & __________

output ____________________

next stage ____________________

V_____ input ____________________

output ____________________

next stage ____________________

V_____ input _______________

output _______________

next stage _____antenna_____

7. Using figure 3, the schematic diagram of a single sideband transmitter, and a list of stages, trace the direct current paths from ground through each stage. Place the component number in the blanks in turn.

Q101 R_____, Q_____, R_____, and T_____ to $V_{CC}$; also R_____, Q_____, and T_____ to $V_{CC}$.

Q102 R_____, Q_____, and R_____ to _____; also R_____, Q_____, and T_____ to _____.

Q103 R_____, Q_____, and R_____ to $V_{CC}$; also R_____, Q_____, RFC_____, and R_____ to _____.

Q104 R_____, Q_____, and R_____ to $V_{CC}$; also R_____, Q_____, and T_____ to _____.

V101 R_____, V_____, RFC_____ to B+; also R_____, V_____, and R_____ to B+.

V102 R_____, V_____, and RFC_____ to _____; also R_____, V_____ and R_____ to _____.

8. Using figure 4, the schematic diagram of a single sideband receiver, trace the signal flow from origin to output. List each stage in turn, name the type of input and output, and the next stage (figure 6-27 in KE P-ST-IX).

Q_____ input _______________

output _______________

next stage _______________

Q_____ input _______________

output _______________

next stage _______________

Q_____ input _______________

output _______________

next stage _______________

Q_____ output _______________

next stage _______________

Q_____ inputs _________ & _________

output _______________

next stage _______________

Q_____ input _______________

output _______________

next stage _____ & _________

Q_____ input _______________

& Q_____ output _______________

next stage _____speaker_____

9. Using figure 4, the schematic diagram of a single sideband receiver and a list of stages, trace the direct current paths from ground through each stage. Place the component number in the blanks in turn (figure 6-27 of Student Text).

Q101 R_____, Q_____, R_____, R_____, R_____, R_____, and R_____ to $V_{CC}$; also R_____, Q_____, and L_____ to $V_{CC}$.

Q102 R_____, Q_____, L_____, and R_____ to _____; also R_____, Q_____, L_____ and R_____ then T_____ to $V_{CC}$.

Q103 R_____, Q_____, T_____, R_____, and R_____ to _____; also R_____, Q_____, T_____, and R_____ to _____.

Q107 R_____, Q_____, T_____, and R_____ to $V_{CC}$; also R_____, Q_____, L_____, and R_____ to $V_{CC}$.

Q108 L_____, R_____, Q_____, R_____ and RFC_____ to _____; also L_____, R_____, Q_____, and RFC_____ to _____.

Q104 Q_____, R_____, and T_____ to $V_{CC}$; also Q_____ and T_____ to $V_{CC}$.

Q105 R_____, Q_____, T_____, and R_____ to _____; also R_____, Q_____, and T_____ to _____.

Q106 R_____, Q_____, T_____, and R_____ to _____; also R_____, Q_____, and T_____ to _____.

CONFIRM YOUR ANSWERS.

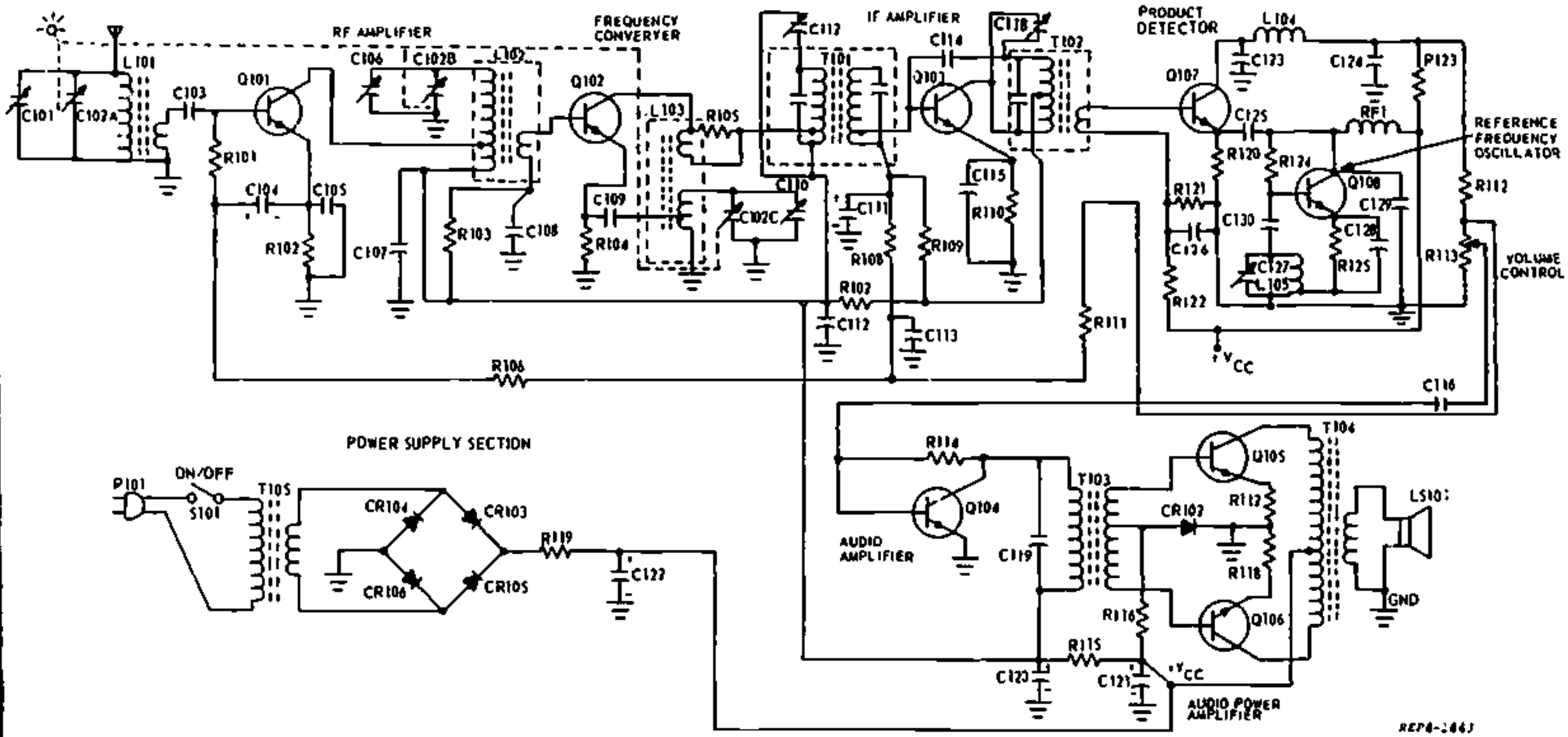


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**Figure 4. SSB Receiver**

ANSWERS TO A:

1. True
2. c
3. a
4. b
5. carrier
6. c
7. False
8. b
9. d
10. c
11. b
12. a. 5
    b. 1
    c. 6
    d. 4
    e. 7
    f. 3
    g. 2
    h. 8

If you missed ANY questions, review the material before you continue.

ANSWERS TO B:

1. False
2. c
3. sideband and carrier
4. a. 6
   b. 7
   c. 4
   d. 3
   e. 2
   f. 5
   g. 1

If you missed ANY questions, review the material before you continue.

