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AMATEUR RADIO THEORY COURSE

PREPARATION FOR NOVICE, TECHNICIAN, GENERAL AND CONDITIONAL CLASSES OF F.C.C. LICENSES.

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AMATEUR RADIO THEORY COURSE

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EXPLANATION OF COURSE

This Radio Communications course has been written for the purpose of preparing you for the FCC Amateur examinations. The material contained in this course covers the written examination requirements for the Novice, Technician, General and Conditional classes of licenses.

The course is divided into 3 sections. The first section consists of 3 lessons on basic DC and AC theory. Some of the AC theory isn't required for the amateur exams, but was given to provide you with a solid theoretical background for further work in radio. Section 2 discusses vacuum tubes and some of its uses. Section 3 takes up transmitters, receivers, antennas and the FCC rules and regulations.

After each section, there is a study guide that assists you by pointing out the important information in each lesson. You should read this study guide before and after each section.

There are a number of practice questions at the end of each lesson. These will check your knowledge of the material in the lesson. After each section there is an examination that tests your knowledge of the important points of the section. The correct answers to all of these questions will be found in Appendix 6.

There are 2 final examinations at the end of the course. The first is for those preparing for any license, except the Novice Class license. The second is strictly a Novice exam. for those who wish to take the Novice test. The correct answers to the final exams will be found in Appendix 6.

Most of the questions in this course are of the multiple choice type because this type of question is used exclusively by the FCC.

It is suggested that you study the entire course regardless of which exam you are preparing for. This will give you an excellent background in radio communications. However, if you are strongly interested in obtaining your Novice license in a hurry, you can read only those parts that cover the necessary information for the Novice exam. Appendix 5 lists the paragraphs and questions that the prospective Novice operator must study.

Appendix 7 contains a series of questions and answers that cover new technical information that has recently been included in Novice, General, Technician and Conditional Classes of FCC examinations.

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Section 1

INTRODUCTION TO RADIO

Let us begin by defining communication as a means or system by which we exchange our thoughts, opinions, information and intelligence with others. We are all familiar with the various methods of communication in use today. These methods may be simple and direct or highly developed technically. For example, people engaged in conversation either directly or by using a telephone illustrate the most common and simple means of exchanging ideas. Or, the system of communication may be more complex as in radio transmission and reception between two radio amateur operators, universally known as hams.

Before the discovery and development of Electricity and Radio, people used simple and crude methods for transmitting intelligence. The early Indians used smoke signals and drum beats to convey messages from one tribe to another. Although these sound and sight systems of transmitting messages, were adequate for early man, they proved to be more and more archaic as man moved upward on the ladder of civilization. As mankind progressed into modern times, the invention of the telegraph and telephone became milestones in the history of the progress of communication. The telegraph and telephone were then radically different from any previous communication system in that they used electrical devices for both the sender and the receiver, and a wire or cable as the medium for the transmission. It thus became possible to communicate between any two points on the face of the earth which could be bridged by a cable or wire.

The next significant stage in the progress of message transmission was the development of a system of communication called the WIRELESS. The Wireless was superior to the Telegraph and Telephone since it used the air as a transmission medium rather than a wire or cable. Today, wireless transmission is known as RADIO COMMUNICATIONS. And you, the prospective Amateur Radio Operator will, in this course, study all of the technical aspects of a basic Radio Communications System so that you will be well equipped to operate your own radio transmitting station.

Let us at this point consider briefly a basic radio communications system as illustrated in block diagram form in figure 1. The basic operation of this system is as follows; Someone speaks into the microphone which changes sound energy into electrical energy. This electrical energy is fed into the sender or TRANSMITTER, as it is commonly called. The transmitter generates electrical vibrations which, together with the energy output of the microphone, are fed to the transmitting antenna. The transmitting antenna radiates the electrical vibrations out into space in the form of electrical waves. These electrical waves travel outward from the antenna in a manner similiar to the outward motion of ripples from a central point of disturbance in a pool of water.

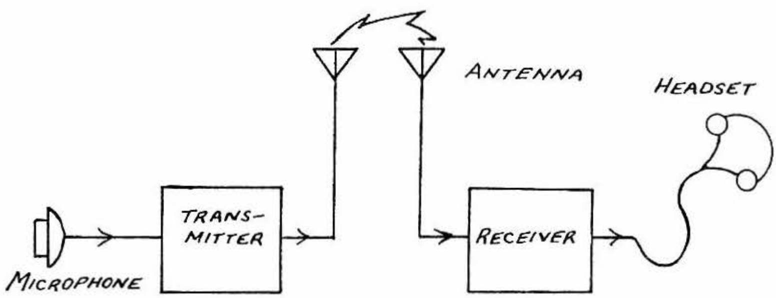


Fig.1. Block diagram of basic radio communications system.

At the receiving end of the radio communications system, the receiving antenna intercepts the radio waves and sends them into the receiver. The receiver converts the radio waves into electrical vibrations which energize the earphones. The earphones then convert the electrical energy back into the original sound that was spoken into the microphone attached to the transmitter. This brief description gives you a basic, non-technical picture of how a Radio Communications System operates.

Your amateur radio course will first consider the basic principles of electricity and radio. After you have analyzed these principles, you will study the functions of the numerous circuits which are basic to an understanding of radio. The course will then wind up with a detailed study of a complete radio transmitter from beginning to end.

Section I Lesson 1

DIRECT CURRENT THEORY

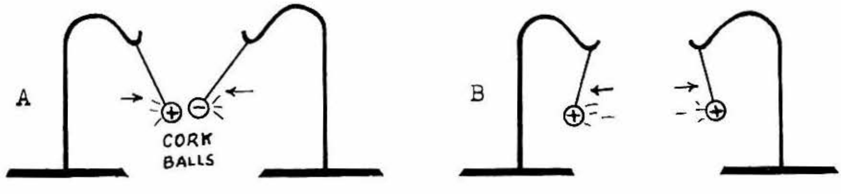
1-1. Matter and Electricity

Matter is a general term used to describe all the material things about us. Matter includes all man-made structures, woods, metals, gases, etc.; in other words, everything tangeable. All matter, regardless of its size, quality, or quantity can be broken down fundamentally into two different types of particles. These particles which are too small to be seen under a powerful microscope are called ELECTRONS and PROTONS. Electrically, we say that the Electron is NEGATIVELY charged and the Proton is POSITIVELY charged. Also, the Proton is about 1800 times as heavy as the Electron.

1-2. The Law of Electric Charges

Any object, such as a piece of glass, normally has a neutral or zero charge; that is, it contains as many electrons as protons. If this piece of glass can be made to have an excess of electrons, it is said to be negatively charged. Conversely, if the piece of glass can somehow be made to have a deficiency of electrons, the protons will predominate, and it is then said to be positively charged.

If a positively charged body is brought near a negatively charged body, the two objects will be drawn together. On the other hand, if two positively charged bodies, or two negatively charged bodies are brought near each other they will try to move away from each other. This reaction is the basis for our first law of electricity; the LAW OF ELECTRIC CHARGES. The law states; like charges repel, unlike charges attract. This law is illustrated by fig.1-1A and 1-1B. In 1-1A. a positively charged ball of



A. Unlike charges attract B. Like charges repel

Fig.1-1. Attraction and Repulsion.

cork is suspended by a piece of string near a negatively charged ball of cork. The two bodies swing towards each other since they attract each other. Figure 1-1B illustrates the two positively charged balls repelling each other.

1-3. Difference of Potential

If we were to connect a copper wire between the negative and the positive balls of cork, an electron flow would result. The excess electrons from the negative ball would flow onto the positive ball where there is an electron deficiency and therefore an attraction for the electrons. This flow continues until the deficiency and excess of electrons has disappeared and the balls become neutral or uncharged. This flow of electrons between the two differently charged bodies is caused by the difference in charge. A difference in charge between two objects will always result in the development of an electrical pressure between them. It is this electrical pressure that causes a current flow between these two bodies when they are connected by a piece of copper wire. This electrical pressure is defined as a DIFFERENCE OF POTENTIAL.

1-4. Conductors and Insulators

Materials through which current can easily flow are called CONDUCTORS. Most metals are good conductors. Conductors incorporate a large number of free electrons in their atomic structure. These free electrons are not held tightly, and will move freely through the conductor when stimulated by external electrical pressure. Examples of good conductors, in the order of their conductivity, are silver, copper, aluminum, and zinc.

Those materials through which current flows with difficulty are called INSULATORS. The electrons are tightly held in the atomic structure of an insulator, and, therefore, cannot move about as freely as in conductors. Examples of insulators are wood, silk, glass, and bakelite. In radio work, a distinction is made between insulators which are good enough only for power frequencies, and those which are good only for radio frequencies. Examples of good radio frequency insulators are: quartz, pyrex, mycalex and polystyrene. Wood, silk, glass and bakelite can be used for power frequencies, but not for radio frequencies. We will further discuss the differences between power and radio frequencies in a later section.

1-5. Resistance

The ability of a material to oppose the flow of current is called RESISTANCE. All materials exhibit a certain amount of resistance to current flow. In order to compare the resistances of various materials we require some standard unit of resistance measurement. The unit of resistance that was adapted for this purpose is the OHM, and the Greek letter Ω is its symbol. (For a list of common radio abbreviations refer to Appendix I.) One ohm is defined as the amount of resistance inherent in 1000 feet of #10 copper wire. For example, 5000 feet of #10 copper wire would have a resistance of 5 ohms, 10,000 feet of #10 copper wire would have 10 ohms, etc. Although the ohm is the basic unit, the MEGOHM, meaning 1,000,000 ohms, is frequently used. The instrument used to measure resistance is the OHMMETER.

There are four factors which determine the resistance of a conductor. They are:

1. Length - The resistance of a conductor is directly proportional to its length. The longer the conductor, the greater is the resistance. The current has to flow through more material in a longer conductor and, therefore, meets more opposition.

2. Cross-sectional area - The resistance of a conductor is inversely proportional to the cross-sectional area. This means that the resistance becomes smaller as the thickness or area becomes larger. For example, if we double the cross-sectional area of a conductor of a given length, the resistance will be cut in half. If we triple the area, the resistance will be cut to one-third of its original resistance. The current will flow through a conductor of larger cross-sectional area with greater ease because it has a wider path. If we decrease the cross-sectional area of the conductor, less electrons can squeeze through. Hence a greater resistance.

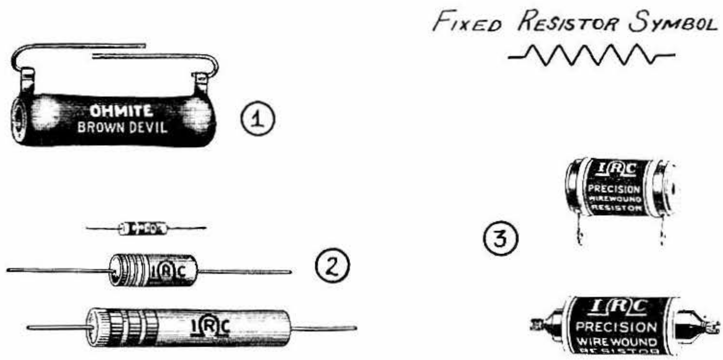
3. Temperature - In practically all conductors, with the exception of carbon, the resistance varies directly with the temperature. As the temperature of a conductor rises, its resistance increases; as the temperature drops, the resistance decreases.

4. Material make-up - The resistance of a conductor depends upon the material of which it is made. Because of their material structure, some conductors have more resistance than others. For example, silver has a very low resistance, whereas nichrome has a high resistance.

1-6. Resistors

The resistor is a common radio part with a built-in specific amount of resistance. Resistors which are made of mixtures of carbon and clay are called carbon resistors.

Carbon resistors are used in low power circuits. Wire wound resistors, which contain special resistance wire, are used in high power circuits. Fig.1-2 illustrates several types of fixed resistors which are used in radio circuits, together with the symbol which is used to represent them on circuit diagrams. When it becomes necessary to vary the amount of resistance in a circuit, we use adjustable and VARIABLE RESISTORS. The adjustable resistor is usually wire-wound, and has a sliding collar which may be moved along the resistance element to select any desired resistance value. It is then clamped in place. Fig.1-3,1 shows an adjustable resistor.



1. High wattage wire-wound.
2. Carbon resistors
3. Precision resistors.

Fig.1-2. Fixed resistors.

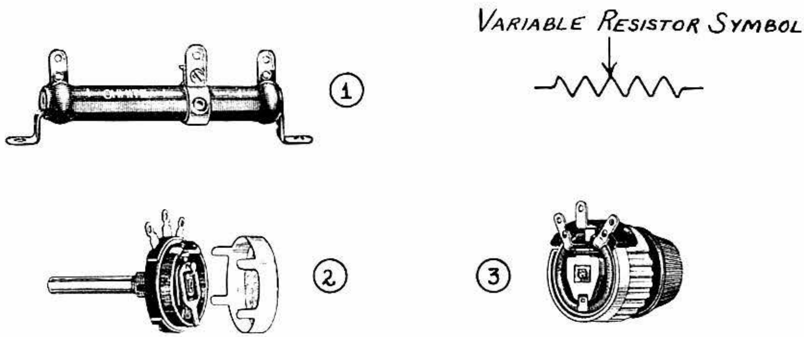
Variable resistors are used in a circuit when a resistance value must be changed frequently. Variable resistors are commonly called potentiometers or rheostats, depending on their use. The resistance is varied by sliding a metal contact across the resistance in such a way so as to get different amounts of resistance. The volume control in a radio is a typical example of a variable resistor. Fig.1-3,2 shows a potentiometer used as a volume control for a radio receiver; Fig.1-3,3 shows a potentiometer wound of heavier wire for use in a power supply circuit.

1-7. Conductance

The reciprocal, or opposite of resistance is called CONDUCTANCE.

$$\text{conductance} = \frac{1}{\text{resistance}} \qquad (1\text{-}1)$$

Conductance is the ability of an electrical circuit to pass or conduct electricity.



1. Adjustable power resistor.
2. Potentiometer for volume control.
3. Potentiometer for power supply.

Fig.1-3. Variable resistors.

A circuit having a large conductance has a low resistance; a circuit having a low conductance has a high resistance. The unit of conductance is the MHO. A resistance of one ohm has a conductance of one mho; a resistance of 10 ohms has a conductance of .1 mho ($\frac{1}{10} = 0.1$). In other words, to determine the conductance we divide the number 1 by the amount of the resistance in ohms. We frequently use the term MICROMHO, meaning one millionth of a mho.

1-8. Voltage and Current

Voltage is another term for the difference of potential or electrical pressure which we spoke about in a preceding paragraph. It is the force which pushes or forces electrons through a wire, just as water pressure forces water through a pipe. Some other terms used to denote voltage are EMF (standing for electro-motive force), IR DROP, and FALL OF POTENTIAL. The unit of voltage is the VOLT, and the instrument used to measure voltage is the VOLTMETER. The KILOVOLT is equal to 1000 volts.

Current is the flow of electrons through a wire as a result of the application of a difference of potential. If an increasing number of electrons flow past a given point in a specified amount of time, we have a greater current flow. The unit of current is the AMPERE, and it is equal to 6,300,000,000,000,000,000 electrons flowing past a point in one second. MILLIAMPERE and MICROAMPERE are terms used to denote one-thousandth and one-millionth of an ampere respectively. Current is measured by an AMMETER.

We have one more important term to define, and that is the COULOMB. The coulomb is the unit of electrical quantity. The coulomb is the number of electrons contained in one ampere. One coulomb flowing past a point in one second is equal to one ampere.

1-9. The Dry Cell

Several methods are used to produce current flow or electricity. The method by which the dry cell, used in an ordinary flashlight, produces electricity is familiar to everyone. The dry cell contains several chemicals combined to cause a chemical reaction which produces a voltage. The voltage produced by all dry cells, regardless of size, is $1\frac{1}{2}$ volts. A battery is composed of a number of cells. Therefore, a battery may be 3 volts, 6 volts, $7\frac{1}{2}$ volts, etc., depending upon the number of cells it contains. The fact that a cell is larger than another one indicates that the larger cell is capable of delivering current for a longer period of time than the smaller one. Fig. 1-4 illustrates a typical $1\frac{1}{2}$ volt cell and a 45 volt battery.

① ②

1. $1\frac{1}{2}$ volt flashlight cell. 2. 45 volt "B" battery.

Fig. 1-4. The dry cell.

Every cell has a negative and a positive terminal. The electrons leave the cell at the negative terminal, flow through the circuit, and return to the cell at the positive terminal. This type of current flow is known as DIRECT CURRENT (d-c). Direct current flows only in <u>one</u> direction.

1-10. <u>Electrical Circuits</u>

Fig.1-5A is a diagram of a complete electrical circuit. The arrows indicate the direction of the current

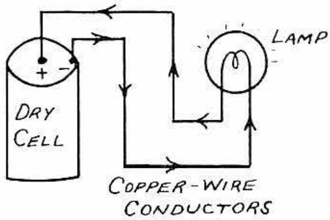


Fig. 1-5A. Complete electrical circuit.

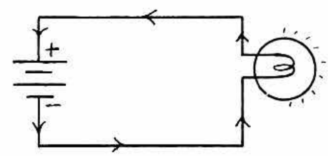


Fig. 1-5B. Schematic diagram.

flow. So long as we can trace the current from the negative point of the cell, all around the circuit, and back to the positive point, we have a complete circuit. The important thing to remember is that current will only flow through a complete circuit.

<u>The necessary parts for a complete circuit are:</u>

1.- A source of voltage - the dry cell in Fig.1-5A.
2.- Connecting leads - the copper wire conductors in Fig.1-5A
3.- A load - the bulb in Fig.1-5A.

If there were a break in the conducting leads, or in the wire of the bulb, no current would flow and the bulb would go out. We would then have an OPEN CIRCUIT. Fig.1-6A illustrates the open circuit condition.

If we place a piece of wire directly across the two cell terminals, no current will flow through the bulb. This condition is illustrated in Fig.1-7A. The current by-passes the bulb and flows through the path of least resistance, which is the piece of wire. This condition is known as a SHORT CIRCUIT; it is to be avoided because it causes a severe current drain which rapidly wears the battery down.

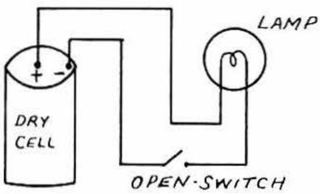


Fig. 1-6A. Open circuit.

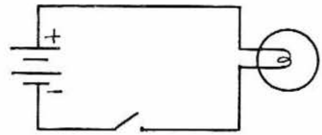


Fig. 1-6B. Schematic diagram.

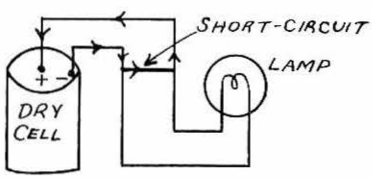


Fig. 1-7A Short circuit

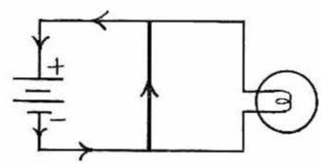
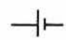


Fig. 1-7B. Schematic diagram.

1-11. Schematics

In drawing an electrical circuit on paper, we find it impractical to draw the actual battery or lamp as was done in Figures 1-5A, 1-6A, and 1-7A. Instead, we use simple symbols to represent the various electrical parts. For instance:

A cell is shown as 

A battery is shown as 

A resistor is shown as 

You will find a complete table of radio symbols in Appendix II. Figures 1-5A, 1-6A, and 1-7A can now be redrawn in the manner as shown in figures 1-5B, 1-6B, and 1-7B. Note that we indicate the negative battery terminal by a short line, and the positive terminal by a long line.

1-12. Ohm's Law

We have discussed the significance of voltage, current, and resistance. Now we shall further study the important relationships that exist between these three factors. If we were to increase the battery voltage of fig.1-5A, more electrons would flow through the circuit because of the greater electrical pressure exerted upon them. If we were to decrease the voltage, the flow of electrons would decrease. On the other hand, if the resistance of the circuit were made larger, the current would decrease because of greater opposition to current flow. If the resistance were made smaller, the current would increase by the same reasoning. These relationships are formulated into a law known as OHM'S LAW which is stated as follows: The current is directly proportional to the voltage and inversely proportional to the resistance. Ohm's law, mathematically stated, says that the current, in amperes, is equal to the voltage, in volts, divided by the resistance, in ohms.

<u>The three formulas of Ohm's law are</u>:

(1-2) $I = \frac{E}{R}$ (1-3) $E = IR$ (1-4) $R = \frac{E}{I}$

"I" stands for the current in amperes, "E" is the voltage in volts, and "R" is the resistance in ohms. It is obvious that it is quicker to use letters such as I, E, and R, than to actually write out the words. Also, note that IR means I multiplied by R. If two out of the three factors of Ohm's law are known (either E,I,or R), the unknown third factor can be found by using one of the above three equations. Several examples will clarify the use of Ohm's law:

<u>Problem</u>: 1) Given: Current is .75 amperes
Resistance is 200 ohms

Find: The voltage of the battery.

<u>Solution:</u> Since we are interested in finding the voltage, we use formula 1-3 because it tells us what the voltage is equal to. We then substitute the known values and solve the problem as follows:

1) $E = IR$
2) $E = .75 \times 200$
3) $\underline{\underline{E = 150V}}$

200
x.75
1000
1400
150.00

Problem: 2) Given: Battery voltage is 75 volts
Resistance of bulb is 250 Ohms

Find: Current in circuit.

Solution: Use formula 1-2 to find the current.

1) $I = \frac{E}{R}$

2) $I = \frac{75}{250}$

$250 \overline{)75.0}$ .3
750

3) $I = .3$ amp.

Problem: 3) Given: Current in circuit is 2 amp.
Battery voltage is 45 volts.

Find: Resistance of circuit.

Solution: Use formula 1-4, and substitute for E and I to find R.

1) $R = \frac{E}{I}$

2) $R = \frac{45}{2}$

3) $R = 22.5$ ohms.

1-13. Resistances in Series

If two or more resistances are connected end to end as shown in Fig. 1-8A, any current flowing through one will also flow through the others. The arrow indicates the

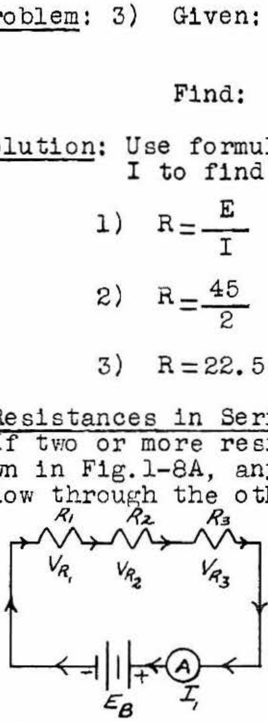


Fig. 1-8A. Series circuit.

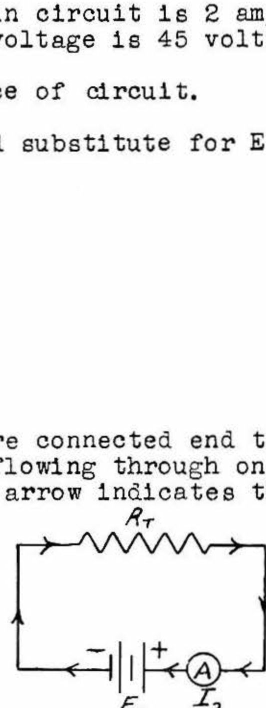


Fig. 1-8B. Equivalent circuit.

direction of current flow. The above circuit is called a SERIES CIRCUIT. Since the same current flows through each resistor, the CURRENT IS THE SAME AT EVERY POINT IN A SERIES CIRCUIT. Similarly, the total current is the same as the current in any part of the series circuit. To put it mathematically:

$$(1\text{-}5) \quad I_{(TOTAL)} = I_{R_1} = I_{R_2} = I_{R_3}$$

It is important to note that the current in Fig. 1-8A will remain unchanged if the separate series resistors are replaced by a single resistor whose resistance value is equal to the sum of the three resistors. Fig.1-8B illustrates the equivalent circuit of Fig.1-8A.

THE TOTAL RESISTANCE IN A SERIES CIRCUIT IS EQUAL TO THE SUM OF THE INDIVIDUAL RESISTANCES.

(1-6) $R_T = R_1 + R_2 + R_3$, etc. where R_T is total resistance

Whenever current flows through a resistance in a circuit, a part of the source voltage is used up in forcing the current to flow through the particular resistance. The voltage that is used up in this manner is known as the VOLTAGE DROP or fall of potential across that particular resistor. The voltage drop is equal to the current through the part multiplied by the resistance of the part.

If we add up the voltage drops across all the parts of a series circuit, the sum would be equal to the source or battery voltage.

(1-7) $E_B = V_{R_1} + V_{R_2} + V_{R_3}$, etc.

where E_B is the battery voltage
V_{R_1} is the voltage across R_1
V_{R_2} is the voltage across R_2, etc.

Problem:

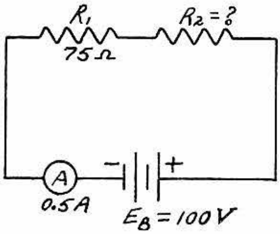


Fig.1-8C. Problem

Find the resistance of R_2 in Fig. 1-8C;

Solution:

(1) Since we know the total current and the battery voltage, we can use ohms law to find the total resistance.

$$R_T = \frac{E}{I} = \frac{100}{.5} = 200\,\Omega$$

(2) Since the total resistance in this series cir- is 200Ω, and $R_1 = 75$; then $R_2 = R_T - R_1$

(3) $R_2 = 200 - 75$

(4) $R_2 = \underline{\underline{125\,\Omega}}$

1-14. Resistances in Parallel

The circuit in Fig.1-9A is called a PARALLEL CIRCUIT. R_1 and R_2 are in parallel with each other. The current in

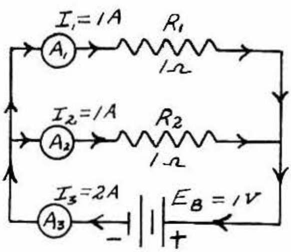


Fig.1-9A. Parallel circuit.

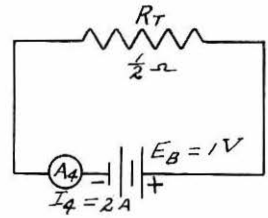


Fig.1-9B. Equivalent circuit.

the circuit now has two paths to flow through from the negative end of the battery to the positive end. If we remove resistor R_1 or R_2 from the circuit, the current has only one path to flow through from the negative to the positive end of the battery. Since it is easier for the current to flow through two paths instead of one, the total resistance of a parallel combination is less than the resistance of either resistor in the circuit. The more resistors we add in parallel, the less becomes the total resistance; because we increase the number of paths through which the current can flow. An analogy for this would be to consider the number of people that can pass through one door in a given time compared to the number of people that can pass through several doors in the same time.

If each resistor in Fig.1-9A had a value of one ohm, it would be twice as easy for the current to pass through the parallel combination than it would be for it to pass through either one of the resistors alone. The total parallel resistance would therefore be one-half of either one of the resistors, or one-half ohm. Fig.1-9B shows the equivalent circuit of Fig.1-9A.

The total resistance of any TWO resistors in parallel may be found by using the following formula.

$$(1\text{-}8) \qquad R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

(In Fig.1-9B, R_T is the total resistance of R_1 and R_2 in parallel. The current flowing in the equivalent circuit must be equal to the total line current of Fig.1-9A.)

For example, if R_1 and R_2 of Fig.1-9A were 3 and 6 ohms respectively, the total resistance would be:

1) $R_T = \frac{R_1 \times R_2}{R_1 + R_2}$ 2) $R_T = \frac{3 \times 6}{3+6} = \frac{18}{9} = \underline{\underline{2 \text{ ohms}}}.$

The total resistance of ANY NUMBER of resistors in parallel may be found by applying the following formula.

$$(1\text{-}9) \quad R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \text{ etc.}}$$

For example, if three resistors of 5, 10, and 20 ohms were connected in parallel, the total resistance would be;

1) $R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$ 2) $R_T = \frac{1}{\frac{1}{5} + \frac{1}{10} + \frac{1}{20}}$ (least common denominator is 20)

3) $\frac{1}{\frac{4+2+1}{20}} = \frac{1}{\frac{7}{20}}$ 4) $1 \times \frac{20}{7} = \underline{2\frac{6}{7} \text{ ohms.}}$

1-15. Characteristics of a Parallel Circuit

1. The total resistance of several resistors hooked in parallel is less than the smallest resistor.

2. Different amounts of current flow through the different branches of a parallel circuit. The amount of current flowing through each branch depends upon the resistance of the individual branch. The total current drawn from the battery is equal to the sum of the individual branch currents.

3. The voltage across all the branches of a parallel circuit is the same; in Fig.1-9A the voltage across R_1 is the same as the voltage across R_2.

An example will illustrate the above principles. Refer to Fig.1-9C.

Given: current through R_1 is 0.2A
$R_1 = 50\ \Omega$
$R_2 = 200\ \Omega$

Find: 1. Current through R_2.
2. Total current.

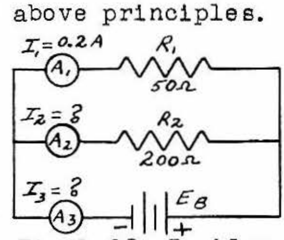


Fig.1-9C. Problem.

Solution: Since we know the resistance of R_1 and the current through R_1, we can find the voltage across R_1 by using ohms law.

1) $E_{R_1} = I_{R_1} \times R_1$ 2) $E_{R_1} = .2 \times 50$ 3) $E_{R_1} = \underline{10V}$

Since R_1 is in parallel with R , the voltage across R_2 is the same as that across R_1. Therefore, $E_{R_2} = 10V$ also.

Knowing the resistance of R_2 (given) and the voltage across it, we can find the current through R_2 :

$$I_{R_2} = \frac{E_{R_2}}{R_2} = \frac{10}{200} = \underline{\underline{.05 \text{ amp.}}}$$

$\underline{\text{current through } R_2}$

In a parallel circuit, the total current is equal to the sum of the individual branch currents; therefore:

1) $I_T = I_{R_1} + I_{R_2}$

2) $I_T = .2A + .05A = \underline{\underline{.25 \text{ amp.}}}$

$\underline{\text{total current}}$

1-16. Series-parallel Circuits

Circuits A and B of Fig.1-10 are called SERIES-PARALLEL circuits. In circuit A, the 10 ohm resistors are in

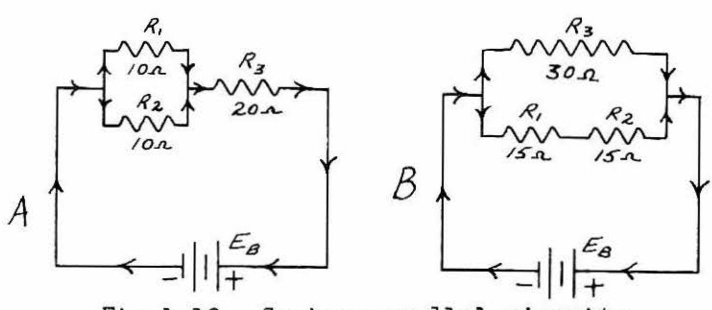


Fig.1-10. Series-parallel circuits.

parallel with each other. But, this parallel combination is in series with the 20 ohm resistor. The total resistance of circuit A is computed as follows:

First find the resistance of the two 10 ohm parallel resistors using formula 1-8.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{10 \times 10}{10 + 10} = \frac{100}{20} = 5\,\Omega$$

Since the parallel resistors are in series with the 20Ω resistor, then the total resistance of this combination is:

$$5 + 20 \text{ or } \underline{\underline{25\Omega}}$$

In diagram B, the two 15 ohm resistors are in series with each other. This series combination is in parallel with the 30 ohm resistor. The total resistance of series-parallel circuit B is computed as follows:

The resistance of the two 15 ohm resistors in series is $15 + 15$ or 30 ohms. Since this 30 ohms is in parallel with the 30 ohm resistor, the total resistance of the combination is:

$$R_T = \frac{30 \times 30}{30 + 30} = \frac{900}{60} = \underline{\underline{15\Omega}}$$

1-17. Power

Whenever current flows through a resistance, there is friction between the moving electrons and the molecules of the resistor. This friction causes heat to be generated, as does all friction. We could also say that electrical energy is changed to heat energy whenever current flows through a resistor. The unit of energy is the JOULE. The rate at which the heat energy is generated is the power that the resistor consumes. This power consumption in the form of heat represents a loss because we do not make use of the heat generated in radio circuits.

We should know how much heat power a resistor is consuming or dissipating. This is important because a resistor will burn up if it cannot stand the heat that is being generated by current flow. Resistors are therefore rated, not only in ohms, but in the amount of power that they can dissipate without overheating. The unit of electrical power is the WATT. A resistor rated at 5 watts is one which can safely dissipate up to 5 watts of power. If this resistor is made to dissipate 10 watts, by increased current flow, it will burn up.

Exactly how much power is dissipated in a particular circuit, and upon what factors does the power dissipation depend? Since the power is the result of friction between the flowing electrons and the resistance in the circuit, the actual power dissipated depends upon the current and the resistance. The more current that flows, the more electrons there are to collide with the molecules of the resistance material. Also, the greater the resistance, the greater is the resulting friction. The actual power dissipated in a resistor can be found by the following formula:

$$(1\text{-}10) \qquad P = I^2 \times R$$

where: P is the power in watts
I is the current in amperes
R is the resistance in ohms.
(I^2 means $I \times I$.)

Problem: Find the power dissipated in a 2000 ohm resistor with 50 milliamperes flowing through it.

Solution: First change milliamperes to amperes. This is done by moving the decimal three places to the left. Thus 50 milliamperes $= .05$ amperes. Then substitute the values given in formula 1-10:

1) $P = I^2 \times R$

2) $P = .05 \times .05 \times 2000$

3) $P = \underline{\underline{5 \text{ watt}}}$

1) $\begin{array}{r} .05 \\ \times .05 \\ \hline .0025 \end{array}$

2) $\begin{array}{r} .0025 \\ \times 2000 \\ \hline 5.0000 \end{array}$

By using ohms law, and algebraically substituting in formula 1-10, we can arrive at two more formulas for obtaining power dissipation.

$$(1\text{-}11) \qquad P = E \times I \qquad\qquad (1\text{-}12) \qquad P = \frac{E^2}{R}$$

where: P is the power in watts, E is the voltage in volts, I is the current in amperes and R is the resistance in ohms.

Formula 1-11 states that the power is equal to the product of the voltage across the resistor and the current through the resistor.

The Wattmeter is the instrument that is used to measure power. The Watt-hour meter is the instrument that is used to measure energy.

PRACTICE QUESTIONS - LESSON I

(For answers, refer to back of study guide Section I)

1-1.* The unit of power is; a. the ampere. b. the coulomb. c. the watt. d. the joule.

1-2.* The instrument used to measure resistance is; a. the wattmeter. b. the ohmmeter. c. the ammeter. d. the voltmeter.

1-3. The resistance of two equal resistors connected in parallel is;

a. the sum of the two resistors.
b. one-half of one of the resistors.
c. one-quarter of one of the resistors.
d. the average value of the resistors.

1-4.* The unit of electrical quantity is the; a. ohm. b. watt. c. joule. d. coulomb.

1-5. A kilovolt is; a. 100 volts. b. one-thousandth of a volt. c. 1000 volts. d. one-millionth of a volt.

1-6. The total current in a parallel circuit is;

a. the same in each branch.
b. equal to the sum of the individual branch currents.
c. equal to the current in each branch multiplied by two.
d. none of the above.

1-7. Which of the following factors does not influence the resistance of a conductor? a. length. b. diameter. c. temperature. d. color.

1-8.* Of the following formulas, pick out the incorrect one. (a) $I = \frac{E}{R}$ (b) $E = RI$ (c) $R = \frac{I}{E}$ (d) $P = I^2 R$

1-9. The total current in a series circuit is equal to;

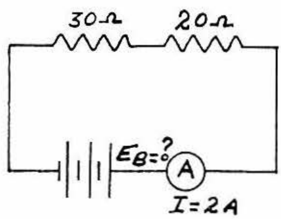
a. the current in any part of the circuit.
b. the sum of the currents in each part.
c. the total resistance divided by the voltage.
d. the sum of the IR drops.

1-10. A short circuit;

a. is found in every good electrical circuit.
b. causes a heavy current to be drained from the electrical source.
c. prevents current from flowing.
d. decreases the conductance of the circuit.

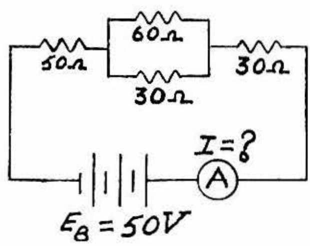
1-11. Find the power dissipated by a 2500 ohm resistor that is carrying 75 milliamperes.

1-12* Find the source voltage of the following circuit;



1-13. A 20 ohm resistor, a 15 ohm resistor, and a 30 ohm resistor are all hooked in parallel. What is their total resistance?

1-14* What is the total current in the following circuit;



1-15* What is the voltage across the 50Ω resistor in question 1-14?

1-16* The unit of energy is; a. watt. b. joule. c. coulomb. d. electron.

1-17* The instrument used to measure power is the; a. ohmmeter. b. power meter. c. wattmeter. d. wavemeter.

SECTION I LESSON 2

MAGNETISM

2-1. The Magnet

We are all familiar with the effects of magnetism. A horseshoe magnet will attract and pull to it iron filings. A powerful crane electromagnet will pick up heavy pieces of iron. A compass needle will point to the north pole. A magnet, therefore, is any object which has the ability of attracting to itself magnetic materials such as iron or steel. Fig.2-1 shows a horseshoe magnet attracting particles of iron filings.

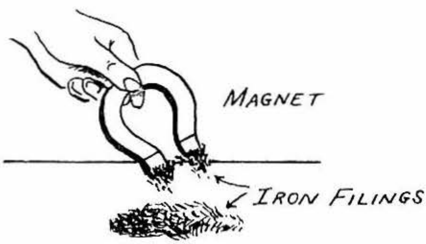


Fig.2-1. Magnet's attractive power.

When a magnetized bar of iron is suspended from a string tied around its center so that it is free to rotate, it will come to rest with one end pointing almost directly north. The end that points north is called the NORTH POLE, and the opposite end of the magnetized bar of iron is called the SOUTH POLE.

2-2. Law of Magnetic Poles

If the north pole end of one magnet is brought near the north pole end of another magnet, the magnets will repel each other. The same reaction of <u>repulsion</u> will occur if two south pole ends are brought close to each other. If, however, a north pole end and south pole end are brought close to each other, the magnets will attract each other. The reason that the north pole of a suspended magnet points to the earth's north geographical pole is that the earth itself is a magnet. The earth's south magnetic pole is located near the north geographical pole. The results of experiments in magnetic attraction and repulsion were formulated into the law of poles which states that OPPOSITE POLES ATTRACT EACH OTHER, WHEREAS LIKE POLES REPEL EACH OTHER. Fig.2-2 illustrates this principle.

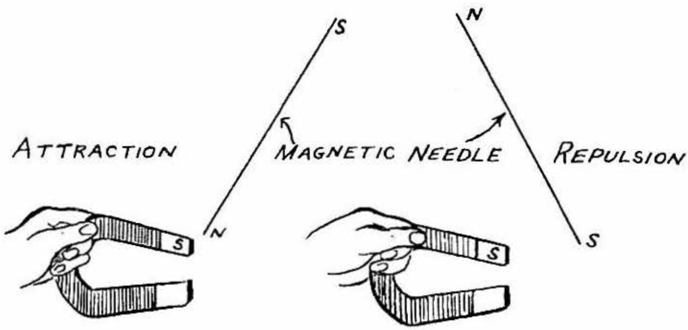


Fig. 2-2. Attraction and repulsion

2-3. Magnetic Lines of Force

We cannot see the forces of repulsion or attraction which exist between the pole pieces of two magnets. We must assume that the north pole of one magnet sends out some kind of invisible force which has the ability to act through air and pull the south pole of the other magnet to it. If we had unique vision we would be able to see certain lines leaving the north pole of one magnet and crossing over to the south pole of the other magnet. These lines are known as magnetic lines of force, and as a group are called a MAGNETIC FIELD or FLUX. Fig. 2-3 illustrates the magnetic field as it exists around a bar magnet.

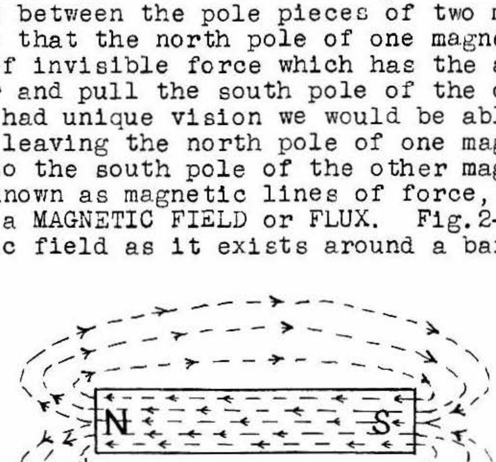


Fig. 2-3. Magnetic lines of force.