ANSWERS TO C:

1. R111 and Q104, R111 and Q104
2. Q101, R101 and R118, Q101 and T102
3. True
4. False
5. V101 and RFC102
6. R116 and R117
7. ground, R116 and RFC103
8. ground, R113 and R114
9. True
10. False
11. False
12. False
13. True
14. True
15. True
16. True
17. B
18. c
19. True
20. Q104 and V101
21. False
22. True

If you missed ANY questions, review the material before you continue.

ANSWERS TO D:

1. a
2. a
3. c
4. d
5. b
6. c
7. True
8. d
9. c
10. ground R118 and T103; also ground, R118 and T104
11. R110, Q103, R109, R107 and R115; also R110, Q103, R107, and R115
12. False
13. True
14. R104, L102; also R104, R105, and L103
15. False
16. R102, Q101, R106; also R102 and L102
17. R117 and T103; also emitter collector
18. T103
19. R120, T102, R122 to $V_{CC}$; also R120, and L104 and R123
20. True

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK:

1. c
2. True
3. True
4. a. 3
   b. 6
   c. 7
   d. 8
   e. 1
   f. 5
   g. 4
   h. 2
5. a. 4
   b. 5
   c. 6
   d. 3
   e. 2
   f. 7
   g. 1
6. Q101 — input - audio; output - amplified audio; next stage - CR101

   Q102 — output - carrier; next stage - CR101

   CR101 — inputs - audio and carrier; outputs - upper and lower sidebands; next stage - filter

   Filter — inputs - upper and lower sidebands; outputs - either upper or lower sidebands; next stage - Q104

   Q103 — output - RF oscillations; next stage - Q104

   Q104 — inputs - sideband and RF oscillations; output - sideband raised to higher frequency; next stage - V101

V101 input - RF
output - amplifier RF
next stage - V102

V102 input - RF
output - amplified RF
next stage - antenna

7. Q101 R102, Q101, R118, T102; also R102, Q101, and T102

Q102 R105, Q102, R103 to $V_{CC}$; also R105, Q102, and T103 to $V_{CC}$

Q103 R107, Q103, R108; also R107, Q103, RFC101, and R109 to $V_{CC}$

Q104 R111, Q104, and R110; also R111, Q104, and T106 to $V_{CC}$

V101 R113, V101, and RFC102; also R113, V101, and R114

V102 R115, V102, and RFC103 to B+; also R116, V102, and R117 to B+

8. Q101 input - RF
output - amplified RF
next stage - Q102

Q102 input - RF
output - IF
next stage - Q103

Q103 input - IF
output - amplified IF
next stage - Q107

Q108 output - RF (carrier frequency)
next stage - Q107

Q107 inputs - RF carrier + IF
output - audio
next stage - Q104

Q104 input - audio
output - amplified audio
next stage - Q105 and Q106

Q105 & Q106 input - audio
output - amplified audio
next stage - speaker

9. Q101 R102, Q101, R101, R106, R108, R109, and R107; also R102, Q101, and L102

Q102 R104, Q102, L102, and R103 to $V_{CC}$; also R104, Q102, L103, and R105 then T101 to $V_{CC}$

Q103 R110, Q103, T101, R108, and R107 to $V_{CC}$; also R110, Q103, T102, and R107 to $V_{CC}$

Q107 R120, Q107, T102, and R122; also R120, Q107, L104, and R123

Q108 L105, R125, Q108, R124, and RFC107 to $V_{CC}$; also L105, R125, Q108, and RFC107 to $V_{CC}$

Q104 Q104, R114, and T103; also Q104 and T103

Q105 R117, Q105, T103, and R116 to $V_{CC}$; also R117, Q105, and T104 to $V_{CC}$

Q106 R118, Q106, T103, and R116 to $V_{CC}$; also R118, Q106, and T104 to $V_{CC}$

---

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY.

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ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-71

Technical Training

# Electronic Principles (Modular Self-Paced)

## Module 71

## PULSE MODULATION SYSTEMS

1 August 1975

AIR TRAINING COMMAND

7-13

Designed For ATC Course Use

ATC Keesler 6-4614

DO NOT USE ON THE JOB

Radar Principle Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-71
1 August 1975

# ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

## MODULE 71

## PULSE MODULATION SYSTEMS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS



### OVERVIEW

1. SCOPE: This module contains material on the basics of a pulse modulated system and includes the following: the block diagrams of a transmitter and receiver with a description of each block, and the schematic diagram of a transmitter and receiver with a description of signal and current paths.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given a labeled block diagram and a list of statements that describes each block of a pulse transmitter, match each block with the proper statement.

b. Given a labeled block diagram and a list of statements that describes each block of a pulse receiver, match each block with the proper statement.

c. Given a schematic diagram of a pulse modulation transmitter, trace

(1) the RF and Intelligence signal flow from origin to output.

(2) direct current path through each stage in a closed loop.

d. Given a schematic diagram of a pulse modulation receiver, trace

(1) the signal flow from origin to output.

(2) direct current path through each stage in a closed loop.

### LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text IX

Supersedes Guidance Package, KEP-GP-71, 1 June 1974.

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AUDIO-VISUALS:

Television Lesson, TVK 30-952, Pulse Amplitude Modulation

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU NEED HELP.

---

## ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the back of this Guidance Package.

Contact your instructor if you experience any difficulty.

Begin the program.

---

The material presented in this module will assist you in understanding the use and operation of pulse modulated systems.

A. Turn to the Student Text, Volume IX, and read paragraphs 6-156 through 6-184. Return to this page and answer the following questions.

1. Four forms of pulse modulation used in time-division multiplexing are illustrated in figure 1. Match each with the statement of that type of modulation by placing the statement number behind the figure letter.

(1) A pulse whose amplitude is fixed and its position in reference to time is proportional to the frequency of the modulating signal.

(2) The number of pulses in each group represents the amplitude of the modulating signal.

(3) A pulse whose amplitude is proportional to the amplitude of the modulating signal at the instant of sampling.

(4) The pulse width or duration, of each sample is proportional to the amplitude at the point of sampling.

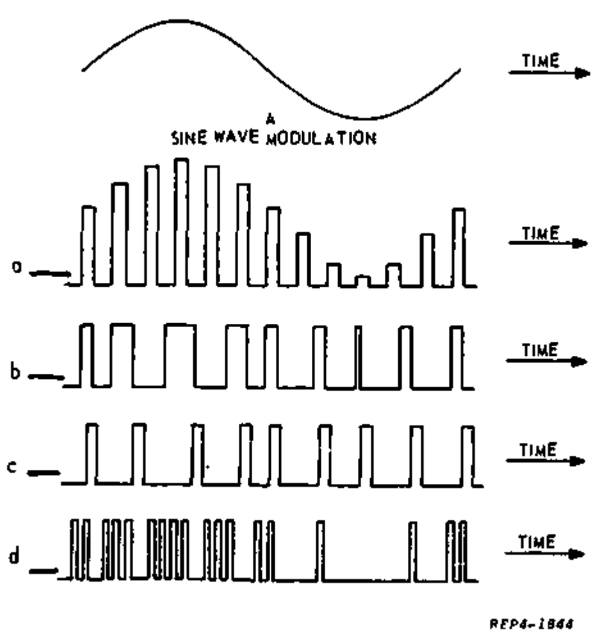


Figure 1

6. From the labeled block diagram in figure 3 and the list of statements that describes each block of a pulse transmitter, match each block with the proper statement.

| | |
|---|---|
| ____ a. pulse forming network | (1) The stage that determines when the transmitted pulse is developed. |
| ____ b. timer | (2) The stage used to charge the PFN to nearly twice the supply voltage. |
| ____ c. transmitter | (3) The stage that supplies the DC power for the transmitter. |
| ____ d. power supply | (4) The stage that determines the duration of the transmitted burst of RF energy. |
| ____ e. charging choke and diode | (5) The stage that discharges the PFN through the pulse transformer. |
| ____ f. switch | (6) The stage that couples the rectangular pulse into the oscillator stage. |
| ____ g. pulse transformer | (7) The stage that produces the RF oscillations to be radiated into space. |

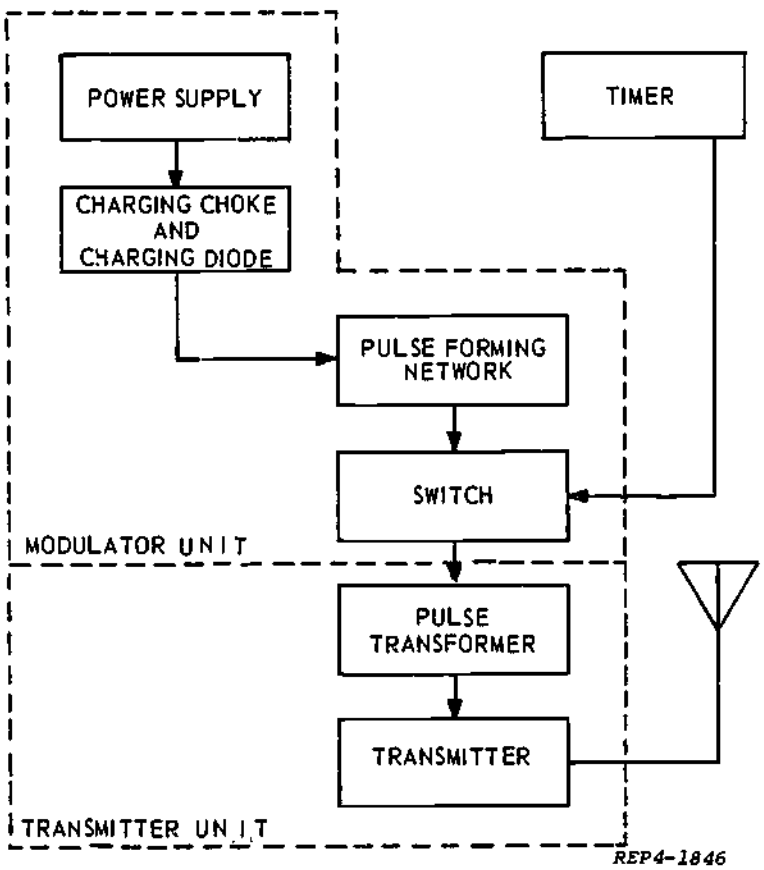


Figure 3

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

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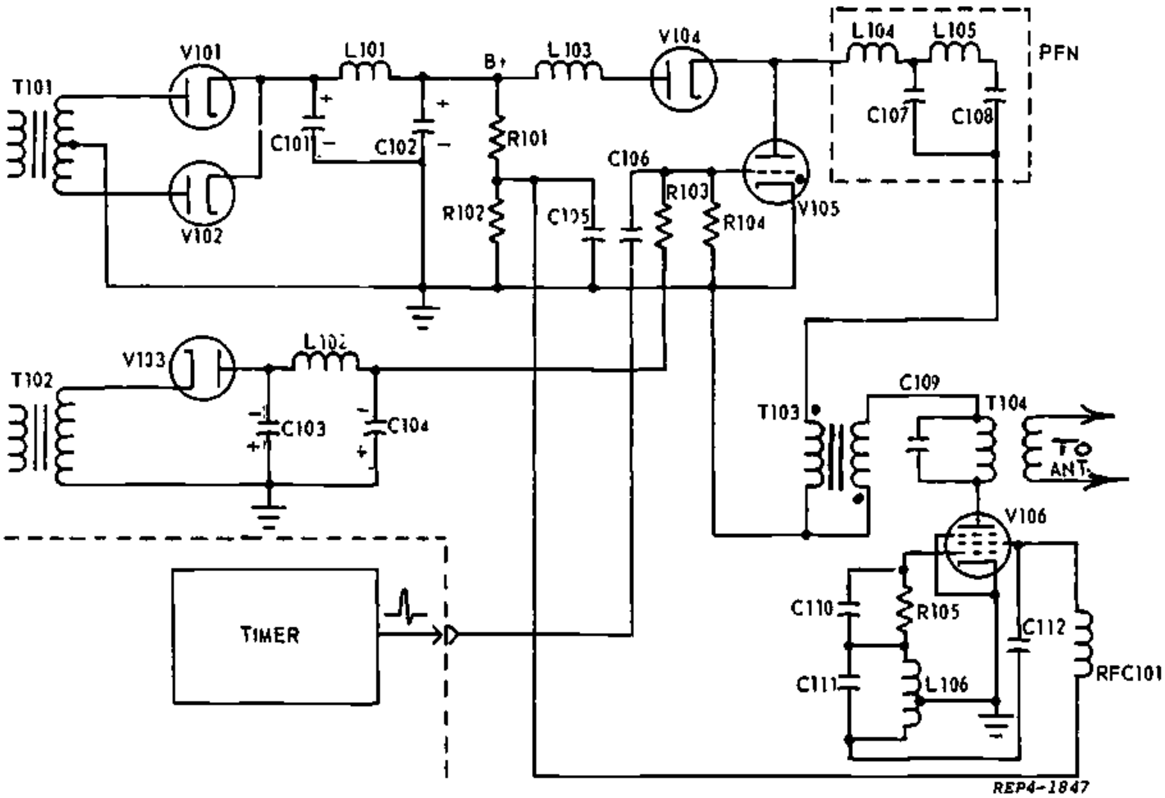


Figure 4. Pulse Modulated Transmitter

B. Turn to Student Text, Volume IX, and read paragraphs 6-185 through 6-187. Return to this page and answer the following questions.

NOTE: Use figure 4 in answering questions 1 through 8.

1. A path for direct current in the V106 circuit is from ground, through V106 to the screen grid, RFC ________, and R ________ to B+.

2. The bias network for V105 is from the negative power supply through R ________ and R ________ to ground.

3. The charge path of the PFN is from ground through T ________ to C ________ and C ________, then through L ________ and L ________, V ________, L ________, and L ________, V ________ or V ________ to ground.

4. The discharge of the PFN is from C ________ and C ________ through T ________, V ________, L ________ and L ________, back to C ________ and C ________.

5. During the discharge of the PFN, a path of current flow in V106 is from ground through V106, T104, and T103 back to ground. (TRUE/FALSE)



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6. A positive voltage pulse is applied to the grid of V105 to

______ a. allow the PFN to charge.

______ b. determine how long the PFN will take to discharge.

______ c. determine when the PFN will discharge.

______ d. cut V105 off.

7. Oscillations are produced in the plate circuit of V106 during the

______ a. charge time of the PFN.

______ b. time that V104 conducts.

______ c. discharge time of the PFN.

______ d. timer PW only.

8. The signal on the grid of V __________ causes the __________ to discharge through T __________, producing a positive voltage pulse on the plate of V __________, allowing RF oscillations to be coupled to the secondary of T ______.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

---

C. Turn to Student Text, Volume IX, and read paragraphs 6-188 through 6-196. Return to this page and answer the following questions.