Notice that the lines of force leave the magnet at the north pole and return to the magnet at the south pole. Note, also, that the magnetic field continues flowing inside the magnet from the south to the north pole. The complete path of the magnetic flux is called the magnetic circuit. Fig. 2-4 shows the lines of force produced by a bar magnet as shown by the arrangement of iron filings.

Fig. 2-4. Picture of iron filings.

Fig. 2-5 illustrates the magnetic field of attraction as it exists between the north and the south pole of two separate magnets. Notice that the magnetic field appears to be actually pulling the two pole ends together.

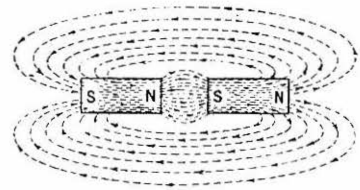


Fig. 2-5. Unlike magnetic poles attract.

Fig. 2-6. illustrates the magnetic field of repulsion between two like poles. Notice that the magnetic fields are actually pushing each other away.

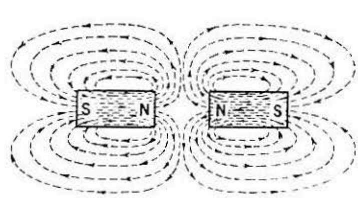


Fig. 2-6. Like magnetic poles repel.

2-3. <u>The Magnetic Circuit</u>

Magnetic flux flowing in a magnetic circuit is analogous to electric current flowing in an electrical circuit. The magnetic flux has a direction of flow as well as a given strength or amplitude. Just as a current will flow only when the electrical circuit is complete, similarly, a magnetic flux can exist only if there exists a complete magnetic path.

2-4. Shielding

If a non-magnetized object, such as a tennis ball, were placed in the path of a magnetic field, as shown in Fig. 2-7, the lines of force would pass right through the ball just as light shines through a piece of glass. However, if the tennis ball is covered up with a thick layer of soft iron, the lines of force will take the path of least magnetic resistance, as illustrated in Fig. 2-8.

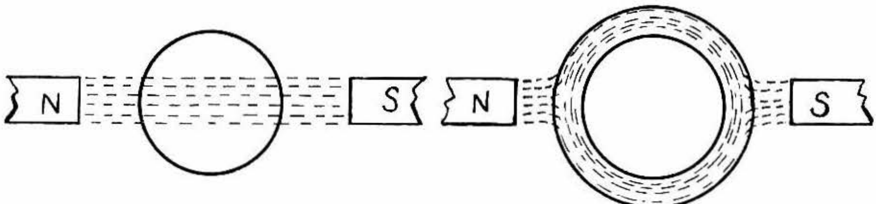


Fig. 2-7. No shielding. Fig. 2-8. Shielding.

Notice that the area in the center of the ball is now free of magnetic flux. The above example illustrates the principle of magnetic shielding which is so extensively used in electronic circuits.

People who work near strong magnetic fields usually encase their watches in soft iron through which the magnetic field will not penetrate. The delicate watch movement is therefore protected from being adversely affected by the magnetic field.

2-5. Temporary and Permanent Magnets

Soft iron can be magnetized easily by placing it in a magnetic field. However, as soon as the iron is removed from the magnetic field, it loses its magnetism. Such a magnet is called a TEMPORARY MAGNET. Steel or hard iron, on the other hand, which is difficult to magnetize, retains its magnetism after it has been removed from the magnetic field. A magnet of this type is called a PERMANENT MAGNET. Permanent magnets are usually made in the shape of a bar or a horse-shoe. The horse-shoe type has the stronger magnetic field because the magnetic poles are closer to each other. Horse-shoe magnets are used in the construction of headphones and loudspeakers.

2-6. Residual Magnetism

We stated above that a temporary magnet loses its magnetism when it is removed from a magnetic field. This is not entirely true because a small amount of magnetism does remain. This small amount is called the RESIDUAL MAGNETISM. Its importance will become apparent when we study the subject of generators.

2-7. Electromagnetism

The same type of magnetic field that we have been discussing, exists around all wires carrying current. This can be proven by placing a compass next to a current-carrying conductor. It will be found that the compass needle will turn until it is at right angles to the conductor. Since a compass needle lines up in the direction of the magnetic field, the field must exist in a plane at right angles to the conductor. Fig.2-9 illustrates a current-carrying conductor with its associated magnetic field; the current flows from left to right and the magnetic field is in a counter-clockwise direction. In Fig.2-10, the current flows from right to left and the magnetic field is in a clock-wise direction.

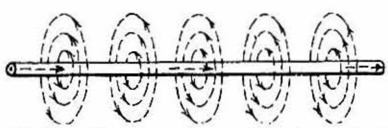


Fig.2-9. Current left to right.

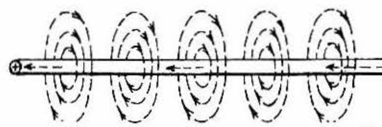


Fig.2-10. Current right to left.

This magnetic field, of which only a number of cross-sections are shown, encircles the wire all along its length like a cylinder. Notice that the direction of the magnetic field, as indicated by the arrows, depends upon the direction of current flow in the wire.

2-8. The Coil

If the same conductor is wound in the form of a coil, the total magnetic field about the coil will be greatly increased; since the magnetic fields of each turn add up to make one resultant magnetic field. See Fig.2-11. The coil is called a SOLENOID or ELECTROMAGNET. The electromagnet has a north and south pole just like a permanent magnet. The rule for determining which end is the north pole and which end is the south pole states as follows: If we grasp the coil with the left hand so that the finger tips point in the direction of the current, the thumb will automatically point to the north pole of the electromagnet. Thus, we see that the polarity of an electromagnet depends upon both the way in which the turns are wound and the direction of the current flow. If we reverse either the direction of the current flow or the direction of the windings, the north pole will become the south pole; and the south pole

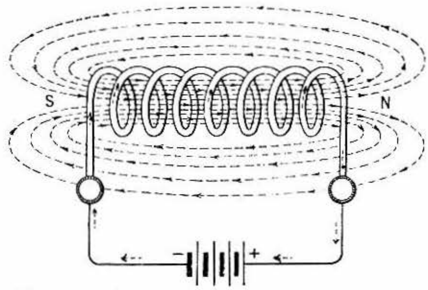


Fig. 2-11. Magnetic field produced by current flowing through coil of wire or solenoid.

will become the north pole.

A compass placed within a coil carrying an electric current, will point to the north pole of the coil. The needle itself would be at right angles to the wire. The reason for this is that the compass needle lines itself up in the direction of the magnetic lines of force. You will recall that inside a magnet, the direction of the field is from the south pole to the north pole. This is also true in an electromagnet as illustrated in Fig. 2-11.

There are various factors which influence the strength of an electromagnet. They are:

1. The number of turns.- An increase in the number of turns in a coil increases the magnetic strength of the coil.

2. The amount of current.- If we increase the amount of current in a coil, the magnetic strength increases.

3. Permeability of the core.- The core of the coil is the material within the coil. It may be air, glass, wood or metal. If we wind the coil on an iron core, we find that the strength of the electromagnet is increased by several hundred times over what it is with an air core. The iron is said to have more permeability than air; PERMEABILITY is the ability of a substance to conduct magnetic lines of force easily. Permeability is to a magnetic circuit as conductance is to an electrical circuit. If we have a core with a high permeability, we will have a large number of magnetic lines of force. This will result in a stronger magnetic field. Iron and permalloy are examples of materials having high permeability. Air is arbitrarily given a permeability of "one". The permeability of air is the basis for comparing the permeability of other materials. Iron and steel, for example, have a permeability of several hundred depending upon the exact material.

2-9. Reluctance

Magnetic reluctance is similar to electrical resistance. Magnetic reluctance is the opposition that a substance offers to magnetic lines of force. It is the property of a material that opposes the creation of a magnetic flux within itself. The unit of reluctance is the REL or the OERSTED.

2-10. Magnetomotive Force

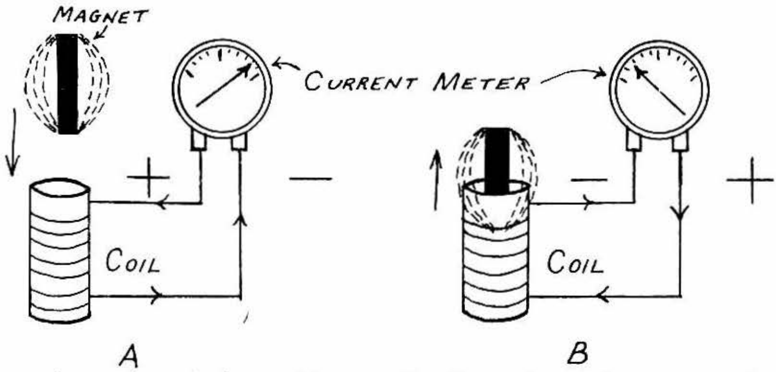
The magnetomotive force of a magnetic circuit is similar to the electromotive force of an electrical circuit. The magnetomotive force is the force which produces the magnetic lines of force of flux. The unit of magnetomotive force is the GILBERT. The number of gilberts in a circuit is equal to $1.26 \times N \times I$, where N is the number of turns in the coil, I is the number of amperes. $N \times I$, alone, is also known by the term AMPERE-TURNS. It is the number of turns multiplied by the number of amperes flowing in the circuit.

Electromagnets are used in the manufacture of earphones, microphones, motors, etc.

2-11. Induced Voltage

If a coil of wire is made to cut a magnetic field, a voltage is induced in the coil of wire. The same reaction will occur if the magnetic field cuts the coil of wire. In other words, as long as there is relative motion between a conductor and a magnetic field, a voltage will be generated in the conductor. An induced voltage is sometimes called an induced e-m-f; e-m-f stands for electromotive force.

Fig.2-12A shows an iron bar magnet being thrust into a coil of wire. The dotted lines about the magnet represent magnetic lines of force. The relative movement between the coil and magnet will result in the turns of wire of the coil cutting the lines of force of the magnetic field. The net result of this action will be an induced voltage generated in the turns of the coil. This induced voltage will in turn cause a current to flow in the coil. A galvanometer (an instrument used to detect the presence of small currents) will deflect to the right indicating a current flow as a result of the induced e-m-f. Fig.2-12B shows the magnet being pulled out of the coil. The galvanometer needle will now deflect to the left indicating that the current is now in the opposite direction. Reversing the direction of the motion of the magnet in relation to the coil reverses the direction of the induced current as indicated by the position of the galvanometer needle and



A. Magnet moving into coil. B. Magnet moving out of coil
Fig. 2-12. Inducing a voltage in a coil of wire.

the polarity of the current flow.

This method of electromagnetic induction is used in the generators which supply us with our electricity. If we wish to increase the strength of the induced e-m-f, we can do the following:

1. Use a stronger magnet.
2. Use more turns on the coil.
3. Move the magnet or the coil back and forth at a faster rate.
4. Have the coil cut the lines of force at right angles if it is not already doing so. In other words, the more lines of force cut per second, the stronger is the resultant, induced e-m-f.

In order to determine the direction in which the induced current will flow, we use LENZ'S LAW. Lenz's law states that: when a moving magnetic field induces an e-m-f in a coil, a current will flow in such a direction as to form a magnetic field within the coil which will oppose the motion of the original magnetic field.

PRACTICE QUESTIONS - LESSON 2

(For answers, refer to back of study guide section I)

2-1.* The unit of magnetomotive force is; A. joule. b. gilbert. c. ohm. d. rel.

2-2. Permeability is;

a. another name for magnetomotive force.
b. the ability of a coil to induce a voltage into another coil.
c. the ability of a material to conduct magnetic lines of force.
d. the ability of a magnet to retain its magnetism.

2-3. If we placed a compass inside a coil carrying direct current, the north pole of the compass would;

a. point to the south pole of the coil.
b. point to the north pole of the coil.
c. point to the center of the coil.
d. shift back and forth until the current was shut off.

2-4. The opposition to the magnetic lines of force in a magnetic circuit is known as; a. ampere-turns. b. reluctance. c. resistance. d. reactance.

2-5. The magnetism remaining in a material after the magnetizing force has been removed is known as; a. residual magnetism. b. permeability. c. conductance. d. residual permeability.

2-6. Ampere-turns may be defined as;

a. the square root of the number of turns multiplied by the current.
b. the number of turns multiplied by the square root of the current.
c. the number of turns multiplied by the current.
d. one-half the number of turns multiplied by the current.

2-7. The unit of reluctance is; a. the mho. b. the gilbert. c. the ampere turns. d. the oersted.

2-8. Inside of a bar magnet, the path of the lines of force is;

a. from the north pole to the south pole.
b. from the south pole to the north pole.
c. either way depending on the type of magnet.
d. there are no lines of force inside a magnet.

2-9. Shielding is accomplished by;

a. inserting the object to be shielded in a non-magnetic container.
b. inserting the object to be shielded in a lead container.
c. inserting the object to shielded in a coil of wire.
d. inserting the object to be shielded in a soft iron container.

2-10. The strength of an electromagnet will NOT be increased if;

a. we increase the number of turns.
b. increase the permeability of the core.
c. change the iron core to an air core.
d. increase the current flow through the coil.

Section I Lesson 3

ALTERNATING CURRENT THEORY

3-1. Introduction

Up to this point we have been studying DIRECT CURRENT which flows in one direction only. (The abbreviation for direct current is d-c.) We are now going to study a current which periodically reverses its direction of flow. This type is known as ALTERNATING CURRENT. A battery will generate a direct current, and an alternating current generator will generate an alternating current. The abbreviation for alternating current is a-c. For a list of radio abbreviations refer to Appendix I.

3-2. Development of the Alternating Current Wave

Fig. 3-1 illustrates a loop of wire which can be rotated between the poles of a magnet. The magnetic field

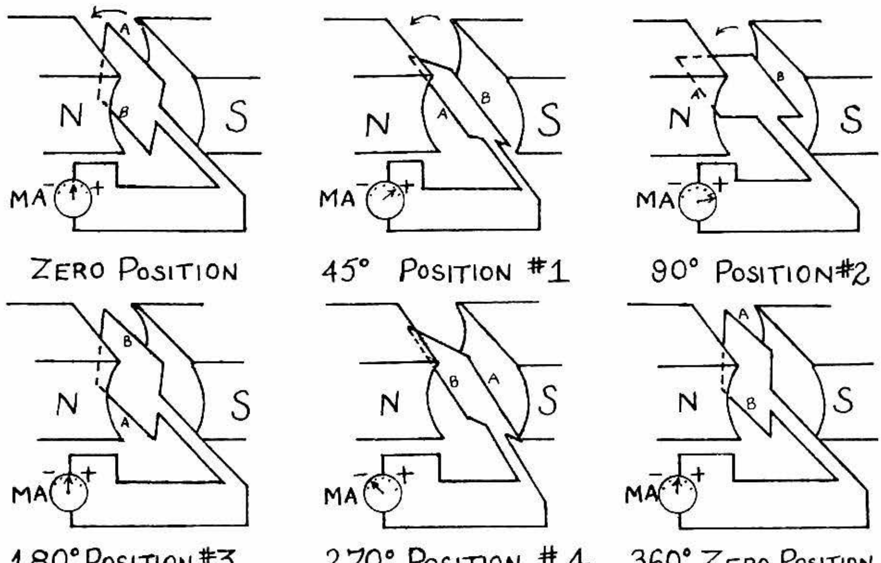


Fig. 3-1. Generating the alternating current sine wave.

which exists in the space between the north and south pole is not shown in the diagram. If the loop of wire is rotated through the magnetic field, an e-m-f (electromotive force) will be induced in the wires of the loop. This e-m-f will cause a current to flow in the circuit of the loop of wire. The milliammeter in series with the loop will indicate the current flow. From our previous study of magnetism (refer to lesson 2 paragraph 11) we know that an e-m-f will be induced in a conductor when it cuts through a magnetic field. One of the factors influencing the strength of the induced e-m-f is the relative cutting position of the loop as compared to the direction of the magnetic field. When the conductors of the loop cut perpendicular to the magnetic field, a maximum induced voltage will be generated. When the conductors of the loop are moving parallel to the magnetic field, no lines of force will be cut, and therefore no voltage will be generated. If the loop is rotated at a constant speed in a counter-clockwise direction, a current will flow whose strength and direction will vary with different positions of the loop. The strength and direction of the current for different loop positions is indicated in fig.3-1. The resulting curve obtained is illustrated in fig.3-2. At

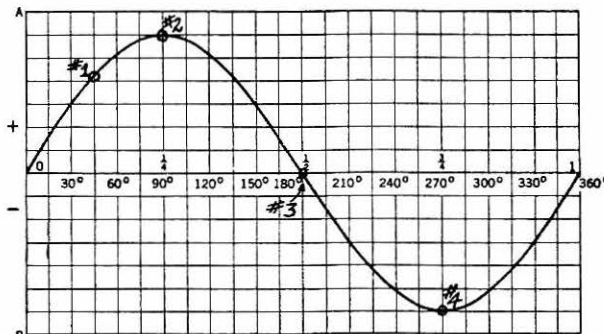


Fig.3-2. The sine wave.

zero degrees, the loop begins its rotation with the ammeter indicating zero current. (The conductors of the loop are moving parallel to the magnetic lines; therefore no induced e-m-f will be generated.) When the loop has reached position #1, (45 degrees) the current flow is indicated to be in a direction which we shall arbitrarily call positive; when the loop has reached position #2, (90 degrees) the current is at a maximum since the conductors are cutting into the magnetic field at right angles. The current flow is still in a positive direction. From position #2 to position #3, the current decreases in value and is still positive. At position #3, (180 degrees) the current is zero once again, as it was at the start. This is because the conductor is moving parallel with the magnetic field but is not actually cutting it. From position #3, through #4 and back to the starting position, the current goes through the same amplitude changes as it had gone through from starting position (zero degrees) to position #3 (180 degrees). However, from position #3 back to position zero, the direction of the current HAS REVERSED ITSELF and is now considered negative. The opposite to positive, or negative direction, is shown on the graph by drawing the curve below the horizontal line. The curve of fig. 3-2 representing a varying current through the loop, is a waveform known as an ALTERNATING CURRENT wave. The mathematical name for a fundamental alternating current wave is a SINE WAVE.

To summarize: Alternating current, as opposed to direct current, continuously varies in strength and periodically reverses its direction of flow.

3-3. Characteristics of the Sine Wave

A sine wave has the following important characteristics:

1. The complete wave as shown in fig. 3-3 is known as a CYCLE. The wave is generated in one complete revolution of the armature from 0 to 360 (degrees).

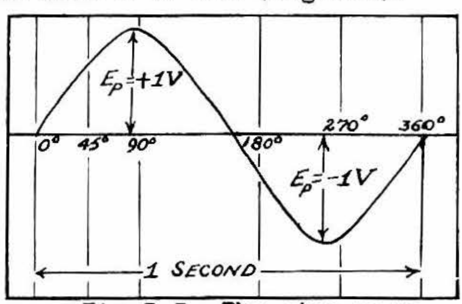


Fig. 3-3. The sine wave.

2. An alternation is one-half cycle, from 0° to 180°, or from 180° to 360°.

3. The frequency of a sine wave is the number of complete cycles which appear in one second. In fig. 3-3 we have completed one cycle per second. If 60 such cycles were completed in one second, the frequency would be 60 cycles per second. The time taken for one cycle would be 1/60th of a second. This time in seconds is known as the PERIOD OF THE WAVE.

4. The height of the wave at any point is known as its AMPLITUDE. The highest point of the wave is called the maximum or PEAK AMPLITUDE, which in our example is one volt. In a sine wave, the peaks always occur at 90 degrees and

270 degrees; the zero points always occur at 0, 180, and 360 degrees.

3-4. Frequency

The unit of frequency is cycles per second or simply cycles. The abbreviation for cycles per second is cps.

The frequency of the a-c power that is supplied to most homes in the country today is 60 cycles per second. This is known as the POWER FREQUENCY. Radio waves transmitted by radio stations have a frequency much higher than the 60 cps. power frequency; radio waves have a frequency usually above 400,000 cps. An electrical frequency higher than 400,000 cps. is known as a radio frequency (r-f). Fig. 3-4 illustrates a low frequency of 60 cps and a high frequency of 1,000,000 cps.

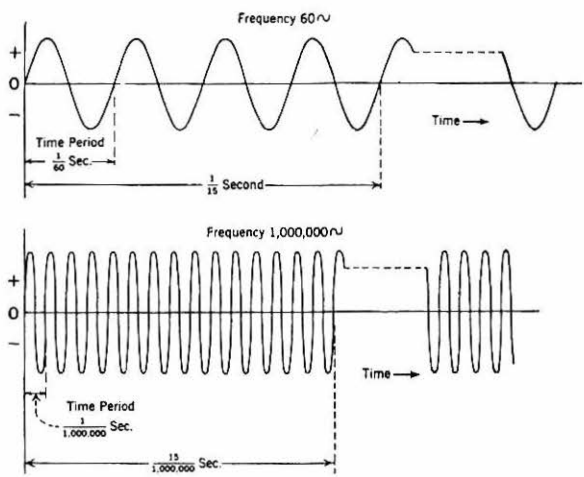


Fig. 3-4. Low and high frequency wave.

Sound waves which can be heard by the human ear are called audible sounds or audio sounds. The frequency of the audio sounds lie in the range from 16 to 16000 cps. When a sound wave frequency is converted into an electrical frequency it is known as an audio frequency (a-f). For example, when our voice is amplified by a public address system, the sound wave from our throats strikes the microphone and is converted into an electrical frequency, or an audio frequency.

When a frequency is given as a large number of cps, it can be converted into smaller units of kilocycles per second or megacycles per second; just as pennies can be converted into dollars.

For example:

a. 1000 cycles per second = 1 kilocycle. The abbreviation for kilocycle is kc. (The prefix kilo always means 1000). Therefore, in order to convert cycles per second into kilocycles per second, we divide the number of cycles per second by 1000.

$$1,000,000 \text{ cps} = \frac{1,000,000}{1000} = 1000 \text{ kc}$$

b. 1,000,000 cps = 1 megacycle per second. The abbreviation for megacycle is mc. Therefore, in order to convert cps into megacycles, we divide the number of cps by 1,000,000.

$$1,000,000 \text{ cps} = \frac{1,000,000}{1,000,000} = 1 \text{ mc}$$

Radio men very often shorten the term cycles per second to cycles. Instead of talking about a 5000 cycle per second wave, they talk about a 5000 cycle wave.

3-5. The Meaning of Phase Relationship

Two alternating current generators are connected in parallel across a load. If their armatures are started rotating together from exactly the same point, two e-m-f's (electro-motive forces) will be produced in the wire connecting the generators to the load. Assume that the peak output of generator #1 is 7 volts, and the peak output of generator #2 is 5 volts. Since both armatures start from the same position, at the same time, and at the same speed, they will both produce the maximum and minimum voltages at the same instant. This is illustrated in fig. 3-5.

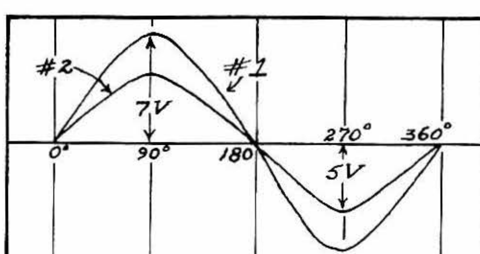


Fig. 3-5. In phase.

The output of these generators are then said to be IN PHASE WITH EACH OTHER.

If, on the other hand, armature #2 is started an eighth of a revolution (45 degrees) after armature #1 has started, the output of the two generators will reach maximum and minimum points at different times. They will now be OUT OF PHASE as shown in fig. 3-6. It should be observed that the

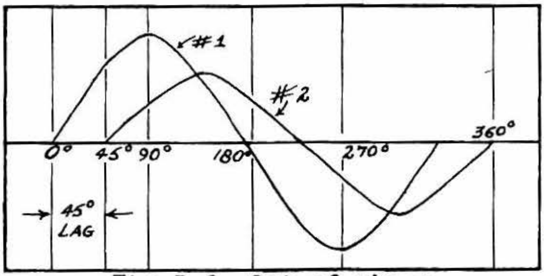


Fig. 3-6. Out of phase.

same voltages are being considered here as in fig. 3-5, but that the 5 volt wave LAGS 45° behind the 7 volt wave. These waves are said to be out of phase by 45°. If the 5 volt wave had started 90° later than the other, the 5 volt wave would be lagging the 7 volt wave by 90°. The angle by which one wave leads or lags another wave is known as the PHASE ANGLE.

3-6. Effective Value of an a-c Wave.

Let us consider a d-c voltage of 100 volts, and an a-c wave whose peak is 100 volts. (see fig. 3-7) We can see that the d-c voltage is really peak voltage at all times; that is, it remains constant. The a-c wave reaches its peak value only for a fraction of each cycle. If we connect a lamp first to the d-c voltage and then to the a-c, the lamp will light up more brilliantly when connected to the d-c. This is because the d-c voltage remains at 100 volts continuously, whereas the a-c voltage reaches a 100 volt peak only at two points during the cycle. In order for the lamp to light with equal brilliance on a-c as well as on d-c, we must raise the a-c voltage to 141 peak volts. Effectively then, 141 peak volts of a-c will light up a lamp as brilliantly as does 100 volts of d-c. The EFFECTIVE value of the 141 peak a-c wave is therefore 100 volts. See fig. 3-8.

The effective value of an a-c wave (either voltage or

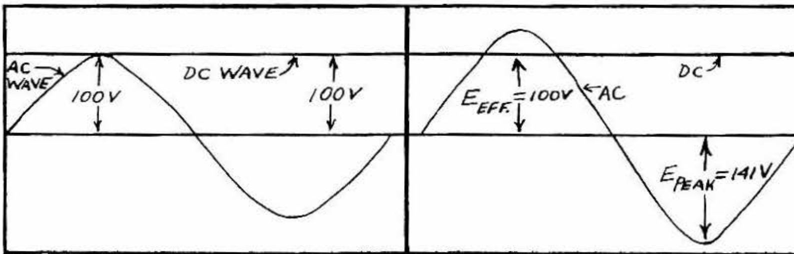


Fig. 3-7. D.C. wave equals peak of A.C. wave.

Fig. 3-8. Effective value of a sine wave.

current) is 0.707 times as great as its peak value. For example, the effective value of the above a-c wave is 0.707 x 141 volts or 100 volts, which is also the value of the d-c wave. The magnitude of an a-c wave is usually given by its effective value from which the peak value can be calculated to be 1.41 x the effective value. The effective voltage or current is frequently referred to as the rms (root-mean-square) value.

3-7. Calculation of Peak and Effective Value

The peak value of an a-c wave can be calculated from its effective value by using the following formula:

$$\text{3-1)} \quad E_{peak} = 1.41 \times E_{eff}$$

The effective value of an a-c wave can be calculated from the peak value by using the following formula:

$$\text{3-2)} \quad E_{eff} = 0.707 \times E_{peak}$$

Formulas 3-1 and 3-2 apply for all sine waves whether voltage or current . The value given to an a-c wave will always be the effective value, unless stated otherwise. A-c voltmeters and ammeters will always read the effective value of the a-c wave unless it is indicated otherwise.

3-8. Inductance

In paragraph 2-8 we learned that a current-carrying coil of many turns behaves just like a magnet. The current will cause a magnetic field to surround the coil. If the current flowing through the coil is alternating, the magnetic field surrounding the coil will also be alternating. In fig. 3-9 we have a coil which has an alternating current flowing through it. This alternating current produces an alternating magnetic field around the coil which expands and collapses in phase with the alternating current. When

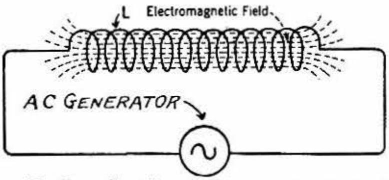
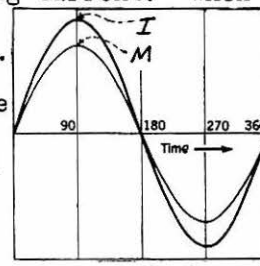


Fig. 3-9. Coil with a-c flowing through it.

Fig. 3-10. Current wave and magnetic field in phase.



the current is zero, the magnetic field is zero; and when the current reaches its peak at 90°, the magnetic field has reached its maximum value. This is shown in fig. 3-10. Evidently, since the field starts from zero and builds up to a maximum, it is an expanding field; this expanding field must cut through the conductors of the coil itself. According to Lenz's law, the cutting action induces an e-m-f in the coil which opposes the original current. The process wherein an induced e-m-f is generated in a coil which opposes the original current flow is called SELF-INDUCTION. The coil of wire is known as the INDUCTANCE. The unit of inductance is the HENRY; and the abbreviation of henry is h. The symbol for inductance is L. Smaller and more practical units of inductance are the millihenry (mh) and the microhenry (μh).

$$1 \text{ millihenry} = \frac{1}{1000} \text{ of a henry}$$

$$1 \text{ microhenry} = \frac{1}{1{,}000{,}000}$$

3-9. Factors Affecting Inductance of a Coil

1. Number of turns - The inductance of a coil varies as the square of the number of turns. For example, if we have two coils of the same length and diameter, and coil #1 has four turns while coil #2 has eight turns, the inductance of coil #2 will be four times the inductance of coil #1

$$\frac{L_2}{L_1} = \left(\frac{8}{4}\right)^2 = \frac{64}{16} = \frac{4}{1}\ ; \quad L_2 = 4 \times L_1$$

2. Core material - The inductance of a coil varies with the core material. An iron-core coil will have a higher inductance than an air-core coil. Since the iron-core has a high permeability as compared to air there will be a stronger magnetic field around the iron-core coil which results in a high inductance.

3. Length of coil - As the length of a coil increases, the number of turns remaining constant, the inductance of the coil decreases. This is because the resistance of the magnetic circuit increases due to the increased coil length which results in a weakening of the magnetic field.

4. Diameter of coil - The inductance of a coil varies directly as the square of the diameter. For example, if we double the diameter of a coil, the inductance will increase four times.

3-10. Inductive Reactance

An inductance resists a change of current flow due to the counter-electromotive force of self-induction. This resistance or holding-back effect is measured in ohms. Instead of being called a resistance, however, it is called a reactance; an INDUCTIVE REACTANCE. The abbreviation for inductive reactance is X_L.

The formula for computing inductive reactance is:

3-3) $X_L = 2\pi fL$ ohms

where: the symbol $\pi = 3.14$
f = frequency of the applied voltage in cps.
L = inductance of the coil in henries.

(If the inductance is given in mh or μh, it must first be converted into henries before it can be used in formula 3-3)

Problem: Find the inductive reactance of a 10 millihenry coil at a frequency of 60 cycles per second.

Solution: First convert 10 mh to h; then use formula 3-3.

1) $10 \text{ mh} = \frac{10}{1000} \text{ h} = \frac{1}{100} \text{ h}$

2) $X_L = 2\pi fL$ ohms

3) $2 \times 3.14 \times 60 \times \frac{1}{100} = 3.768$ ohms

3-11. Phase Angle in an Inductive Circuit

A pure inductive circuit has no resistance. In a pure inductive circuit, the current lags the impressed voltage by 90° as shown in fig. 3-11. The waveform E starts 90° ahead of the waveform I as shown in the diagram of figure 3-11. We say that the phase angle bet-

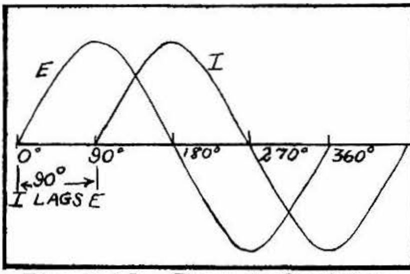


Fig. 3-11. Pure inductive circuit.

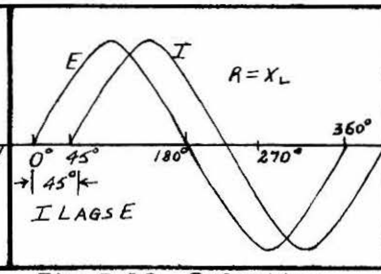


Fig. 3-12. Inductive-resistive circuit.

ween the voltage and current is 90°. Since in actual practice a coil or inductance will always have some resistance (the resistance of the wire), the phase angle between the impressed e-m-f and the current becomes less than 90°. The greater the proportion of resistance, the smaller will be the phase angle. Fig. 3-12 illustrates the current lagging the impressed voltage by 45° in a circuit containing equal amounts of resistance and inductive reactance. When there is all resistance and no inductance, the phase angle becomes 0 degrees. The current and voltage are then in phase. This is to be expected since it is the counter e-m-f of the inductance which causes the current to lag.

3-12. <u>Impedance of an Inductive Circuit</u>

In fig. 3-13A the total resistance which opposes the flow of current is $R_1 + R_2$. The total resistance to current flow in a series circuit is the sum total of the individual resistances. If the circuit consists of resistance and in-

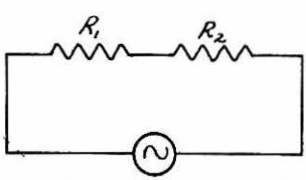


Fig. 3-13A. Resistive circuit.

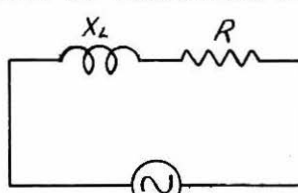


Fig. 3-13B. inductive-resistive circuit.

ductive reactance, as shown in fig. 3-13B, the total resistance to the flow of current is called the IMPEDANCE. The symbol for impedance is <u>Z</u>. The unit of impedance is the <u>ohm</u>.

Unlike a resistive circuit, the impedance of an inductive circuit is NOT equal to the simple sum of the resistance plus the inductive reactance.

The impedance of an inductive circuit can be calculated by using the following formula:

$$3\text{-}4) \quad Z = \sqrt{R^2 + X_L^{\,2}} \text{ ohms}$$

where: Z is the total impedance in ohms
X_L is the inductive reactance in ohms
R is the series resistance in ohms

Problem: If a circuit contains a coil and resistor in series, and if the coil has a reactance of 12 ohms and the resistance is 5Ω what is the(1) total impedance, and(2) what is the current? The source voltage is 130 volts.

Solution: Note that the impedance IS NOT simply the sum of $R+X_L$ or 17 ohms. The impedance in an INDUCTIVE CIRCUIT must be calculated by using formula 3-4.

1) $Z=\sqrt{R^2+X_L^{\,2}}$

2) $\sqrt{5^2+12^2} = \sqrt{25+144} = \sqrt{169}$

3) $Z = 13$ ohms

The current in the circuit is simply the total voltage divided by the impedance according to ohms law.

$$I = \frac{E}{Z} = \frac{130}{13} = \underline{10 \text{ amperes}}$$

3-13. The Condenser

We have thus far studied two radio parts which exert a holding-back effect upon current; 1) resistors, 2) coils or inductors which exert a holding-back effect upon a-c current only. We shall now investigate another holding-back device which has a tremendous application in radio; the CONDENSER or CAPACITOR.

A condenser is a device having in its simplest form, two conducting plates separated from each other by an insulating material called a DIELECTRIC. The dielectric may be air, mica, oil, paraffined paper, etc. Fig.3-15 illustrates a two plate condenser connected across a battery.

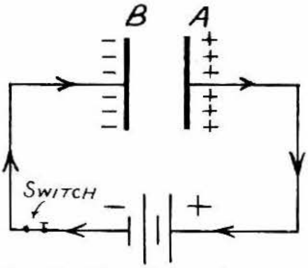


Fig. 3-15. Charging the condenser.

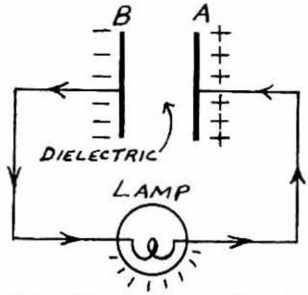


Fig. 3-16. Condenser discharge

Note: ⊣⊢ is the symbol for a condenser. When the switch is closed, a certain number of free electrons on plate A will be attracted to the positive side of the battery. Plate A is left with a positive charge; at the same, time, plate B will have the same number of electrons pushed on to it by the negative side of the battery. This electron flow continues until a charge is built up on the condenser plates which develops a voltage equal to the battery voltage. The plates of the condenser are now said to be electrically charged. The charge on the condenser plates depends upon the size of the plates (the capacity), and the force of the battery (the e-m-f). Notice that the accumulated electrons on plate B cannot cross to the other plate because of the insulator dielectric in between.

When the condenser has become fully charged, the voltage across the condenser is equal to the battery voltage. If we disconnect the battery from the condenser, the condenser will continue to hold its charge. If a lamp is now connected across the charged condenser (see fig. 3-16), the electrons on plate B will flow through the lamp and onto positive plate A; because electrons are attracted to a positively charged body. During the brief duration of the electron flow, the lamp will light for an instant indicating that a current has passed through it. The electrons will continue to flow until plate B no longer has a surplus of electrons. Plate B is then said to have a zero charge. Plate B is now neutral, and of course plate A will have regained its electrons so that it is also neutral. The condenser is now said to be DISCHARGED. A condenser, then, is a device in which electricity may be stored for a period of time until it is ready for use.

A condenser is a storage tank for electricity just as a gallon jug, for example, is a storage place for water.

If we force water into the jug under pressure, the amount of water that will go into the jug will be determined by the capacity of the jug and, also, the pressure or force that the pump exerts on the water. Similarly, the amount of electricity that a condenser will hold depends upon the same factors as apply to the water jug, namely, electrical pressure and capacity. The greater the capacity, and the greater the pressure (voltage), the more electrons the condenser will store up on its plates.

3-14. Capacitance

The capacitance of a condenser is determined by the size, shape, number and spacing of plates and the dielectric material. The symbol for capacitance is C. The unit of capacitance is the FARAD; the abbreviation for farad is fd. Since the farad is an extremely large unit of capacitance, it is very rarely used. The more common smaller units of capacitance are the microfarad and the micro-microfarad. The symbol for microfarad is μ fd; the symbol for micromicrofarad is $\mu\mu$fd.

$$1 \text{ microfarad} = \frac{1}{1{,}000{,}000} \text{ of a farad}$$

$$1 \text{ micromicrofarad} = \frac{1}{1{,}000{,}000{,}000{,}000} \text{ of a farad}$$

The range of capacitance used in radio work may vary all the way from 5 $\mu\mu$fd up to 100 μfd. (refer to appendix I for a discussion of radio symbols).

3-15. The Dielectric

The dielectric is nothing more than the name for the insulating material between the plates of a condenser. Examples of dielectrics used in condensers are mica, ceramic, glass, oil, waxpaper, etc. Condensers with different dielectric materials will have different capacities. For example, a condenser with a mica dielectric will have a larger capacity than an air dielectric condenser. The dielectric determines the ability of a condenser to hold more or less charge.

3-16. The Variable Condenser

Fig. 3-17 shows the schematic symbol of a condenser whose capacity can be varied. The condenser is known as a variable condenser, and is used wherever the capacitance in a circuit must be continuously variable as, for example, tuning controls in all radio receivers and transmitters.

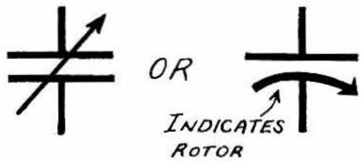
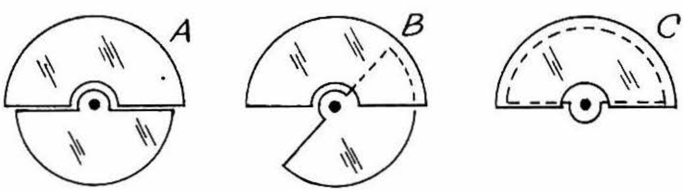


Fig. 3-17. Variable capacitor symbol.

Most variable capacitors are of the air dielectric type. A single variable capacitor consists of two sets of metal plates insulated from each other and so arranged that one set of plates can be moved in relation to the other set. The stationary plates are the stator; the movable plates, the rotor. As the rotor is turned so that its plates mesh with the stator plates, the capacity increases. If several variable condensers are connected on a common shaft so that all may be controlled at the same time, the result is known as a ganged condenser. Fig. 3-19 illustrates the rotor position of a variable condenser for minimum, intermediate, and maximum capacity.



A. Minimum. B. Intermediate. C. Maximum.
Fig. 3-19. Variable condenser settings.

3-17. Voltage Rating

Condensers are rated not only in capacity, but also in the maximum voltage they will stand before breaking down. If the voltage across a condenser is too high, the electrical pressure will force electrons to jump from the negative plate to the positive plate. This will puncture the dielectric and, in most cases, will ruin the condenser.