NOTE: Use figure 5 in answering questions 1 through 4.

1. The narrower the PW, the narrower the required bandwidth of the receiver. (TRUE/FALSE)

2. The video amplifiers used in pulsed receivers are very narrow band amplifiers. (TRUE/FALSE)

3. Increasing the bandwidth beyond the optimum point reduces the signal-to-noise ratio. (TRUE/FALSE)

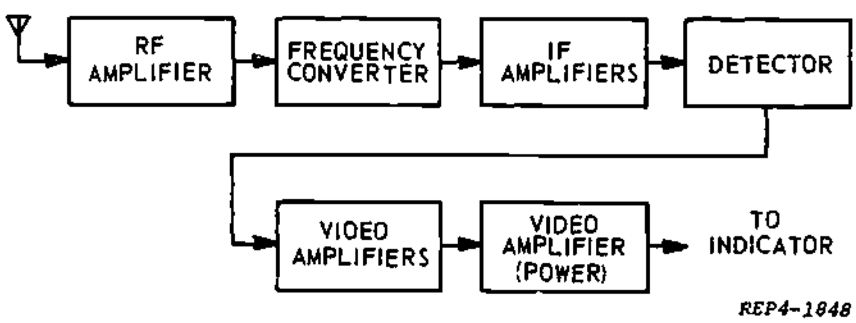


Figure 5.

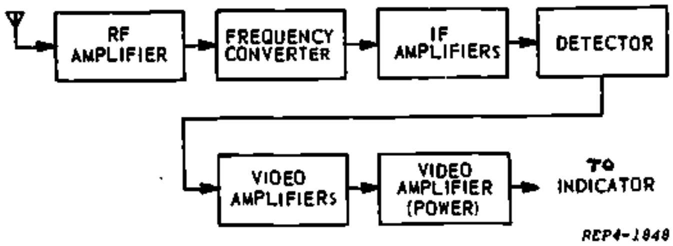


Figure 5. (Repeated)

4. From the labeled block diagram and the list of statements that describes each block of a pulse receiver, match each block with the proper statement.

_____ a. Frequency converter

_____ b. Video amplifier (power)

_____ c. Detector

_____ d. RF amplifier

_____ e. IF amplifiers

_____ f. Video amplifiers

(1) The nonlinear stage that produces the IF frequencies.

(2) The stage that heterodynes the sidebands against the carrier.

(3) The stage that couples the signal out of the receiver.

(4) The stage that amplifies the video signal from the detector.

(5) The stage that isolates the local oscillator from the antenna and amplifies the received RF signal.

(6) The stage that amplifies a select band of frequencies to be applied to the detector.

CONFIRM YOUR ANSWERS AT THE BACK OF THIS GUIDANCE PACKAGE.

D. Turn to Student Text, Volume IX and read paragraphs 6-197 through 6-198. Return to this page and answer the following questions.

NOTE: Use the receiver schematic diagram in figure 6 in answering questions 1 through 16.

1. The amplified RF from the RF amplifier is coupled to

_____ a. the base of Q102 by L102.

_____ b. the base of Q102 by R103.

_____ c. The collector of Q102 by T101 and R105.

_____ d. The collector of Q104 by C119.

2. What type signal is present in the collector circuit of Q104?

_____ a. Modulated IF

_____ b. RF Carrier

_____ c. Video

_____ d. IF

3. What signal is developed in the tank circuit of L103, C102-C, and C110?

_____ a. Modulated IF

_____ b. RF

_____ c. Unmodulated IF

_____ d. Local oscillatitions

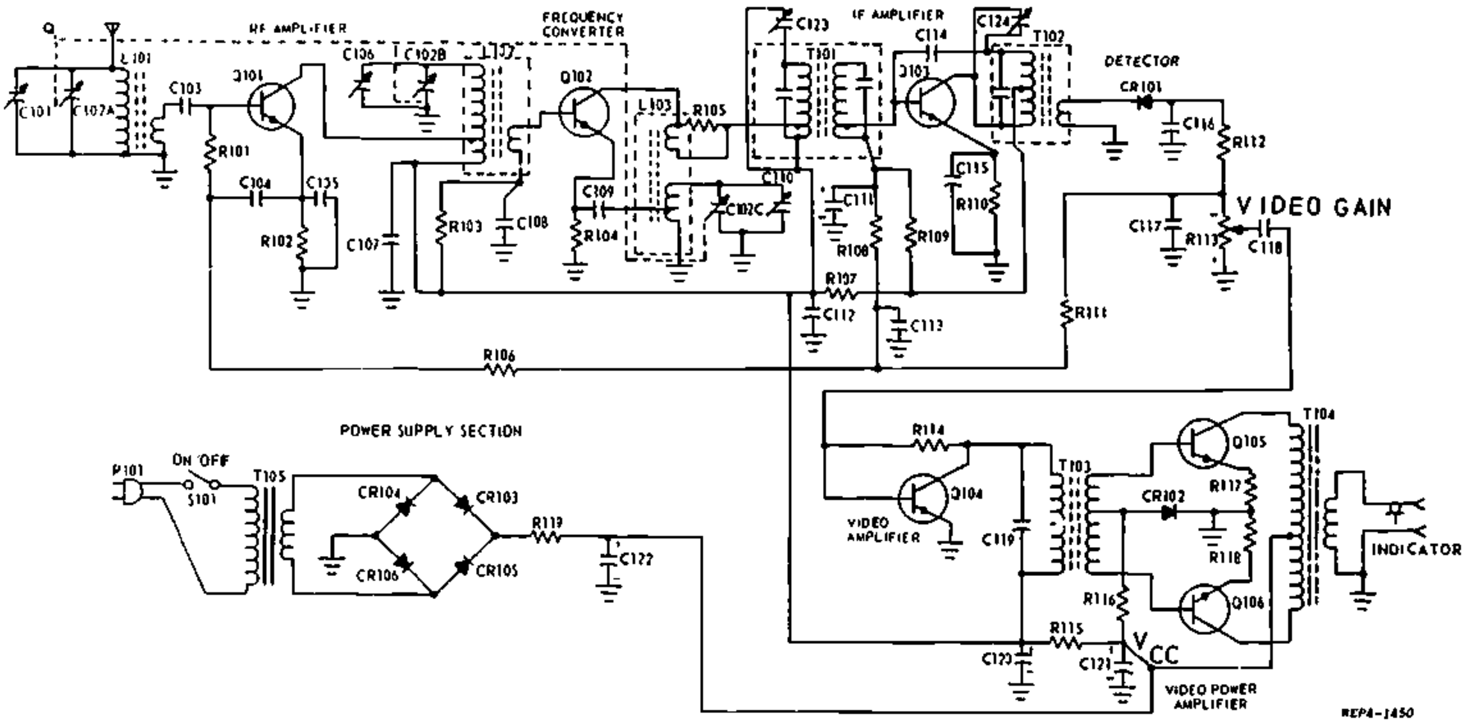


Figure 6. Pulse Modulated Receiver

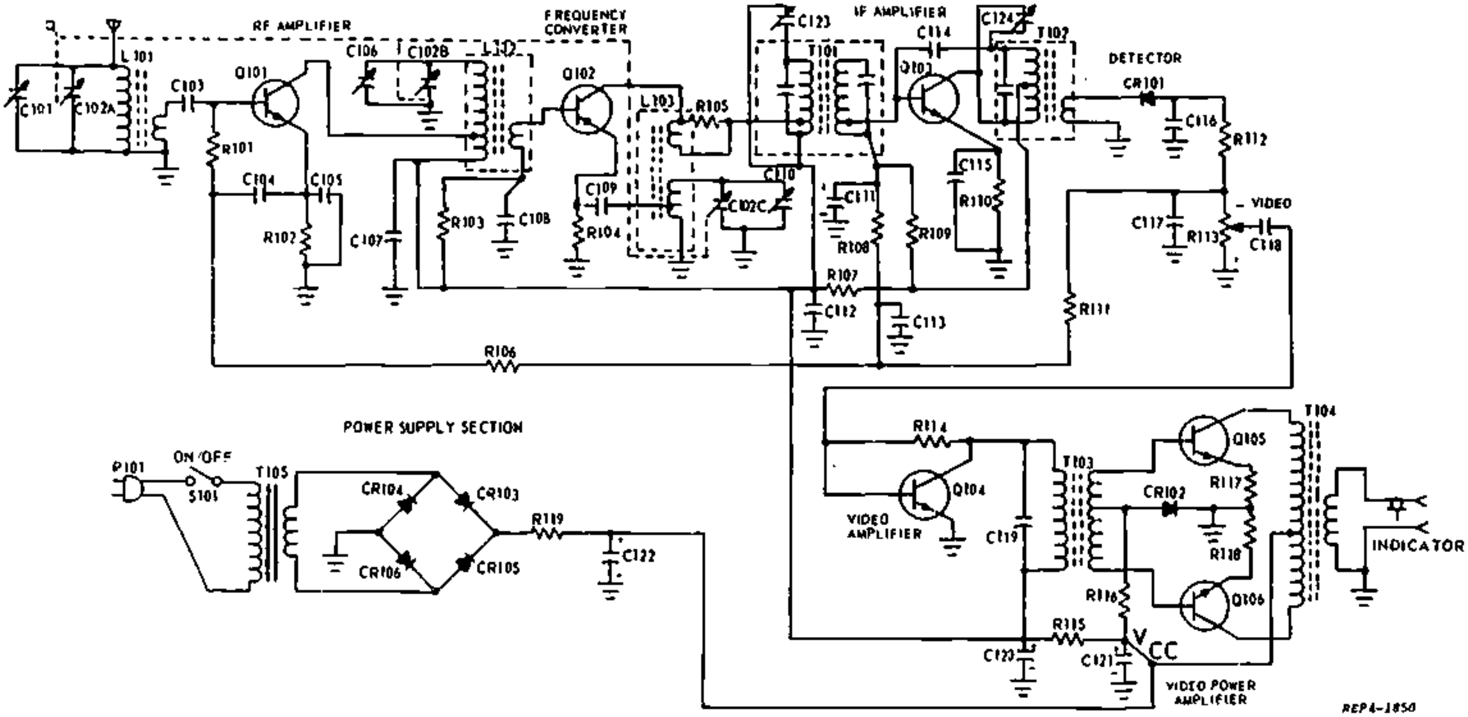


Figure 6. Pulse Modulated Receiver
(Repeated)

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Electronic Principles Department
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-72
July 1974

# TROUBLESHOOTING TECHNIQUES

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other sources you may study enabling you to satisfy the learning objectives.

## CONTENTS



Supersedes KEP-GP-72, dated 1 January 1974 - existing stocks will be used.

# TROUBLESHOOTING TECHNIQUES

1. SCOPE: This module contains material on the following: schematic diagram layout, the troubleshooting steps used in electronic maintenance, and the purpose of each stage in a typical AM radio receiver.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

   a. Given a list of statements, select the one that describes the layout of a radio receiver schematic diagram.

   b. Given a list of troubleshooting steps, arrange them in a logical sequence.

   c. Given a transistor receiver schematic diagram, indicate the frequencies used at each point where a signal generator would be connected to align a receiver.

AT THIS POINT YOU MAY TAKE THE MODULE SELF-CHECK.

IF YOU DECIDE NOT TO TAKE THE MODULE SELF-CHECK, TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

LIST OF RESOURCES

## TROUBLESHOOTING TECHNIQUES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest

Adjunct Guide with Student Text

AUDIO VISUALS:

TV Lesson, Troubleshooting Procedures, TVK-30-610

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK.

CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

TROUBLESHOOTING TECHNIQUES

A schematic diagram is a plan or diagram of an electronic circuit using standard symbols. Student Handout (SH) IX-1, Transistor Receiver, contains a block diagram and a schematic diagram of a typical radio receiver. Both diagrams are divided by dotted lines to show the RF, IF, and Audio sections.

Troubleshooting requires a logical step-by-step procedure to isolate the problem. Basically, these steps are:

1. An Operational Check
2. Visual Check
3. The Half-Split Method
4. The Stage-by-Stage Method
5. Component Isolation

The operational check is used to determine the section or stage of the system that is not operating properly. Some of these checks may consist of meter readings, oscilloscope readings; or power, frequency, signal to noise ratio, and percent of modulation checks.

The half-split method is used by dividing a complex system in half and determining which half contains the malfunction. This process is repeated until the fault is isolated to a stage.

The stage-by-stage method is a process where each stage is checked in turn starting at the output and working toward the input. An RF signal generator may be used to inject a signal into the various stages while an oscilloscope may be used to monitor the output. When injecting the signal into the RF section of the receiver in SH IX-1 a modulated 535 kHz to 1605 kHz signal is used. In the IF section, a modulated 455 kHz signal is used. When injecting a signal into the audio section it is most common to use a 400 Hz or 1000 Hz signal.

The component isolation step occurs when the trouble has been isolated to a stage. Voltage and resistance checks are then used to determine the faulty component.

The visual check is made during any of the steps. Some of the things that can be determined by this check are frayed insulation, burnt components, evidence of arcing, broken leads or smoke from overheated components.

Once the bad component is replaced, another operational check is needed. This insures that all the troubles are cleared and the equipment is operating at peak performance.

Theoretical trouble shooting is also important. During the half-split or stage-by-stage methods, it is necessary to consult the block diagram. Here a knowledge of the purpose and operation of each stage is required. When the trouble is isolated to a stage, the schematic diagram must be used. When the voltage and resistance checks are made within the stage, a knowledge of the purpose of each circuit component and its relationship to other components is necessary. For example, if a good signal were found on the base of amplifier Q105 and there was no output from the collector, the trouble would be isolated to that stage. The first step in locating the

DIGEST

defective component would be a voltage check. For example, if the collector was found to be at $V_{CC}$ and zero volts on the emitter there should be two possible troubles. The transistor could be bad or resistor R117 could be open, further resistance checks would isolate the bad component.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

TROUBLESHOOTING TECHNIQUES

INSTRUCTIONS:

Study the reference materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the top of the next even numbered page following the questions.

If you experience any difficulty, contact your instructor.

Begin the program.