A typical condenser would be rated as follows:

Capacity - 8 μfd

d-c working voltage - 450 v

"d-c working voltage" indicates that the condenser may be used in any circuit as long as the d-c voltage or the a-c peak voltage across it does not exceed 450 v.

3-18. Condensers Connected in Series Combination

When two or more condensers are connected in series combination, the plate of one condenser is connected to the plate of another condenser, as shown in fig. 3-20.

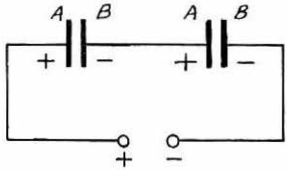


Fig. 3-20. Condenser in series.

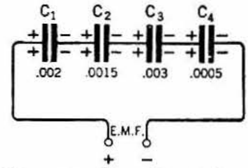


Fig. 3-21. Problem.

Plate A of one condenser is connected to B of another, and so on. The polarity at the plates of each respective condenser is shown. It indicates that when one plate of one condenser is charged negatively, the plate of an adjoining condenser is charged positively. The e-m-f's or voltages impressed across the condensers in a series circuit are not the same unless their capacities are equal. The voltage drop is inversely proportional to the capacity of individual condensers. Therefore, although condensers may be of similar voltage rating, a lower capacity in a series combination will be subject to a higher potential.

The effect of connecting condensers in series is to decrease the total capacity of the circuit, just as the total resistance of a circuit is decreased when resistors are connected in parallel.

The total capacity of condensers connected in series is equal to the reciprocal of the sum of the reciprocals of the capacities of the individual condensers. The total capacity can be computed by using the following formula:

$$3\text{-}5)\quad C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\ \text{etc.}}$$

Problem: If four condensers with capacities as shown in fig. 3-21 are connected in series, what is the total capacity?

Solution: Substitute in formula 3-5 the capacity values of the four condensers shown in fig. 3-21.

$$C_T = \frac{1}{\frac{1}{.002} + \frac{1}{.0015} + \frac{1}{.003} + \frac{1}{.0005}}$$

DIVIDING .002 INTO 1, WE GET 500, ETC.

2) $C_T = \dfrac{1}{500 + 667 + 333 + 2000}$

3) $C_T = \dfrac{1}{3500} = \underline{\underline{.00029\,\mu fd}}$

From the above example it should be clear that in a series arrangement of condensers the total capacity of the series combination (bank) is always less than the capacity of any individual condenser in the bank.

3-19. Condensers Connected in Parallel Combination

When two or more condensers are connected in a parallel arrangement, plates A and A of one set are connected together, and plates B and B of the opposite set are connected together as shown in fig. 3-22. Connecting condensers in parallel have the effect of greatly increasing the effective plate area. Since the effective plate area is increased, the effective capacity is also increased, as shown in fig. 3-22.

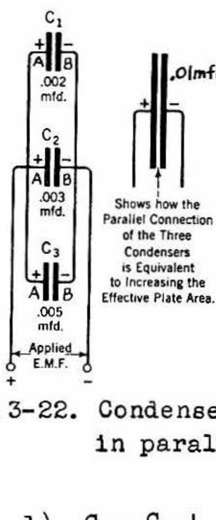


Fig. 3-22. Condensers in parallel

When condensers are connected in parallel, the resulting capacity is equal to the sum of the individual capacities. The total capacity can be computed by using the following formula:

3-6) $C_T = C_1 + C_2 + C_3$, etc.

Problem: If three condensers of .002 μ fd, .003 μ fd, and .005 μ fd are connected in parallel, what is the total capacity?

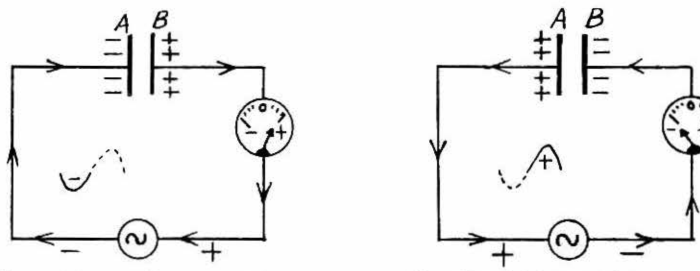
Solution: Use formula 3-6.

1) $C_T = C_1 + C_2 + C_3$

2) $C_T = .002 + .003 + .005 = \underline{\underline{.01\,\mu\ fd.}}$

3-20. The Condenser in an Alternating Current Circuit

If a condenser is placed across an a-c generator in series with an a-c ammeter, the following action occurs. When the left side of the generator is negative, (fig. 3-23A)



A. Negative alternation. B. Positive alternation.

Fig. 3-23. Condenser across a-c generator.

electrons flow from the negative terminal of the generator to condenser plate A. At the same time, electrons flow off plate B and through the ammeter to the right side of the generator. When the polarity of the a-c generator reverses, the electrons reverse in direction and flow from the left plate through the generator and ammeter onto the right plate. (see fig. 3-23B) This reversal of current flow occurs many times in one second, depending upon the frequency of the generator. The ammeter registers a reversal of current flow since electrons flow through it first in one direction and then in the other. In other words, although an electric current does not flow through the condenser itself, it does flow in and out of the plates of the condenser, and therefore flows back and forth through all the components connected in series with the condenser. When it is said that a-c current flows through a condenser, what is actually meant is that the current is flowing in and out of the plates of the condenser.

3-21. Capacitive Reactance

Fig. 3-23A shows a condenser connected across an a-c generator. At the instant shown, (left side of generator is negative, right side is positive) electrons rush from the left side of the generator to the left plate of the condenser. At first, only a few electrons will have reached the condenser plate A. However, these few electrons will attempt to repel the electrons that are approaching this condenser plate. This same action occurs on the plate B when the polarity of the generator reverses itself. (see fig. 3-23B) The first few electrons to reach the right plate of the condenser will oppose the electrons that are approaching this plate. Every time the polarity of the generator reverses, the first few electrons that pile up on the condenser will repel the remaining electrons. Thus we see that a condenser offers a certain amount of opposition to alternating current. This opposition is actually a COUNTER-E-M-F, since the original charge on the condenser plates represents an opposition voltage to the generator voltage. This counter-e-m-f will vary inversely with the capacity of the condenser and the frequency of the a-c generator. The higher the frequency of the generator, the less time there will be for electrons to charge the condenser. The condenser counter-e-m-f, therefore, decreases with increase in generator frequency. As the capacity of the condenser increases, the charge will be distributed over an effectively larger plate area, decreasing the counter-e-m-f. The counter-e-m-f, therefore, decreases with an increase in condenser capacity.

The opposition or resistance that the condenser offers to a-c is called CAPACITIVE REACTANCE. The symbol for capacitive reactance is X_c, and its unit is the OHM.

In order to compute the capacitive reactance of a condenser in an a-c circuit, the following formulas are used:

1.- when the capacity is given in farads;

$$3\text{-}7) \quad X_c = \frac{1}{2\pi fC} \ \Omega$$

where: X_c = capacitive reactance in ohms
$2\pi = 6.28$
f = frequency of a-c in cycles
c = capacity in farads

2.- when the capacity is given in microfarads;

$$3\text{-}8) \quad X_c = \frac{1,000,000}{2\pi fc}$$

where: X_c = capacitive reactance in ohms
$2\pi = 6.28$
f = frequency of a-c in cycles
c = capacity in microfarads

<u>Problem</u>: Find the capacitive reactance of a 15 μfd condenser in an a-c circuit where the frequency of the generator is 1 kilocycle.

Solution: Use formula 3-8.

1) $X_c = \dfrac{1,000,000}{2\pi fc}$

2) $X_c = \dfrac{1,000,000}{6.28 \times 1000 \times 15}$

3) $X_c = \dfrac{1,000,000}{94,200} = \underline{\underline{10.6\,\Omega}}$

In an a-c circuit, a condenser acts opposite to that of an inductance. Whereas an inductance tends to prevent current changes by means of a self-induced e-m-f, a condenser tends to prevent a voltage change by bucking the flow of current into it.

3-22. The Phase Angle

In an inductive circuit we found that the current lags the impressed voltage. In a capacitive circuit the opposite is true; THE CURRENT LEADS THE IMPRESSED VOLTAGE. This can be analyzed as follows: When a voltage or battery is first placed across a condenser, there cannot be any back e-m-f acrows the condenser because its plates are initially uncharged. A condenser can only have a voltage across its plates provided there is a charge on its plates. If the charge is initially zero, then the voltage must be initially zero. Since the condenser offers no initial back e-m-f, the initial current into it is a maximum. Therefore, the current is at a maximum when the voltage is still zero; or, the current leads the voltage. When the current falls to zero, the voltage just reaches its maximum value.

The current leads the source voltage by 90° in a pure capacitive circuit (see fig. 3-24). If we introduce some

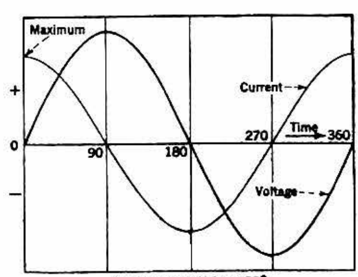


Fig. 3-24. Pure capacitive circuit.

resistance into the circuit, the current will lead the voltage by less than 90°. When the resistance and capacitive reactance are equal, the current will lead the voltage by 45°. The greater the resistance in the circuit, the smaller the phase angle.

3-23. Impedance of Series Circuits

In paragraph 3-12 we discussed the impedance of a series circuit containing resistance and inductive reactance. We learned that the total impedance of the circuit was not the simple sum of the resistance and the inductive reactance. The same is true for the impedance of a circuit containing resistance and capacitive reactance (see fig. 3-25). The formula that is used to determine the impedance

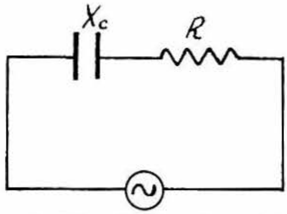


Fig. 3-25. R-C circuit.

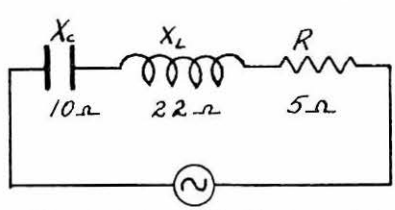


Fig. 3-26. R-L-C circuit.

of an inductive circuit is; $Z=\sqrt{R^2+X_L^2}$. To determine the impedance of a capacitive circuit, we use the same formula except that we substitute X_c for X_L. The formula now becomes:

$$3\text{-}9)\quad Z=\sqrt{R^2+X_c^2}\text{ ohms}$$

where: R = series resistance in ohms
X_c = capacitive reactance in ohms

Problem: If in a resistive-capacitive circuit $X_c = 4$ ohms, and $R = 3$ ohms, what is the total impedance?

Solution: Use formula 3-9.

1) $Z=\sqrt{R^2+X_c^2}$

2) $Z=\sqrt{3^2+4^2}$

3) $Z=\sqrt{25}=\underline{\underline{5\text{ ohms}}}$

3-24. Impedance of Series R-L-C Circuits

Observe the series circuit of fig. 3-26. Notice that this circuit contains resistance, inductance and capacitance. What is the relationship of X_L to X_c, and how can we figure out the impedance of such a circuit? The effect of X_L and X_c on the current in a series a-c circuit can be understood by considering the game "Tug-of-war". The rope represents the current, and the men pulling on the rope in opposite directions represent the action of X_L and X_c on the current. X_L and X_c act on the current in opposition. If X_L and X_c are equal, they will have no effect on the current since their effects will cancel. If X_L is larger than X_c, it will be the difference between X_L and X_c which will effect the current. Conversely, if X_c is larger than X_L, it will also be the difference between X_c and X_L which will affect the current. Before we can determine the impedance of the circuit we must calculate the total reactance. The total reactance of the circuit is the difference between the two reactances, X_L and X_c. This difference is then added to the resistance in a manner similar to that of formula 3-9.

The following formula is used to find the impedance of a circuit containing Resistance, Inductance and Capacitance.

$$3\text{-}10) \quad Z = \sqrt{R^2 + (X_L - X_c)^2}$$

where: Z is the impedance in ohms
R is the resistance in ohms
X_L is the inductive reactance in ohms
X_c is the capacitive reactance in ohms

<u>Problem</u>: Find the impedance of a circuit which contains a resistance of 5 ohms, an inductive reactance of 22 ohms, and a capacitive reactance of 10 ohms. (fig. 3-26)

<u>Solution</u>: Use formula 3-10.

1) $Z = \sqrt{R^2 + (X_L - X_c)^2}$

2) $Z = \sqrt{5^2 + (22 - 10)^2} = \sqrt{25 + (12)^2}$

3) $Z = \sqrt{25 + 144} = \sqrt{169} = \underline{\underline{13 \text{ ohms}}}$

3-25. Series Resonance

In paragraph 3-24 we studied a series a-c circuit containing resistance, inductance and capacitance. In order to find the impedance of such a circuit we had to use formula 3-10.

Let us assume that the values of L and c, and the frequency of the a-c generator are so chosen that X_L and X_c are equal. In this case the quantity, $(X_L - X_c)$ in formula 3-10 would be equal to zero. The two reactances are equal and cancel each other. (recall the analogy of the game of tug-of-war) The only opposition that remains in the circuit is the resistance, R. Therefore, the impedance in a circuit containing equal amounts of inductive and capacitive reactance, is equal to the resistance in the circuit. At this point, the current flowing in the circuit reaches its maximum value; and the impedance of the circuit is at its minimum value. The condition where the inductive reactance is equal to the capacitive reactance in a circuit is known as RESONANCE. Since the components of this circuit are in series, the circuit is known as a SERIES RESONANT CIRCUIT. The frequency of the generator at resonance is called RESONANT FREQUENCY.

If the frequency of the a-c generator is increased, the inductive reactance will go up, and the capacitive reactance will go down. The difference between the reactances is a number larger than zero. Our circuit is therefore no longer resonant. The impedance of the circuit has increased since the resistance is no longer the sole opposition to current flow. The impedance of the circuit is now determined by formula 3-10. Since the circuit impedance has increased, the current will now decrease below its resonance value.

If the generator frequency is decreased, the inductive reactance goes down, and the capacitive reactance goes up. The reasoning in the preceding paragraph applies here as well. In this case, the current also decreases below its resonance value. We can therefore conclude that the current is a maximum at resonance, and decreases either side of the resonant frequency.

3-26. The Resonance Curve

If we were to draw a curve of the variations of current with changes in generator frequency, we would obtain a curve known as a RESONANCE CURVE as illustrated in fig. 3-27. The vertical direction stands for the amount of current flowing in the circuit for different frequencies. The horizontal direction stands for the different generator frequencies. As the frequency of the generator is varied above and below, the resonant frequency, the current will vary in the manner indicated. Notice that the current

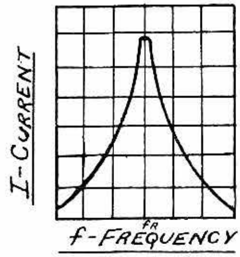


Fig. 3-27. The resonance curve.

reaches a peak only at resonance, and decreases in value at either side of resonance.

3-27. Resonant Frequency of a Series Circuit

For every value of inductance and capacitance in a series circuit, there is ONE frequency at which the inductive reactance equals the capacitive reactance. This frequency is referred to as the resonant frequency. The resonant frequency can be calculated by using the following formula:

$$3\text{-}11) \quad f_R = \frac{1}{2\pi\sqrt{Lc}}$$

where: f_R is the resonant frequency in cycles
2π is 6.28
L is the inductance in henries
c is the capacitance in farads

In order to find the resonant frequency, when L and c are given in more common units such as microhenries and microfarads, the above formula is modified as follows:

$$3\text{-}11A) \quad f_R = \frac{1{,}000{,}000}{2\pi\sqrt{Lc}}$$

where: f_R is the resonant frequency in cycles
2π is 6.28
L is the inductance in microhenries
c is the capacitance in microfarads

It is important to remember that the resonant frequency of a circuit goes up when either the inductance or capacitance goes down. This becomes apparent if we inspect the above formula.

3-28. Parallel Resonance

Fig. 3-28 illustrates a coil and condenser connected in parallel across an a-c generator. Note that R_L represents the d-c resistance of the coil. If the frequency of the generator is adjusted so that X_L is equal to X_C, we would have a condition of resonance known as PARALLEL RESONANCE. Notice that the conditions for resonance are the same here as in a series resonant circuit. The circuit in fig. 3-28 is called a PARALLEL RESONANT CIRCUIT. In a parallel resonant circuit, there are two different currents flowing; first, there is the line current (I_{LINE}) which flows from the generator through the resonant circuit, and back to the generator. At resonance the line current is very low in value. The line current increases in value above and below resonance. At resonance, the line current supplies just enough energy to the parallel circuit to overcome the losses in the resistance of the coil. Secondly, there is the current which flows back and forth between the coil and condenser. This current, I_C, is called the INTERNAL CIRCULATING CURRENT. At resonance, the internal circulating current is very high compared to the line current. Since the reactances of the coil and condenser are equal and cancel each other, the only opposition to the internal circulating current at resonance is the resistance of the coil "R_L".

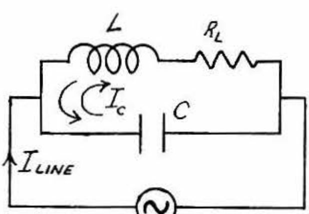


Fig. 3-28. Parallel resonance.

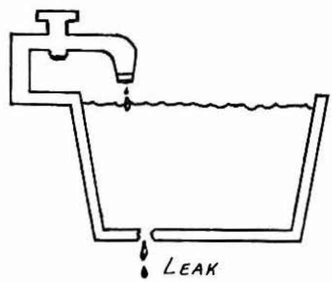


Fig. 3-29. Water tank.

To understand the operation of the parallel resonant circuit more clearly, we can compare it to a water tank with a small leak in its bottom, as illustrated in fig. 3-29. The small leak represents the resistance of the coil. The tank represents the circuit of the coil and condenser in parallel. (The parallel combination of a coil and condenser is actually given the name TANK CIRCUIT). The water in the tank represents the energy present in the tank circuit due to the internal circulating current flowing between the coil and condenser. The faucet represents the generator, and the water flowing from the faucet into the tank represents the line current.

If there were no leak, the water tank would not lose any water, and there would be no need to add water from the faucet. Similarly, if the electronic circuit had no resistance, no energy would be dissipated as the internal circulating current flows back and forth between the coil and condenser. (Energy can only be dissipated in a resistor according to the I x R factor.) Therefore, the generator would not have to supply any energy since none would be lost in the circuit. Consequently, the line current will be zero. Practically speaking, there will always be some resistance present in the tank circuit. Energy will necessarily be dissipated in the tank circuit since the internal circulating current must flow through the resistance. In order to replenish this lost energy, the generator will have to supply energy by way of the line current flowing into the tank circuit.

3-29. Impedance of the Parallel Circuit

The average tank circuit encountered in radio has a very low coil resistance. The energy dissipated will therefore be very low, and the line current will also be very low. Since the line current is small, the impedance (opposition to the line current) of a tank circuit at the resonant frequency must be very high. Compare this with the low impedance of a series resonant circuit. We will also find that the impedance of the tank circuit decreases as the frequency of the energy that is injected into the tank circuit varies above and below the resonant frequency. Thus, the impedance is a maximum at resonance.

3-30. Summary of Characteristics of Resonant Circuits

We will now summarize the characteristics of parallel and series resonant circuits. See the following page for a comparison chart.

3-31. A-C Power

In paragraph 1-17, we learned that the power loss in a d-c circuit is determined by using the following formulas:

1) $P = EI$ 2) $P = I^2R$ 3) $P = \frac{E^2}{R}$

where: R is the total resistance in the circuit.

This power is dissipated in the form of heat, which as far

	Series Resonant	Parallel Resonant
Impedance	low.	High.
Current	high.	line current - low. Internal circulating current - high.
E across Circuit	low.	high.
Formula for resonant frequency	$f_R = \frac{1}{2\pi\sqrt{Lc}}$	$f_R = \frac{1}{2\pi\sqrt{Lc}}$

as electrical devices is concerned, is wasted energy.

The power loss in a pure resistive a-c circuit is similarly determined using the same formulas where E and I are in effective values.

3-12) $P = E_{eff.} \times I_{eff.}$ watts $\qquad P = I^2_{eff.} \times R$ watts

$$P = \frac{E^2_{eff.}}{R}$$

In an a-c circuit containing either inductance or capacitance, the voltage and current are out of phase. (They are not acting together at the same instant.) Therefore, the above formulas cannot be used to determine the TRUE POWER loss in a reactive circuit. The product of E_{eff} and I_{eff} would in this case be known as the APPARENT POWER loss. This power is actually larger than the true power consumed in the circuit. The true power is the heat dissipated in the circuit. The electric company charges you for the true power consumed over a period of time. Power can only be dissipated or used up in a resistive element. Power cannot be dissipated in a capacitive or pure inductive circuit.

The apparent power can be determined from the readings of a voltmeter and ammeter placed in the circuit as illustrated in fig. 3-30. The product of these readings, volts times amperes or VOLT-AMPERES, is the apparent power. The

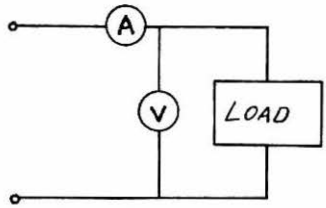


Fig. 3-30. Determining apparent power.

true power dissipated will always be indicated by an instrument called a wattmeter.

The one formula which can be used to determine the true power consumed in both d-c and a-c circuit is:

$$P = I^2 R$$

Where: I is either the d-c current or the effective a-c current, and R is the resistance in circuit.

3-32. The Transformer

The voltage supplied to most communities in the United States is the standard 110 volts, a-c. Many home radios require a voltage higher than 110 volts, a-c, in order to operate satisfactorily. To fill this need, a device is incorporated in those radios to step-up the line voltage of 110 volts to a higher voltage. The device which can increase or decrease the value of an a-c voltage is known as a TRANSFORMER.

3-33. Principle of the Transformer

You will recall from our early discussion of a-c voltage, that an e-m-f will be induced in a loop of wire which cuts into a magnetic field. So long as there is relative motion between the loop and the magnetic field, a voltage will be generated. If the loop is kept stationary and the magnetic field cuts across the loop of wire, the result obtained will be the same as if the loop were in motion instead of the magnetic field. In either case, a voltage will be induced in the conductors of the loop. The transformer operation is based upon a varying magnetic field inducing a voltage in a stationary coil of wire.

3-34. <u>Operation of the Transformer</u>

Every time current flows through a conductor, a magnetic field builds up around the conductor. The magnetic field is in phase with the current at all times. Therefore, if an alternating current flows through a coil of wire, an alternating magnetic field will exist about this coil. This alternating magnetic field expands outwardly away from the coil and collapses back into the coil periodically. If a second coil with a lamp across it is placed in the vicinity of coil #1, as illustrated in fig. 3-31, the alternating magnetic field will cut across coil #2 and induce an a-c voltage in it; this will cause the lamp to light. Notice that no electrical connection exists between

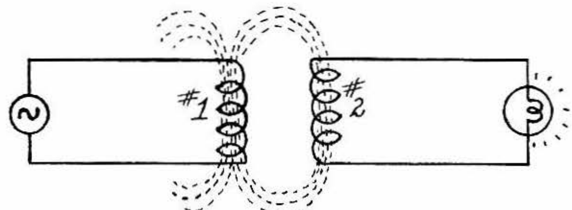


Fig. 3-31. Magnetic coupling.

the coils. Energy is transferred from coil #1 to coil #2 by means of the varying magnetic field. We say that the coils are MAGNETICALLY COUPLED. This method of transferring energy from one coil to another is known as TRANSFORMER ACTION. The entire device consisting of two coils magnetically coupled is known as a TRANSFORMER. Coil #1 which is connected to the voltage source is called the PRIMARY. Coil #2, in which the induced voltage is developed, is called the SECONDARY.

Fig. 3-32 shows the schematic symbols of typical transformers used in radio circuits.

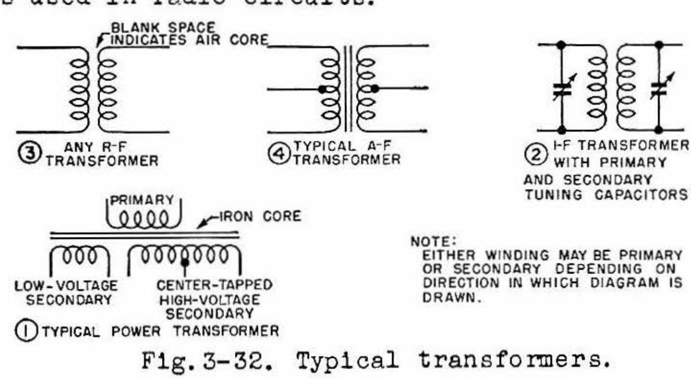


Fig. 3-32. Typical transformers.

3-35. The Power Transformer

The transformer in fig. 3-33B is known as an air-core transformer. Its use is confined to radio frequencies and it will be considered later on. A transformer which is used to transfer a-c power at the power frequency of 60 cycles per second is known as a POWER TRANSFORMER.

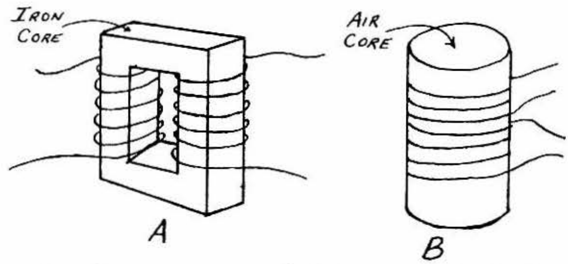


Fig. 3-33. Iron-core and Air-core transformers.

In order for a power transformer to operate efficiently, the primary and secondary are wound on an iron core as illustrated in fig. 3-33A.

Power transformers can only be used on a-c because an alternating magnetic field is required to induce an e-m-f in the secondary. It is dangerous to apply d-c to the power transformer primary. The primary has a low d-c resistance and, therefore, a high d-c current will flow through it. This high current will either blow a line fuse or damage the transformer beyond repair.

3-36. Voltage and Turns Ratio

One of the most common uses of a transformer is to step-up the 110 volts a-c that is supplied to the average home. All a-c radios and television sets require several hundred volts to operate. They must therefore incorporate a transformer which will step-up the 110 volts. A fundamental principle of transformer action states that the voltage ratio between the secondary and the primary varies directly as the turns ratio. An example will clarify this point. If there are three times as many turns on the secondary as on the primary, the voltage of the secondary will be three times the voltage that is applied to the primary. Fig. 3-34 illustrates a transformer whose secondary has three times as many turns as the primary. If the primary voltage is 110 volts, the secondary voltage which is applied to the load will be 330 volts. If there are ten times as many turns on the secondary as on the primary, the secondary voltage will be ten times as great as the primary voltage.

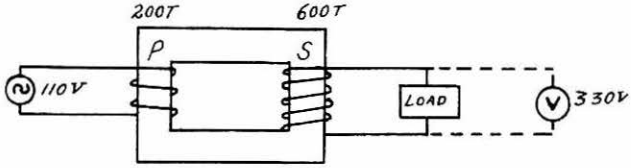


Fig. 3-34. 1 to 3 step-up transformer.

A transformer whose secondary voltage is greater than the primary voltage is known as a STEP-UP TRANSFORMER.

Fig. 3-35 shows a transformer where the turns on the secondary are less than the turns on the primary. In this case the voltage will be stepped down from primary to secondary. This transformer is known as a STEP-DOWN TRANSFORMER.

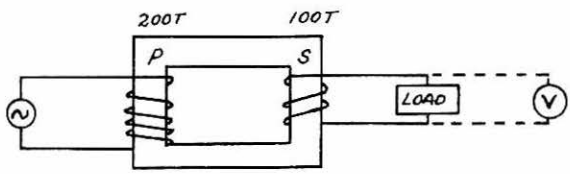


Fig. 3-35. 2 to 1 step-down transformer.

3-37. Transformer Losses

There are three types of losses which are encountered in the operation of a transformer. They are:

1.- EDDY CURRENTS
2.- HYSTERESIS LOSSES
3.- COPPER LOSSES

EDDY CURRENTS are wasted currents induced in the iron core of the transformer by the varying magnetic field. These currents take a circular path through the core material as shown in fig. 3-36A. Since the resistance in their path in a solid core material is low, the eddy currents will be large. Eddy currents serve only to heat up the iron core and therefore represent a power loss. Eddy current losses can be reduced by having the core made up of LAMINATIONS (thin insulated iron sheets) instead of solid iron. See fig. 3-36B. The laminations limit eddy currents by increasing the resistance in their path of flow.

HYSTERESIS LOSSES represent the energy that is used up in forcing the iron core to reverse the direction of its magnetic field every time the current reverses its

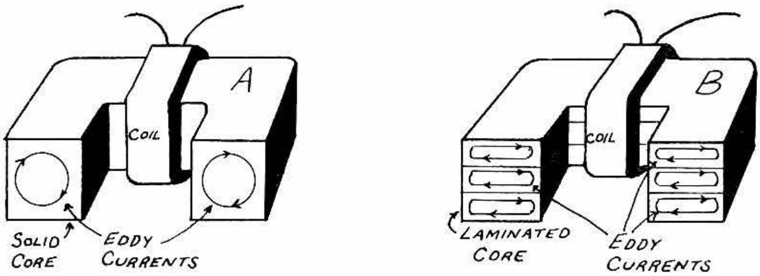


Fig. 3-36A. High eddy-current flow in solid core.
Fig. 3-36B. Low eddy-current flow in laminated core.

direction. Hysteresis losses can be minimized by using cores made of special materials. Hysteresis losses together with eddy current losses are known as IRON-CORE LOSSES.

The third type of loss encountered in transformers is COPPER LOSSES. Copper losses are caused by the resistance of the wire which makes up the turns of the windings. Current flowing through the resistance of the winding develops an I^2R power loss in the form of wasteful heat. Copper losses can be minimized by using a heavier wire for the windings; a thicker wire will have a lower resistance, and therefore, a lower I^2R loss.

3-38. Maximum Power Transfer

In order that there be a maximum transfer of energy from a generator to a load, the impedance of the load should equal the internal impedance of the generator. This law applies to all circuits in radio and electricity.

Sometimes a load such as a speaker voice coil may have a very low impedance as compared to the very high internal impedance of the vacuum tube which is to energize the speaker. In order that there be maximum energy transfer between the vacuum tube (generator) and the speaker (load), a matching transformer (output transformer) is interposed between the two. The transformer steps up the impedance. We say that the transformer MATCHES the load to the generator, effecting maximum power transfer.

PRACTICE QUESTIONS - LESSON 3

(For answers, refer to back of study guide section I)

3-1. Alternating current;

a. flows only in one direction
b. reverses its direction of flow periodically
c. flows more in one direction than in the other
d. none of the above

3-2.* The frequency of a sine wave is;

a. the time in seconds for one cycle
b. the amplitude of the wave
c. the number of cycles per second
d. the angle of rotation

3-3. The peak amplitude of a sine wave occurs at; a. 45° b. 270° c. 360° d. 180°

3-4. One complete cycle has;

a. one positive alternation
b. one negative alternation
c. two negative alternations
d. a positive and negative alternation

3-5. One kilocycle equals; a. $\frac{1}{1000}$ of a cycle. b. 25 cycles. c. 1000 cycles. d. 1 cycle.

3-6. The phase angle is;

a. always large
b. the angle by which current leads resistance
c. the angle by which one wave leads or lags another
d. the angle between 0° and 90°.

3-7. If the effective value of the wave is 100 volts, the peak value is; a. 78 volts. b. 70.7 volts. c. 141 volts. d. 250 volts.

3-8. If the peak value is 155 volts, the effective value is; a. 185. b. 220. c. 155. d. 110.

3-9. The inductance of a coil varies;

a. inversely with the number of turns
b. directly as the square of the number of turns
c. directly with the number of turns
d. directly as the square-root of the number of turns

3-10. Inductive reactance is;

a. the opposition a coil offers to a-c current flow
b. the a-c current flowing through the coil
c. the d-c resistance of the coil
d. the coil inductance

3-11. In an inductive circuit;

a. the current leads the voltage
b. the current lags the voltage
c. the voltage lags the current
d. the current and voltage are in phase

3-12. A condenser is;

a. two conducting plates connected by a wire
b. a resistance
c. two insulated plates separated by air
d. two conducting plates separated by a dielectric

3-13. A condenser is;

a. a short-circuit for d-c
b. an open-circuit for d-c
c. offers little opposition to d-c current flow
d. is a d-c generator

3-14. A-C flows;

a. in and out of a condenser
b. through a condenser
c. around the plates of a condenser
d. can't flow through a condenser

3-15. The reactance of a condenser;

a. remains constant
b. increases with increase in frequency
c. decreases with an increase in frequency
d. is very high

3-16. Condensers in series;

a. add like resistors in series
b. add like resistors in parallel
c. are equal to the smaller condenser
d. are equal to the larger condenser

3-17. At resonance;

a. the resistance is equal to the voltage
b. the current is zero

c. $X_L = X_c$

d. the voltage varies

3-18. In a series resonant circuit;

a. the impedance is a minimum
b. the impedance is a maximum
c. the current lags the voltage
d. the current leads the voltage

3-19. In a parallel resonant circuit;

a. the line current equals the circulating current
b. the line current is much smaller than the circulating current
c. the line current is larger than the circulating current.
d. the line current is constant

3-20. In a transformer, the secondary voltage;

a. always equals the primary voltage
b. is less than the primary voltage
c. equals the primary voltage times the turns ratio
d. is high

3-21.* Short-circuiting a turn of a coil in a tuned circuit will;

a. increase the resonant frequency
b. have no effect on the resonant frequency
c. decrease the resonant frequency
d. increase the "Q"

STUDY GUIDE

Section 1

Your Amateur Communications Course has been written with two purposes in mind:

1. To aid you to successfully pass the written part of the Federal Communications Commission examinations for the Amateur licenses.
2. To give you, the prospective radio amateur, a complete understanding of radio theory so that you can properly operate a radio amateur receiving and transmitting station.

At the present time, the government is issuing five types of Amateur licenses. They are: the Novice Class, the Technician Class, the General Class, the Conditional Class and the Amateur Extra Class.

In order to qualify for any of these licenses, you must pass a written test as well as an examination in the sending and receiving of International Morse Code.

The written test for the Novice Class license consists of 20 questions. The written test for the Amateur Extra Class license has 100 questions. The written tests for all the other classes of amateur licenses have 50 questions. Most of the questions are of the multiple choice type. Some of the remaining questions are problems; the rest ask for diagrams. The written part of the Novice Class examination contains only multiple choice questions.

Before the prospective amateur can take the written examination, he must pass the code test. The code speed for the Novice Class and Technician Class licenses is 5 words per minute. It is 13 words per minute for the General Class and Conditional Class licenses. The Amateur Extra Class license requires 20 words per minute.

If your code speed is not up to the FCC requirements, write to the American Electronics Co. for information regarding code courses that prepare one for the FCC code examinations.

This radio theory course comes to you in three sections. Each section contains a number of lessons and a study guide such as this one. The study guide assists you by calling special attention to the material that you will be questioned about on the FCC examinations. At the end of each lesson you will find a series of questions that will review the important information in the lesson. The questions with an asterik are similar to questions that are asked on the government examination. Know them thoroughly! The answers to the study questions at the end of each lesson will be found in the study guide.

After you have thoroughly studied the lessons and practice questions in a section, you will be ready to take an "FCC-type" examination that tests your knowledge of the most important material contained in the section. This examination is found at the back of each study guide. Bear in mind that these questions are not the actual questions that are asked in the government license examination. They are, however, similar. Also, the practice questions contain the same information that you will be responsible for on the examination given by the FCC. For example, our practice question may ask for the third harmonic of a given fundamental frequency. The government examination question may state the third harmonic and ask for the fundamental frequency. Thus you can see where an understanding of the practice questions will enable you to correctly answer the actual FCC question.

When taking a practice FCC-type examination, do not refer back to the text material to obtain the correct answers. You will not be allowed to use any reference material when taking the actual license examination. Answer all the questions as best as you can. When you are finished with all the questions of a particular test, check them against the correct answers. If you have wrong answers, look up the material in the text to learn why your answer is incorrect. Make sure that you know and understand the correct answer before you go on.

While most of the questions on the examination are of the multiple choice type, some will involve the drawing of circuit diagrams, while others will involve the solution of simple problems in arithmetic.

The multiple choice question consists of a statement and four answers, labeled a, b, c and d. Only one of these answers correctly finishes the statement.

For example: 1. The United States is a:
a. democracy
b. kingdom
c. colony
d. dictatorship

The only correct answer to the question is "a".

The same question can be worded in a negative way.

For example: 2. The United States is not a:
a. democracy
b. union of states
c. kingdom
d. land of many religions

The only correct answer to the question is "c".

The first three lessons of section 1 are:

1. D-c theory
2. Magnetism
3. A-c theory

These three lessons are extremely important because they contain fundamental material that is basic to an understanding of the lessons that follow. Therefore, you should study Section 1 thoroughly and completely.

The following outline is a guide to the material in Section 1 that you will most likely be questioned about on the FCC license examinations.

Lesson #1 Direct Current Theory

1. You must know the basic units of electrical resistance, current, electromotive force, power, energy, and electrical quantity.
(refer to practice questions 1,2,4,16,17)
2. You must know the names of the instruments used to measure current, potential difference, power, and resistance.
3. You should be thoroughly familiar with the application of Ohm's law.
(refer to practise question 8,12,14,15)

Lesson #2 Magnetism

1. You must know the unit of magnetomotive force (refer to practice question 1)

Lesson #3 A-C Theory

1. You must know the unit of frequency (refer to question 2)

2. You should know that the instrument used to measure frequency is called a frequency-meter.

3. You should be familiar with the theory of tuned circuits. (refer to question 21)

4. You must be able to understand the theory of the transformer, and be able to work out problems on transformer action.
(refer to question 20)

ANSWERS TO PRACTICE QUESTIONS

Lesson #1

1.- c	6.- b	11.- 14.06 watts	16.- b
2.- b	7.- d	12.- 100V	17.- c
3.- b	8.- c	13.- 6.7Ω	
4.- d	9.- a	14.- .50A	
5.- c	10.- b	15.- 25V	

Lesson #2

1.- b	4.- b	7.- d	10.- c
2.- c	5.- a	8.- b	
3.- b	6.- c	9.- d	

Lesson #3

1.- b	6.- c	11.- b	16.- b
2.- c	7.- c	12.- d	17.- c
3.- b	8.- d	13.- b	18.- a
4.- d	9.- b	14.- a	19.- b
5.- c	10.- a	15.- c	20.- c
			21.- a

"FCC-TYPE EXAMINATION" SECTION I

After each question you will find a series of four answers labeled a,b,c,and d. Only one of these is the correct answer to the question. Choose the answer which you believe to be correct and print its corresponding letter on the line provided on the answer sheet.

Example: An electron is; a. positive b. green c. negative d. white

The correct answer is negative; therefore, on the line adjacent to number 1 on the answer sheet you would print the letter c.

When working on the examination, first answer the questions you know and leave the doubtful ones for later. You may find that the wording of the easy questions will give you a clue as to the correct answer for the doubtful ones.