---

A. Turn to Student Text, Volume IX, and read paragraphs 7-1 through 7-17, using Student Handout, K EP-SH-IX-1. Return to this page and answer the following questions:

1. Normally, the signal input is on the ____________ side of the diagram and the output signal is on the ____________ side.

2. Signal flow in the diagrams is from ____________ to ____________ .

3. In an electronic schematic containing 50 resistors, R1 would be on the ____________ and R50 would be on the ____________ .

4. Radio receivers and transmitters are often divided into ____________ in accordance with the frequencies they contain.

5. Name the three basic sections according to frequency, found in a radio receiver.

   a. ____________

   b. ____________

   c. ____________

6. The IF amplifier section of our receiver is designed to operate at ____________ kHz.

7. The detector extracts the ____________ signal from the ____________ signal.

8. The purpose of the AVC is to prevent the receiver from being ____________

9. In the AVC circuit of our receiver, when a strong signal is received, the forward bias is (increased) (decreased).

10. In this radio receiver, the converter oscillator is tuned ____________ kHz (above) (below) the incoming RF frequency.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

---

ANSWERS TO A:

1. left - right
2. left - right
3. left - right
4. sections
5. a. RF
   b. IF
   c. AF
6. 455 kHz
7. audio, IF
8. overdriven
9. decreased
10. 455 kHz, above

If you missed ANY questions, review the material before you continue.

B. Return to the Student Text, Volume IX, and read paragraphs 7-16 through 7-37. Return to this page and answer the following questions.

1. List three checks that may be made during the operational check:

   a. ______________________

   b. ______________________

   c. ______________________

2. A logical way to troubleshoot is to start with the section near the ______________.

3. Two methods of troubleshooting are half-split and ________ ________ ________.

4. When the trouble is isolated to one stage, the next step involves making ______________

and ______________ checks.

5. The first step after the initial operational check would be the ________________

6. Arrange the following troubleshooting steps in the proper order:

1. ____________ A. Component Isolation
2. ____________ B. Operational Check
3. ____________ C. Stage by stage method
4. ____________ D. Half Split
5. ____________ E. Visual Check

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

---

C. Turn to Student Text, Volume IX, and read paragraphs 7-38 through 7-48. Return to this page and use the receiver schematic (SH-IX-1) to answer the following questions.

1. There is no output from the RF section and all DC voltages are normal. Which of the following could be the trouble?

_____ a. R102 open.

_____ b. C101 short.

_____ c. R101 short.

_____ d. C105 open.

2. There is no output from the speaker and it is found that Q105 and Q106 have normal DC voltages. All other stages have zero volts present. Which of the following could be the trouble?

_____ a. R115 open.

_____ b. R107 open.

_____ c. R111 open.

_____ d. C122 short.

3. The output is good from the center arm of the volume control but no output from audio amplifier Q104. All DC voltages are normal. Which of the following could be the trouble?

_____ a. R114 open.

_____ b. C118 open.

_____ c. C120 short.

_____ d. Emitter shorted to ground.

ADJUNCT GUIDE

ANSWERS TO B:

1. (Any three of the following)

   a. Front panel meter readings

   b. Built in oscilloscope readings

   c. Transmitter power and frequency readings

   d. Receiver signal to noise ratio readings

   e. Audio distortion and percent of modulation checks

2. output

3. stage-by-stage

4. voltage and resistance

5. Visual

6. (1) B

   (2) E

   (3) D

   (4) C

   (5) A

If you missed ANY questions, review the material before you continue.

4. The output is distorted, collector of the IF amplifier Q103 is lower than normal, the emitter is zero volts. Which of the following could be the trouble?

_____ a. C115 short.

_____ b. R107 open.

_____ c. R110 open.

_____ d. Primary T102 open.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

## NOTES

ANSWERS TO C:

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

If you missed ANY questions, review the material before you continue.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

## TROUBLESHOOTING TECHNIQUES

1. Arrange the following list of troubleshooting steps in the logical order:

| | | | |
|---|---|---|---|
| 1. | ____________ | A. | Stage-By-Stage Method |
| 2. | ____________ | B. | Visual Check |
| 3. | ____________ | C. | Operational Check |
| 4. | ____________ | D. | Component Isolation |
| 5. | ____________ | E. | Half-Split Method |

2. What is the frequency of the IF amplifiers in our AM radio receiver?

3. Frequencies from the output of the detector circuit of our AM radio receiver are in the ______________________________ frequency range.

4. In a schematic diagram, the lower numbered component parts are found on the ______ side of the drawing.

5. The RF frequency range of our AM radio receiver is ________________ kHz to ______________ kHz.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

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MODULE SELF-CHECK

ANSWERS TO MODULE SELF-CHECK:

1. (1) C

   (2) B

   (3) E

   (4) A

   (5) D

2. 455 kHz

3. audio

4. left

5. 550 kHz to 1600 kHz.

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

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PREPARE THE MAN

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-73

Technical Training

# RECEIVER TROUBLESHOOTING

## MODULE 73

## ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

1 June 1974

AIR TRAINING COMMAND

7-14

Designed For ATC Course Use

DO NOT USE ON THE JOB

Electronic Principles Department
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-73
1 June 1974

# ELECTRONIC PRINCIPLES

## MODULE 73

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. This Guidance Package contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS



Supersedes Guidance Package KEP-GP-73, 1 January 1974, which will be used until the stock is exhausted.

# RECEIVER TROUBLESHOOTING

1. SCOPE: The purpose of this module is to teach you practical troubleshooting. You will troubleshoot a transistor radio receiver using common test equipment. As a result of this procedure, you will isolate various malfunctions.

2. OBJECTIVE: Given a transistor radio receiver, schematic diagram, and signal generator, locate four out of five faulty components.

TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

LIST OF RESOURCES

## RECEIVER TROUBLESHOOTING

To satisfy the objectives of this module, you may choose according to your training, experience, and preference, any or all of the following:

READING MATERIAL:

None

LABORATORY EXERCISE:

73-1 Receiver Troubleshooting

TURN TO LABORATORY EXERCISE 73-1 AND BEGIN, CONSULT YOUR INSTRUCTOR IF YOU NEED ASSISTANCE.

# TRANSMIT AND RECEIVE SYSTEMS

## RECEIVER TROUBLESHOOTING

OBJECTIVE:

Given a transistor radio receiver, schematic diagram, multimeter, oscilloscope, and a signal generator, locate four out of five faulty components.

EQUIPMENT:

Transistor Radio Receiver Trainer D-5575 with Headsets

Oscilloscope

AN/PSM-6 Multimeter

RF Signal Generator DD-4867

REFERENCES:

Student Text Volume IX, Chapter 7
KEP -SH-2, Transistor Receiver

**CAUTION: OBSERVE BOTH PERSONAL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.**

The transistor receiver trainer has been designed for use in practical troubleshooting. The compartment on the right side of the trainer contains nine switches. Each allows a specific trouble to be inserted into the set. YOU WILL NOT OPEN THIS DOOR AT ANY TIME. Troubles will be inserted into the trainer by your instructor.

The following malfunctions are simulated by the switches:

a. Open lead from the secondary at T104 to the headset jack.

b. Center tap open on T104 primary.

c. Bias resistor, R116 open.

d. Shorted Detector, CR101

e. Bottom of T101 secondary open.

f. Emitter circuit of Q101 open.

g. Bottom of L102 primary open.

h. Bias resistor, R103 open.

i. Emitter circuit of Q104 open.

LABORATORY EXERCISE

PRELIMINARY INSTRUCTIONS:

OSCILLOSCOPE PREPARATION. Turn the oscilloscope ON and allow it to warm up. You will be using only a single channel for observing amplitude modulated signals. It will not be necessary for you to make voltage or frequency measurements with the oscilloscope during this exercise.

MULTIMETER PREPARATION. Place the meter in a position where you can easily see it in the rear of your work area. You will be making voltage readings on the 10 V and 2.5 VDC voltage ranges.

RF SIGNAL GENERATOR PREPARATION. You will be using the RF Signal Generator to inject audio, IF, and RF signals into the radio receiver during the troubleshooting process. As you study the following information, carefully observe the control locations on your generator, as you will not be given detailed instructions later in the exercise.

1. Place the function switch in Standby and allow the set to warm up as you study the instructions.

2. The generator has three operational conditions controlled by the function switch:

a. CW (Continuous Wave). A constant amplitude RF sine wave is produced at a frequency determined by the setting of the main tuning control.

b. MCW (Modulated Continuous Wave). An RF wave amplitude modulated with a 400 Hz audio signal.

c. AUD (Audio). A 400 Hertz audio frequency.

3. There are two output jacks on the generator;

a. The audio output is located at the lower left. The 400 Hz signal is available at this jack when the function switch is in the AUD position.

b. The RF output jack is located in the lower right side of the panel. The RF frequency output is selected by the main tuning control when the function switch is in either the CW or MCW positions.

4. The meter switch has two positions:

a. MOD - In this position the meter reads the percent of modulation and is controlled by the modulation control at theleft side of the panel.

b. RF Carrier - In this position the meter reads the Carrier Level in microvolts and is controlled by the Fine Attenuator control.

CAUTION: Place this control in the RF Carrier Position for this exercise. Always monitor the meter and DO NOT allow it to reach full scale deflection. It should never exceed a Carrier Level of 8.

5. The Step Attenuator switch controls the amplitude of the RF output signal. Place it in the X10 k (fully CW) position as a starting point.

6. The range switch controls the frequency range of the main tuning control.

7. When troubleshooting with the RF generator, you will need an audio signal, IF signal (455 kHz MODULATED), and a modulated RF signal in the range from 550 kHz to 1600 kHz (1.6 MHz). These will be obtained as follows:

a. Audio

(1) Set the Function Switch to AUD

(2) Connect the generator probe to the Audio Output jack.

(3) Adjust the output amplitude by using the Modulation Control.

b. Modulated 455 kHz IF.

(1) Set the Function switch to MCW.

(2) Set the Range switch to B.

(3) Adjust the main tuning control to 455 kHz.

(4) Connect the generator probe to the RF output jack.

NOTE: A capacitive probe must be used with this jack.

(5) Adjust the amplitude of the modulating signal by using the Modulation Control.

c. Modulated RF.

(1) Set the function switch to MCW.

(2) Set the Range switch to either B or C depending on the frequency you desire.

(3) Adjust the main Tuning control to the frequency you desire.

(4) Connect the generator probe to the RF output jack.

NOTE: A capacitive probe must be used with this jack.

(5) Adjust the amplitude of the modulating signal by using the Modulation Control.

NOTE: During the troubleshooting, refer to the above instructions for setting up the signal generator.

LABORATORY EXERCISE

RADIO RECEIVER PREPARATION. Plug your transistor radio receiver trainer into a 60 Hz AC outlet and turn the trainer on by turning the Volume control. Tune the receiver to a station to insure that the trainer is working. On the left end there is an external antenna connection. It may be necessary to touch this terminal with your hand while tuning the receiver to a station. If you are unable to obtain a station, call your instructor. Once you determine the receiver is working, tune it so that no station is being received. DO NOT open the door at the right end at any time.

When following the troubleshooting instructions, use the handout schematic diagram. Follow the signal paths through the receiver and the paths for current flow through the stages.

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PROCEDURE A:

1. This exercise is necessary to establish the exact normal voltages at the test points on your trainer. The test points are labeled TP101 through TP113. Omit TP115 as it is an audio frequency that is visible when using the oscilloscope.

2. Measure each voltage carefully with the PSM-6 Multimeter and record them on your handout schematic in the spaces provided. Since these are very low voltages, some troubles may cause only slight variations. Therefore, accuracy in your measurements are important.

3. When your measurements are complete, compare them with the following readings. Since there is a difference between receiver trainers, yours may differ slightly. If you have a great difference in readings, recheck your findings. If there is still a great difference, call your instructor.

| | |
|---|---|
| TP101 = +0.65 | TP108 = +0.51 |
| TP102 = +7.0 | TP109 = +0.64 |
| TP103 = +0.6 | TP110 = +8.4 |
| TP104 = +7.0 | TP111 = +0.64 |
| TP105 = +1.38 | TP112 = +8.4 |
| TP106 = +7.0 | TP113 = +8.4 |
| TP107 = +5.8 | |

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PROCEDURE B:

1. Remove all test leads from your trainer and have your instructor insert trouble number 1.

2. Set up the signal generator as previously instructed to produce an audio signal and inject it into test point TP108. Do you hear the 400 Hz audio signal?________

NOTE: When injecting audio signals into test points, TP109, TP111, TP110, TP112, and TP115 you WILL NOT hear an output in the headset. The amplitude of the audio signal from the signal generator is not strong enough to drive the amplifiers and the headset. However, you will observe the signal on your oscilloscope. During the troubleshooting procedures, you should observe the audio output signal on the oscilloscope at TP115 and listen for it at the same time in your headset. Adjust volts/Div control on the oscilloscope as needed to obtain a visual presentation.

3. Place the oscilloscope probe in TP107. Is the audio signal present? ________

4. Place the oscilloscope probe in TP115. Is the audio signal present on the secondary of T104? ________

5. Which of the following troubles could cause this trouble? ________

   a. Open lead to the headset jack.

   b. Open center tap on the primary of T104.

   c. Resistor R116 open.

   d. Short CR101.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

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PROCEDURE C:

1. Remove all test leads from your receiver and have your instructor clear trouble number 1 and insert trouble number 2.

2. Set up the signal generator to produce an audio signal and inject it into TP108. Do you hear the 400 Hz tone in the headset? ________

3. Place the oscilloscope probe in TP107. Is the audio present? ________

4. Place the oscilloscope probe in TP115. Is the audio present? ________

5. Place the oscilloscope probe in TP110. Is the audio present? ________

6. Make voltage measurements with the multimeter and compare the normal voltages with the actual voltages.

TP109 and TP111 Normal = ________ Actual = ________

TP110 and TP112 Normal = ________ Actual = ________

7. Which of the following troubles could cause these indications? ________

   a. An open lead from the secondary of T104 to the headset jack.

   b. Open center tap on the primary of T104.

   c. Resistor R116 open.

   d. Resistor R103 open.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

LABORATORY EXERCISE

ANSWERS TO LAB PROCEDURE B:

1. No response required.

2. No

3. Yes

4. Yes

5. a. Open lead to the headset jack.

ANSWERS TO LAB PROCEDURE C:

1. No response required.

2. No

3. Yes

4. No

5. No

6. TP109 and TP111 Normal = +0.64 Actual = +.65
   TP110 and TP112 Normal = +8.4 Actual = zero

7. b. Open center tap on the primary of T104.