1. The unit of electrical resistance is; a. ampere b. volt c. ohm d. joule

2. The unit of electrical current is; a. ampere b. volt c. watt d. farad

3. The unit of electromotive force or potential difference is; a. ampere b. volt c. watt d. coulomb

4. The unit of power is; a. ampere b. volt c. watt d. coulomb

5. The unit of energy is; a. watt b. ampere c. joule d. henry

6. The unit of electrical quantity is; a. ampere b. volt c. coulomb d. watt

7. The instrument used to measure electric currents is; a. wattmeter b. ammeter c. voltmeter d. ohmmeter.

8. The instrument used to measure potential difference is; a. wattmeter b. ammeter c. voltmeter d. ohmmeter

9. The instrument used to measure power is; a. wattmeter b. ammeter c. voltmeter d. ohmmeter

10. The instrument used to measure resistance is; a. wattmeter b. ammeter c. voltmeter d. ohmmeter

11. The unit of magnetOmotive force is; a. henry b. coulomb c. farad d. gilbert

12. The unit of capacitance is; a. henry b. coulomb c. farad d. gilbert

13. The unit of inductance is; a. henry b. coulomb c. farad d. gilbert

14. The line current in a parallel circuit is equal to;

a. the sum of the branch currents divided by 2
b. the source voltage divided by the smallest resistor.
c. the sum of the individual branch currents
d. a very small value

15. Ohms law states that;

a. the current is equal to the voltage times the resistance
b. the resistance is equal to the voltage divided by the current
c. the voltage is equal to the current divided by the resistance
d. the current is equal to the resistance divided by the voltage

16. The voltage drop in a 300 Ω resistor through which 5 ma flow is; a. 1500 volts b. 60 volts c. .017 volts d. 1.5 volts

17. The voltage drop in a resistor is 13 volts when 4 ma flow through it. The resistor is; a. 3250 Ω b. 52 Ω c. 3.25 Ω d. 308 Ω

18. If the primary of a 60 cycle power transformer were connected directly to the mains carrying d-c current;

a. the primary winding would burn out due to an excessive current flow
b. nothing would happen
c. the secondary winding would burn up due to an excessive current flow

19. The unit of frequency is;

   a. kilometers per second
   b. meters per second
   c. cycles per second
   d. degrees per second

20. The instrument used to measure frequency is;
a. wattmeter b. frequency meter c. wavemeter
d. ohmmeter

21. The peak value of an a-c wave is; a. 0.707 x E_{eff}
b. $\frac{E_{eff}}{1,410}$ c. $\frac{E_{eff}}{1.41}$ d. E_{eff} x 1.41

22. The inductive reactance of a coil is;

   a. the resistance to d-c current flow
   b. the induced voltage in volts
   c. the opposition in ohms that a coil builds up to a-c current flow
   d. always constant

23. In a pure capacitive circuit;

   a. the voltage leads the current by 45°
   b. the current leads the voltage by 45°
   c. the voltage leads the current by 90°
   d. the current leads the voltage by 90°

24. Capacitive reactance is;

   a. the opposition in ohms that a condenser builds up to a-c current flow
   b. the voltage charge on a condenser
   c. the resistance to d-c current flow
   d. always constant

25. In a circuit containing equal amounts of resistance and inductive reactance;

   a. the voltage leads the current by 45°
   b. the current leads the voltage by 90°
   c. the voltage lags the current by 45°
   d. the current is in phase with the voltage

26. If the two plates of a condenser touch, the condenser is said to be; a. open b. good c. shorted
d. a variable condenser

27. A condenser is used to;

a. pass d-c and block a-c
b. pass d-c only
c. pass a-c and block d-c
d. generate an a-c voltage

28. In a power transformer the secondary to primary turns ratio is 6 to 1. If 110 volts are applied to the primary, a voltmeter across the secondary will measure;
a. 660 volts b. 330 volts c. 18.5 volts d. 9000 volts

29. In a series resonant circuit;

a. the current is a minimum and the impedance is a minimum
b. the current is a maximum and the impedance is a minimum
c. the current is a maximum and the impedance is a maximum
d. the current is a minimum and the the impedance a maximum

30. In a parallel resonant circuit;

a. the current is a minimum and the impedance is a minimum
b. the current is a maximum and the impedance is a minimum
c. the current is a maximum and the impedance is a maximum
d. the current is a minimum and the impedance is a maximum

AMATEUR RADIO COURSE

SECTION II LESSON 4

THE VACUUM TUBE

4-1. The Development of the Vacuum Tube

Thomas A. Edison was one of the great pioneers in the development of the vacuum tube. Edison invented the incandescent light bulb whose basic principles were later put to use by men, such as Fleming and DeForest, in the development of the modern vacuum tube.

Edison's incandescent electric lamp which was the forerunner of the modern electric bulb, consisted of a resistance wire called a filament enclosed within a glass envelope. The air within the glass envelope had been removed to create a vacuum. The ends of the resistance wire protruded through the glass as illustrated in fig.4-1. If a current passes through the resistance wire it will heat up and glow. We can then say that the filament wire has been heated to INCANDESCENCE. While working with his electric light, Edison discovered that the incandescent wire emitted, or boiled off, electrons. These electrons remained around the wire in the form of an electron cloud or SPACE CHARGE. This phenomenon of electron emission is known as the EDISON EFFECT, and is the basis of operation of all vacuum tubes.

4-2. Electron Emission

Many metallic substances will emit electrons when heated to incandescence. For instance, the resistance wire in the light bulb emits electrons. These emitted electrons are wasted since they serve no useful purpose.

The vacuum tube is similar to the light bulb in that it also contains a resistance wire which emits electrons when heated. The vacuum tube, however, is designed to make use of the emitted electrons. In addition to the resistance wire, the vacuum tube has a positively charged collector of electrons called THE PLATE. The positive plate attracts the emitted electrons as illustrated in fig. 4-2.

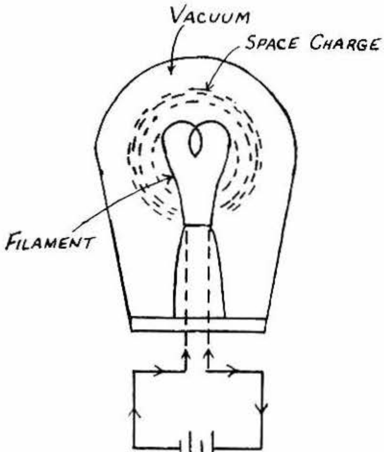


Fig.4-1. The electric lamp.

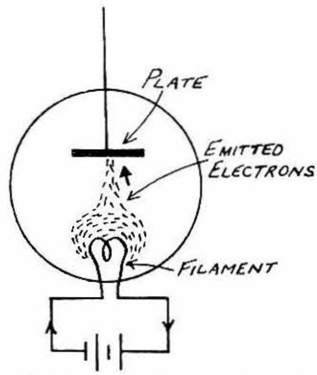


Fig.4-2. Positive plate attracting electrons.

The purpose of the battery in fig.4-2 is to force current through the filament, thereby heating it.

4-3. The Cathode

The element in the vacuum tube which supplies the electrons for the tube operation is known as the CATHODE. The cathode, as does the resistance wire, emits or boils off electrons when energy in the form of heat is supplied to it. There are two different types of cathodes used in vacuum tubes. They are the directly heated and the indirectly heated types. We will now discuss these two types in detail.

1.- The directly heated cathode. This type is also known by the name FILAMENT-CATHODE. An example of filamentament-cathode is illustrated in fig.4-3. The heating current is passed directly through the cathode wire which is made of tungsten. The current heats up the cathode wire which then emits electrons from its surface. Directly heated filament-cathodes usually require very little heating power. They are therefore used in tubes designed for portable battery operation because it is necessary to impose as small a drain as possible on these batteries.

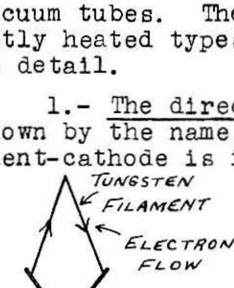


Fig. 4-3. Directly heated cathode.

Examples of battery-operated filament-cathode tubes are the 1A7, the 1R5, and the 1U4

All vacuum tubes are classified by tube numbers. If you desire to know the purpose and characteristics of a particular tube, you simply look up its tube number in any tube manual for the information wanted.

2.- The indirectly-heated cathode. This type is also known as the HEATER-CATHODE and is illustrated in fig. 4-4A.

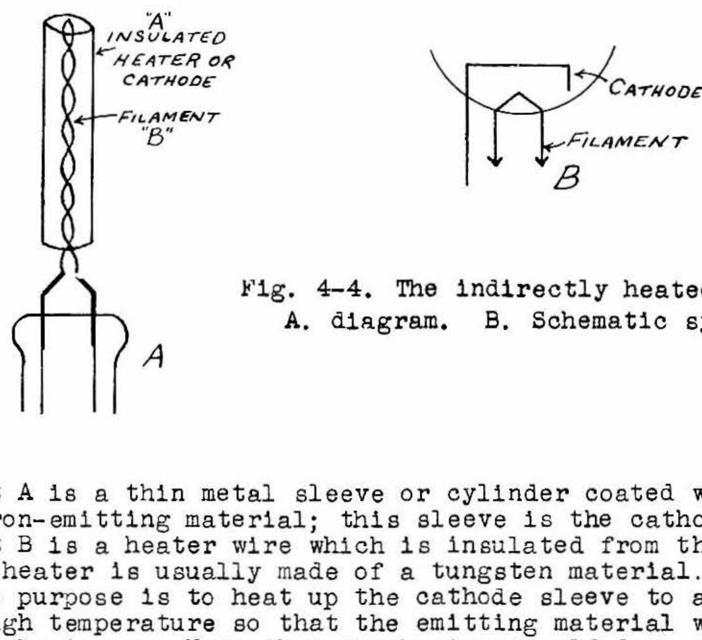


Fig. 4-4. The indirectly heated cathode.
A. diagram. B. Schematic symbol.

Part A is a thin metal sleeve or cylinder coated with electron-emitting material; this sleeve is the cathode. Part B is a heater wire which is insulated from the sleeve. The heater is usually made of a tungsten material. Its sole purpose is to heat up the cathode sleeve to a high enough temperature so that the emitting material will boil off electrons. Note that the heater itself does not give off the electrons. The heater wire is known as the filament. Fig. 4-4B shows the schematic symbol for the heater-cathode.

Almost all present day receiving tubes designed for a-c operation are of the indirectly-heated cathode type.. We will always refer to the electron emitting surface as the cathode, and the heater as the filament.

4-4. Filament Operating Voltage

The first number in a tube designation usually indicates the proper filament operating voltage. For example, a 6H6 tube should have its filament operated at 6.3 volts. All filaments should be operated at their designated operating voltages which is determined by the manufacturer. If the filament is operated above its rated voltage, the excessive current will shorten the filament life. Operating the filament below its rated voltage will decrease electron emission and lower the tube operating efficiency.

4-5. The Diode

Let us see how electrons emitted from the cathode can be collected and made to do useful work. Electrons are negatively charged and will be attracted by a positively charged object. Therefore, if a positively charged object called a PLATE is put into the vacuum tube, it will serve as a collector of electrons. A vacuum tube which contains a plate and a cathode is known as a DIODE. The schematic symbol for the diode is shown in fig. 4-5. B is a directly heated diode and A is an indirectly-heated diode.

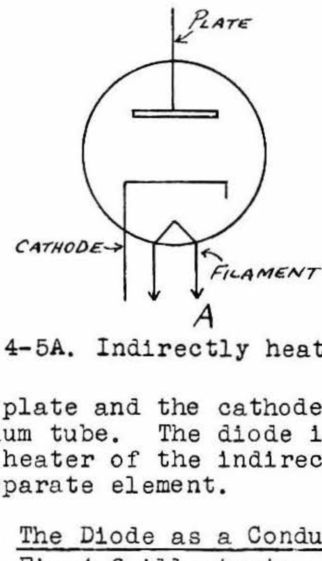


Fig. 4-5A. Indirectly heated

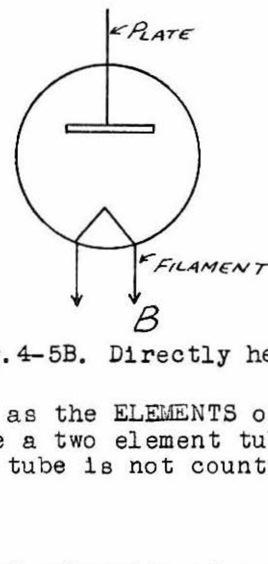


Fig. 4-5B. Directly heated

The plate and the cathode are known as the ELEMENTS of the vacuum tube. The diode is therefore a two element tube. The heater of the indirectly-heated tube is not counted as a separate element.

4-6. The Diode as a Conductor

Fig. 4-6 illustrates a simplified schematic of a diode with the plate connected to the positive terminal of a battery; the cathode is connected through a switch to the negative terminal. The instant the switch is closed, the ammeter in the circuit will register a current flow indicating that electrons are flowing from the cathode to the plate. The diode is said to be CONDUCTING. The diode conducts because the plate is positive with respect to the

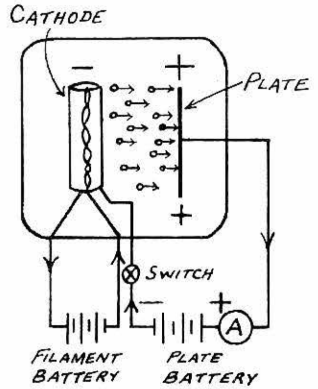


Fig. 4-6. Electron flow plate is positive.

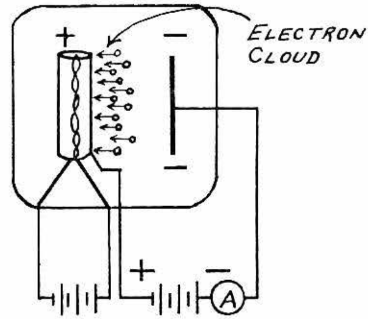


Fig. 4-7. Diode action when plate is negative.

cathode. The plate therefore attracts to it the negatively charged electrons emitted by the cathode. The electrons flow from the plate to the positive terminal of the battery. They then flow through the battery and back to the cathode, where they once more can be emitted to the plate. If the battery voltage is increased, the plate will become more positive and will therefore attract more electrons. The ammeter will consequently register a larger current flow. Conversely, if the battery voltage is decreased, the plate will attract less electrons, and the ammeter will register a smaller current flow.

When the diode conducts, it represents a very low resistance path between the cathode and plate. To all practical purposes, we can consider a conducting diode as a closed switch (short circuit) between the cathode and plate.

4-7. <u>The Diode as a Non-conductor</u>

If we reverse the battery connections as shown in fig. 4-7., the plate becomes negative and the cathode positive. Since the negative plate will not attract electrons, the diode will NOT CONDUCT. The diode, therefore, acts like an open switch (open-circuit) and permits no current flow. The ammeter will consequently read zero amperes. The emitted negatively-charged electrons are repelled by the negative plate and remain close to the cathode where they form an ELECTRON CLOUD. The cloud of electrons around the cathode is known as a SPACE CHARGE. The space charge, by virtue of its large negative charge, prevents the plate from receiving any more electrons. When the plate becomes positive once again, the space charge is rapidly dispelled since it is attracted to the plate. The cathode is free once again to emit electrons.

Let us now summarize the operation of the diode:

1) electrons flow in one direction only,- from cathode to plate.

2) Electron flow to the plate will take place only when the plate is positive with respect to the cathode.

3) The current flow will vary with the plate to cathode voltage.

4) The diode acts as a conductor (short circuit) when the plate is positive;

5) The diode acts as a non-conductor (open circuit) when the plate is negative.

4-8. The Diode Characteristic Curve

Fig. 4-8 illustrates a diode connected to a source of variable voltage. The heater circuit has been omitted for

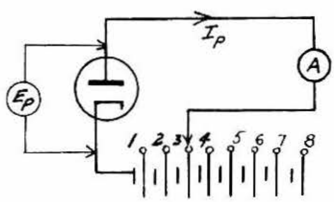


Fig. 4-8. Diode with variable plate voltage supply.

E_p	I_p
22.5	1.0
45	1.5
67	3.0
90	6.0
112	9.0
135	12.0
157	13.0
180	13.01

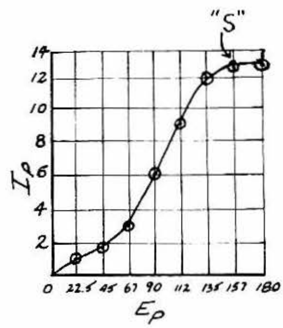


Fig. 4-9. plot of plate current against plate voltage

the purpose of simplicity. "A" is a milliammeter connected in series with the tube. The voltage applied to the plate of the diode can be varied by changing the position of the plate tap from position #1 to position #8. As the tap is moved from position #1 to position #8, the plate to cathode voltage increases. For every value of plate voltage there will be a different value of diode plate current as measured by the milliammeter. The table in fig. 4-9 is a tabulation of plate current readings for various values of plate voltage. If we plot these readings on the graph in fig. 4-9, and then draw a line through the different points, we obtain a curve known as the DIODE CHARACTERISTIC CURVE. I_p is the electronic symbol for plate current; E_p is the electronic symbol for plate to cathode voltage, or simply plate voltage. The plate-current, plate-voltage curve shows the amount of current that a particular diode will conduct for a given plate voltage. The curve indicates that the plate current increases as the plate voltage increases up to point "S". Beyond point "S" the curve becomes practically horizontal. In other words, as the plate voltage increases beyond point "S", the plate current remains essentially constant. This point "S" is known as the saturation point. It is the point at which the plate is collecting all of the electrons that the cathode is capable of emitting.

The characteristic curve is important because it tells us at a glance what the plate current will be for any particular plate voltage. This information is useful if we are designing a diode circuit for a certain application. Characteristic curves for diodes as well as all other tubes, may be found in tube manuals.

4-9. <u>Summary of Filaments and Diode Tubes</u>

1) The emmission of electrons from a filament is the principle upon which all electron tubes are based.

2) Electrons are negatively charged particles which are attracted to a positively charged object, such as a plate.

3) A diode consists of an emitting surface called the cathode (whether it is directly or indirectly heated), and a receiver of electrons called the plate. These elements are placed within an evacuated (vacuum) glass or metal bulb to prevent the hot filament from burning up, and to provide a clear path from the cathode to the plate for the fast-moving electrons.

PRACTICE QUESTIONS - LESSON 4

(For answers, refer to back of Study Guide Section II)

4-1.* The diode tube has; a. one element b. two elements c. three elements d. four elements

4-2. Electron emission;

a. is undesirable in vacuum tubes
b. is necessary to the operation of a light bulb
c. can only take place when the filament is cold
d. is the giving off of electrons by a metal when heated to incandescence.

4-3. The plate is;

a. a positively charged collector of electrons
b. a positively charged emitter of electrons
c. not necessary to the operation of a diode
d. connected directly to the cathode

4-4. The cathode;

a. is not necessary to the operation of a diode
b. is a positively charged collector of electrons
c. repels electrons
d. emits electrons for tube operation

4-5. The directly-heated cathode type tube;

a. has the heating current pass directly through the cathode
b. has a separate filament and cathode
c. does not require heater current
d. is the same as the indirectly-heated cathode type tube

4-6. The diode acts as an open-circuit;

a. when the tube conducts
b. when the plate is negative with respect to the cathode
c. when the plate emits electrons
d. when the cathode is negative with respect to the plate

4-7. A diode tube allows current to flow;

a. only from cathode to plate
b. only from cathode to heaters
c. in either direction
d. straight up

4-8. The indirectly-heated cathode type tube;

a. has the heating current pass directly through the cathode
b. has a separate filament and cathode
c. does not require heater current
d. has no cathode

4-9. When the plate of a diode is positive, relative to the cathode;

a. current will flow from plate to cathode
b. the cathode stops emitting
c. the tube conducts
d. an electron cloud forms

4-10. When the plate of a diode is negative, relative to the cathode;

a. the cathode stops emitting
b. the tube conducts
c. current will flow from cathode to plate
d. the tube acts as an open-circuit

SECTION II LESSON 5

RECTIFICATION, FILTERING

5-1. Rectification

Vacuum tubes in receivers and transmitters will only operate when connected to a direct current source of power. Portable radios, for example, are energized by batteries which are in themselves a source of direct current. As previously noted, the electrical power that is delivered to most homes throughout the country today is alternating current. If we were to connect the tubes in our radios directly to the a-c wall outlet, the radio would not operate because a radio tube needs a source of d-c power. We all know that our radios do operate when we plug them into the a-c socket. Obviously, there must be something in the radio which converts the alternating current into direct current. The device in a radio which converts the alternating current into direct current is known as a RECTIFIER. The process of conversion is known as RECTIFICATION.

5-2. The Diode as a Half-wave Rectifier

The ability of the diode to pass current in only one direction makes it possible to convert alternating current into direct current. Let us see how this takes place. Fig. 5-1 illustrates a simple diode rectifier circuit.

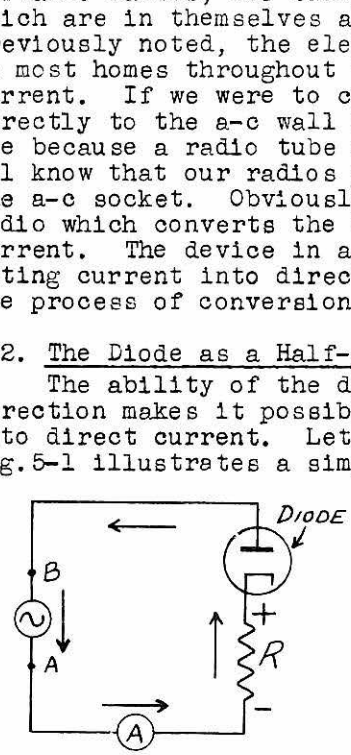


Fig. 5-1. Diode used as half-wave rectifier.

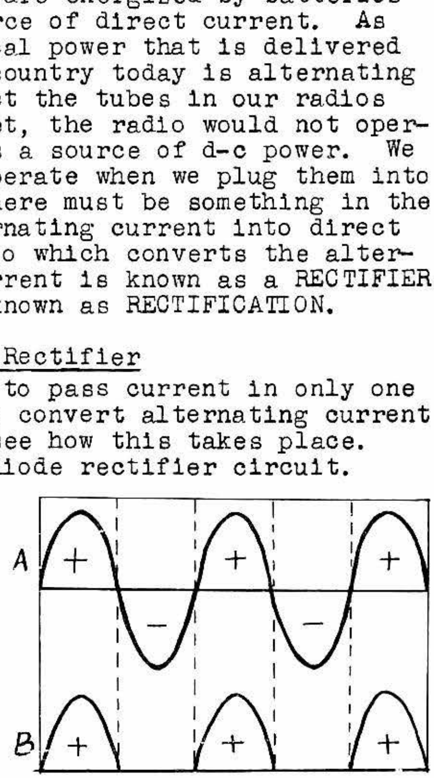


Fig. 5-2. Half-wave rectifier wave-forms.

When terminal "B" of the a-c generator is positive with respect to terminal "A", the diode plate becomes positive with respect to its cathode. The diode therefore conducts current in the direction indicated by the arrow. The d-c milliammeter will deflect to the value of the current flow.

On the next half of the alternating current cycle, the polarity of the generator will be reversed, making the plate negative with respect to the cathode. The diode becomes a non-conductor, and the current will stop flowing. As the milliammeter needle returns to zero, the polarity of "A" and "B" is again reversed; the diode conducts, and once again current flows. Examination of fig. 5-2 shows what is really happening. Fig. 5-2A is the sine wave which is generated across the terminals of the a-c generator. Fig. 5-2B is the wave which is obtained across the load resistor R_L. Alternations 1 and 2 are the positive halves of the cycle when the plate of the diode is positive with respect to the cathode. At that time, the diode conducts and acts as a short circuit. The positive voltage cycles are therefore impressed directly across the resistor R_L. During the negative half of each a-c cycle, the tube does not conduct and is an open circuit. During these times there is no voltage developed across the resistor since there is no current flow. The current through the resistor is therefore a pulsating direct current, and the voltage across the resistor is a pulsating direct voltage. Even though the current flows in spurts or pulses through the resistor, the current is still d-c because it flows only in ONE direction. This action of the diode in passing only one-half of the a-c input wave to the load resistor is known as HALF-WAVE RECTIFICATION.

The ends of the load resistance have been marked with a polarity, because electrons are entering and emerging from this resistance. The end they enter becomes more negative than the end from which they emerge. The pulsating direct-voltage, if properly filtered, can be utilized to operate a radio receiver.

A transformer can be considered as an a-c generator. We can, therefore, replace the a-c generator of fig. 5-1 with a transformer as shown in fig. 5-3, without altering the operation of the circuit.

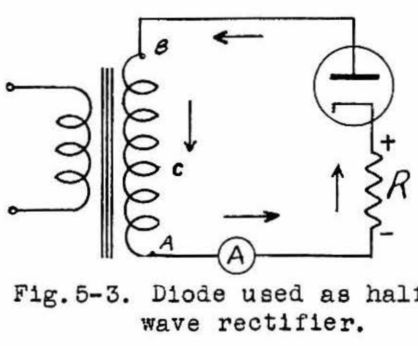


Fig. 5-3. Diode used as half-wave rectifier.

5-3. The Diode as a Full-wave Rectifier

In half-wave rectification, only the positive half of the a-c input is used. The negative alternations are completely cut off and wasted. If we could somehow utilize the negative as well as the positive alternation, we would be operating our rectifying system more efficiently. This is accomplished in full-wave rectification.

We can modify the half-wave rectifier circuit of fig. 5-3 by adding another diode and center-tapping the transformer secondary. The resulting circuit is illustrated in fig. 5-4. The cathodes of the diodes are connected together, and the circuit is known as a FULL-WAVE RECTIFIER.

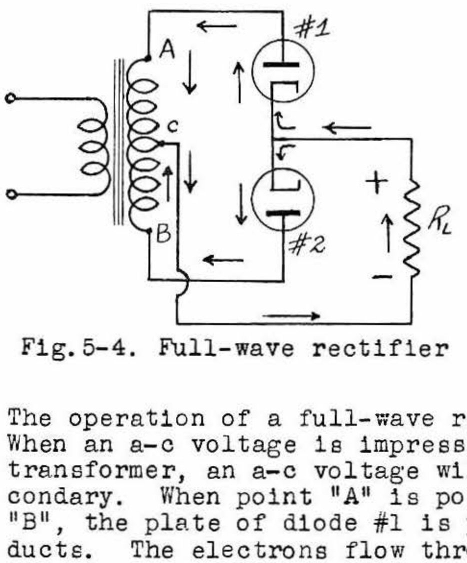
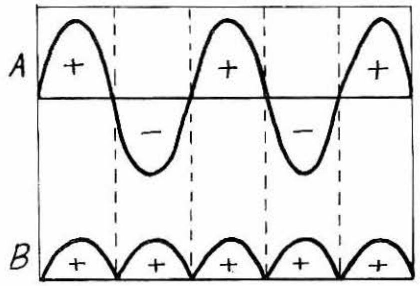


Fig. 5-4. Full-wave rectifier



A. input wave-form.
B. Output wave-form.

Fig. 5-5. Full-wave rectifier wave-forms.

The operation of a full-wave rectifier is as follows; When an a-c voltage is impressed across the primary of the transformer, an a-c voltage will be induced across the secondary. When point "A" is positive with respect to point "B", the plate of diode #1 is positive and the tube conducts. The electrons flow through the transformer, from A to C, out of C into the load resistance R_L, and back to the cathode of diode #1. During all this time, the plate of diode #2 is negative and does not conduct. On the next half of the a-c cycle, the bottom of the transformer, point "B", goes positive while the top, point "A", goes negative. The plate of diode #2 is now positive and the plate of diode #1 is negative; now, diode #2 conducts, and diode #1 does not. The electrons flow through the transformer from B to C, into the load resistor R_L, and back to the cathode of diode #2. Notice that the current flows through the load resistor in the same direction as it did previously. Notice, also, that the current flows through the resistor in the same direction during both the positive and negative halves of the input cycle. We have very definitely used both halves of the a-c input cycle, and have accomplished full-wave rectification. Fig. 5-5A shows the a-c across the transformer secondary. Fig. 5-5B shows the pulsating d-c flowing through the load. Compare this output with the rectified wave picture of fig. 5-2B

5-4. Voltage of Half-wave and Full-wave Rectifiers

In the half-wave rectifier, the entire transformer secondary delivers voltage to the tube. In the full-wave rectifier, only one half of the transformer secondary delivers voltage to a conducting tube at any one time. A full-wave rectifier delivers one half of the total transformer secondary voltage to the load as compared to a half-wave rectifier (provided the same transformer is used for both rectifiers).

For example; If the full transformer secondary voltage (A to B) is 400 volts (see figures 5-3 and 5-4), the full 400 volts will appear across the load of the half-wave rectifier; whereas only 200 volts will appear across the load in the full-wave rectifier.

5-5. Summary of Rectification

1) A single diode may be used as a half-wave rectifier for converting a-c to d-c. Only half of the input a-c wave is used, and the full voltage of the secondary of the power transformer is obtained as useful d-c output.
2) A double diode may be used as a full-wave rectifier. Both halves of the a-c wave are used, and the output voltage is only half of the total transformer secondary voltage.

5-6. Filtering

Fig. 5-6 illustrates the output voltage waveform of a battery. Notice that the voltage output remains constant. It does not vary with time. The output voltage of the battery is pure d-c. Remember, this is the type of voltage that the vacuum tubes of a radio require in order to operate properly. Now, look back to figs. 5-2 and 5-5 which show the output wave shapes of a half-wave and full-wave rectifier system. Compare these wave shapes to that of the battery output waveshape.

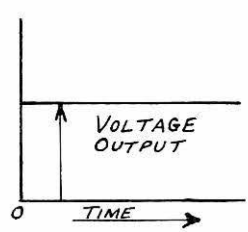


Fig. 5-6. Pure d-c

It is evident that the output of the rectifier systems is far from being pure d-c. The output is actually a pulsating d-c, or a d-c with a superimposed a-c wave called a ripple. If we could somehow remove, or filter out, the a-c component from the pulsating d-c, we would end up with a straight line or pure d-c. Since we are striving to get a pure d-c output from our rectifier systems, it is obvious that we are going to have to remove the ripple from the output waveform. The method of removing the ripple from the d-c output is known as FILTERING. The device which does the filtering is known as the FILTER.

The output waveform of the rectifier is actually a combination of d-c plus a ripple. The d-c and the ripple are called the COMPONENTS of the pulsating wave shape. The ripple is known as the a-c component.

5-7. Ripple Frequency

The ripple has a very definite fundamental frequency. Examination of fig. 5-2 should indicate to you that the ripple frequency for a half-wave rectifier is the same as the line frequency or 60 CYCLES.per second. Recall the definition of frequency which is the number of times a wave shape repeats itself in one second. Examination of fig. 5-5 should also indicate to you that the ripple frequency for a full-wave rectifier is twice the line frequency or 120 CYCLES PER SECOND.

5-8. The Filtering System

Filtering out the ripple component is accomplished by connecting a filter system to the output of the rectifier tube. A filter system is a circuit consisting of condensers and inductors. The condensers are known as filter condensers, and the inductors are known as filter chokes. A rectifier system in combination with a filter system which provides a source of pure d-c voltage is known as a POWER SUPPLY.

5-9. Condenser Input Filter

Fig. 5-7 shows a condenser input filter system connected to the output of a full-wave rectifier. The filter is enclosed within the dotted line. The filter is recognized as a condenser input because the filter component nearest to the rectifier is a condenser C_1. The complete filter is given the name π filter. π is a greek letter pronounced pi. The π filter is the one most commonly found in radio receivers today. Notice that the filaments of the rectifier tubes are heated by means of a low voltage

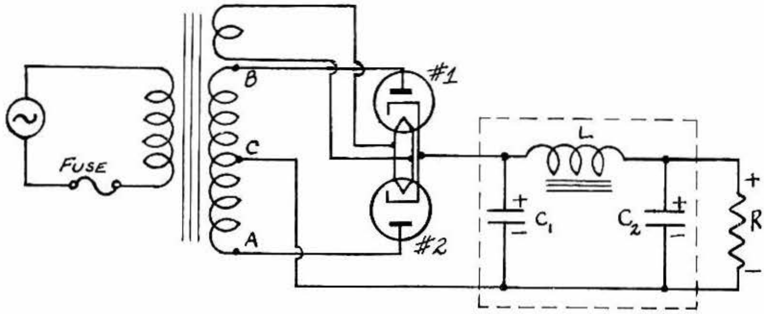


Fig. 5-7. Full-wave rectifier circuit.

(usually 5 or 6 volts) filament winding on the transformer secondary.

The filter operates to remove the a-c component in the following manner. Point B in fig. 5-8 illustrates the rectified wave shape at the input to the filter. Remember, that this wave is a combination of a d-c voltage and an a-c ripple component. Now, C_1 is a very high capacity condenser of about $20 \mu f$. A $20 \mu f$ condenser has a very low reactance to a 120 cps. ripple component. It will, therefore, short-circuit, or by-pass most of the ripple component. The d-c voltage, on the other hand, is not affected by the presence of condenser C_1. Remember that a condenser acts like an open-circuit to a d-c voltage. We say that a condenser blocks d-c. Point C shows the resulting wave shape after it is acted upon by condenser C_1. Notice that some of the ripple still remains superimposed on the d-c wave. The choke, L_1, has a very low d-c resistance. The d-c will, therefore, pass right through L_1 without any opposition. The choke will, however, generate a very strong counter e-m-f to oppose the a-c ripple. The result is that practically all of the remaining ripple will be prevented from passing through the choke. The wave shape appearing on the other side of the choke is shown at point D. The wave shape is practically pure d-c with just a very slight ripple remaining. Condenser C_2 acts in exactly the same manner as C_1. It will short circuit the remaining ripple leaving just the pure d-c as illustrated at point E. The pure d-c voltage can now be satisfactorily applied to the vacuum tubes for their proper operation. The d-c voltage

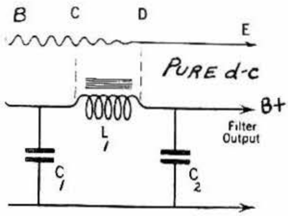


Fig. 5-8. filtering

which is applied to the vacuum tubes is known as the B+ VOLTAGE.

5-10. Voltage Regulation

The load current is the current that is drawn from the power supply by the vacuum tubes of the receiver or transmitter. If the load current varies, the B+ voltage will also vary. The B+ voltage is at a maximum when the load current is zero. As the load on the power supply increases, the B+ voltage drops. At full load current, the B+ voltage is at a minimum. A good power supply is one whose B+ voltage varies very little under varying load conditions. We say that such a power supply has good VOLTAGE REGULATION. A power supply with poor voltage regulation is one whose B+ voltage varies considerably with changes in load conditions.

The vacuum tubes in a radio receiver draw a constant load current from the power supply. A receiver power supply is therefore not required to have good voltage regulation characteristics. A transmitter, on the other hand, presents a varying load to the power supply. The transmitter power supply should therefore have good voltage regulation characteristics.

In order to improve the voltage regulation of a power supply, a resistor is often bridged across the output condenser C_2 as shown in fig. 5-7. This resistor is known as a BLEEDER RESISTOR. A bleeder resistor improves the voltage regulation by acting as a minimum load for the power supply. It also serves to discharge the filter condensers when the power is turned off.

The bleeder resistor may also be used as a voltage divider to supply different voltages for use in the receiver or transmitter.

5-11. Advantages of Full-wave Over Half-wave Rectifier

A filter system will do a better job of filtering for a full-wave rectifier system than for a half-wave rectifier. Condensers C_1 and C_2 in the π filter are more effective for filtering if their reactances are as low as possible. Recall the formula for capacitive reactance:

$$X_c = \frac{1}{2\pi f c}$$, as given in section 3-21

From this formula we see that the higher the frequency, the lower the condenser reactance. The ripple frequency for a full-wave rectifier of 120 cps. is twice that of a half-wave rectifier of 60 cps. The reactances of C_1 and C_2 will be one-half as much at 120 cps. as compared to what they would be at 60 cps. X_{c_1} and X_{c_2} will therefore more effectively by-pass a 120 cps. ripple than a 60 cps. ripple.

Also note that the counter e-m-f, or opposition of the choke will be twice as great at 120 cps. as compared to its opposition at 60 cps. This is because the reactance of an inductance is directly proportional to the frequency: $(X_L = 2\pi fL)$.

5-12. <u>The Bridge Connected, Full-wave Rectifier</u>

The main disadvantage of full-wave rectification as compared to half-wave rectification, is that only half of the transformer secondary voltage is converted into useful d-c voltage.

<u>For example:</u> If a center-tapped transformer has a full secondary voltage of 500 volts, the output voltage of a half-wave rectifier connected across the entire transformer would be 500 volts; whereas the output of a full-wave rectifier would be only 250 volts. We would like to be able to use the full-wave rectifier principle and still be able to convert the full transformer secondary voltage into useful d-c output. How then can we modify the full-wave rectifier circuit in fig. 5-7 to accomplish this? Fig. 5-9 shows how this can be done. The circuit is known

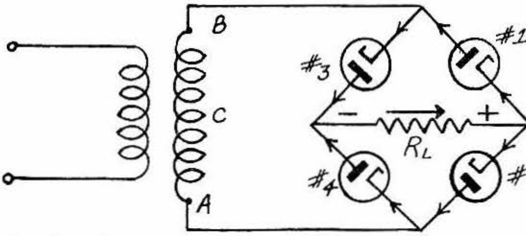


Fig. 5-9. Bridge connected full-wave rectifier.

as a BRIDGE CONNECTED FULL-WAVE RECTIFIER. The system uses four rectifier tubes. The plate of V_1 and the cathode of V_3 are connected to the top of the transformer secondary (point B). The plate of V_2 and the cathode of V_4 are connected to the bottom of the transformer secondary (point A) Notice that the center-tap connection, point C, is NOT used.

The bridge type of rectification operates as follows: When the top of the transformer secondary is positive, the plate of V_1 and the cathode of V_3 are positive; whereas, the plate of V_2 and the cathode of V_4 are negative. V_3 and V_2 will be cut off and V_1 and V_4 will conduct. The current flows from the bottom of the transformer, through V_4 , into the load resistor R_L through V_1 and back to the top of the transformer. Thus the full secondary voltage is impressed across the load resistor. When the polarity of the a-c voltage reverses, the bottom of the transformer now becomes positive. V_1 and V_4 , are now cut off, and V_3 and V_2 conduct. The current flows from the top of the transformer through V_3 , into the load resistor R_L , through V_2 and back to the bottom of the transformer. Again the full secondary voltage is impressed across the load. Notice that the current flows in the same direction through the load resistor during both halves of the a-c cycle.

A bridge type full-wave rectifier combines the advantages of a full-wave and a half-wave rectifier as indicated below:

1) the ripple frequency is 120 cps., and, therefore, is easy to filter out.

2) the d-c output voltage is the same as the output of a half-wave rectifier (assuming we use the same transformer).

a.- therefore, if a full-wave rectifier is converted to a bridge rectifier (using the same transformer), filter condensers of twice the working voltage rating would be required.

5-13. <u>The Electrolytic Condenser</u>

The average value of filter condenser for a receiver lies in the range between 4 and 50 μfd. At these high values of capacity, the ordinary paper or mica condenser would be too large for practical use. A special type of condenser called an ELECTROLYTIC CONDENSER, was designed to have a large value of capacity in a small size container. The electrolytic condenser depends on a chemical action to produce a very thin film of oxide which forms the dielectric.

All electrolytic condensers are polarized; that is, they have a positive and negative terminal. The positive terminal must always be connected to the positive d-c voltage point in the circuit, and the negative must similarly be connected to a negative d-c point. If these rules are not observed, the condenser will short-circuit under operation and will have to be replaced. The short-circuit may also damage the rectifier tube.

The principle disadvantage of the electrolytic condenser is its comparatively short life and its high leakage current. A condenser is said to have leakage when a small value of d-c current flows through its dielectric. In other words, the dielectric is not an absolutely perfect insulator. A good electrolytic condenser will have a low value of leakage current never exceeding 3 or 4 ma at its rated working voltage. Electrolytic condensers are used chiefly in power supplies where leakage current is not important.

The working voltage of an electrolytic condenser should never be exceeded under actual operation as the condenser may break down and short-circuit.

5-14. The filter Condenser in Transmitter Power Supply

The filter condensers in a transmitter power supply require a higher working voltage than those used in a receiver power supply. For example, a 1000volt transmitter power supply requires a filter condenser with a working voltage higher than 1000 volts. It is impractical to design an electrolytic condenser with a working voltage much above 600 volts. Therefore, the only condenser that can be used in the above example would have to be either of a paper, oil-filled, or pyranol dielectric type. Filter condensers used in transmitter power supplies are generally between 2 and 4μfd.

5-15. Filter Condensers Connected in Series

Filter condensers are often connected in series to double their total voltage rating. For example, fig.5-11

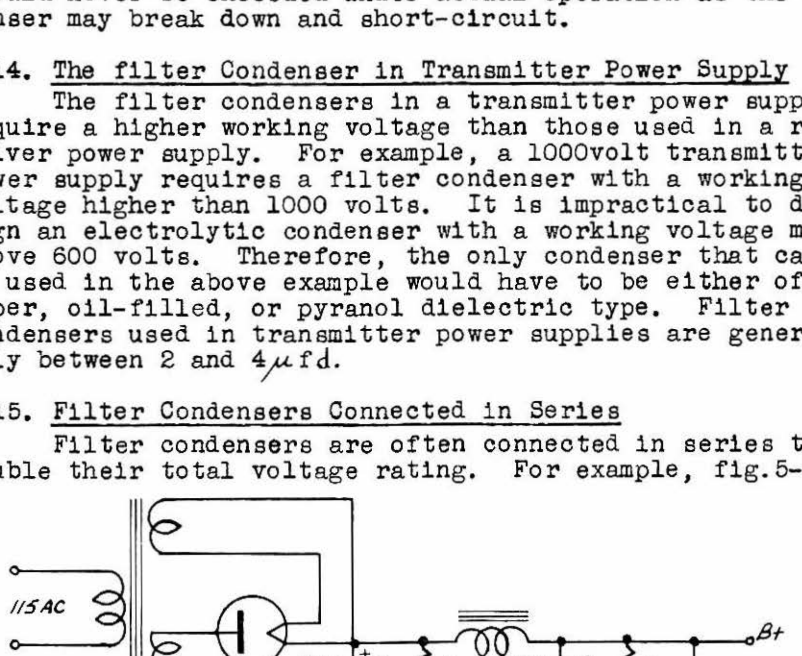


Fig.5-11. Half-wave rectifier

illustrates a half-wave power supply with two 400 volt filter condensers in series. The two condensers in series can stand a total voltage of 800 volts. Since the two condensers are in series, their total capacity is 2μfd (see lesson 3-18). The resistors which are connected across the condensers are called balancing or EQUALIZING resistors. Their purpose is to equalize the d-c voltage drop across the different condensers. If the equalizing resistors are removed, unequal voltage drops may result across the series condensers due to either unequal capacities or unequal leakage resistances. This may result in too great a voltage stress across one of the series condensers causing it to break down. For example, if the equalizing resistors are removed, condenser C_1 may have 500 volts across its plates, and therefore condenser C_2 will have 300 volts across its plates. Since 500 volts exceeds the working voltage of condenser C_1, it will break down. Inserting equalizing resistors into the circuit will insure that only 400 volts will build up across each condenser. The equalizing resistors also serve to discharge the filter condensers when power is removed from the set.

5-16. The Short-circuited Filter Condenser

If condenser C_1 of fig. 5-7 shorts, the rectifier tube will conduct excessive current. As a result, the safety fuse in series with the primary of the power transformer will blow. The fuse acts as a protective device for the components in the rectifier circuit against damage due to the large current flow. If there is no fuse, the plates of the vacuum type rectifier tube will become red hot due to the bombardment of the plate by the large electron flow. The tube will become damaged and will have to be replaced. The primary or secondary windings of the transformer may also burn out due to the excessive current.

If condenser C_2 in fig. 5-7 were to short, the rectifier tube will conduct very heavily through the choke coil. The choke coil may therefore burn out in addition to the above mentioned components.

If either C_1 or C_2 shorts, there obviously will be no B+ voltage, and the radio or transmitter will not function.

5-17. The Filter Choke

Filter chokes in a receiver power supply run from 10 to 30 henries. Chokes are designed to have as low a d-c resistance as possible. As a consequence, the d-c voltage drop across the choke will be low; and, therefore, the remaining B+ voltage will be as high as possible.

5-18. The Swinging Choke

The ordinary filter choke, just described, is suitable for receiver power supplies which supply a constant load current. Transmitter power supplies, however, supply a varying load current to the transmitter tubes. If an ordinary choke is used in a transmitter power supply, the B+ voltage will be found to vary as the load current varies. This results in poor voltage regulation which is highly undesirable. We must use a special choke which will operate to improve the voltage regulation of the transmitter power supply. This special choke is called a SWINGING CHOKE. A swinging choke has a very small air gap cut into the core material. The air gap causes the inductance of the choke to vary with the load current. As the load current increases, the inductance decreases; and, as the load current decreases, the inductance increases. This variable inductance characteristic improves the voltage regulation of the power supply by keeping the B+ voltage constant. Swinging chokes are used only where large load current changes take place - such as in transmitters.

5-19. The Choke Input Filter

Fig. 5-12A illustrates a filter in series with an additional choke. Since the choke is now the first filter

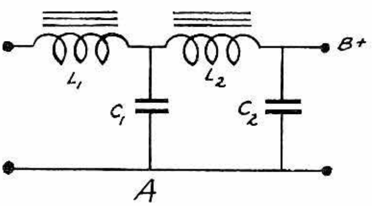


Fig. 5-12A. Choke input

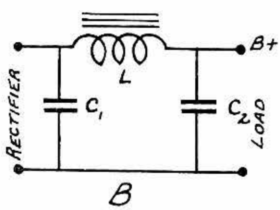


Fig. 5-12B. Condenser input

component connected to the rectifier tube, the filter is called a CHOKE INPUT FILTER.

A choke input filter (fig. 5-12A) has the following characteristics as compared to a condenser input filter (fig. 5-12B)

1) The output voltage is less than that of the condenser input filter system.

2) The regulation is much improved over condenser input.

a. For well-regulated transmitter power supplies, the input filter choke, L_1, should be a swinging choke. The second choke would be a regular type choke.

5-20. Summary of Filtering Action

1) Filtering smooths out the ripple in a rectified d-c wave.

2) A condenser input filter is used when a high output voltage is desired, and where regulation is not too important. Receiver power supplies almost always use condenser input filters.

3) A choke input filter is used where regulation is of first importance - as in a transmitter power supply.

4) Improvement in regulation can be obtained by connecting a resistor across the filter output terminals. (see fig.5-7) This resistor is known as a bleeder because it discharges, or "bleeds" the charged filter condensers after the power is shut off. The bleeder may also be used as a voltage divider to obtain various voltages for different applications in the receiver.

5) The output ripple frequency of a half-wave system is equal to the line frequency of 60 cps. The ripple frequency for the full-wave rectifier is double the line frequency, or 120 cps. For equal filtering action, the filter condensers in a half-wave power supply should have a higher capacity than the filter condensers in full-wave power supply.

5-21. <u>The Mercury Vapor Rectifier</u>

In previous discussions, (lesson 4, paragraph 6) the rectifier tube was considered a short circuit when conducting. Actually this is not the case. When a high vacuum rectifier tube conducts, it has a fairly constant internal resistance of 100 ohms or so. This internal resistance remains constant; it does not change with fluctuations in load current. The voltage drop across the tube, however, does change. As the load current increases, the voltage drop across the tube increases. As the load current decreases, the voltage drop across the tube decreases. This varying tube voltage drop will in turn cause the B+ voltage to vary. The result is that a high vacuum rectifier system under varying load conditions will have poor regulation. It is, therefore, desirable to use a rectifier tube with a constant voltage drop, regardless of fluctuations in load current. A MERCURY VAPOR RECTIFIER TUBE fulfills this requirement. It differs from a high vacuum rectifier tube in that it has mercury gas enclosed in the glass envelope.

The theory of conduction in a mercury vapor tube is as follows: The space between the cathode and plate is filled with mercury vapor atoms. An electron traveling at high speed from the cathode to the positive plate will hit a mercury atom with great force. The tremendous impact will cause an electron to be knocked out of the structure of the mercury atom. This electron will be attracted to the positive plate just as if it had been emitted by the cathode. The result is that for every emitted electron that crashes into a mercury atom, two electrons will end up at the plate. As the load current increases, the cathode current of the mercury vapor tube increases. The increased cathode current will produce many more electrons by atom bombardment of the mercury gas. The resulting large increase in the number of electrons flowing to the plate causes the internal resistance of the tube to drop. We say that the CONDUCTIVITY of the tube has increased. The final result is, that as the load current increases, the internal resistance of the tube decreases. The product of an increasing current and a decreasing resistance is a constant voltage drop across the tube. This will produce a constant B+ voltage regardless of load current changes. The voltage drop across most mercury vapor tubes is a constant 15 volts. This constant voltage characteristic of the mercury vapor rectifier tube greatly improves the regulation of the rectifier system.

When a mercury atom loses an electron by bombardment it becomes IONIZED. The atom is now called a POSITIVE ION. IONIZATION is caused by the bombardment of mercury atoms by high velocity electrons. Ionization is accompanied by a characteristic bright blue glow of the mercury vapor gas.

The filaments of a mercury vapor tube must be heated for at least one minute before the plate voltage is turned on. This allows any liquid mercury that may have condensed on the walls and on the filaments to vaporize. If the filament and plate voltages are turned on at the same time, the heavy positive mercury ions will bombard and possibly ruin the cathode. If the filament is turned on before the plate voltage, there will be a sufficient number of electrons to neutralize the ions, and eliminate the possibility of damage to the cathode by ion bombardment.

It is important to maintain proper filament operating temperature. A high filament voltage increases ionization and reduces tube life, while a low voltage produces overloading. The mercury vapor tube is used in transmitter power supplies because of its high current load capabilities and excellent voltage regulation.

5-22. Inverse Peak Voltage

A rectifier does not conduct during one-half of the input a-c cycle. The plate is then negative with respect to the cathode. During this non-conducting time there will be a high negative voltage on the plate. Fig.5-13 illustrates a half-wave condenser input rectifier during the half cycle when it is not conducting. The voltage across the transformer secondary is 300 volts peak, and the input condenser is charged up to 300 volts. Notice that the two voltages are in series and in phase across the rectifier tube. The maximum voltage between plate and cathode during non-conduction is 600 volts. This voltage is called the INVERSE PEAK VOLTAGE. If this inverse voltage exceeds the rating given by the manufacturer, there is a great danger of an arc-back occuring between the two elements. A tube can be ruined in this fashion. High vacuum tubes have a higher peak inverse voltage rating than mercury vapor types. This is an advantage which allows them to be used at higher relative voltages as compared to the mercury vapor type. Due to the low peak inverse voltage rating for mercury vapor tubes, choke input filter systems are necessary. The input choke clips the peak of the a-c wave and thus prevents the inverse peak voltage from rising too high. The input choke also limits the initial current surge, thus preventing damage to the filaments.

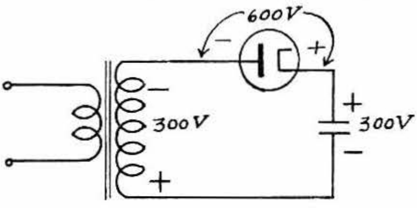


Fig. 5-13. Inverse-peak voltage

5-23. Radio Frequency Interference

Gaseous rectifier tubes tend to produce radio frequency interference. This radio frequency interference is called HASH. Hash can be minimized by enclosing the rectifier tube in a grounded shield can, and connecting a radio frequency choke in series with the rectifier plate lead at the tube socket. Hash condensers can also be connected across the transformer secondary. Their purpose is to bypass the r-f interference to ground. (See fig. 5-14)

5-24. Typical Mercury Vapor Rectifier Power Supply

Fig. 5-14 illustrates a full-wave, single-phase mercury vapor rectifier power supply with a choke input filter for best regulation. The filter components are given values suitable for either amateur radio telephone or radio telegraph operation. Notice that there are separate on-off switches for the filament and plate circuits. The filament on-off switch is always switched on first to allow the filaments a chance to warm up. C_1 and C_2 are the hash suppressor condensers. The bleeder resistor is tapped to provide two output voltages. The input choke is a swinging choke for increased voltage regulation. L_1 and L_2 are the hash suppressor chokes.

5-25. Comparison of Mercury Vapor Tube and High Vacuum Rectifier Tube

Below is a comparison of the merits of the mercury vapor and high vacuum rectifiers.

High Vacuum

1. Poor regulation
2. Filament and plate voltage can be turned on at same time.
3. A high peak inverse voltage rating.

Mercury Vapor

1. Excellent regulation
2. Filaments must be turned on at least 60 seconds before the plate voltage.
3. A lower peak inverse voltage rating.

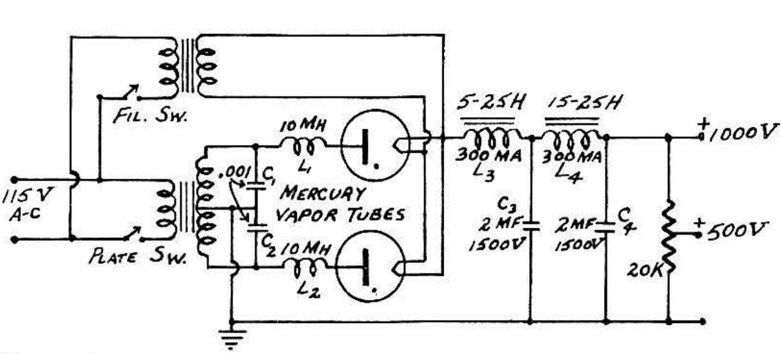


Fig. 5-14. High voltage power supply for transmitter.

PRACTICE QUESTIONS - LESSON 5

(For answers, refer to back of Study Guide Section II)

5-1.* If the high voltage secondary of a transformer was changed from a full-wave, center-tapped connection to a bridge rectifier connection, the output voltage rating would;

a. remain the same
b. be doubled
c. be halved
d. be tripled

5-2.* A swinging choke;

a. is used in a power supply which supplies a fixed load.
b. is used mostly in receiver power supplies
c. tends to keep the output voltage constant with varying load
d. has a high capacity

5-3.* The ripple frequency of a full-wave rectifier system is;

a. the same as that of a half-wave rectifier system
b. is twice that of a half-wave rectifier system
c. one-half that of a half-wave rectifier system
d. 60 cycles per second

5-4.* A mercury vapor rectifier;

a. has a constant internal voltage drop
b. has a very high internal voltage drop
c. has a higher internal voltage drop than a high vacuum rectifier
d. has no internal voltage drop

5-5.* A mercury vapor rectifier has a;

a. constant current rating
b. high inverse peak voltage rating
c. high internal voltage drop
d. relatively high current rating

5-6.* A mercury vapor rectifier;

a. is always connected to a condenser input filter
b. does not require a filter
c. should be connected to a choke input filter
d. none of the above

5-7.* The purpose of a filter in a plate power supply system is;

a. to provide a-c voltage
b. smooth out the a-c ripple component in the output
c. limit the peak inverse voltage
d. filter out the d-c component

5-8.* A shorted filter condenser in an unfused power supply would;

a. increase the d-c voltage
b. half the ripple frequency
c. increase the output current
d. probably burn out the rectifier tube

5-9.* A bleeder resistor;

a. improves the voltage regulation
b. should be replaced
c. is very critical
d. improves the ripple frequency

5-10.* If the primary of a 60 cycle power transformer were connected to d-c mains;

a. the output would be pure d-c
b. the primary winding would most probably burn out
c. the d-c output would decrease
d. the ripple frequency would increase

5-11.* A choke input filter as compared to a condenser input filter will;

a. provide a higher output voltage
b. cause a higher ripple frequency
c. limit the d-c voltage
d. provide the best voltage regulation

5-12.* The purpose of equalizing resistors is to;

a. improve the voltage regulation
b. equalize the d-c drop across the different filter condensers connected in series.
c. limit the ripple voltage
d. prevent an arc-back

5-13.* In a mercury vapor rectifier system;

a. the filament and plate voltages may be applied simultaneously
b. the plate voltage must always be turned on first

c. the filament voltage must always be turned on first
d. the filament voltage is turned on 10 seconds after the plate voltage

5-14.* A filter choke with a low d-c resistance is desirable in a power supply because;

a. the ripple frequency is decreased
b. the voltage regulation is made worse
c. the output voltage is increased
d. the peak inverse voltage is increased

5-15.* The visible operating characteristic of mercury vapor rectifiers is;

a. a bluish-green glow
b. red plates
c. green cathode
d. hot anode

5-16.* Draw a schematic diagram of a full-wave, single-phase power supply using a center-tapped high voltage secondary with a filter circuit for best regulation, showing a bleeder resistor providing two different output voltages and a method of suppressing "hash" interference from the mercury vapor rectifier tubes. Give the names of the component parts and approximate values of filter components suitable for amateur operation.

5-17.* Draw a simple schematic diagram of a half-wave rectifier with a filter which will furnish pure d-c at highest voltage output, showing filter condensers of unequal capacitance connected in series, with provision for equalizing the d-c drop across the different condensers.

SECTION II LESSON 6

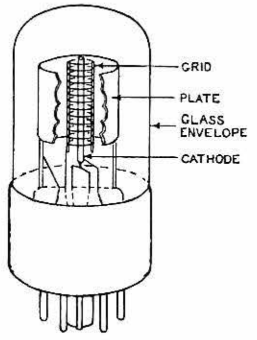
TRIODE, TETRODE, PENTODE

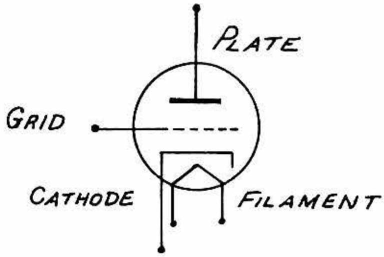
6-1. Introduction

In lesson 3, we studied the construction and purpose of a diode vacuum tube. We studied the action of the diode vacuum tube as a rectifier in changing alternating current to direct current. We will now go into the details of the operation of the vacuum tube when used as an amplifier. An amplifier makes larger, or amplifies, the small voltages that are present in the radio receiver. The vacuum tubes that are used for amplification purposes are three, four, and five element tubes. The three element tube is called a TRIODE; four and five element tubes are called TETRODES AND PENTODES respectively. We shall now proceed to study each one of these tubes in detail.

6-2. The Triode

The TRIODE is different from the diode in that it contains one more element. This new element is called the CONTROL GRID. The control grid is a thin piece of wire wound in the form of a spiral mesh which surrounds the cathode. Electrons emitted by the cathode can pass easily through the grid structure and onto the plate. Fig.6-1A shows the actual physical arrangement of the cathode, grid, and plate structure in a typical triode. Notice that the grid is placed much closer to the cathode than to the plate.





B. Schematic symbol

A. Cut away section of a triode.

Fig.6-1. The triode.

Fig.6-1B illustrates the schematic representation of the triode. The grid is shown by means of a dotted line between the cathode and plate.

6-3. <u>Operation of a triode</u>

Fig.6-2 shows a triode circuit which is used to study the effect of grid voltage variations upon the plate current. The symbol for the plate voltage is E_p. The plate voltage is measured between the plate and cathode. The symbol for plate current is I_p. Plate current is measured by placing an ammeter in series with the plate circuit. E_g is the symbol for control grid voltage measured between the control grid and the cathode. All tube voltage measurements

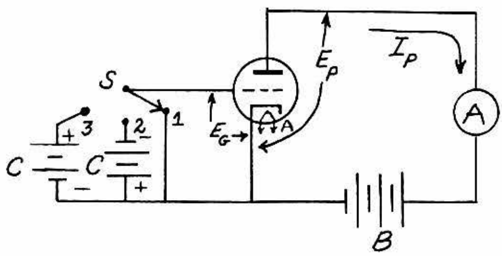


Fig.6-2. Effect of grid voltage on plate current flow.

are taken with the cathode as a reference point.

Refer to the letters A,B, and C beneath the battery symbols in the diagram (fig.6-2). These letters indicate the voltages applied to the different elements in the tube. The "A" voltage is applied to the heater, or filament. The "B" voltage is applied to the plate; the "C" voltage is applied to the grid. "S" is a three-position switch in the control grid circuit. With the switch in position #1, the control grid is connected directly to the cathode. With the switch in position #2, the control grid is connected to the negative terminal of a battery. With the switch in position #3, the control grid is connected to the positive terminal of a battery. Let us see how changes in the control grid voltage affect the operation of the triode. With the switch in position #1, and the plate positive, electrons will flow from the cathode through the grid structure to the plate. Since the grid is connected directly to the cathode, it will not affect the flow of plate current. Therefore, all the emitted electrons will pass through the grid and onto the plate.

If the switch is thrown to position #2, the grid becomes negative with respect to the cathode. The negatively charged grid will repel many of the negatively charged electrons back into the area surrounding the cathode.

Hence, the number of electrons which are able to reach the plate is reduced. This effect is illustrated in fig.6-3.

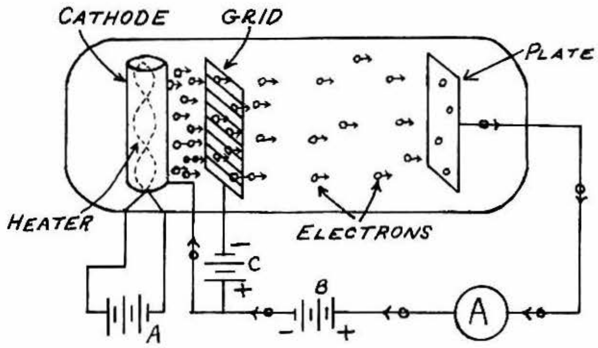


Fig.6-3. Effect of negative grid on plate current flow.

The milliammeter in the plate circuit will show a reduction in plate current when the grid voltage is changed from a zero voltage to a negative voltage.

If the switch is thrown to position #3, the grid becomes positive with respect to the cathode. The plate current will increase since the positive control grid attracts the negative electrons and allows many more electrons to be drawn to the plate than it did in switch position #1 and #2. A positive grid actually pulls electrons from the cathode to the plate. Thus, we see how the control grid acts as a control valve for plate current flow. As we vary the voltage on the grid, the plate current varies. The control grid, therefore, controls the flow of electrons to the plate.

6-4. <u>Plate Current - Grid Voltage Curve</u>

In order to further study the relationship between the plate current and the grid voltage, let us take measurements to see exactly how the plate current varies with changes in the grid voltage. Fig.6-4 illustrates a schematic of a triode whose grid voltage can be varied by means of a potentiometer placed across the "C" battery. Let us plot on a graph the milliammeter plate current readings for different values of grid voltage. Fig.6-5 illustrates the resulting graph. The horizontal line represents the grid voltage in volts, and the vertical line represents the plate current in milliamperes. The plate current measurements are taken with the plate voltage kept constant at 150 volts. If we draw a line through the points that represent the various plate current readings, we obtain a curve known as the $E_g - I_p$ characteristic curve. Notice that if the grid is made sufficiently negative (minus 10 volts), the plate current drops to zero. At this point,

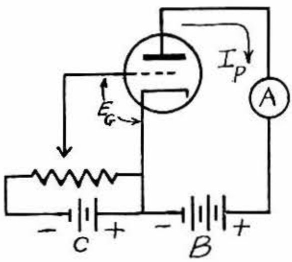


Fig. 6-4. Obtaining data for $E_G - I_P$ curve.

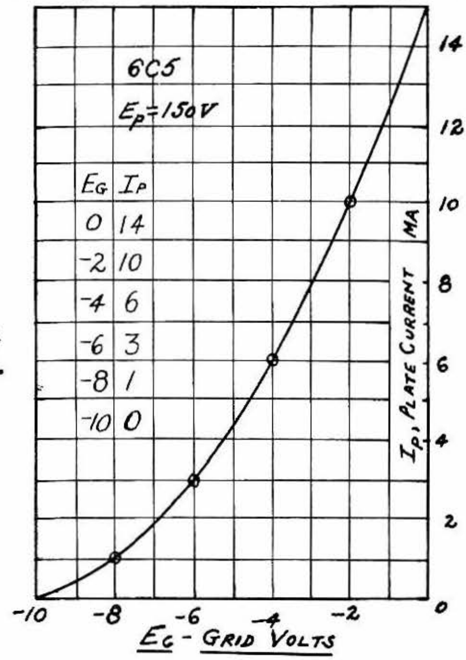


Fig. 6-5. Grid voltage, plate current curve.

the highly negative grid repels all electrons back to the cathode area. As the grid voltage is made less negative, the electrons begin to flow to the plate. If we continue to make the grid voltage less negative (more positive), the plate current will continue to increase. When we make the grid voltage positive, the plate current keeps on increasing. As the grid voltage is made more positive, the plate current continues to rise. A point is soon reached where the plate current can no longer increase regardless of further increases in positive grid voltage. This point is called the SATURATION POINT. The voltage that is applied to the grid is called GRID BIAS VOLTAGE, or simply BIAS. The BIAS that cuts the plate current to zero is called the CUT-OFF BIAS. In fig. 6-5, the cut-off bias is -10 volts. Whenever the voltage on the grid prevents current from flowing, we say that we have a BLOCKED GRID.

The curve of fig. 6-5 was obtained with the plate voltage held constant. Suppose we take data of grid voltage and plate current readings for different values of plate voltage. The result of plotting all these points is a series of curves called a FAMILY OF CURVES. This is illustrated in fig.6-6. Each curve is plotted with the grid voltage varied while the plate voltage is kept constant. Notice that for a given grid voltage, the plate current increases with increase in plate voltage. This is to be expected since an increase in plate voltage should result in an increase in plate current.

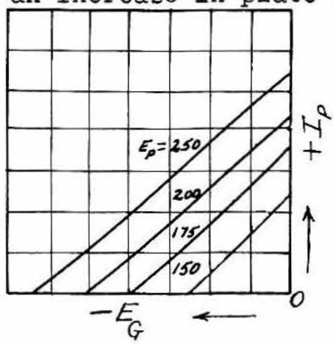


Fig.6-6. Family of $E_G - I_P$ curves.

6-5. The $E_p - I_p$ Characteristic Curve for the Triode

In fig.6-5, the plate voltage was kept constant and plate current readings were plotted as we varied the grid voltage. Another popular characteristic curve is the E_p - I_p curves of fig.6-7. Here, the grid voltage is kept constant and plate current readings are plotted as we vary the plate voltage. Notice that the plate current rises as the plate voltage increases. The $E_p - I_p$ curves are the ones that are usually illustrated in tube manuals.

6-6. The Triode as an Amplifier

In paragraph 6-1, it was stated that multi-element tubes are used to amplify weak signals. We will now proceed to study in exactly what manner a triode amplifies a signal voltage that is applied to its grid.

The control grid is physically much closer to the cathode than the plate is. The grid voltage will therefore have a greater effect on the plate current than will the plate voltage. A small change in grid voltage will cause a large change in plate current; whereas, a small change in plate voltage causes a small change in current. Let us see, graphically, how a changing voltage such as an a-c signal on the grid of a triode causes the

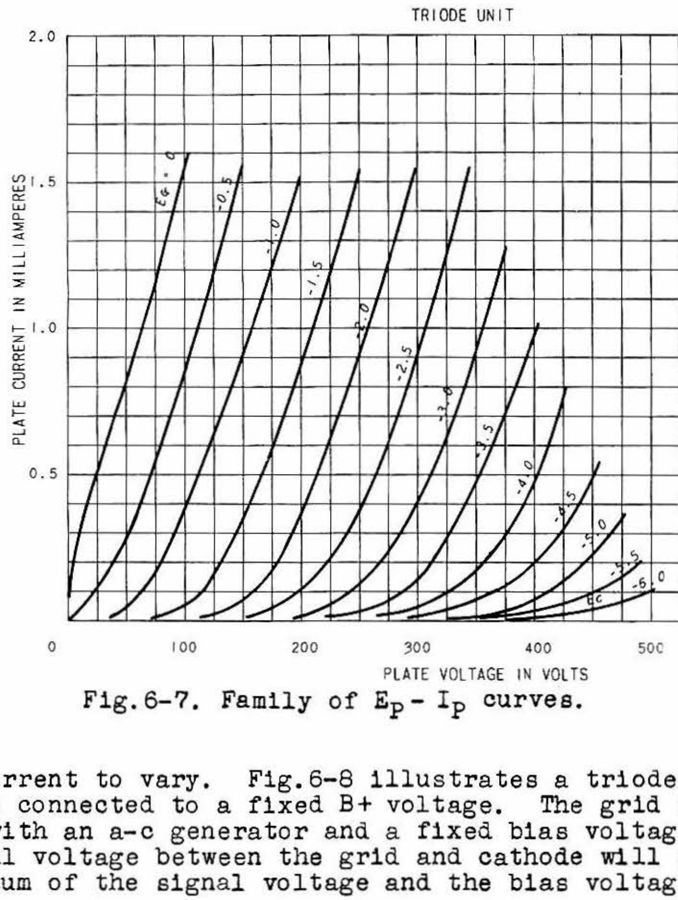


Fig. 6-7. Family of $E_P - I_P$ curves.

plate current to vary. Fig. 6-8 illustrates a triode whose plate is connected to a fixed B+ voltage. The grid is in series with an a-c generator and a fixed bias voltage. The total voltage between the grid and cathode will always be the sum of the signal voltage and the bias voltage.

Let us see what happens on the positive half-cycle of the a-c signal. Since the signal voltage of + 1 volt and the -3 volts of bias are in series, the resultant voltage between grid and cathode will be -2 volts. (the sum of + 1 and -3 = -2) On the negative half of the a-c cycle, -4 volts will be applied between the grid and cathode of the tube. (the sum of -1 volt and -3 volts = -4 volts) From the $I_p - E_g$ curve of fig. 6-9, it can be seen that when there is no a-c signal applied to the grid, the plate current will be fixed at 8 milliamperes because of the three volts of bias supplied by the bias battery. The value of 8 milliamperes is obtained from the curve by working vertically from the -3 volt point on the grid voltage line until the curve is reached. From this point we go straight across until we hit the vertical plate current line. In this case we reach the vertical line at 8 milliamperes. On the peak of the positive half of the a-c signal,(when there are -2 volts on the grid), the plate current rises to 10 milliamperes. On the negative half of the incoming signal,(when there are -4 volts on the grid), the plate current decreases to 6 milliamperes. Note that the waveform of the plate current variation is an exact reproduction of the a-c signal applied to the grid of the tube. A 2 milliampere variation is caused in the plate current by applying a one volt signal to the grid.

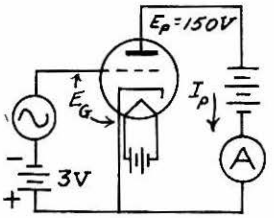


Fig.6-8. Triode with an a-c signal on the grid.

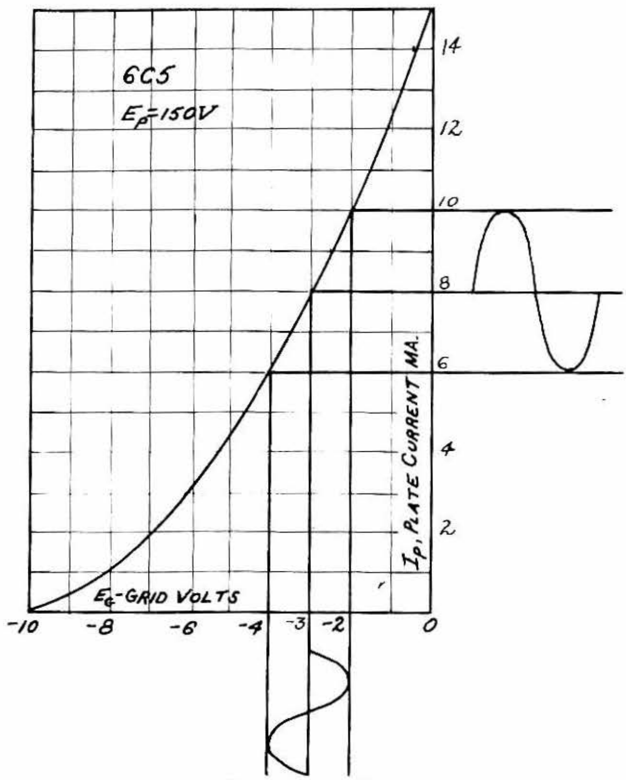


Fig.6-9. Plate current wave-form resulting from an a-c grid voltage.

Thus far we have converted grid voltage variations into plate current variations. In order to make use of these plate current variations, some device must be placed in the plate circuit to act as a load across which the varying plate current will develop a varying voltage. The plate load may be a resistor, an inductor, or a tuned circuit. Fig.6-10 shows a resistor used as a plate load in a triode amplifier circuit. Except for the plate load resistor, this circuit is the same as that in fig.6-8. As we explained before, the 1 volt signal will cause a total plate

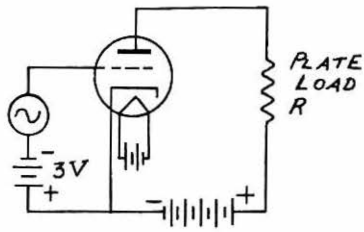


Fig.6-10. Triode using a resistor as a plate load.

current variation of 4 milliamperes (from 6 to 10 ma.). This 4 ma variation will cause a total voltage variation of 40 volts to be produced across the 10,000 ohm resistor. This can easily be proven by Ohm's law. One form of Ohm's law states that:

$$E = I \times R$$

$$E = .004 \times 10{,}000$$

$$E = \underline{\underline{40\ V}}$$

Thus it can be seen that a 2 volt a-c signal (2 volts peak to peak) can produce a 40 volt variation in the plate circuit. In other words, the original signal or variation that was applied to the grid has been AMPLIFIED twenty times. $\left(\frac{40}{2} = 20\right)$

From fig.6-9 it can be seen that the voltage variation in the plate circuit is not only an amplified, but also a faithful reproduction of the grid signal. The circuit in fig.6-10 is therefore the basis for all amplification circuits in radio and television.

6-7. Vacuum Tube Characteristics

Since many different types of vacuum tubes are used in radio and television circuits, it is important to classify tubes according to the performance which may be expected of them. The three most important factors by which tubes are classified are the AMPLIFICATION FACTOR, the TRANSCONDUCTANCE, and the PLATE RESISTANCE.

1. Amplification Factor - The AMPLIFICATION FACTOR of a tube is the maximum voltage amplification which can be

expected from the tube. It is a theoretical value never reached in actual circuit use. Stated mathematically, it is the ratio of the change in plate voltage to the change in grid voltage; both voltages to cause the same change in plate current. For example, Let us assume that a certain tube is operating with a plate voltage of 250 volts, a grid voltage of -10 volts, and a plate current of 18 ma. If we should change the plate voltage to 280 volts and leave the grid voltage constant, the plate current would go up to 23 ma. This means that a plate voltage change of 30 volts results in a plate current change of 5 ma. Suppose that a grid voltage change from -10 volts to -13 volts returns the plate current from 23 ma back to 18 ma. We can say that a grid voltage change of 3 volts has the same effect on the plate current as a plate voltage change of 30 volts. The amplification factor would therefore be the plate voltage change (30 volts) divided by the grid voltage change (3 volts) or 10.

The amplification factor is commonly designated by the Greek letter μ. The formula for the μ, or mu, of a tube is:

$$\text{6-1) Amplification factor } (\mu) = \frac{\Delta E_p}{\Delta E_g}$$

The terms ΔE_p and ΔE_g mean a small change in plate voltage and a small change in grid voltage respectively.

2. Transconductance - The TRANSCONDUCTANCE, or MUTUAL CONDUCTANCE, of a tube is what is known as the figure of merit of the tube. It tells us how much of a plate current variation we can get for a certain amount of grid voltage variation. Transconductance is defined as the ratio of a small change in plate current to the change in grid voltage that produced it. The formula for transconductance is:

$$\text{6-2) Transconductance } (G_m) = \frac{\Delta I_p}{\Delta E_g}$$

where: ΔI_p is a change in plate current
ΔE_g is the change in grid voltage that caused ΔI_p.

G_m is the symbol for transconductance

The basic unit of the transconductance of a tube is the MHO. The mho was previously mentioned in lesson 1, paragraph 7 as the unit of conductance. Since the transconductance of a tube is equal to current divided by voltage (see formula 6-2) which is the opposite or reciprocal of resistance, then the mho is the unit to be used for the G_m of a tube. The transconductance is the most desirable tube factor in the choice of a vacuum tube to be used as a voltage amplifier.

3. Plate Resistance - The PLATE RESISTANCE of a tube is the internal resistance between the cathode and plate to the flow of varying plate current. Mathematically speaking, it is the ratio of a small change in plate voltage to the change in plate current that this voltage change produces. Expressed as an equation:

$$6\text{-}3) \quad \text{Plate Resistance } (R_p) = \frac{\Delta E_p}{\Delta I_p}$$

A tube may be considered to be a variable resistor in its operation as an amplifier. If the grid is made positive, the current flow from cathode to plate is increased. This means that the resistance from the cathode to the plate has gone down. On the other hand, if the grid is made more negative, the plate current will go down. This means, of course, that the plate resistance has gone up.

6-8. Efficiency of Vacuum Tubes

We often use the term EFFICIENCY when we speak about the performance of a certain device or machine. Efficiency refers to how much power can be gotten out of a device as compared to how much power is put into it. For instance, if 100 watts of electrical power are used up in a light bulb and only 2 watts of equivalent light power are produced, we can say that the electric bulb is a low efficiency device. The bulb generates into light only 2% of the power that is put into it. (the other 98 watts are dissipated inside the bulb in the form of heat.) On the other hand, an electric motor may draw 100 watts of electric power and produce 75 watts of equivalent mechanical power. We can say that the motor is a high efficiency device. The motor produces, in the form of useful work, 75% of the power put into it.

In radio, we classify vacuum tubes according to their efficiency in delivering useful power to a load.

The plate efficiency of a vacuum tube is defined as the ratio of the a-c plate power output to the d-c plate power input. It is given in a percentage, and its mathematical formula is:

$$6\text{-}4) \quad \text{Plate Efficiency} = \frac{\text{a-c output power}}{\text{d-c input power}} \times 100$$

For example, if the a-c power output of a vacuum tube is 150 watts, and the d-c power input is 200 watts, the efficiency is 150 divided by 200 or 75%.

The a-c power output of a tube is the power in watts that the tube delivers to its load. The load may be the loudspeaker or the grid of a following tube. The d-c power input, on the other hand, is the product of the d-c plate voltage applied to the stage and the d-c plate current. For instance, if the plate voltage is 750 volts, and the plate current is 150 milliamperes, then the power input is 112.5 watts. The power input is derived in the following manner:

$$\text{Power input in watts} = E_p \times I_p$$
$$P \text{ input} = 750 \times .15$$
$$P = \underline{\underline{112.5 \text{ watts}}}$$

Note that the 150 milliamperes were changed to amperes by moving the decimal three places to the left.

6-9. Maximum Plate Dissipation

In the above problem concerning the plate efficiency of a vacuum tube, it is apparent that only a certain percentage of the applied power (input power) appears as output power. What happened to the remainder of the input power? The remainder of the input power is wasted in the form of heat within the tube, exactly as in a light bulb. Remember that the tube represents a resistance between the cathode and plate. Power loss applies to the resistance of a tube as well as any ordinary resistor. The plate current in flowing through the plate resistance dissipates heat. The power dissipated on the plate in the form of heat is equal to $I_p^2 R_p$. Where I_p is the plate current and R_p is the plate resistance.

There is a limit to the amount of power in watts that a tube can dissipate in the form of heat in its plate without damaging the tube. This limit is known as the MAXIMUM PLATE DISSIPATION. This can be found in any tube manual for a particular tube.

6-10. Limitations of a Triode

In the early days of radio, triodes were used exclusively in radio receivers and transmitters. Later on the tetrodes and pentodes made their appearance and replaced the triode in many applications. The reason for this change was that the triode had certain characteristics which limited its application in radio work. Before we discuss the tetrode and pentode, we shall first examine in detail the limitations of the triode.

In lesson 3, paragraph 13, we learned that two conducting surfaces separated by an insulator form a condenser. Since the plate and grid of a tube are two conducting surfaces separated by a vacuum dielectric, there exists a capacitance between the plate and grid. By the same reasoning, a capacitor is formed between the grid and cathode, and between the plate and cathode. These internal tube capacitances are called INTERELECTRODE CAPACITANCES. The interelectrode capacitance between the plate and the grid exerts a detrimental effect upon the action of a triode amplifier. This capacitance gives rise to a condition known as OSCILLATION which is extremely undesirable. Oscillations come about in the following manner: A varying grid voltage causes a varying plate voltage which is then passed on to the next stage. However, because of the undesirable grid to plate capacitance, the voltage variations from the plate circuit are FED BACK to the grid circuit and are reamplified until oscillations or howling takes place. This is especially true at radio frequencies. Later on, we will discuss this condition of oscillation in greater detail.

Another defect of the triode results from the fact that the plate current depends not only upon the grid voltage but also upon the plate voltage. Because of this, the gain of a triode, used as an amplifier, is kept down. For example, a positive grid signal will cause the plate current to go up; the increasing I_p will increase the voltage across the load resistor. The voltage across the load resistor and the voltage between plate and cathode are in series and therefore must always add up to the fixed B+ voltage value. If the voltage across the load resistor goes up, the plate voltage must go down. The decreased plate voltage,in turn, will cause the plate current to decrease somewhat, counteracting the effect of the signal on the plate current. Thus the amplification is kept down. The way to circumvent this defect would be to make the plate current independent of the plate voltage. Variations in plate voltage would then have no effect on the plate current. This is achieved in the tetrode and pentode.

6-11. The Tetrode

In an effort to reduce the grid-plate capacitance within the tube, a fourth element was added to the conventional triode. This fourth element is called a SCREEN GRID; the screen grid is placed between the control grid and the plate. The top view of a tetrode is shown in Fig. 6-11A; the schematic symbol of a tetrode is shown in Fig. 6-11B. The screen is wound in the form of a spiral grid, similar to the control grid. The screen grid shields the

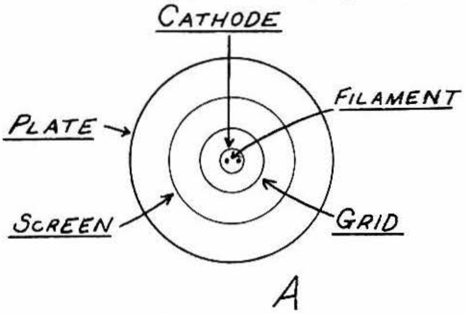


Fig. 6-11A. Top view of a tetrode.

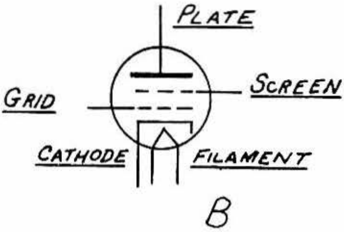


Fig. 6-11B. Schematic symbol for a tetrode.

control grid from the plate and thereby reduces the grid-plate capacitance.