PROCEDURE D:

1. Remove all test leads from your receiver and have your instructor clear trouble number 2 and insert trouble number 3.

2. Set up the signal generator to produce an audio signal and inject it into TP108. Do you hear the 400 Hz tone in the headset? __________

3. Insert the oscilloscope probe into TP107. Is the audio signal present? ________

4. Insert the oscilloscope probe into TP115. Is the audio signal present? ________

5. What are the voltages at TP109 and TP111? __________ and __________.

6. Which of the following troubles could cause these indications? ___________

   a. CR101 shorted.

   b. emitter circuit of Q104 open.

c. Open center tap of T104 primary open.

d. Resistor R116 open.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

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PROCEDURE E:

1. Remove all test leads from your receiver and have your instructor clear trouble number 3 and insert trouble number 4.

2. Set up the signal generator to produce an audio signal and inject it into TP108. Do you hear the 400 Hz tone in the headset? ________

3. Set up the signal generator to produce a modulated 455 kHz signal and inject it into TP105. Set the VOLTS/Div control on the oscilloscope to 0.1 and connect the oscilloscope probe to TP106. Do you see an output? ________

4. Place the oscilloscope probe into TP108. Is there a signal present? ________

5. Which of the following troubles could cause these indications? ________

a. Resistor R103 open.

b. CR101 shorted.

c. Bottom of T101 secondary open.

d. Resistor R116 open.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

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PROCEDURE F:

1. Remove all test leads from your receiver and have your instructor clear trouble number 4 and insert trouble number 5.

2. Set the signal generator to produce an audio signal and insert it into TP108. Do you have an audio output? ________

3. Set up the signal generator to produce a modulated 455 kHz and inject it into TP103. Do you have an audio output? ________

4. Inject the signal into TP106. Do you have an audio output? ________

5. Inject the signal into TP105. Do you have an audio output? ________

6. Make the following voltage measurements with the multimeter and show the normal and actual values:

TP105 Normal ______________ Actual ______________
TP106 Normal ______________ Actual ______________

LABORATORY EXERCISE

ANSWERS TO PROCEDURE D:

1. No response required.
2. No
3. Yes
4. No
5. Zero volts on both.
6. d. Resistor R116 open.

ANSWERS TO PROCEDURE E:

1. No response required.
2. Yes
3. Yes
4. No
5. b. CR101 shorted

7. Which of the following troubles could cause these indications: __________

   a. Bottom of T101 secondary open.

   b. CR101 shorted.

   c. Resistor R103 open.

   d. Bottom of L102 primary open.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

PROCEDURE G:

1. Remove all test leads from your receiver and have your instructor clear trouble number 5 and insert trouble number 6.

2. Set up the signal generator to produce an audio signal and inject it into TP108. Do you have an output? __________

3. Set up the signal generator to produce a modulated 455 kHz and inject it into TP105. Do you have an output? __________

3. Inject the modulated 455 kHz signal into TP103. Do you have an output? ________

NOTE: The modulation control on the signal generator may need to be turned clockwise.

4. Set up the signal generator to produce a modulated 900 kHz. Place the Step Attenuator to x1 k and adjust the Fine Attenuator control to 8. Set the receiver tuning dial to 900 kHz and inject the signal into TP101. Do you have an output? ________

5. Which of the following troubles would cause these indications? ________

a. Bottom of T101 secondary open.

b. CR101 shorted.

c. Emitter circuit of Q101 open.

d. Resistor R116 open.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

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PROCEDURE H:

1. Remove all test leads from your receiver and have your instructor clear trouble number 6 and insert trouble number 7.

2. Place the Step Attenuator to x10 k. Then set up the signal generator to produce an audio frequency and inject it into TP108. Do you have an output? ________

3. Set up the signal generator to produce a modulated 455 kHz signal and inject it into TP105. Do you have an output? ________

4. Inject the modulated 455 kHz signal into TP103. Do you have an output? ________

NOTE: The modulation control on the RF signal generator may need to be turned clockwise.

5. Set up the signal generator to produce a modulated 900 kHz signal. Set the Step Attenuator Switch to x1 k. Adjust the receiver tuning dial to 900 and inject the signal into TP101. Do you have an output? ________

6. Make voltage measurements with the multimeter and compare the normal and actual values:

TP101 Normal = ____________ Actual = ____________

TP102 Normal = ____________ Actual = ____________

LABORATORY EXERCISE

ANSWERS TO PROCEDURE F:

1. No response required.
2. Yes
3. No
4. Yes
5. No
6. TP105 Normal = +1.38 Actual = Zero volts

   TP106 Normal = +7.0 Actual = +7.7
7. a. bottom of T101 secondary open.

ANSWERS TO PROCEDURE G:

1. No response required.
2. Yes
3. Yes
4. No
5. c. Emitter circuit of Q101 open.

7. Which of the following troubles would cause these indications? _________

   a. Resistor R103 open.

   b. Bottom of T101 secondary open.

   c. Emitter circuit of Q104 open.

   d. Bottom of L102 primary open.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

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PROCEDURE I:

1. Remove all test leads from your receiver and have your instructor clear trouble number 7 and insert trouble number 8.

2. Set up the signal generator to produce an audio frequency and inject it into TP108. Do you have an output? __________

3. Place the Step Attenuator Switch to 100. Set up the signal generator to produce a modulated 455 kHz signal and inject it into TP105. Do you have an output? _________

4. Inject the modulated 455 kHz signal into TP104. Do you have an output? ________

5. Inject the modulated 455 kHz signal into TP103. Do you have an output? ________

6. Make voltage measurements with the multimeter and compare the normal and actual voltages.

TP104 Normal = ______________ Actual = ______________

TP103 Normal = ______________ Actual = ______________

7. Which of the following troubles could cause these indications? __________

a. Emitter circuit of Q104 open.

b. Resistor R103 open.

c. Bottom of L102 primary open.

d. Resistor R116 open.

CONFRIM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

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PROCEDURE J:

1. Remove all test leads from your receiver and have your instructor clear trouble number 8 and insert trouble number 9.

2. Set up the signal generator to produce an audio frequency and inject it into TP108. Do you have an output? __________

3. Inject the audio signal into TP107. (It may be necessary to turn the modulation control CW on the generator.) Do you get an output? _________

4. Measure the voltage at TP107 and compare it with the normal voltage.

TP107 Normal = ____________ Actual = ______________

5. Which of the following troubles could cause these indications? __________

a. Resistor R116 open.

b. CR101 shorted.

c. Emitter circuit of Q104 open.

d. Center tap open on T104 primary.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

LABORATORY EXERCISE

ANSWERS TO H:

1. No response required
2. Yes
3. Yes
4. Yes
5. No
6. TP101 Normal = +0.65 Actual = +0.55
   TP102 Normal = +7.0 Actual = Zero
7. d. Bottom of L102 primary open.

ANSWERS TO I:

1. No response required
2. Yes
3. Yes
4. Yes
5. No
6. TP104 Normal = +7.0 Actual = +7.2
   TP103 Normal = +0.6 Actual = Zero
7. b. Resistor R103 open.

ANSWERS TO J:

1. No response required
2. No
3. Yes
4. TP107 Normal = +5.8 Actual = +7.4
5. c. Emitter circuit of Q104 open

CONSULT YOUR INSTRUCTOR FOR A PROGRESS CHECK.



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