In order for the screen grid to act as an effective shield, it must be grounded for a-c. But, as we shall soon see, the screen grid must at the same time be kept at a high positive d-c potential. Refer to the schematic circuit of a tetrode in fig. 6-12. The screen is grounded for a-c through condenser C. Thus, we can use a tetrode as an r-f amplifier without incurring oscillations.

A typical screen grid, or tetrode (four elements) tube connected in a circuit is shown in fig. 6-12. The screen

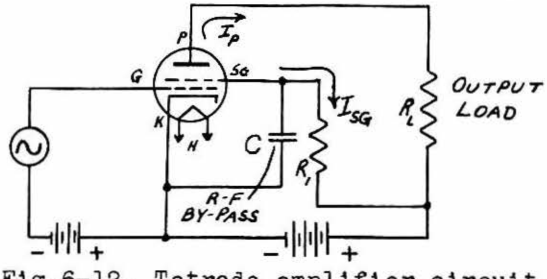


Fig. 6-12. Tetrode amplifier circuit.

grid is operated at a d-c potential somewhat lower than that of the plate. The positive screen grid acts like the plate of a triode in attracting electrons emitted by the cathode. A few of the electrons will hit the screen grid resulting in screen current flow. The screen current flows through resistor R_1. R_1 is called the screen dropping resistor. The screen current in flowing through R_1 causes a voltage drop across it. The screen grid voltage is therefore the B+ voltage minus the voltage drop across the resistor R_1. The screen voltage is measured from the screen grid to the cathode.

Since the screen grid is similar to the control grid in construction, most of the electrons will pass through the screen and reach the plate. Since the plate is a solid element and more positive than the screen grid, it will receive most of the electrons emitted by the cathode in the form of plate current.

6-12. Increased Amplification of Tetrode

Because the screen grid is closer to the cathode than the plate, the screen grid has practically complete control over the plate current. The plate current is therefore not influenced by plate voltage variations. Since the screen is at a-c ground potential, there will be no variation in the screen voltage when an a-c signal is being applied to the grid. The screen grid therefore exerts a constant pull on the electrons that make up the plate current. The only element in the tetrode that causes the plate current to vary is the control grid. The control grid, however, no longer shares its control over the plate current with the plate, as it did in the triode. Small variations of voltage on the control grid will cause the plate current to vary without any interference from a varying plate voltage. The plate resistance and the amplification factor of the tetrode are, as a result, greatly increased.

6-13. The Pentode

The introduction of the screen grid in the tetrode successfully reduced the plate-grid capacitance and increased the amplification factor. The tetrode, however, suffers from one important defect. This defect is known as SECONDARY EMISSION. The Pentode (five element tube) was developed to overcome the bad effects of secondary emission.

Secondary emission is a condition which arises when high velocity electrons strike a metal object such as a plate. The force of the impact will cause additional electrons to be knocked out of the atomic structure of the plate. For every electron that strikes the plate, two or three electrons will be knocked out of the plate. In a triode, these secondary emission electrons normally find their way back to the highly positive plate and cause no ill-effect in the operation of the tube. In the tetrode, as long as the plate is more positive than the screen, the secondary emission electrons fall back to the plate, and tube operation will be normal. However, if the screen is operated at a high voltage, and a large signal voltage is applied to the control grid, the plate voltage may drop below the screen voltage at the positive peak of the input signal. The result of this lowered plate voltage is to cause the secondary emission electrons to flow to the positive screen grid instead of returning to the plate. Thus, the number of electrons reaching the plate drops, while at the same time, the screen current is increased. This results in a reduction in the amplification of the tube and distortion in its output.

In the pentode, a third grid is placed between the screen grid and the plate. (see fig.6-13) The third grid is similar in physical construction to the screen grid and

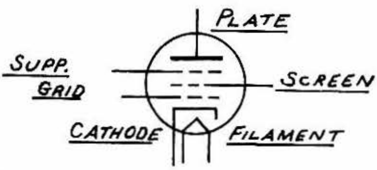


Fig. 6-13. Schematic symbol for pentode.

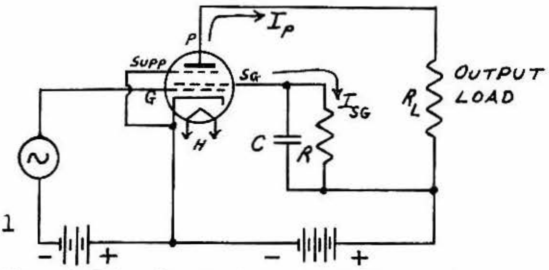


Fig.6-14. Pentode amplifier circuit.

the control grid. This third grid is connected to the cathode so that it will be highly negative with respect to the plate and will force the secondary emission electrons back to the plate. Because it suppresses secondary emission, the third grid is called the SUPPRESSOR GRID. The negative suppressor grid will not interfere with the flow of electrons from the cathode to the plate even though it does suppress the secondary electrons coming from the plate. The reason for this is that the electrons from the cathode are traveling at such a high velocity when they reach the vicinity of the suppressor grid, that they go right on through to the highly positive plate. On the other hand, the secondary electrons coming from the plate are moving at a rather low velocity and are easily pushed back to the plate. Fig.6-14 illustrates a pentode hooked up as an amplifier. Note that the only difference between this circuit and the tetrode amplifier circuit of fig.6-12 is the addition of the suppressor grid.

6-14. The Beam Power Tube

A beam power tube is a pentode with special construction features. A beam power tube has greater power handling ability than the ordinary tetrode or pentode. With very small grid voltages, a beam power tube can develop large amounts of power in its plate circuit. The tube is therefore said to have high power sensitivity.

The beam power tube is constructed so that the individual wire turns of the control grid and the screen grid line up with each other horizontally. This means that every turn of the screen grid mesh is directly behind a turn of the control grid mesh. Thus, electrons flowing from the cathode travel through the control grid and onto the plate without striking the screen grid. The screen grid current is therefore very low and, since the plate gets the electrons which would normally have gone to the screen grid, the plate power output is increased. Because of the physical alignment of the control grid and the screen grid, the

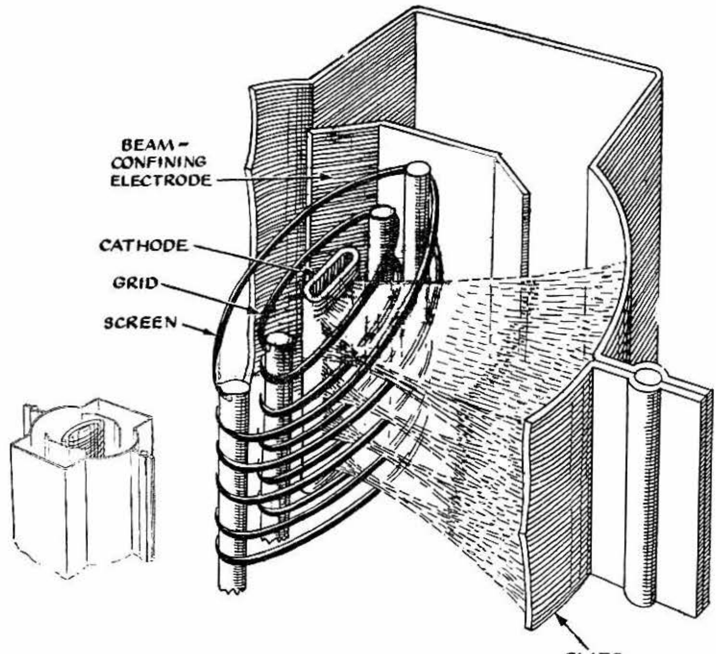


Fig. 6-15. The beam power tube (courtesy RCA)

electrons flow to the plate in sheets, or beams. Fig. 6-15 illustrates this condition. To further concentrate and form the heavy beams of plate current, deflecting plates are incorporated into the tube structure. These deflecting plates are placed between the screen grid and the plate, and extend partway around the tube, as shown in fig.6-15. These beam forming deflecting plates are internally connected to the cathode and therefore acquire a negative charge with respect to the plate. As a result, the deflecting plates repel the electrons into concentrated, heavy beams of plate current. No actual suppressor grid is necessary because secondary emission from the plate is suppressed by the space charge which forms between the plate and screen grid. The space charge has been indicated by the dashes in fig.6-15. The space charge of the electron beam is caused by the slowing up of electrons in the area between the screen grid and the plate. By operating the plate of the beam power tube at a lower potential than the screen grid, the plate is made negative with respect to the screen. The electrons are therefore slowed down when they pass through the screen on their way to the plate. Stray secondary emission electrons cannot return to the screen grid outside of the beam area because of the beam forming plates. Some beam power tubes use an actual suppressor grid in place of the space charge effect.

The beam power tube has:

1. high power sensitivity
2. high power output
3. high plate efficiency

6-15. Thyratrons

A THYRATRON is a gas-filled triode or tetrode tube. The thyratron is used to control large amounts of power flow by means of control grid action. When the grid of a thyratron is sufficiently negative, no plate current flows. However, if the bias is lowered to the point where plate current begins, the gas in the tube immediately ionizes and a heavy plate current flows. At this point the control grid loses control over the plate current. Varying the bias voltage after plate current starts will have no effect on the plate current. The only way to stop the flow of plate current is to remove the plate voltage, or lower it below the ionization potential of the gas. The thyratron grid, therefore, acts as a trigger to turn on relatively large currentsin the plate circuit. Thyratrons also function as high voltage rectifiers, such as the 884 and 885 triodes, or the 2D21 tetrode.

6-16. Gas in a Vacuum Tube

The thyratron and the mercury vapor rectifier are special type tubes with gas-filled envelopes. The ordinary vacuum type tube is supposed to be free of any gas or air. If a vacuum tube does contain gas which was not excluded during the manufacturing process, it is known as a SOFT tube. The visible indication of a soft tube is a blue or purple haze, sometimes accompanied by a reddened plate. The plate current of a soft tube is excessively high. A soft tube is often erratic in its operation and should be replaced.

Most vacuum tubes contain a GETTER. A getter is a small piece of metal made of barium or some similar chemical. This chemical removes or destroys stray gases that remain in the vacuum tube after the evacuation process.

PRACTICE QUESTIONS - LESSON 6

(For answers, refer to back of Study Guide, Section II)

6-1. Increasing the negative voltage on the control grid will;

a. decrease the plate voltage
b. increase the plate current
c. decrease the plate current
d. have no effect on the plate current

6-2. The grid voltage of an indirectly heated tube is the voltage between the;

a. grid and cathode
b. grid and plate
c. grid and filament
d. grid and B+

6-3. A tube is said to have a blocked grid when;

a. the grid is negative enough to cut off plate current.
b. the grid is positive enough to saturate the plate
c. the grid cuts off grid current
d. the grid cuts off filament current

6-4. The tube that cannot amplify is the;

a. pentode b. tetrode c. triode d. diode

6-5. The amplification factor of a tube is;

a. the change in plate current over the change in grid voltage that causes the plate current change
b. the change in plate voltage over the change in grid voltage, both of which cause the same change in plate current.

c. the change in the plate resistance over the change in plate current
d. the change in plate voltage over the change in plate current chased by the change in plate voltage.

6-6. An increase in positive grid voltage causes;

a. the plate current to decrease
b. the plate resistance to decrease
c. the plate resistance to increase
d. the plate voltage to increase

6-7.* The d-c plate power input to a tube having a plate voltage of 800 volts and a plate current of 85 ma is;

a. 6,800W b. 68,000W c. 680W d. 68W

6-8.* The d-c plate power input to a tube having a plate voltage of 550 volts and a plate current of 120 ma is;

a. 66,000W b. 670W c. 66W d. 660W

6-9.* The d-c plate power input to a tube having a plate voltage of 750 volts and a plate current of 150 ma is;

a. 112.5W b. 10W c. 100W d. 112,500W

6-10.* The d-c plate power input to a tube having a plate voltage of 650 volts and a plate current of 110 ma is;

a. 40W b. 71,500W c. 3,000W d. 71.5W

6-11. The screen grid;

a. reduces the plate-grid capacitance
b. increases the plate-grid capacitance
c. increases the space charge surrounding the cathode
d. shields the filament from the cathode

6-12. The suppressor grid;

a. is found in a tetrode
b. is positively charged with respect to the cathode
c. repels electrons back to the plate
d. repels electrons back to the screen

6-13.* An important advantage of a tetrode over a triode is;

a. reduced possibility of oscillation in a tetrode r-f amplifier
b. repulsion of secondary emission electrons
c. increased cathode emission
d. reduced possibility of rectification

6-14. A soft tube is one with;

a. very high voltages on its elements
b. very low voltages on its elements
c. a shield surrounding its plate
d. unwanted gas in it

6-15*. A triode has; a. no grids b. one grid c. two grids d. three grids

6-16*. A pentode has; a. no grids b. one grid c. two grids d. three grids

6-17*. The maximum safe heat radiation capability of the plate of a tube is indicated by the following rating;

a. transconductance expressed in mhos.
b. maximum plate dissipation expressed in watts
c. plate resistance expressed in ohms.
d. grid bias expressed in volts

6-18*. A tetrode r-f amplifier will not oscillate because;

a. there are no space charges in a tetrode
b. the plate of a tetrode is much larger than the plates of other tubes
c. it is impossible for any r-f amplifier to oscillate
d. the screen grid reduces the plate-grid interelectrode capacity

6-19*. Answer the following questions concerning fig. 6-16;

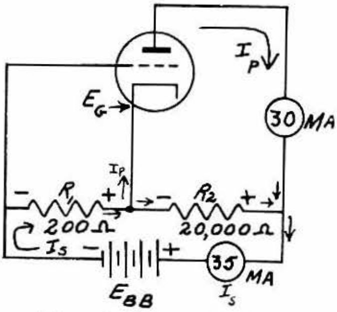


Fig. 6-16. Problem.

a. what is the d-c grid bias?
b. what is the d-c plate voltage?
c. what is the B supply voltage?

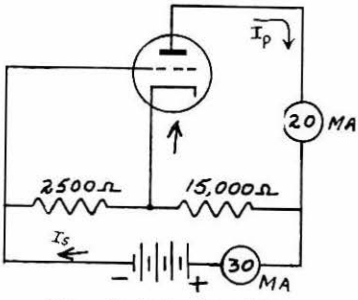


Fig. 6-17. Problem.

6-20*. Concerning fig. 6-17;

a. what is the d-c grid bias?
b. what is the d-c plate voltage?
c. what is the B supply voltage?

SECTION II LESSON 7

AUDIO AMPLIFIERS

7-1. Introduction

At this point, we understand that when a small amplitude signal is applied to the grid of a triode or pentode, it will be amplified and will appear many times larger in the plate circuit. This property of grid-controlled vacuum tubes makes possible their use as AMPLIFIERS. An amplifier may be defined as a device which transforms a small input signal into a large output signal.

7-2. Amplifier Application

Amplifiers find many practical applications. For example, the signal that is developed in the crystal pick-up of a record player is much too weak to be applied directly to a loud speaker. This weak signal must first be amplified (made larger) before it can properly drive a loud speaker. A lecturer addressing an audience in a large auditorium must have his voice amplified in order for him to be heard by everyone in the hall. The amplifier that accomplishes this is called a PUBLIC ADDRESS SYSTEM. Amplifiers are also extensively used in fields such as motion pictures, electrical recording, and photo-electronics. Since amplifiers find such a wide application, it is important that we thoroughly understand their operation.

7-3. A Typical Amplifier

Fig.7-1 illustrates a simple resistance-coupled amplifier. This amplifier consists of the following basic components:

1. a vacuum tube such as a triode or pentode
2. a power source for the filament of the vacuum tube which is called an "A" supply.
3. a source of d-c power (B+) for the plate circuit of the vacuum tube which is called a "B" supply.
4. a bias voltage supply called a "C" supply.
5. a means of coupling the signal to be amplified to the grid circuit of the amplifier.
6. a means of coupling the amplified signal from the plate circuit to the load. In fig.7-1, the transformer couples the signal from the plate to the speaker.

When an amplifier consists of one vacuum tube it is called a one-stage amplifier. If additional amplification

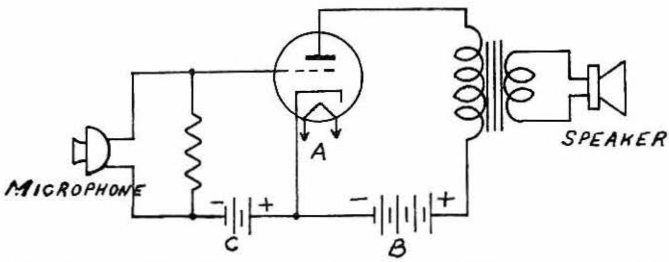


Fig. 7-1. Simple one-stage amplifier circuit.

of the signal is required, a second vacuum tube is connected in series with the first tube. The amplifier is then a two-stage amplifier; the vacuum tubes are said to be connected in CASCADE.

7-4. Amplifiers Used in Radio Receivers

The modern radio receiver uses two types of amplifiers in its operation; they are:

1.- The Radio-frequency (r-f) amplifier: This amplifier amplifies the weak radio-frequency signals picked up by the aerial of the receiver. A radio frequency signal is a high frequency radio wave (usually above 400 kilocycles (kc)) which is sent out into space by the radio transmitter.

2.- The Audio-frequency (a-f) Amplifier: This amplifier amplifies the sound frequencies or audio frequencies which are applied to the loud speaker. Audio frequencies are in the range between 16 and 16,000 cps.

7-5. Classification of Amplifiers

Amplifiers are classified according to the work they are intended to perform and the manner in which they are operated. The classification is determined by the grid bias of the amplifier which in turn determines the portion of the cycle during which plate current flows. Amplifiers are classified into three general categories, class A, class B, and class C. The audio amplifier is invariably operated either class A or class B. (we will discuss r-f amplifiers in a later lesson)

7-6. Characteristics of a Class A Amplifier

Characteristics of a Class A amplifier are as follows:

1.- Plate current flows for the entire cycle of the input signal. In other words, the tube conducts current continuously. The average plate current, as measured by a d-c milliammeter, remains constant with or without the application of a signal on the grid.

2.- The grid is never driven so far negative that the tube is cut off.

3.- The signal never drives the grid positive with respect to the cathode. A positive grid would result in grid current flow which would cause the amplified signal to become distorted.

4.- A class A amplifier operates with poor efficiency because plate dissipation occurs throughout the entire cycle of the input signal. Poor efficiency results in low power output from medium-sized tubes.

7-7. Linear Amplification

A class A amplifier reproduces a signal almost exactly. In other words, the amplified output signal is an exact reproduction of the input signal. Linear class A operation is illustrated in fig. 7-2. This figure shows the

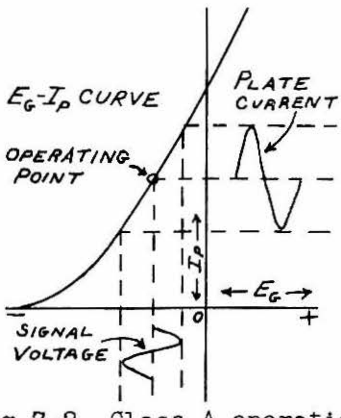


Fig. 7-2. Class A operation.

plate current-grid voltage ($E_g - I_p$) characteristic curve of a class A amplifier. For class A operation, the bias voltage or operating point is chosen to be at the mid-point of the "linear", or straight line, portion of the characteristic curve. The grid signal swings the grid voltage over the linear portion of the curve. The plate current variation is therefore an exact reproduction of the grid signal.

7-8. The Bias Voltage Supply

All amplifiers operate with a certain bias voltage whose value depends upon the class of operation. The two methods of obtaining bias voltage for an a-f amplifier are:

1.- fixed bias
2.- self-bias, or cathode bias

Fig.7-1 illustrates an amplifier with fixed bias. The fixed bias can be obtained from a source called a "C" battery whose terminals are connected as shown in this diagram. The fixed bias voltage can also be obtained from a negative d-c voltage point in the power supply. The bias voltage is of constant value and cannot be changed. The only way to change the bias is to insert another "C" battery of different voltage. The disadvantage to fixed bias operation is that an external means of biasing is required.

Fig.7-3 illustrates an amplifier with cathode bias. The biasing circuit consists of a resistor, R, and condenser, C, connected from cathode to ground. The bias voltage is developed by the d-c plate current flowing from ground through the resistor to the cathode. Since the current flows into the resistor from ground, this side of the resistor is negative with respect to the cathode side. The purpose of the condenser, C, is to by-pass the a-c component of plate current around the resistor. If the a-c component of current were allowed to flow through the biasing resistor, a varying bias voltage would be developed. Under normal amplifier operation this is not desirable. The a-c component of plate current therefore flows through the by-pass condenser, C, while the d-c component of plate current flows through the biasing resistor, R, establishing a source of fixed bias voltage. The advantage of cathode bias is that it eliminates the need for a separate source of bias voltage. Most receiver circuits use this self-biasing principle.

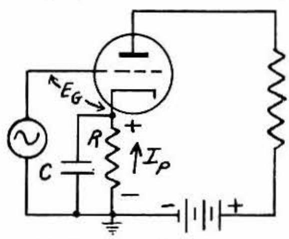


Fig.7-3. Cathode-bias.

It may sometimes be necessary to compute the value of the biasing resistor, R. For example: Suppose we wish to operate a certain tube as a class A amplifier. The tube manual states that for class A operation, the bias for that tube is -3 volts and the plate current will be 10 ma. (.01 A) Since we know the voltage across the resistor and the current through it, we can easily find the value of the resistor by using ohm's law:

$$R_k = \frac{E}{I} = \frac{3}{.01} = 300 \text{ ohms}$$

7-9. Coupling Systems in Amplifiers

Audio amplifiers are usually classified according to the method of coupling the signal from one stage to another. There are two common types of a-f coupling used in receivers and transmitters. One is transformer coupling and the other is resistance-capacity coupling.

7-10. Transformer Coupled Amplifier

A simple transformer coupled audio-amplifier is shown in fig. 7-4. V_1 and V_2 are the voltage amplifiers. T_1 is is a special type of matching transformer (refer to paragraph 38 in lesson 3) known as an audio interstage transformer. For maximum power transfer from the plate of V_1

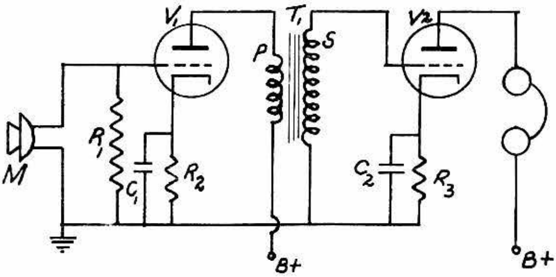


Fig. 7-4. Two-stage transformer-coupled amplifier.

to the grid of V_2, the transformer is so designed that its primary impedance approximately matches the plate circuit impedance, and its secondary impedance matches the grid circuit impedance. The turns ratio for this type of transformer is usually 1 to 3 step up from plate to grid. The secondary therefore has about three times as many turns as the primary.

The coupling operates as follows: The signal is coupled from the plate of the first stage to the grid of the second stage by means of the audio interstage transformer, T_1. The varying plate current of V_1 generates a varying magnetic field about the primary of transformer T_1. This varying magnetic field in turn induces a voltage in the secondary of T_1 which is applied as a signal voltage to the grid of V_2. This signal is then amplified by V_2 and applied to the headphones.

Let us now discuss the functions of the parts indicated on the diagram: "M" is the microphone which supplies the input signal to the grid of V_1. "R_1" is the grid load resistor which serves two purposes:

a) Microphone current flowing through the resistor establishes a necessary alternating current voltage drop between the grid and cathode. This voltage drop is the signal which is to be amplified.

b) Electrons which collect on the grid can leak off to ground through the resistor. These electrons might otherwise accumulate sufficiently on the grid to cause the tube to cut-off. This condition is known as a blocked grid. "R_2" is the cathode biasing resistor chosen to provide the correct tube bias for class A operation. "C_1" is the cathode by-pass condenser. It provides a very low-impedance path around the bias resistor for the audio currents. "T_1" is the interstage audio transformer. "R_3" is the bias resistor. "C_2" is the by-pass condenser.

7-11. Advantages of Transformer Coupling

The advantages of transformer coupling are:

1) High gain due to step-up ratio of transformer

2) Low d-c resistance of transformer primary permits the use of a low B+ voltage. With the B+ voltage low, we are assured that the plate voltage will not be too low.

7-12. Disadvantages of Transformer Coupling

The disadvantages of transformer coupling are:

1) Distortion of the signal due to the transformer characteristics.- An amplifier which reproduces faithfully and amplifies equally the band of audio frequencies which is applied to its input is said to have low distortion or HIGH FIDELITY. The average transformers used in a transformer-coupled amplifier introduce some distortion into the signal. As a result, the amplifier is said to have POOR FIDELITY. High fidelity transformer-coupled amplifiers are very difficult to design and therefore are quite expensive.

2) The transformers are too large and expensive.

3) The transformers must be magnetically shielded to prevent pick-up of hum.

4) Transformer coupling is usually limited to triode amplifiers with the result that high gain of pentodes is not realized.

7-13. Resistance-Capacity Coupled Amplifier

The disadvantages of the transformer-coupled amplifier are overcome in the design of a resistance-capacity coupled amplifier. The major difference between the two amplifiers is that the interstage coupling transformer is replaced with a resistance-capacity coupling network in the R-C amplifier. The elimination of the transformer allows for the use of pentode amplifiers with a consequent increase in the overall gain of the amplifier. The elimination of the audio-coupling transformer also does away with the distortion associated with its use. Generally speaking, the R-C amplifier is the superior of the two amplifiers considered because of its simplicity, compactness, cheaper cost, and higher fidelity output.

Fig. 7-5 illustrates a three-stage, resistance-coupled (R-C) amplifier. V_1 and V_2 are voltage amplifiers. V_3 is a pentode power amplifier with an output coupling transformer.

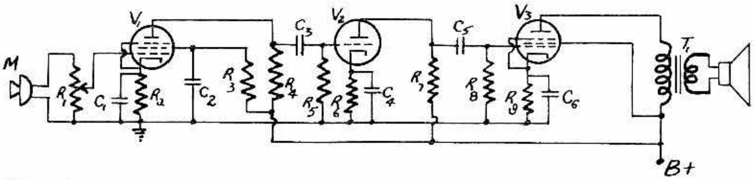


Fig. 7-5. Three-stage resistance-coupled amplifier.

The coupling network between the plate of V_1 and the grid of V_2 consists of a resistance-capacity network. The condenser "C_3" is known as a COUPLING or BLOCKING condenser. Its function is to pass the audio current from the plate of V_1 to the grid of V_2 while, at the same time, to block the positive plate voltage of V_1 from being applied to the grid of V_2. If the coupling condenser becomes shorted, the d-c plate voltage of V_1 would be applied directly to the grid of V_2. The positive voltage on the grid of V_2 would result in excessive grid and plate current flow, and would cause the audio signal to become distorted. The capacity of C_3 is determined by the reactance it should have for the lowest audio frequency that it is to pass on to the grid of V_2. This reactance should be very low for the lowest audio frequency that is to be passed on. The a-c signal for the grid of V_2 is developed across the resistance, R_5, by the audio currents which flow through the coupling condenser, through R_5 to ground, and back to the cathode of V_1.

The following is a summary of the functions of the components in fig. 7-5.

Parts		Function
R_1	...	Volume control, grid load resistor
C_1, C_4	...	Cathode by-pass condenser
R_2, R_6	...	Cathode bias resistor
R_3	...	Screen dropping resistor

C_2	...	Screen by-pass condenser
R_4, R_7	...	Plate load resistor; high impedance for audio
C_3, C_5	...	Coupling and blocking condenser; transfers the audio voltage to grid of V_2; does not allow the d-c voltage from the plate of V_1 to reach grid of V_2.
R_5, R_8	...	Grid resistor. Connects grid to d-c ground potential, but does not by-pass audio to ground
C_6	...	Cathode by-pass condenser for a-c
R_9	...	Cathode bias resistor
T_1	...	Output matching transformer (step-down) matches the high plate impedance of V_3 to the low voice coil impedance of the speaker

7-14. Power Output Measurements

You may sometimes want to determine how much power you are feeding into your speaker voice coil. The procedure is quite simple and is illustrated in fig.7-6.

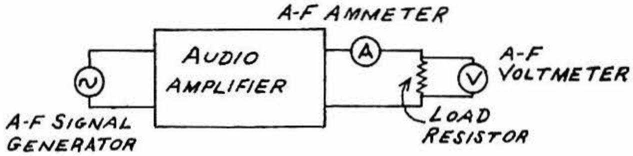


Fig.7-6. Power out-put measurements.

Disconnect the speaker voice coil and replace it with an equivalent resistance of the proper power rating. Then connect an audio frequency signal generator to the input of the amplifier, and an a-c ammeter and voltmeter to the output as indicated. An audio-frequency signal generator is an electronic device which can generate audio-frequency voltages. With the amplifier volume control set at maximum, adjust the output of the signal generator at 5000 cps for maximum power output. The point of maximum power output can be determined by observing the output waveform by means of an oscilloscope. Maximum distortionless power output is the point just before distortion is observed in the waveform. At this point, take readings of the voltmeter and ammeter. The product of the voltmeter and ammeter readings will be equal to the electrical power output of the amplifier in watts.

7-15. Frequency Response

An amplifier is said to have a FLAT FREQUENCY RESPONSE when it amplifies equally all frequencies applied to the input grid . A frequency response curve is a graph which plots the amplifier voltage output in either volts or decibels over a frequency range. Fig.7-7 illustrates the response curve for a typical transformer-coupled amplifier and

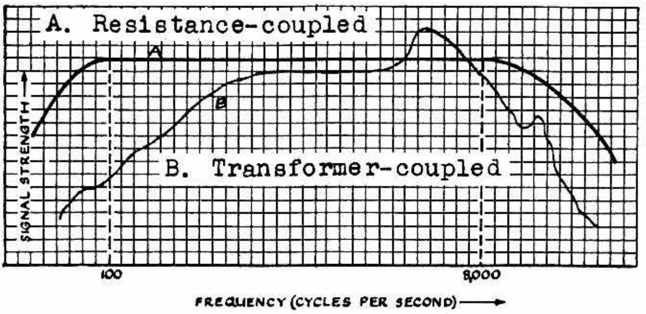


Fig.7-7. Frequency response curve.

a resistance-coupled amplifier. The R-C amplifier has the flatter curve and has, therefore, a flatter frequency response. A flatter response means better fidelity.

7-16. Distortion in Class A Amplifier

Fig.7-8A illustrates a pure sine wave of a certain frequency. A pure sine wave is an a-c wave which is free

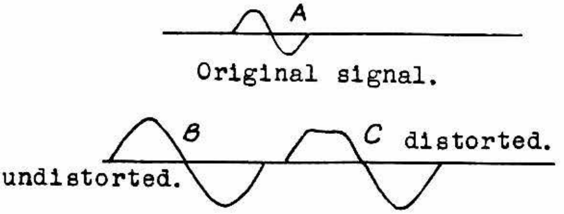


Fig.7-8. Distortion in class A amplifier.

of distortion. The ideal audio amplifier is one which will amplify a sine wave, not changing its waveshape or distorting it. The amplified plate signal must therefore be an exact duplicate of the grid signal. Fig.7-8B illustrates an amplified version of the sine wave of fig.7-8A. Fig.7-8B has the same waveshape as fig.7-8A and therefore is still considered a pure sine wave (undistorted) even though it is amplified.

Fig.7-8C is no longer a pure sine wave. It is a distorted sine wave.

7-17. Causes of Distortion in Class A Amplifiers

Fig.7-9 illustrates the $E_g - I_p$ curve for a properly operated class A amplifier. The bias point,"A", is at the mid-point of the linear portion of the curve. The input signal is of the correct amplitude so that the plate signal is an amplified and undistorted version of the input signal. A d-c ammeter in the plate circuit will indicate the same plate current reading when the signal is applied to the grid and when it is removed. This is because the average plate current remains the same.

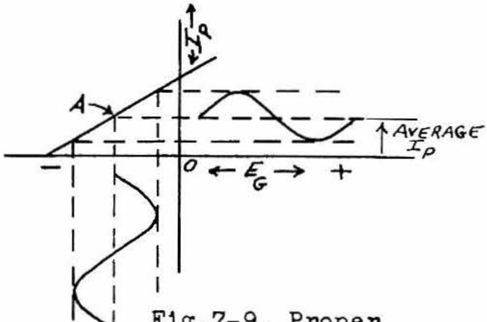


Fig.7-9. Proper class A operation.

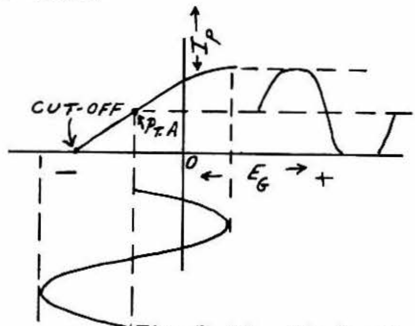


Fig.7-10. Distortion due to excessive signal voltage.

The causes of distortion in a Class A amplifier are as follows:

1) <u>too strong a signal on the grid</u> (signal overloading):- Excessive excitation voltage will drive the grid positive with respect to the cathode on the positive peaks of the signal. A positive grid draws grid current which results in distortion of the signal. The negative peaks of the signal may drive the grid so negative that the tube will cut-off. Cut-off condition results in distortion to the signal as shown in fig.7-10.

2) <u>improper grid bias</u>:- The result of operating the amplifier with too little grid bias is shown in fig.7-11. The positive peaks of the signal voltage drive the grid into the positive grid voltage region of grid current. The resulting distortion is a flattening or clipping of the positive peaks of the plate current output signal. The d-c ammeter will now read a decreased plate current when a signal is applied, as compared to a no-signal reading. The clipping of the positive peaks of the plate current signal causes the average value of plate current to decrease below

the no-signal level (see fig.7-11)

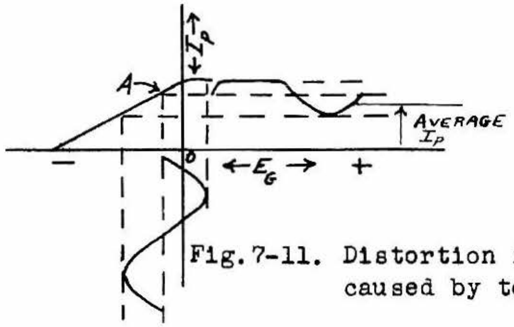


Fig.7-11. Distortion in class A operation caused by too little bias.

The result of operating the amplifier with an excessive negative grid bias is shown in fig.7-12. The negative peaks of the signal drive the tube into cut-off. The resulting distortion is a clipping of the negative peak of

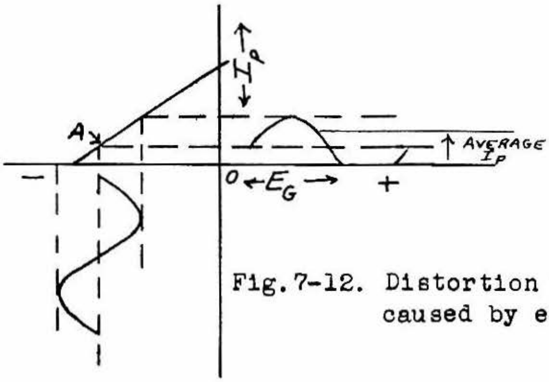


Fig.7-12. Distortion in Class A operation caused by excessive bias.

the plate current output signal. The d-c ammeter will read an increase in plate current when a signal is applied, as compared to a no-signal reading. The clipping of the negative peaks of the plate current signal causes the average value of the plate current to increase.

PRACTICE QUESTIONS - LESSON 7

(For answers, refer to back of Study Guide, Section II)

7-1.* Draw a diagram of a two stage, resistance-coupled amplifier.

7-2.* In a class A amplifier, the grid bias is adjusted for operation over;

a. the non-linear portion of the $E_g - I_p$ curve
b. the bottom of the $E_g - I_p$ curve
c. all over the $E_g - I_p$ curve
d. over the linear portion of the $E_g - I_p$ curve

7-3.* In a class A amplifier, the output signal;

a. is similar to a sine wave
b. is a faithful reproduction of the input signal
c. is smaller than the input signal
d. is twice the frequency of the input signal.

7-4.* In a class A amplifier;

a. plate current flows continuously
b. plate current is cut-off during the negative half of the input signal
c. plate current is cut-off during the positive half of the input signal
d. the tube is always cut-off

7-5.* In a class A amplifier;

a. the grid is driven positive during the positive peaks of the input signal
b. the grid draws current during the positive peaks of the input signal
c. the signal never drives the grid positive with respect to the cathode
d. the grid bias is below cut-off

7-6.* In a class A amplifier;

a. the average plate current decreases with application of a signal
b. the average plate current increases with application of a signal
c. the average plate current remains constant with application of a signal
d. the average plate current varies with application of a signal

7-7.* In a class A amplifier;

a. the grid is never driven into cut-off
b. the grid is driven into cut-off during the negative signal swing
c. the grid is driven into cut-off during the positive signal swing
d. the grid bias is at cut-off

7-8.* The plate efficiency of a class A amplifier is;

a. quite high
b. relatively low
c. the best of all the amplifiers
d. is 100%

7-9.* Draw a schematic diagram of a pentode audio power amplifier stage with an output coupling transformer and load resistor, showing suitable instruments connected in the secondary for measurement of the audio-frequency voltage and current; and name each component part

7-10.* If R_2 of fig. 7-5 is 1500Ω, and the plate current of V_1 is 15 ma, the bias voltage for V_1 is; A. 2.25 V

b. 0.35 V c. 30V d. 22.5 V

7-11.* An upward fluctuation of class A amplifier current when signal voltage is applied to the grid indicates;

a. insufficient negative grid bias
b. excessive negative grid bias
c. positive grid bias
d. proper operation

7-12.* A downward fluctuation of the class A amplifier plate current when signal voltage is applied to the grid indicates;

a. insufficient negative grid bias
b. excessive negative grid bias
c. positive grid bias
d. proper operation

7-13.* Improper class A bias results in;

a. distortion of the output waveform
b. decrease in amplification
c. phase distortion
d. improved operation

SECTION II LESSON 8

MICROPHONES, REPRODUCERS
POWER AMPLIFIERS

8-1. Sound

A class A audio amplifier is used to amplify the small signal output of a microphone. The action of a microphone depends upon certain characteristics of a sound wave. We have therefore reached a point in our discussion of amplifiers where a brief resume of the nature of sound becomes necessary.

SOUND is defined as a disturbance in a material medium caused by the vibration of any body at a certain definite frequency. A sound wave travels through a material medium such as air or steel in the form of a compressional wave. This compressional wave travels out from a region of disturbance in exactly the same manner as ripples do when a pebble is dropped into a pool of water. Vibrating objects, such as your vocal cords, cause regions of compressed air followed by rarefied air to move outward and away from them in the form of concentric spheres. These vibrations or disturbances reach the ear and cause the eardrum to move inward and outward according to the pressure exerted by compressions and rarefactions. The human ear is capable of hearing such disturbances only if they occur within the range from 16 to 16,000 cycles per second. The FREQUENCY RESPONSE of the ear is therefore said to be from 16 to 16,000 cps. This range of frequencies is designated by the term AUDIO FREQUENCIES. Although a frequency vibration of 30,000 cps will cause the diaghragm in the ear to vibrate, the nerves in the ear are incapable of detecting the vibration.

8-2. The Microphone

An amplifier can only amplify an electrical frequency. Therefore, a sound frequency such as music or voice must first be converted into an equivalent electrical frequency in order that it may be amplified.

A microphone is a device which translates or converts sound impulses into changing electrical potentials called the signal. The signal which is now of an electrical nature can be impressed between the grid and cathode of the first amplifier tube for purposes of amplification. There are many types of microphones in use today; we shall discuss a few of the common ones.

8-3. The Single Button Carbon Microphone

Construction:- The active element consists of a hollow button filled with packed carbon granules. (see fig. 8-1) A 6 volt battery is connected in series with the button, so that any current flowing in the battery circuit must flow through the carbon granules.

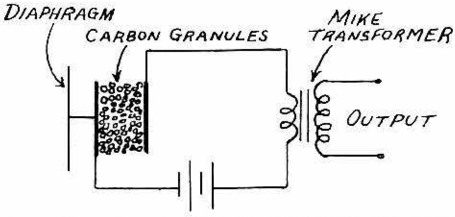


Fig. 8-1. Single-button carbon microphone.

Operation:- The resistance of the single button, carbon microphone changes with mechanical pressure. This is because a change in mechanical pressure causes the packing of the carbon granules inside the button to vary. If The packing varies, the resistance of the carbon button will vary. When the sound input strikes the diaphragm of the microphone, it vibrates at the frequency of the sound. This vibration causes the resistance of the carbon inside the diaphragm to vary at the same frequency. The varying resistance will cause the current in the series circuit to vary in the same manner. The result is that an audio current with the same frequency as the sound flows through the primary of the microphone transformer.

Connection:- The impedance of the button is about 100 ohms. A microphone transformer is used to match this low impedance to the high grid impedance of the first stage.

Frequency response:- The single button carbon microphone responds well to audio frequencies between 250 to 2700 cps. Since many of the tones of musical instruments lie above 2700 cps, the carbon microphone is suitable only for voice pick-up. The general range of voice frequencies is below 2700 cps.

Other Characteristics:-

1. The carbon microphone is the most sensitive of all microphones in use at the present time. For a given level of sound input, this microphone will generate a higher signal voltage than any other microphone.

2. The carbon microphone is not directional; it picks

up sound impulses equally well from all directions.

3. Constant current through the granules gives rise to an annoying background hiss.

4. Excessive current should not be passed through the carbon granules, or the carbon button jarred while the current is on, because packing of the carbon granules will result. The microphone then becomes inoperative.

Advantages:- The main advantage of the single button carbon microphone is that it doesn't require the careful adjustment of button balance necessary in the double button type. Other advantages are its relatively low cost, very high output, and low current consumption.

8-4. The Ribbon or Velocity Microphone

Construction:- This microphone is activated by moving air particles. A thin, corrigated, metallic ribbon is suspended between the poles of a strong permanent magnet.

Operation:- Sound energy strikes the ribbon which vibrates back and forth cutting the magnetic field. The cutting action induces an e-m-f in the ribbon; this e-m-f is the audio signal. The e-m-f frequency is determined by the frequency of the sound wave which strikes the ribbon. The impedance of the short piece of ribbon may be as low as 0.5 ohms. A matching transformer is employed to match the low output impedance of the ribbon microphone to the high grid input impedance.

Frequency Response:- The frequency response is from 30 to 12,000 cps. This wide frequency range is satisfactory for the transmission of music as well as sound.

Comments:- To prevent booming effect, the microphone should be placed at least 14 inches away from the source of sound. This microphone is bi-directional; maximum pick-up occurs at the front and back of the head. It is desirable as a broadcast microphone because it has a flat frequency response.

8-5. The Crystal Microphone

Construction:- The active element in a crystal microphone is a crystalline material, usually Rochelle salts. Other crystals that may be used are quartz and tourmaline. There are two types of crystal microphones:

1) diaphragm type in which a thin diaphragm is rigidly fixed to one of the major faces of the crystal.

2) sound cell type in which a series of crystals are

excited by sound pressure directly, without the use of a diaphragm. We shall examine the sound cell type of crystal microphone as it is the most commonly used of the two types of crystal microphones.

Operation:- Certain crystals, like Rochelle salts, develop a potential difference between two surfaces when a mechanical pressure is applied to their opposite surfaces. Sound pressure applied to a crystal surface will develop a varying electric potential across the opposite surfaces at the frequency of the sound wave. In this manner sound energy is converted into electrical energy. The varying potential that is developed is applied to the grid circuit of an amplifier for further amplification.

Connection:- The crystal microphone is the simplest of all the types discussed. It requires no battery, since it generates its own potential. The crystal microphone requires no transformer, since it has a high impedance of over one megohm; it is therefore a perfect match to the high impedance of the grid circuit.

Frequency Response:- The frequency response of the crystal microphone is from 50 to 8000 cps. This is satisfactory for speech reproduction but not quite satisfactory for music.

Comments:- A crystal microphone should be handled with care because any shock is liable to impair its operation. It should not be exposed to excessive temperature and humidity changes. It is used in portable, mobile, and police fixed station equipment. A single sound cell is not directional. Multiple cell types can be designed for directional use.

8-6. The Reproducer

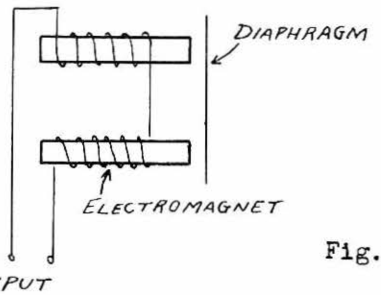
The process of amplification consists of three individual steps:

1) conversion of sound energy to electrical energy by the microphone
2) amplification of the converted electrical energy
3) conversion of the amplified electrical energy back into sound energy through the reproducer.

Of the many types of reproducers in use today, we will study the headphones, the electromagnetic dynamic loudspeaker, and the permanent magnetic dynamic loudspeaker.

8-7. The Radio Headphone

The radio headphone or telephone receiver is the simplest type of reproducer. (See fig.8-2) Its construction is as follows: The leads are connected to a pair of electromagnets inside the case. Separated from the magnets by a few thousandths of an inch, is an iron diaphragm which



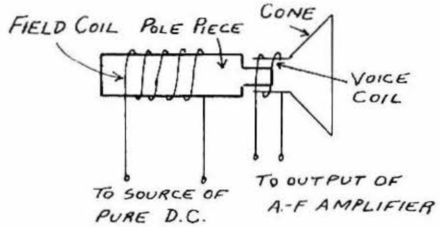


Fig.8-3. The electrodynamic speaker.

Fig.8-2. Simplified diagram of headphone.

is made to vibrate. Audio currents sent through the field of the electromagnet alternately weaken and strengthen its magnetic field; this, in turn, causes the diaphragm to vibrate. This vibration sets the surrounding air into motion. The air transmits these sound vibrations to the ear of the listener.

The impedance of the electromagnetic headphones is about 2000 ohms. This value is high enough for the headphones to be used directly as a plate load for a voltage amplifier triode without the need of a matching transformer.

8-8. The Electro-Dynamic Loud Speaker

The major parts of the electro-dynamic loud speaker are: (see fig.8-3)

1) The Field Coil: The field coil is a powerful electromagnet which must be energized from a pure d-c source. The d-c is usually obtained from the same power supply that supplies power to the amplifier or radio.

2) The Voice Coil: This coil is one of few turns; it has an impedance of from 2 to 20 ohms. The coil is wound around a small cardboard cylinder which fits closely around the pole piece of the field magnet. The voice coil is the only part of the system which is free to vibrate.

3) The Spider: The voice coil is suspended around the pole piece by a very flexible support called the "spider".

4) The Cone: The cone of the speaker is firmly attached to the voice coil. The outer edges of the cone are secured to the metal frame of the speaker housing.

8-9. Operation of the Electro-Dynamic Loud Speaker

Since the voice coil impedance is low, the coil must be connected to the output tube through a matching transformer. (refer back to fig. 7-5) The operation of the speaker is similar to the operation of the headphones. Audio currents flow through the voice coil and set up a varying magnetic field around the voice coil. The magnetic reaction between the voice coil and the field coil causes the voice coil, together with the cone, to vibrate at the audio frequency. The vibrating cone transmits its energy to the air in the form of sound waves.

8-10. Permanent Magnetic Dynamic Speakers

With the development of powerful magnetic alloys, such as Alnico steel, the permanent magnet began to replace the electromagnetic field coil. The resulting speakers are called permanent magnetic dynamic speakers, or simply P.M. dynamic speakers. Except for the fact that a permanent magnet has replaced the electromagnetic field coil, the P. M. speaker operates in exactly the same manner as the electromagnetic speaker.

8-11. The Class A Power Amplifier

A class A voltage amplifier serves only to amplify weak voltage variations. A voltage amplifier is not required to supply a large power output. The average plate current of a voltage amplifier is therefore comparatively low in value. (a representative value would be about 5 ma) A loudspeaker, however, needs a comparatively large current variation through its voice coil in order to operate successfully. The tube which is to drive the loudspeaker must be capable of handling a large plate current swing. Such a tube is known as a POWER AMPLIFIER. The plate current of a receiver power amplifier tube may be about 50 ma.

The characteristics of a power amplifier tube are as follows:

1) A low plate resistance:- Since a power tube must be able to supply large power output, it must be capable of conducting a large plate current. An amplifier tube acts like a resistor. A low plate resistance will enable a large plate current to flow. For example: The plate resistance of the 6SJ7 voltage amplifier is 700,000 ohms, and the plate current is 3.0 ma; whereas the plate resistance of the 6F6

power amplifier is 78,000 ohms, and the plate current is about 35 ma.

2) large signal handling ability: A large signal on the grid means a large plate current variation. The tube must be capable of handling a large signal without going into cut-off or drawing grid current. This means that the grid will normally operate with a comparatively large bias voltage. The bias voltage for the 6F6 power amplifier is -16 volts, as compared to -3 volts for the 6SJ7 voltage amplifier.

3) A low amplification factor: The amplification factor is directly related to the plate resistance. If the plate resistance is low, the amplification factor will be low. The 2A3 triode power amplifier has an amplification factor of only 4.2.

4) Large cathode structure: The cathode structure must be large in order to be able to supply the large plate current requirements.

5) Large plate surface structure: The plate surface must be large to enable it to radiate the heat generated by the large plate current flow.

8-12. The Class B Power Amplifier

A power amplifier operated class A has a comparatively poor operating efficiency. The reason for this is that the tube conducts for the entire cycle of the input signal; this results in a continuous dissipation of heat by the plate. Consequently, the maximum power output possibilities of the class A amplifier are never fully realized.

The modulator stages of radio-telephone transmitters require power audio amplifiers capable of delivering large power output. Class A power amplifiers would not be practical for such an application because of their poor operating efficiency. The class B power amplifier is therefore used because of its high operating efficiency. A class B amplifier is biased to cut-off so that plate current is practically zero. Fig.8-4 illustrates class B operation on the $E_g - I_p$ curve.

8-13. The Characteristics of the Class B Amplifier

The characteristics of the class B amplifier are as follows:

1) Plate current flows only during the positive half of the signal period. The negative half of the signal cuts off the tube. (see fig.8-4) The amplifier operates in a manner similar to that of a rectifier in that it conducts

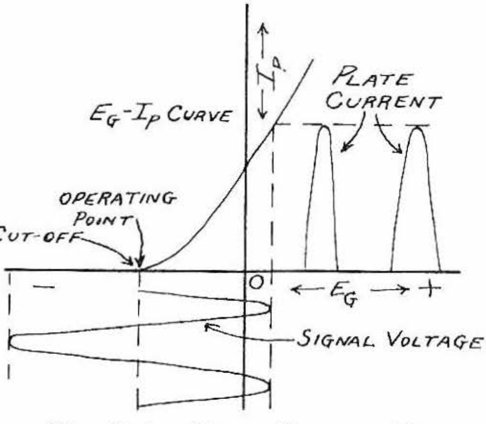


Fig.8-4. Class B operation.

only when the signal is positive.

2) The amplifier is operated over the entire length of its characteristic curve so that large plate current swings can be obtained. The large plate current swing is necessary if large power output is to be realized.

3) The efficiency for class B operation is much higher than that for class A for two reasons:

a. Plate current flows for half a cycle, so that the power wasted in heating the plate is very much reduced.

b. Efficiency of operation increases when a greater portion of the length of the characteristic curve is utilized. The class B amplifier uses a greater portion of its characteristic curve as compared to a class A amplifier.

8-14. Class B Push-Pull Power Amplifier

A class B amplifier tube, when used alone, will distort the signal because only one half of the input cycle is amplified. Two tubes are therefore necessary to amplify both halves of the input cycle. The plate output of each tube is combined with the other to form one continuous wave. This system of amplification is known as push-pull amplification.

Let us study fig.8-5 to visualize the operation of a Class B push-pull amplifier: T_1 is the input transformer. During the positive half of the input signal, let us say that the grid of V_1 (point #1) goes positive, and the grid of V_2 (point #2) goes negative with respect to the center-

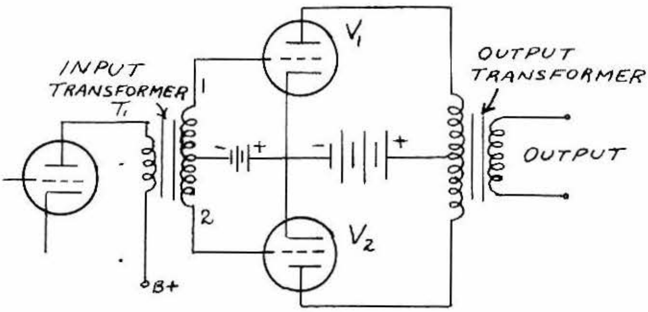


Fig. 8-5. Class B push-pull amplifier.

tap of the transformer secondary. V_1 conducts while V_2 cuts-off. V_1 will therefore amplify the positive half of the signal. During the negative half of the input signal, the grid of V_1 goes negative while the grid of V_2 goes positive. Now V_1 cuts-off and V_2 conducts. V_2, therefore, amplifies the negative half of the input signal. The negative plate signal of V_2 and positive plate signal of V_1 combine in the output to form a complete amplified cycle which is illustrated in fig. 8-6.

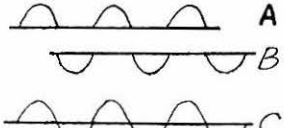


Fig. 8-6. Output of a class B push-pull amplifier

Push-pull operation has enabled us to utilize the high efficiency of a class B amplifier while at the same time eliminating the distortion inherent in class B operation.

8-15. Second Harmonic Distortion

Any distorted waveform may be analyzed and found to consist of a fundamental frequency plus a number of harmonics. Harmonic frequencies are multiples of the fundamental frequency. For example; Let us suppose the original undistorted signal is a 1000 cycle wave. This signal upon being amplified becomes distorted due to the addition of harmonic frequencies to the original waveform during the process of amplification. In our example, the amplified distorted waveform would be found to consist of the original fundamental frequency of 1000 cycles, a second harmonic component of 2000 cycles, a third harmonic component of

3000 cycles, etc. The fundamental and the harmonics all add together to give us the resulting distorted waveshape. The second harmonic is usually the most predominant of all the harmonics present. Fig.8-7 illustrates a distorted wave as the point by point sum of a fundamental plus a second harmonic component.

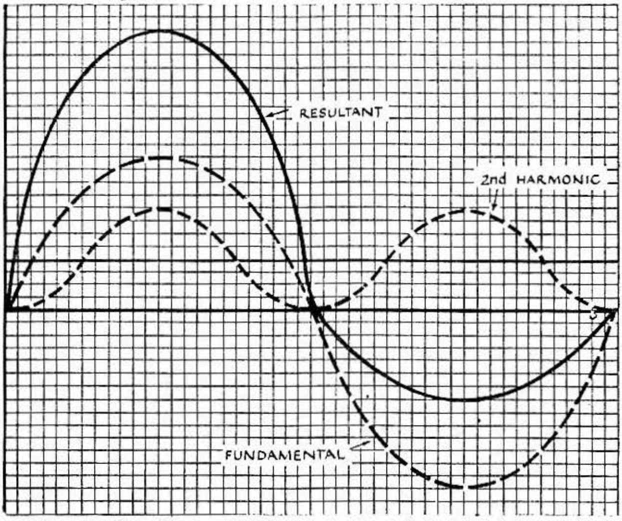


Fig.8-7. Second harmonic distortion.

In an audio amplifier, the distorted signal frequency is converted by the speaker into a distorted sound frequency which sounds unpleasant to the ear. If we could remove this second harmonic from the amplified signal before it reaches the speaker, we would end up with the original undistorted waveform.

Push-pull operation eliminates second harmonic distortion. Fig.8-8 illustrates the distorted output of two class A amplifiers connected in push-pull. A class "A" push-pull amplifier differs from a class "B" push-pull amplifier in that both tubes in the class "A" push-pull amplifier conduct current continuously. Both tubes combine their output during both the positive as well as the negative cycles to give us the resulting waveshape. Notice that the two curves combine together, point by point, to produce the resultant undistorted output curve. The second harmonics of V_1 and V_2 are out of phase with each other across the transformer primary, and consequently cancel each other out. By eliminating even (2nd, 4th, 6th, etc.) harmonic distortion, push-pull operation improves the fidelity of reproduction

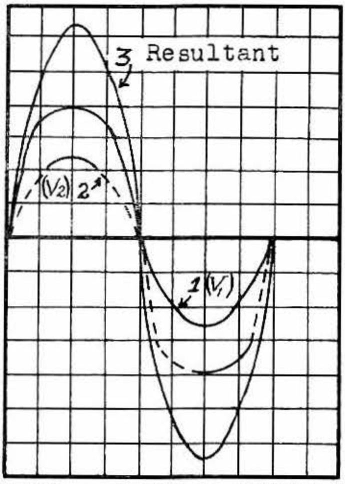


Fig. 8-8. Push-pull operation eliminating second harmonic.

considerably over that obtainable from one tube (single-ended) operation.

8-16. Types of Distortion in Amplifiers

Distortion may take many forms in audio amplifiers and may arise from many sources. We will discuss the more important types of distortion.

1.- Harmonic Distortion: This type of distortion was discussed under push-pull amplifier systems. It is sometimes referred to as non-linear distortion. Non-linear distortion arises when an electron tube is operated on the non-linear portion of its characteristic curve.

2.- Frequency Distortion: Frequency distortion is the result of the inability of an amplifier to amplify all signal frequencies by the same amount. For a clearer picture of this type of distortion, refer back to lesson 7, paragraph 15. Frequency distortion is due to the characteristics of tubes and coupling systems which cause a decrease in gain at the high and low frequencies within the audio range.

3.- Phase Distortion: In passing through an amplification system, signals always encounter a certain amount of delay. If the delay time is different for the different frequencies which go to make up a musical tone, the result will be an alteration of the wave form. The harmonics in the output wave will appear at different phase angles with respect to the fundamental. As a result, the amplified wave, which is the sum of the fundamental and harmonics, has a different waveshape than the input waveform. This distortion is hardly discernible by ear, but it takes on great importance in television.

8-17. Inverse Feedback

Fig.8-9 shows a circuit in which part of the output signal on the plate of the power tube is fed back to the grid through a resistor and condenser. Since the plate and

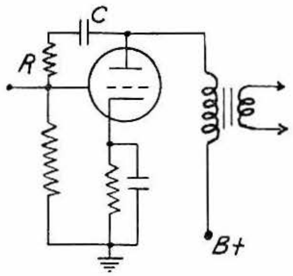


Fig.8-9. Negative feedback.

grid voltages are out of phase, the feedback signal will be out of phase with the grid signal. If the amount of feedback is correctly adjusted, the harmonics causing distortion may be partially cancelled out. Since a portion of the original signal is also being fed back out of phase, the overall gain of the system is reduced. This disadvantage can be overcome by using either high mu tubes or another stage of amplification. As a result of inverse feedback, the distortion is reduced to a great extent.

Inverse feedback is also known as negative feedback and degenerative feedback.

PRACTICE QUESTIONS - LESSON 8

(For answers, refer to back of Study Guide, Section II)

8-1.* One of the advantages of push-pull operation is that;

a. two tubes are required rather than one
b. it eliminates second harmonic distortion
c. it eliminates the fundamental frequency from the output
d. the amplification is decreased

8-2.* Harmonic distortion is caused by;

a. operating on the non-linear section of the tube characteristic curve
b. using pentode tubes
c. class A operation
d. push-pull operation

8-3.* The second harmonic of 500 cps is; a. 500 cps. b. 1500 cps. c. 1000 cps. d. 250 cps.

8-4.* The fifth harmonic is a frequency which is;

a. one-fifth of the fundamental
b. 10 times the fundamental
c. 20 times the fundamental
d. 5 times the fundamental

8-5.* The third harmonic of 350 cps is; a. 117 cps. b. 250 cps. c. 700 cps. d. 1050 cps.

8-6.* One of the advantages of a class B amplifier over a class A amplifier is;

a. low efficiency
b. high gain
c. higher operating efficiency
d. low plate voltage.

8-7.* One of the advantages of a class B amplifier over a class A amplifier is;

a. less plate dissipation
b. low plate resistance
c. low B voltage
d. does not require feedback

8-8.* One of the advantages of class B amplification over class A amplification is;

a. higher power output can be realized
b. high transconductance
c. low interelectrode capacity
d. low plate resistance

8-9.* A microphone;

a. amplifies a sound
b. converts electricity
c. converts sound energy into electrical energy
d. amplifies electrical frequencies

8-10.* Frequency distortion is;

a. delay of harmonic frequencies during amplification
b. harmonic distortion
c. non-linear distortion
d. unequal amplification of the signal frequencies present at the input

STUDY GUIDE SECTION II

You should use the following outline as a guide to the lesson material in Section II that you most likely will be questioned about on the government license examination.

A. Lesson 4 - The Diode

Be sure to understand thoroughly the theory of the diode tube before proceeding to lesson 5 (rectification) which is based upon the operation of the diode. (refer to practice question 1)

B. Lesson 5 - Rectification and Filtering

1. Lesson 5 is one of the most important in the course, as a large number of questions on the license examination will be based upon the material it contains. You should therefore study this lesson thoroughly from beginning to end. Be sure that you can answer every one of the practice questions. (refer to practice questions 1 through 15)

2. You should be able to draw the following schematic diagram :

a.- full-wave, mercury-vapor rectifier system. Know the names of the component parts and approximate values of the filter components (refer to paragraph 24 and fig. 14.

C. Lesson 6 - Triode, Tetrode, Pentode

1. You should know how to calculate the d-c plate power input to a tube when given the d-c plate voltage and d-c plate current. (refer to paragraph 6-8) (refer to practice questions 7,8,9,10)

2. You should know the number of elements which make up the triode, tetrode and pentode. (refer to practice questions 4,15,16)

3. You should know the advantages of a tetrode over a triode (paragraph 6-11) (refer to practice questions 13, 18)

4. Understand what is meant by the term "maximum plate dissipation" in reference to a tube (paragraph 6-9) (refer to question 17).

5. Be able to work out problems similar to practice problems 19 and 20.

a. Here are some hints to assist you in working out problem 19 (refer to fig.6-16). Notice that the only current which flows through R_1,is the total supply current of 35 ma. Therefore $E_g = I_s R_1$. Notice also that the current flowing through the bleeder resistor, R_2, is the difference between the supply current and the plate current ($I_s - I_p$). By Ohms law, $E_b = (I_s - I_p) \times R_2$. The supply voltage is simply the sum of the voltage drop across the two resistors, R_1 and R_2 ; $E_{bb} = E_g + E_b$

D. Lesson 7 - Audio Amplifiers

1. You must thoroughly understand the operation of a class A amplifier. You must be familiar with the resulting distortion caused by improper bias operation. Review carefully paragraphs 7-6, 7-7, 7-16, and 7-17. Be sure that you can answer practice questions 2,3,4,5,6,7,11,12,13,14.

2. a.- You should be able to draw a circuit diagram of a two stage, resistance-coupled amplifier (some of the questions on the government examination may involve the drawing of a circuit diagram) (refer to fig. 7-5)

b.- You should be able to draw the schematic diagram asked for in practice question 9.

3. You should know that the plate efficiency of a class A amplifier is relatively low. (paragraph 7-16) (refer to practice question 8)

4. You should be able to calculate the bias voltage of a cathode biased amplifier (paragraph 7-8) (refer to practice question 10)

E. Lesson 8 - Microphones, Reproducers, Power Amplifiers

1. You must thoroughly understand the operation of the class B amplifier (paragraph 8-12, 8-13). You should know all the advantages that a class B amplifier has over a class A amplifier. (refer to practice questions 6,7,8)

2. You should be familiar with the theory of the push-pull amplifier (paragraph 8-14)

3. You should know what is meant by second harmonic distortion (paragraph 8-15) Be able to answer questions similar to practice questions 2,3,4,5.

4. You should know that a push-pull amplifier cancels out the second harmonic in the plate circuit (paragraph 8-15) (refer to practice question 1)

ANSWERS TO PRACTICE QUESTIONS

Lesson 4

1.- b	6.- b
2.- d	7.- a
3.- a	8.- b
4.- d	9.- c
5.- a	10.- d

Lesson 5

1.- b	6.- c	11.- d	16. Refer Fig. 5-14
2.- c	7.- b	12.- b	17. Refer Fig. 5-11
3.- b	8.- d	13.- c	
4.- a	9.- a	14.- c	
5.- d	10.- b	15.- a	

Lesson 6

1.- c	6.- b	11.- a	16.- d
2.- a	7.- d	12.- c	17.- b
3.- a	8.- c	13.- a	18.- d
4.- d	9.- a	14.- d	19.- a) 7.0 V b) 100.0 V c) 107.0 V
5.- b	10.- d	15.- b	20.- a) 75 V b) 150 V c) 225 V

Lesson 7

1.- see fig. 7-5	6.- c	11.- b
2.- d	7.- a	12.- a
3.- b	8.- b	13.- a
4.- a	9.- see fig. 7-5, 7-6	
5.- c	10.- d	

Lesson 8

1.- b	6.- c
2.- a	7.- a
3.- c	8.- a
4.- d	9.- c
5.- d	10.- d

"FCC-TYPE EXAMINATION" SECTION II

Mark in the space next to the number of the question on the answer sheet, the letter of the answer you think is correct.

1.- One of the advantages of a class B amplifier over a class A amplifier is;

a. a higher transconductance
b. lower interelectrode capacity
c. a higher power output can be realized
d. low plate resistance

2.- The second harmonic of 350 cps is; a. 117 b. 250 c. 700 d. 1050

3.- One of the advantages of a class B amplifier over a class A amplifier is;

a. high gain
b. low power output
c. low plate current
d. higher operating efficiency

4.- Push-pull operation;

a. doubles the second harmonic in the grid circuit
b. improves the signal strength
c. cancels out the second harmonic in the plate circuit
d. cancels the third harmonic in the plate circuit

5.- Refer to fig.6-16 of lesson 6 (practise questions 19)
Let: $R_1 = 300\Omega$, $R_2 = 15,000\Omega$, $I_P = 10$ ma

$I_S = 15$ ma

Find: a) E_g b) E_b c) E_{bb}

6.- Maximum plate dissipation refers to;

a. maximum safe heat radiation capability of the plate in watts
b. transconductance expressed in watts
c. power gain of an amplifier
d. power sensitivity of a tetrode

7.- A pentode has; a. 6 grids. b. 4 grids c. 3 grids d. 8 grids

8.- A tetrode is superior to a triode as a radio-frequency amplifier because of its;

a. suppressor grid
b. increased cathode emission
c. high plate resistance
d. reduced possibility of oscillations

9.- The d-c power input to the plate of a tube having a plate voltage of 800 volts and a plate current of 85 ma is; a. 68 W. b. 680 W. c. 6.8 W. d. 68,000 W.

10.- A mercury vapor tube in operation exhibits;

a. red plate
b. white spot on the cathode
c. drops of mercury on the plate
d. a bluish-green glow

11.- A choke input filter;

a. increases the output voltage
b. lowers the ripple frequency
c. provides the best voltage regulation
d. doubles the ripple frequency

12.- The filament is always allowed to warm up before applying plate voltage with a;

a. mercury vapor tube
b. high vacuum rectifier
c. cold-cathode, gas-filled rectifier
d. beam power pentodes

13.- If a filter condenser shorts;

a. the ripple frequency is increased
b. the rectifier tube will probably burn out
c. the output current will vary
d. B+ voltage will tend to increase

14.- A bleeder resistor;

a. improves the voltage regulation
b. limits the output voltage
c. does not help the voltage regulation
d. does not help discharge filter condensers

15.- Connecting the primary of a power transformer to the d-c line;

a. burns out the primary winding
b. burns out the secondary winding

c. burns out the rectifier tube
d. blows the filter condensers

16.- A mercury-vapor rectifier does not have;

a. low internal resistance
b. high current rating
c. high inverse peak voltage rating
d. constant internal voltage drop

17.- A filter circuit in a power supply does not;

a. use electrolytic condensers
b. filter out the d-c
c. filter out the a-c
d. provide a d-c voltage

18.- A full-wave, bridge rectifier system using the same power transformer as a full-wave rectifier system would have;

a. one-half the output voltage
b. double the output voltage
c. triple the output voltage
d. the same output voltage

19.- The ripple frequency of a half-wave rectifier system is;

a. the same as that of a full-wave rectifier
b. twice that of a full-wave rectifier
c. one-half that of a full-wave rectifier
d. 120 cycles per second

20.- The approximate values of the filter condensers in a transmitter power supply are between;

a. 20 to 40 mfd
b. 100 to 200 mfd
c. 2 to 4 mfd
d. 200 to 400 mfd

21.- In a class A amplifier, the grid bias is adjusted for operation over;

a. the linear range of the characteristic curve
b. the bottom range of the characteristic curve
c. the top range of the characteristic curve
d. the entire range of the characteristic curve

22.- In a class A amplifier, plate current;

a. is cut-off during the negative half of the input signal

b. is cut-off during the positive half of the input signal
c. is continuously cut-off
d. flows during the entire cycle of the input signal

23.- In a class A amplifier;

a. the signal never drives the grid into cut-off or into grid current
b. the grid draws current
c. the grid operates at cut-off
d. grid operates at a positive bias

24.- In a class A amplifier, the average plate current;

a. increases with signal application
b. decreases with signal application
c. drops to zero with signal application
d. remains constant with signal application

25.- The plate efficiency of a class A amplifier is;

a. quite high
b. relatively low
c. the best of all the amplifiers
d. 100%

26.- Improper class A bias results in;

a. decrease in amplification
b. phase distortion
c. distortion of the output waveform
d. improved operation

27.- A decrease in the class A average plate current reading with signal application indicates;

a. excessive grid bias
b. positive grid bias
c. insufficient negative grid bias
d. proper operation

28.- An increase in the class A average plate current reading with signal application indicates;

a. excessive grid bias
b. positive grid bias
c. insufficient negative grid bias
d. proper operation

AMATEUR RADIO COURSE

SECTION III   LESSON 9

OSCILLATORS

INTRODUCTION TO TRANSMISSION AND RECEPTION.

The first eight lessons of this course were devoted to a study of vacuum tubes, fundamental radio theory, and basic circuits. These lessons contain the background material for our discussion of transmitters and receivers. However, before we go into a detailed study of actual transmitter circuits, we will take a bird's eye view of a complete communications system. Instead of drawing out the individual circuits for you, we will draw a series of boxes, each box representing a stage. (A stage is a tube with its associated parts) The function of each stage will be printed inside the box. Such a diagram is known as a block diagram.

Figure 1 illustrates a block diagram of a radio-telephone transmitter. Let us see briefly what the function is of each stage outlined in the block diagram. The heart of

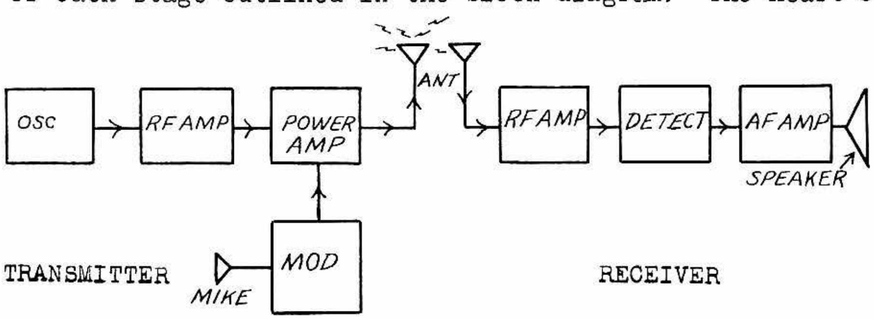


Fig.1 Radio transmitter and receiver.

the transmitter is the oscillator. Its sole purpose is to generate a high frequency alternating current. This high frequency a-c is called radio frequency or r-f. The output of the oscillator is fed to the radio frequency amplifier which simply amplifies the r-f output from the oscillator. The output of the r-f amplifier is then fed to the r-f power amplifier. The r-f power amplifier amplifies the r-f in terms of power. The power amplifier then supplies the antenna with the r-f power that is to be radiated into space. Up to this point we have only discussed the generation and transmission of a radio frequency wave which by itself contains no intelligence. The intelligence that we desire to transmit is the audio in the form of voice or music. Let us see how the audio is radiated into space.

The microphone has already been taken up in detail. Its function is to convert sound energy into electrical energy. The output of the microphone is applied to the modulator which is simply an audio amplifier. The modulator serves two functions: 1) It amplifies the weak audio output of the microphone. 2) It superimposes the audio on to the radio frequency energy that is present at the power amplifier stage by a process called modulation. The audio is combined with the r-f wave because an audio wave by itself is not capable of travelling through space. High frequency such as r-f, however, is capable of travelling through space. The r-f therefore acts as the "carrier" for the audio; the r-f carries the audio from the transmitter to the receiver. The combined audio-r-f output of the power amplifier is fed to the antenna where it is radiated out into space in the form of electromagnetic waves.

At the receiving end of the communications system, the electromagnetic waves induce small voltages into the receiving antenna. These signal voltages are quite weak because the electromagnetic waves have travelled some distance before striking the receiving antenna. The signal voltages must therefore be amplified; this is the function of the first stage in the receiver called the r-f amplifier. The output of this stage is applied to the detector. Just as the oscillator is the heart of the transmitter, the detector is the heart of the receiver. The detector stage separates the audio from the r-f carrier. The carrier has served its purpose in bringing the audio to the receiver. Now, all we are interested in is the audio. The audio output of the detector is then fed to an audio amplifier stage to be amplified. The amplified audio is applied to a speaker which converts the audio electrical variations back into the original sound that energized the microphone of the transmitter.

Thus, we have briefly described the overall picture of a communications system. The remaining lessons will go into the details of each stage of a communications system. We will first consider the oscillator of the transmitter.

9-1. Introduction to Oscillators

Simply speaking, a vacuum tube oscillator is an electronic alternating current generator. It is a device used to generate an alternating current of any desired frequency. All transmitters, and practically all receivers, make use of a vacuum tube oscillator. Vacuum tube oscillators are also employed in various types of instruments used for testing and adjusting radio equipment. Because oscillators find so many applications, various types of oscillator circuits have been developed. The operation, however, of the different types of oscillators is fundamentally the same.

9-2. The Oscillating Tuned Circuit

The heart of an oscillator is a TUNED CIRCUIT which consists of a coil and condenser in parallel. In order to understand how a complete oscillator works, it is first necessary to see how a simple tuned circuit can produce alternating current oscillations. An elementary oscillatory circuit is shown in fig. 9-1. When the switch is thrown to the left, the condenser "C" is placed across the battery.

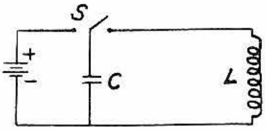


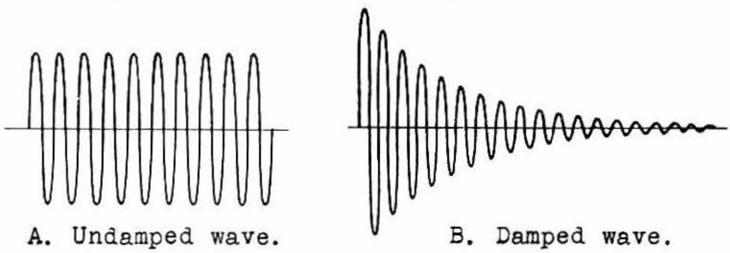
Fig. 9-1. An elementary oscillatory circuit.

The coil "L" is out of the circuit. "C" will immediately charge up to the voltage of the battery. The upper plate of "C" will become positive, and the lower plate will become negative. A certain amount of electrical energy is therefore stored up on the plates of the condenser by the charging process. If the switch is then thrown to the right, the condenser will discharge through the coil "L". The electrons will flow from the lower plate of "C", through the coil and back to the upper plate of "C". The flow of electrons will build up a magnetic field around "L". The energy which was stored in the condenser has been transferred over to the magnetic field surrounding the coil. When "C" is discharged completely, the flow of electrons through "L" tends to cease, causing the magnetic field to start collapsing. The collapsing magnetic field induces a voltage of such a polarity across "L", that it maintains the flow of electrons to the upper plate of the condenser. This occurs because the magnetic field acts to prevent a change in the flow of current

(Lenz's Law). For a review of Lenz's law and the action of an inductance refer to paragraph 3-8. The flow of electrons to the upper plate continues until it is negative with respect to the bottom plate. When the magnetic field has completely collapsed, the energy which was in the magnetic field has been transferred over to the condenser in the form of a stored charge. The condenser is now charged in the opposite polarity to its original charge. The condenser again discharges through "L", and the entire action as outlined above repeats itself. Thus we can see that the current OSCILLATES back and fourth between the coil and the condenser, alternately charging "C" first in one direction and then in the other. This alternating current will produce an alternating voltage across the tuned circuit. The frequency of this a-c voltage is determined by the values of "L" and "C".

9-3. The Damped and Undamped Wave

If there were no resistance in either the coil or the condenser, there would be no energy loss in the form of heat. The oscillations would therefore continue forever at a constant amplitude. A graph, illustrating this condition is shown in fig. 9-2A. The wave is called an UNDAMPED WAVE (continuous oscillations). However, such a situation is



A. Undamped wave. B. Damped wave.

Fig. 9-2. Oscillations.

impossible in actual practise. Some resistance is always present in radio components, especially in a coil. This resistance causes some of the energy which oscillates back and forth in the tuned circuit to be transformed into heat. The heat, of course, is a loss of energy. Therefore, with each succeeding cycle, the amplitude of the oscillating voltage decreases until all of the energy has been dissipated in the form of heat. Fig. 9-2B illustrates the diminishing oscillations which are called a DAMPED WAVE.

9-4. Condition for Oscillation

In radio, it is necessary that the tuned circuit oscillations continue at a constant amplitude. (just like the undamped wave of fig. 9-2A.) If we want the oscillations to continue, we must make up for the resistance losses which occur in the L-C circuit. We must somehow inject electrical energy back into the L-C circuit to sustain the oscillations. Where is this energy to come from, and how do we inject it properly into the L-C circuit? To clarify this question in our mind we can compare the oscillations of energy in the tuned circuit to a child on a swing. In order that the child keep swinging at a constant height, it is necessary that someone give the swing a little push each time the child reaches the top of his swing. In other words, energy must be added to the swing at the right time and of the right amount to overcome the friction in the hinges. Otherwise the swing will gradually come to rest just like the damped wave oscillations. In radio, the answer to the question of how to maintain oscillations lies in the use of the amplifying ability of the electron tube. When a vacuum tube is hooked up to a power supply, the a-c energy developed in the plate circuit is much greater than that applied to the grid circuit; this is due to the tube amplification. If the oscillating circuit of fig. 9-1 were to be connected to the grid circuit of a vacuum tube, an amplified version of the oscillating voltage would appear in the plate circuit. If we could somehow continuously feed back some energy from the plate circuit to the grid circuit to compensate for the resistance losses in the L-C grid circuit, oscillations could continue like the undamped wave of fig. 9-2A. A simple method of doing this is shown in fig. 9-3. L_1 and C_1 represent the tuned circuit,

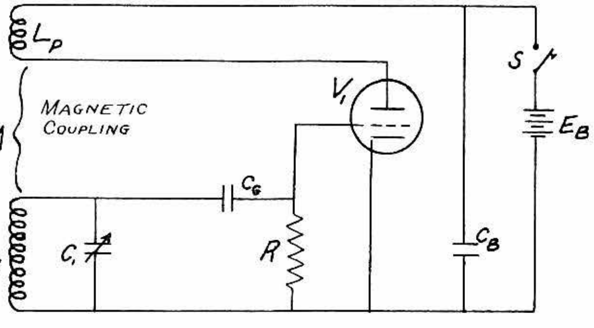


Fig. 9-3. Tickler-coil oscillator or Armstrong oscillator.

sometimes called the TANK CIRCUIT. V_1 is the triode amplifier tube. L_p is a coil of wire wound on the same form and next to L_1. Since L_p is in the plate circuit, it is easy to see that some of the amplified energy from the plate circuit is fed back to the grid circuit through the magnetic coupling between the two coils. If this energy can overcome the losses in the tank circuit, oscillations will be maintained.

The entire circuit of fig. 9-3 is called a vacuum tube oscillator. This particular oscillator has found wide practical use, especially in modern receivers. It is known by the names of the TUNED GRID OSCILLATOR, TICKLER COIL OSCILLATOR, or the ARMSTRONG OSCILLATOR. We shall now discuss in detail the operation of this vacuum tube oscillator.

9-5. Operation of a Vacuum Tube Oscillator

As soon as the switch "S" is turned on, a surge of plate current flows through the plate coil, L_p. This surging current builds up an expanding magnetic field around L_p. The expanding field cuts through L_1 and induces an e-m-f in it. The induced e-m-f across the coil will now charge the condenser of the tuned circuit. The condenser then discharges through L_1 and the oscillatory action, previously described, has now begun. The losses in the tank circuit are overcome by a feed-back of energy from the plate circuit to the grid circuit by means of magnetic coupling between L_p and L_1 indicated by the letter M. In this manner the oscillations of the tuned circuit are maintained at a constant amplitude.

L_p, called the TICKLER COIL, must be wound in such a direction so that an expanding field about it induces a voltage in L_1 so that the grid goes positive. A positive grid will cause the plate current and the field around L_p to further increase, and induce energy back into L_1. The process of transferring energy from L_p of the plate circuit to L_1 of the grid circuit is called INDUCTIVE FEEDBACK or MAGNETIC FEEDBACK. Since the energy fed back to the tuned circuit is sufficient to make up for the energy lost in the resistance of the tank circuit, the oscillations will continue and will not die down. If the tickler coil is wound in such a direction so as to make the grid negative, the oscillator will NOT start oscillating at all.

From the above explanation we realize that the vacuum tube itself does not oscillate. The oscillations actually take place in the tuned circuit. The vacuum tube simply functions as an electrical valve which automatically controls the release of energy back into the tuned circuit. The feed-back energy overcomes losses and maintains oscillations. The above explanation of the operation of an oscillator is basic to all oscillator circuits that will be covered in this lesson.

9-6. Feed-back

Let us continue further with the explanation of how the oscillator works. We will now discuss the question of how much feed-back is necessary to sustain oscillations. Is it necessary to feed back energy continuously from the plate circuit to the grid circuit during the entire cycle of oscillation? Because the grid tank circuit has electrical inertia, this becomes unnecessary. (a swing has mechanical inertia; things set in motion tend to continue in motion by their own momentum) The tank circuit will oscillate properly if it receives energy during only a small portion of the a-c cycle; just as a man pushing a swing need only give the swing a push when it comes to him. The swing continues oscillating back and forth so long as it receives one push during its entire cycle.

Since it is not necessary to feed back energy from the plate to the grid circuit for an entire cycle, plate current need not flow for an entire cycle. All that is required is pulses of plate current which will feed back pulses of energy to the tank circuit. If plate current were to flow for the entire cycle, there would be too much feedback to the grid circuit; and the efficiency of the oscillator would thereby be reduced because an unnecessary flow of plate current represents a waste of power. In a properly designed oscillator, the plate current flows for about ¼ of a cycle (90°). The plate current must therefore be cut-off during the remainder of the cycle (270°).

Fig. 9-4 shows the operating characteristics of an oscillator. Notice that only the peaks of the oscillations bring the tube out of cut-off and cause current to flow.

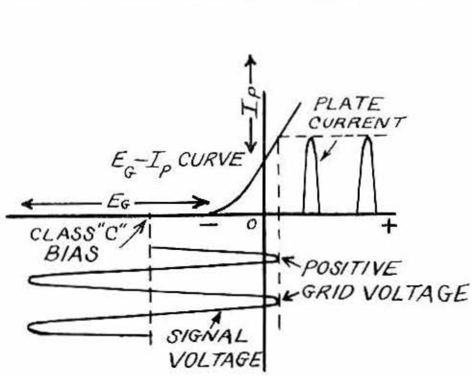


Fig. 9-4. Class "C" operation.

A tube that is biased beyond the cut-off point is said to have CLASS C bias.

9-7. Grid-leak Bias

There are several ways of obtaining high negative bias, as required for class C operation. One way is by means of a battery; another is by means of a negative voltage power supply. However, in the case of an oscillator, the only practical way of obtaining this high negative bias is by means of a resistor and condenser (R C_G) connected in the grid circuit, as shown in fig.9-3. This type of bias is known as GRID-LEAK BIAS. Grid-leak bias is used in all oscillators and in many class C, r-f amplifiers. A simple explanation of grid-leak bias is as follows:

When the peaks of the oscillations in the tank circuit drive the grid positive with respect to the cathode, grid current, I_G, flows in the grid circuit. A positive grid attracts electrons as does a positive plate. The grid current flow charges up condenser C_G in the manner shown in fig.9-5A. During the remainder of the cycle, the grid does not conduct and the condenser discharges through R as shown in fig.9-5B. Current flowing through R produces a voltage such that the top or grid side of R becomes negative with

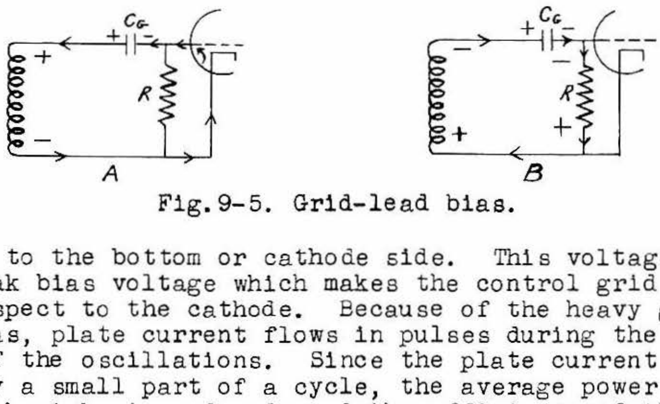


Fig.9-5. Grid-lead bias.

respect to the bottom or cathode side. This voltage is the grid-leak bias voltage which makes the control grid negative with respect to the cathode. Because of the heavy grid-leak bias, plate current flows in pulses during the positive peaks of the oscillations. Since the plate current flows for only a small part of a cycle, the average power wasted inside the tube is reduced, and the efficiency of the oscillator is increased. The fact that the plate current does not flow continuously does not hinder oscillations because it is only necessary to feed back small pulses of energy in every cycle to sustain the oscillations.

9-8. Frequency of Oscillation

The larger the value of the inductance in the tuned circuit, the longer it will take for the condenser to discharge through the inductance. Likewise, the larger the capacitance, the longer it will take the condenser to charge or discharge. Since the time of a cycle of oscillations depends upon the charge and discharge time, it can be seen that the frequency of the oscillator goes down as the inductance or capacitance is increased. On the other hand, the frequency goes up if the inductance or capacitance is made smaller. The formula for the frequency of an oscillator is:

$$9\text{-}1)\quad F = \frac{1}{2\pi\sqrt{LC}}$$

where: F is the frequency in cycles
L is the tank inductance in henries
C is the tank capacitance in farads

In order to vary the frequency of the oscillator, it is necessary to vary the value of the inductance or the capacitance. In most receivers and transmitters a variable condenser is used in the tank circuit to vary the frequency of the oscillator.

9-9. Series-fed and Parallel-fed Oscillators

Fig. 9-3 is a schematic of a series-fed armstrong oscillator. It is called a SERIES-FED OSCILLATOR because the d-c plate current flows through the plate coil, L_P. In some cases it is desirable to arrange the circuit so that the d-c component of the plate current does not flow through the plate coil. This is shown in fig. 9-6. In this circuit the high plate voltage is blocked from the tickler or plate coil by condenser C_2. Only the a-c component of the plate current flows through condenser C_2, and the plate coil, and

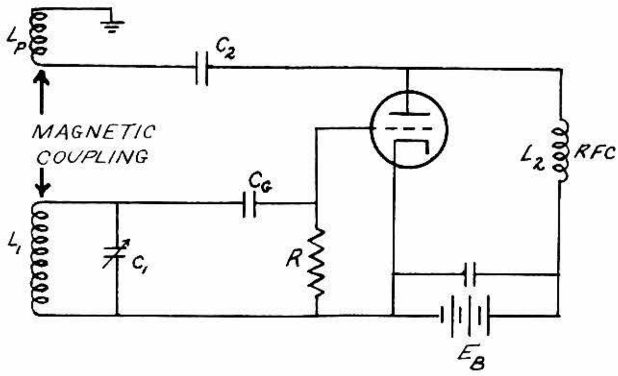


Fig. 9-6. Shunt-fed Armstrong oscillator.

generates the magnetic field which is needed for feedback purposes. The oscillator of fig. 9-6 is known as a PARALLEL-FED or SHUNT-FED OSCILLATOR. The coil labeled RFC (L_2) is known as a radio frequency choke. It is designed to have a high impedance to r-f. The purpose of the radio frequency choke is to prevent the r-f currents from flowing to B+. Because the r-f currents are blocked by coil L_2, they flow through the d-c blocking condenser C_2 and through the tickler feed-back coil to ground.

To summarize: If the d-c component of the plate current flows through the plate coil, the oscillator is series-fed. If the plate current does not flow through the plate coil, the oscillator is shunt-fed.

9-10. The Hartley Oscillator

A popular oscillator that is frequently used in electronic circuits is the HARTLEY OSCILLATOR. Its principle of operation is very similar to that of the Armstrong Oscillator. Instead of having two separate plate and grid coils, the Hartley oscillator has a single coil which is tapped. The Hartley oscillator can always be recognized by its tapped coil. (see fig. 9-7 and 9-8) One part of the

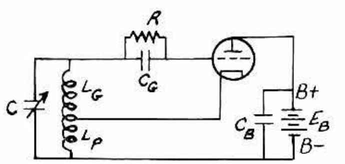


Fig. 9-7. Series-fed Hartley

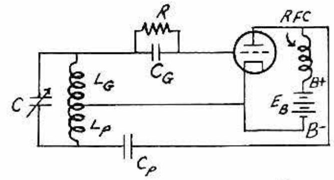


Fig. 9-8. Shunt-fed Hartley

coil, (L_P), is in the plate circuit and the other part, (L_G), is in the grid circuit. Capacitor, C, is across the entire coil. The resonant frequency of this oscillator is determined by C and L_G and L_P in series. You will recall that in the Armstrong oscillator energy is fed back by inductive coupling between the tickler coil and the grid coil. The feedback in the Hartley oscillator is also due to inductive coupling (between L_P and L_G). The tickler coil may be represented by L_P. The amount of feedback can be controlled by varying the position of the tap on the coil. The theory of operation of the Hartley oscillator is exactly the same as the Armstrong oscillator. Fig. 9-7 shows a series-fed Hartley oscillator and fig. 9-8 shows a shunt-fed Hartley oscillator. As previously mentioned, the purpose of the r-f choke in fig. 9-8 is to keep the r-f out of the power supply.

9-11. The Colpitts Oscillator

Fig. 9-9 illustrates a shunt-fed COLPITTS OSCILLATOR. The only difference between the colpitts oscillator and the Hartley oscillator is that the Colpitts oscillator has a split tank condenser whereas the Hartley oscillator has a split tank coil. Condenser C_2 is in the plate circuit and C_1 is in the grid circuit. Energy is fed back from the plate circuit to the grid circuit by means of capacity coupling between condensers C_2 and C_1. This type of feed-

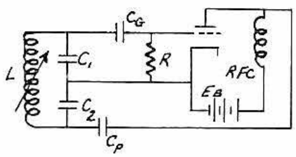


Fig. 9-9. Colpitts oscillator.

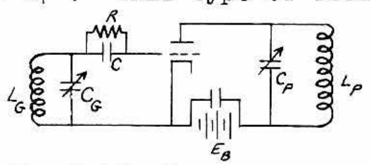


Fig. 9-10. Tuned-plate, tuned-grid oscillator.

back is called CAPACITIVE FEEDBACK. The amount of feed-back is controlled by varying the ratio between the two capacitors. The frequency of this oscillator can be varied by either varying the capacities of the condensers or the inductance of the coil. If the condensers are made variable, they are usually ganged.

9-12. Tuned Plate - Tuned Grid Oscillator

Fig. 9-10 represents a series-fed, TUNED PLATE-TUNED GRID OSCILLATOR with the plate and grid circuits tuned separately. The plate coil, L_P, and the grid coil, L_G, are not magnetically coupled to each other. Physically, they may be quite some distance from each other. How then, is energy transferred from the plate circuit back to the grid circuit to sustain oscillations? The answer is to be found in the internal grid to plate capacitance of the triode. Since the plate and grid in effect are two conductors separated by an insulator (dielectric), we have a capacity effect existing between the grid and plate. This capacity is known as the grid to plate interelectrode capacity; the symbol for which is C_{G-P}. The feed-back energy is fed back from the plate circuit to the grid circuit through this interelectrode capacitance. As a result, oscillations are sustained. Both the plate and grid circuits are tuned approximately to the same frequency.

9-13. Frequency Stability of Oscillators

If an oscillator remains in operation continuously, it will be found that the frequency of the oscillator drifts with time. For example, when an oscillator is first turned on it may start to oscillate at a frequency of 1000 kc.

After the oscillator warms up, the frequency may drift either above or below 1000 kc by as much as 10 kc. Frequency drift is highly undesirable in a broadcast transmitter since it would cause fading of the signal at the receiver end. Similarly, oscillators in test equipment must have a minimum of frequency drift if the equipment is to serve any useful purpose. The causes of oscillator drift and its prevention are subjects of importance to all radio men, especially amateur radio operators.

Oscillator frequency drift may be caused by the following factors:

1.- improper design of the oscillator circuit
   a. choosing the wrong combination of L and C for the tank circuit

2.- poor voltage regulation of the oscillator power supply
   a. changes in B+ voltage will cause voltage variations at the screen and plate which will vary the gain of the tube. Changes in gain will vary the oscillator frequency. A well regulated oscillator power supply is therefore necessary for good frequency stability.

3.- changes in plate resistance and interelectrode capacitance of a tube will cause the frequency to vary.

4.- changes in temperature will cause the inductance and capacitance of the tank circuit to vary. A physical change in either L or C will change the oscillating frequency.
   a. negative-temperature coefficient condensers are used in the tuned circuit to compensate for changes in inductance or capacitance with temperature.

5.- changes in loading of the oscillator
   a. if the output of the oscillator is fed directly into a varying load, the frequency of the oscillator will be affected. The oscillator must be isolated from the varying load in order to maintain good frequency stability. This is accomplished in the electron-coupled oscillator which we will now study.

9-14. <u>The Electron-coupled Oscillator</u>

Fig. 9-11 is a schematic diagram of a series-fed ELECTRON-COUPLED OSCILLATOR. The tank circuits, in the plate and in the grid, are tuned to the same frequency. If you examine the circuit carefully, you will see that the cathode, control grid, and screen grid circuits by themselves form a Hartley oscillator; the screen grid acts as the

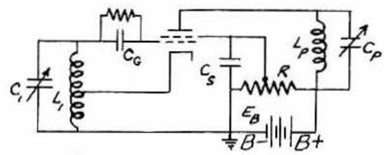


Fig.9-11. Electron-coupled oscillator.

plate of the oscillator. The plate of the tube serves only to couple energy from the oscillator to the load in the plate circuit. It simply collects the electrons from the cathode and transfers them to the load in the plate. The electrons flowing from the cathode to the plate are acted upon by the a-c voltage which appears at the grid of the oscillator. Thus, the electron stream in flowing to the real plate is caused to vary at the frequency of the Hartley oscillator. The plate current in flowing through the tuned plate circuit,(L_P, C_P), injects energy into it and causes it to oscillate at the same frequency as the grid tuned circuit (L_1, C_1). The oscillations in the plate tank circuit are sustained by pulses of energy which are coupled to the plate from the oscillator section via the electron stream of the tube. This is how this type of oscillator came to be called an "electron-coupled oscillator" (E.C.O)

The frequency of the E.C.O. is determined by the tuned circuit in the control grid section. Load variations in the plate section will not reflect back to the grid circuit to vary the oscillator frequency because the only means of coupling between the two parts of the oscillator is through the electron stream which flows only from cathode to plate. There is no interelectrode capacitive coupling between the plate and control grid because electrostatic shielding is offered by the screen grid. The screen grid acts as an electrostatic shield because condenser C_S places it at ground potential with respect to r-f. Thus we see that the tuned circuit in the grid section is well isolated from load variations, and therefore can maintain a constant frequency.

The frequency stability of the electron-coupled oscillator is not affected by voltage variations occuring in the power supply. An increase in the screen voltage causes the oscillator's frequency to shift in one direction; while at the same time, an increase in the plate voltage causes the frequency to shift in the opposite direction. Since the screen grid and plate receive their voltages from the same power supply, any frequency shift due to a varying plate voltage will be cancelled out by an opposite frequency shift which is due to the varying screen voltage. Thus, the frequency of the electron-coupled oscillator will be maintained fairly constant in spite of B+ voltage fluctuations. The screen grid voltage is adjusted by means of the tap on resistor R for maximum frequency stability.

Because of its excellent stability, the electron-coupled oscillator is used extensively in instruments and devices which require a stable oscillator.

9-15. Crystal-controlled Oscillators

The most stable of all oscillators is the CRYSTAL-CONTROLLED OSCILLATOR. The most important difference between the oscillators studied to date and the crystal oscillator is that the oscillator tuned circuit consisting of L and C is replaced by a crystal substance. This crystal is usually made out of quartz, a mineral found in the earth. The quartz crystal has the following peculiar property. If a mechanical vibration is applied to the quartz crystal, an electrical voltage will be developed across its surfaces. On the other hand, if we apply an alternating voltage to the surfaces of the quartz crystal, it will vibrate mechanically at the frequency of the a-c voltage. This property of the quartz is known as the PIEZO-ELECTRIC EFFECT.

If we momentarily apply an a-c voltage to two parallel surfaces of the crystal, it will start to vibrate mechanically; this mechanical vibration will in turn generate an a-c voltage. This a-c voltage will again cause the crystal to vibrate, etc., etc.. This process will continue until all of the energy which was injected into the crystal is used up. The crystal, from an electrical viewpoint, acts in the same manner as a tuned circuit. If energy is injected into a crystal, an electrical oscillation is generated across the crystal surface which continues until all of the energy has been used up. Since the vibrating crystal is similar to a tuned circuit, it can be placed in the grid circuit of the tuned plate-tuned grid oscillator in place of the actual tuned grid circuit. A schematic of a triode crystal oscillator is shown in fig. 9-12. Energy from the plate tuned circuit is fed back to the grid circuit through the grid-plate capacitance of the tube. The energy that is fed back to the grid circuit keeps the crystal oscillating. The oscillations occur at the resonant frequency of the crystal, and the plate circuit is tuned approximately to this frequency. The resonant frequency of a crystal is determined by its physical dimensions.

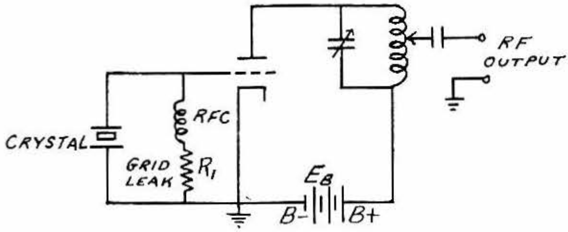


Fig.9-12. Crystal-controlled oscillator

During oscillations, the crystal vibrates at its resonant frequency. The strength of these vibrations depends upon the voltage being fed back to the crystal. If the feed-back is too great, the vibrations may become strong enough to crack or shatter the crystal. The use of a tetrode or pentode (see fig.9-13) overcomes this difficulty, because the screen grid reduces the grid-plate capacitance. This, of course, reduces the feed-back. However, the little energy that does get back is sufficient to sustain the crystal's oscillations. Tetrodes and pentodes are also more sensitive than triodes and require less grid voltage for satisfactory oscillator operation. If the interelectrode capacity feed-back from plate to grid is insufficient to sustain the oscillations of the crystal, a small condenser may be placed between the grid and plate to increase the amount of feed-back. The purpose of the r-f choke in fig. 9-12 is to make sure that the feed-back energy gets to the crystal and is not by-passed to ground through R_1.

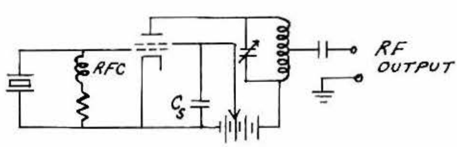


Fig.9-13. Tetrode Crystal Oscillator

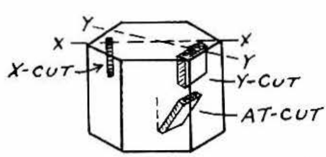


Fig.9-14. Crystal cuts.

9-16. Resonant Frequency of Crystal

The frequency at which the crystal vibrates and generates an alternating voltage is known as the crystal's RESONANT FREQUENCY. This resonant frequency is determined primarily by the THICKNESS of the crystal. The thinner the crystal the higher is its resonant frequency; the thicker the crystal, the lower is its resonant frequency.

Quartz crystals, used in oscillator circuits, must be cut and ground to extremely accurate dimensions. For example, the dimensions of a crystal resonant to 1000 kc would be between ½ inch and 1 inch square. The thickness would be 0.1125 inch. Electrical contact with the quartz crystal is obtained by means of a special crystal holder which has two metal plates. The crystal is placed between these two metal plates and a spring device exerts mechanical pressure against the metal plates.

9-17. Crystal Cuts

The frequency of a crystal is affected by the temperature of the air surrounding it. Different types of crystals show different reactions to temperature changes. Crystals are classified according to the manner in which they are cut from the original raw crystal rock. The different crystal cuts from the raw crystal rock are shown in fig. 9-14. Note that an X cut crystal is one that is cut perpendicular to the X axis; a Y cut crystal is one that is cut perpendicular to the Y axis; and an AT cut crystal is one that is cut at a 35 angle to the Y cut crystal.

The X cut crystal has a NEGATIVE TEMPERATURE COEFFICIENT. This means that the natural resonant frequency of the crystal goes down as the temperature goes up; and its natural resonant frequency goes up as the temperature goes down. In actual practice, the temperature coefficient of an X cut crystal varies from 10 to 25 cycles per megacycle for each degree centigrade change. For example, if the temperature of a 4 mc crystal were to change from 35 centigrade to 45 centigrade, the actual change in frequency would be found by multiplying the number of degrees change of temperature by the crystal frequency. This result of this multiplication is then in turn multiplied by the actual temperature coefficient as given by the manufacturer. The X cut crystal has a greater thickness for a given frequency than either the Y or AT cut crystals.

Y cut crystals have a POSITIVE TEMPERATURE COEFFICIENT. The frequency of vibration goes up as the temperature goes up; and the frequency goes down as the temperature goes down. The Y cut crystal has some undesirable operating characteristics however.

1.- The Y crystal has a tendency to vibrate simultaneously at two different frequencies which may be fairly close to each other.

2.- A slight load or temperature variation may cause the crystal to jump from one frequency to another. This makes the oscillator extremely unstable.

3.- Instability due to a relatively large temperature coefficient which may be as high as 100 cycles per megacycle per degree centigrade. The frequency of the Y cut crystal does not vary smoothly with changes in temperature. A slight change in temperature may cause a sudden large frequency shift.

All three factors would result in unstable oscillator operation.

Both the X cut and the Y cut crystals have been superceded by crystals having a LOW TEMPERATURE COEFFICIENT. This type of crystal is called the AT cut crystal (sometimes called A cut). A low temperature coefficient means that the frequency of vibration varies very little with temperature changes. The frequency drift of an AT cut crystal oscillator is therefore very small. An AT cut crystal oscillator is also capable of a comparatively high output. The AT cut crystal is used extensively in the frequency range from ½ mc to 10 mc.

9-18. Care of Crystals

The care and treatment of quartz crystals is very important for their efficient operation in oscillator circuits. It should be pointed out at this time that a crystal is thin and fragile and should normally never be removed from the crystal holder. If the crystal is dirty and fails to operate, it is necessary to remove it from its holder and clean it. An excellent cleaning agent for quartz crystals is carbon tetrachloride. Soap and water or alcohol can also be used. After cleaning, the crystal should be washed with water and then dried with a clean lint-free cloth. The fingers should not come in contact with the faces of the crystal, since oil or dirt getting on to the crystal surface may prevent it from oscillating. The crystal should be handled by grasping the edges, never the faces.

Care must be taken not to allow a d-c voltage to be placed across a crystal. If a d-c potential is applied to a crystal, the crystal will be physically strained. If the applied d-c potential is strong enough, it might actually crack the crystal.

9-19. Adjustment of a Crystal Controlled Oscillator

The most accurate way of adjusting a crystal controlled oscillator for stable operation is to use a d-c milliammeter placed in the plate circuit. When the plate tank circuit is tuned to the resonant frequency of the crystal, the plate current will drop to a low value. However, as we vary the tuning condenser either side of the resonance point, the rise in plate current on both sides of the resonance point will not be uniform. If you will examine fig. 9-15, you will notice that, as the tuning capacitance (high frequency to a low frequency) increases, the plate current slowly decreases to point C, then suddenly jumps up to some high value; at which time oscillations cease. Between

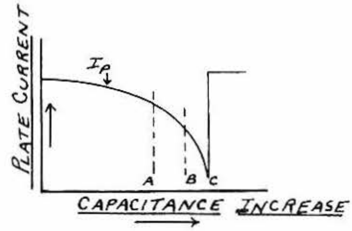


Fig. 9-15. Crystal-oscillator, plate current tuning curve.

points A and C the circuit is oscillating. Before point A and beyond point C, the circuit stops oscillating. At point C, the plate circuit is tuned to the resonant frequency of the crystal, and the efficiency and output of the plate tank circuit are at a maximum. However, the oscillator is unstable because any slight change in the loading conditions, or any slight increase in the tuning capacitance might move the operating point beyond point C, and cause the oscillator to drop out of oscillations. The oscillator is usually operated in the region between A and B. In this region, the oscillator will continue to function properly, even with slight changes in load conditions.

9-19. Problems Relating to Crystal Frequencies

In order to operate a transmitter properly, it is important to know the exact frequency of the crystal oscillator. Since temperature changes affect the frequency of the crystal, we must be able to figure out the new crystal frequency for a given temperature change. The following problems will illustrate how this is done:

Problem 1) A Y cut crystal that is marked 1000 kc has a positive temperature coefficient of 75 cycles per degree centigrade, and is started in operation at 50 degrees centigrade. If the temperature-frequency characteristic is linear, what will the new crystal frequency be at 30 centigrade?

Solution: A linear temperature-frequency characteristic means that the 75 cycles change in crystal frequency will remain constant for each degree change in temperature.

The temperature change is 20 degrees ($50^\circ - 30^\circ = 20^\circ$). Since the temperature coefficient is 75 cycles per degree centigrade, the crystal frequency shift is 1500 cycles (20 x 75) or 1.5 kc. <u>The new crystal frequency will therefore be the original frequency minus the frequency drift.</u> (1000 kc - 1.5 kc) or <u>998.5 kc</u>.

<u>Problem 2)</u> A 3000 kc low drift crystal has a negative temperature coefficient of 4 cycles per megacycle per degree centigrade. The crystal is started in operation at 40°C. If the temperature-frequency characteristic is linear, what will be the frequency at 50° centigrade?

<u>Solution</u>: A 3000 kc crystal is the same as a 3 megacycle crystal, since 1 mc equals 1000 kc. To convert the temperature coefficient (4 cycles per megacycle per degree centigrade) into cycles change per degree centigrade, we multiply the temperature coefficient by the crystal frequency in megacycles. The product is a 12 cycle change per degree centigrade ($4 \times 3 = 12$). The change in temperature is 10°C. ($50^\circ - 40^\circ = 10^\circ$) The frequency change is therefore 10°C x 12 cycles per degree = 120 cycles or 0.12 kc. To convert cycles into kilocycles, we divide the number of cycles by 1000. Therefore: 120 cycles $= \frac{120}{1000}$ kc $= 0.12$ kc.
Since the temperature went up, the frequency of this negative temperature coefficient crystal will go down. The new frequency will therefore be <u>2999.8 kc</u>. (3000 kc - 0.12 kc)

There are many times when an amateur operator may wish to operate as close to the edge of the frequency band as possible. He may do this in order to establish more contacts. The high and low ends of a particular band are often less crowded with calls than is the center of the band. A signal is therefore subject to less interference at the edges of the band. The one danger in operating at the edge of the band is that a slight shift in the oscillator frequency will throw the transmitted signal frequency outside of the particular band in question. Operating outside of an amateur band is unlawful according to the rules and regulations of the Federal Communications Commission. Operating at the edge of the band is therefore a problem to be considered. Let us assume that you are operating in the 20 meter band. The frequency limits for this band are 14,000 kc and 14,350 kc. Let us further assume that you wish to operate as close to the 14,000 kc edge as possible. Would you therefore use a crystal rated at exactly 14,000 kc? Of course not! No manufacturer can guarantee a crystal to be 100% accurate. A crystal stamped 14,000 kc may actually oscillate below 14,000 kc. Or, if the crystal is cut to exactly 14,000 kc, temperature changes may shift the crystal's frequency below 14,000 kc. In both instances you would be operating outside of the allocated band. In order to be on the safe side, you would have to purchase a crystal rated a few kilocycles above 14,000 kc. Exactly how much above depends upon the accuracy rating and the temperature coefficient of the crystal in question. A few problems will illustrate these principles:

Problem 1) A crystal manufacturer guarantees his crystals cut for the 7000 kc - 7300 kc amateur band to be accurate to within .03% of their specified frequency. If you desire to operate as close as possible to 7000 kc, for what whole number frequency in kilocycles should you order your crystal cut? (In ordering, you would also allow for one additional kilocycle to take care of variations in temperature and circuit constants).

Solution: We first find the crystal frequency tolerance in cycles.

1) $.03\%$ of 7000 kc $= \frac{.03}{100}$ of 7000 kc or:

$.0003 \times 7000 \text{ kc} = 2.1 \text{ kc}$

2) To the 2.1 kc we add 1 kc for possible variation due to circuit and temperature constants.

$2.1 \text{ kc} + 1 \text{ kc} = 3.1 \text{ kc}$ (3.1 kc is theoretically the maximum frequency variation of a crystal from its specified frequency of 7000 kc)

3) Since the problem asks for a whole number frequency in kc, we go to the next highest whole number from 3.1 kc which is 4 kc. We would therefore order a 7000 kc + 4 kc or a 7004 kc crystal with a .03% tolerance

Problem 2) A low drift crystal for the 3500 kc - 4000 kc amateur band is guaranteed by a manufacturer to be calibrated to within .05% of its specified frequency. If you wish to operate as close as possible to the upper edge of the band, for what whole number frequency should you order your crystal? Allow one extra kc for variations from temperature and circuit constants.

Solution: 1) The crystal frequency tolerance at 4000 kc in cycles is: $.05\%$ of $4000 = \frac{.05}{100} \times 4000 = 2$ kc

2) To the 2 kc, we add 1 kc for possible

variations due to circuit and temperature constants:

2 kc + 1 kc = 3 kc (this is a whole number and we leave it at that). We would order a <u>3997 kc crystal</u> (4000 - 3)

<u>Problem 3</u>) For what frequency would you order your crystal for operation as close as possible to the lower band limit of 3500 kc, with the same calibration accuracy and allowance given in problem 2?

<u>Solution</u>: 1) the crystal frequency tolerance at 3500 kc in cycles is: .05% of 3500 $= \frac{.05}{100} \times 3500 = 1.75$ kc

2) add 1 kc for variations in circuit and temperature constants: $1.75 + 1 = 2.75$ kc

Since the problem asks for a whole number frequency in kc, we go to the next highest whole number from 2.75 kc which is 3 kc. We would therefore order a <u>3503 kc crystal</u> (3500 + 3 = 3503 kc)

PRACTICE QUESTIONS - LESSON 9

(For answers, refer to back of Study Guide, Section III)

9-1.* An X cut crystal as compared to a Y and A cut of the same frequency is; a. heavier. b. wider
c. rounder d. thicker

9-2.* A quartz crystal in the oscillator of a transmitter does not;

a. determine the frequency
b. stabilize the output frequency
c. provide a high Q oscillating tank circuit
d. amplify the signal

9-3.* A desirable operating characteristic of an A cut crystal is;

a. negative temperature coefficient
b. high output capability
c. positive temperature coefficient
d. high frequency drift

9-4.* A desirable operating characteristic of an A cut crystal is;

a. low frequency of oscillation
b. light weight
c. low Q (poor selectivity)
d. small temperature-frequency coefficient

9-5.* The electron-coupled oscillator as compared to other types of oscillators;

a. has better frequency stability
b. has variable frequency characteristics
c. has parasitic oscillations
d. oscillates above 100 mc

9-6.* The electron-coupled oscillator does not have;

a. excellent frequency stability
b. large frequency variations with variations in supply voltage
c. coupling of energy from oscillator section to plate circuit by means of the electron stream
d. frequency independent of load variations

9-7. The crystal oscillator is;

a. the least stable of all oscillators
b. less stable than the electron-coupled oscillator
c. the most stable of all the oscillators
d. only a Hartley oscillator

9-8.* Draw a simple schematic diagram of a piezo-electric crystal-controlled oscillator using a pentode vacuum tube. Indicate polarity of supply voltages.

9-9.* A certain 28 mc, Y cut crystal has a positive temperature coefficient of 100 cycles per degree centigrade, and is started in operation at 40 centigrade. What will the oscillation frequency be at a temperature of 70 centigrade?

SECTION III LESSON 10

CONTINUOUS-WAVE TRANSMITTERS

10-1. Introduction

The function of a radio transmitter is to transmit intelligence by means of a radio frequency wave. The r-f wave is radiated into space by an antenna system. An antenna is a device which converts a-c energy into electromagnetic radiation known as radio waves. The r-f wave traveling through space is then picked up by a receiver which converts the r-f signal into an audible output.

Radio transmitters may be divided into two types. One is the CONTINUOUS-WAVE type of transmitter which we shall now study; the other is the modulated type of transmitter which we shall study later on.

10-2. Continuous Waves

Continuous waves, abbreviated C.W., are radio waves of constant amplitude. In the C.W. transmitter continuous waves are radiated into space by simply coupling the output of a vacuum tube power oscillator to a suitable antenna system. The International Morse Code is used to convey intelligence by C.W. communication.

The Morse code consists of a series of dots and dashes which represent the letters of the alphabet. In order to transmit code, the C.W. transmission must be interrupted in a dot and dash sequence. This type of emission is actually an r-f wave broken up into sections. An oscillator is made to stop and start oscillating by means of a telegraph key. By allowing the oscillator to operate for longer or shorter amounts of time, we can produce dots and dashes. Fig.10-1 shows the output of an oscillator for the letter "D" (dash-dot-dot).

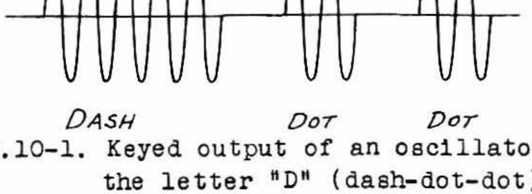


Fig.10-1. Keyed output of an oscillator for the letter "D" (dash-dot-dot).

10-3. One-tube Transmitter

In early type radio transmitters, the oscillator was directly coupled to the antenna system. In order to increase the power output of this type of transmitter, it was necessary to use a larger tube or to increase the operating voltages. There is a limit, however, to the amound of power that one can get from a one-tube transmitter. The power output of an oscillator depends upon r-f currents in the oscillator circuit. Since these currents are relatively weak, very little power can be delivered to the antenna. The radiated wave, therefore, will also be weak. Another defect of the simple oscillator type of transmitter is its poor frequency stability. Fig.10-2 shows a one-tube transmitter. Condenser C_A represents the antenna capacitance to ground which will vary as the antenna swings in the wind. This varying antenna capacitance will be coupled back to the tank circuit and will cause the oscillator frequency to vary. The disadvantage of poor frequency stability can be overcome to a great extent by the use of an intermediate amplifier stage which serves to isolate the antenna from the oscillator. Changes in antenna capacity will therefore not be reflected back into the oscillator tank circuit. At the same time, the amplifier amplifies the output of the oscillator and feeds a more powerful signal into the antenna.

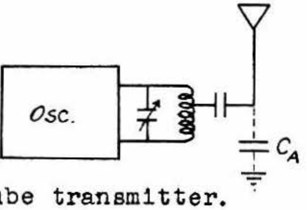
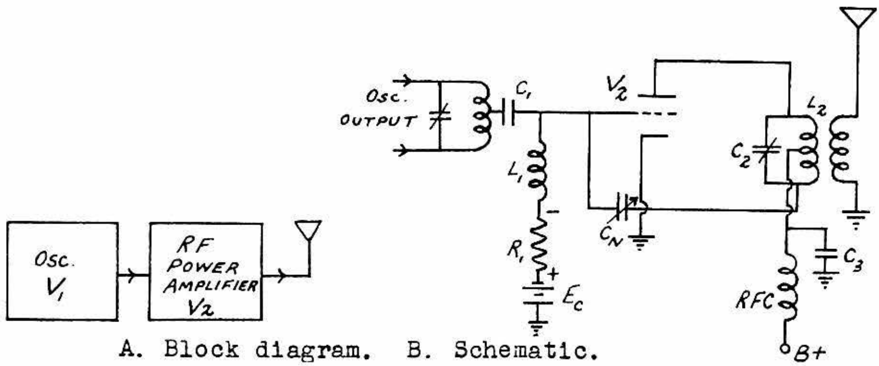


Fig.10-2. One-tube transmitter.

10-4. Master-oscillator Power-amplifier

A transmitter consisting of an oscillator and an amplifier (or a series of amplifiers) is called a MASTER-OSCILLATOR POWER-AMPLIFIER, MOPA for short. Such a transmitter is shown in fig.10-3. The output of the oscillator is amplified by V_2. Condenser C_1 prevents the high d-c voltage on the plate of V_1 from being applied to the grid of V_2. At the same time, it allows the r-f energy to get through to the grid of V_2. The r-f choke L_1 prevents the r-f energy from flowing to ground through R_1. This is because an r-f choke opposes the flow of r-f currents.

The master-oscillator power-amplifier type of transmitter has a decided advantage over the simple oscillator transmitter, in that the frequency stability is greatly improved. High frequency stability is obtained in this system because the oscillator is not coupled directly to the



A. Block diagram. B. Schematic.

Fig.10-3. Master-oscillator power-amplifier transmitter.

antenna; the oscillator is therefore unaffected by any change in the antenna-to-ground capacitance. Changes in antenna-to-ground capacitance will merely react upon the r-f power amplifier circuit resulting in a decrease in the radiated power output. The amplifier of fig.10-3 may feed the antenna directly,or it may be the first of a series of r-f amplifiers, the last of which feeds into an antenna system.

10-5. High Efficiency Class C r-f Amplifier

In lesson 7, we studied the biasing methods for audio amplifiers. You will recall that a-f amplifiers are operated with cathode bias as class A voltage amplifiers. The audio amplifier tubes were operated as class A or class B amplifiers because we were interested in obtaining good fidelity of reproduction. The class A amplifier sacrifices efficiency for excellent fidelity. In the case of an r-f amplifier we are not interested in fidelity since we are not amplifying an audio signal. We are interested in efficiency of operation. An r-f amplifier operates most efficiently in a transmitter as a Class C amplifier. In order to operate the tube as a class C amplifier, the bias must be between one and one-half to four times the bias value necessary for cut-off. This condition is shown graphically in fig.10-4. You will notice that with a pure sine wave applied to the grid, the plate current consists of small pulses which certainly do not resemble the input sine wave. Since the plate current wave does not resemble the grid signal, the fidelity of a class C amplifier is poor. One important point to notice is that the plate current flows for only a fraction of the period of the input signal. Compare this to a class A amplifier where the plate current flows

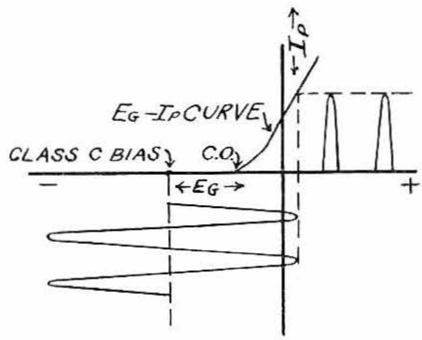


Fig.10-4. Class "C" bias operation.

continuously. Obviously, more power is wasted in plate dissipation in a class A amplifier as compared to a class C amplifier. Since the plate dissipation is decreased in the class C amplifier,(as compared to the class A amplifier) the useful power output is increased. The efficiency of a class C amplifier is therefore excellent. It is approximately 70% efficient.

The question that always arises at this point is: Of what good are the plate current pulses if we are only interested in obtaining an amplified version of the sine wave input? The answer lies in the ability of the plate tank circuit to reproduce a pure sine wave from pulses of energy which are applied to it every cycle. From the discussion of the oscillatory circuit (paragraph 9-5), it will be recalled that when the plate tank circuit is tuned to the resonant frequency of the grid circuit, the plate current pulses will reinforce the oscillations in the plate tuned circuit at just the right instant, sustaining oscillations. The surges of plate current give the tank circuit the shot of energy or the FLYWHEEL EFFECT which results in the tuned circuit making up that portion of the sine wave missing in the plate current pulses. Thus, we see that, although the plate current is made up of pulses, the signal fed to the antenna or the next stage is a pure sine wave.

10-6. Minimizing Harmonic Output

It is very important that the output waveform of an r-f amplifier contain a minimum of harmonic components (in other words, the output should be as close to a pure sine wave as possible). If the harmonic components are radiated by the antenna, unlawful interference with adjacent transmissions may result.

A class C, r-f amplifier should have the following characteristics if generation of harmonicsis to be kept to a minimum:

1.- The plate tank circuit should have a low inductance to capacitance ratio. (low L-C ratio)

2.- The amplifier should operate with the proper grid bias and grid signal.

3.- Push-pull operation will eliminate second harmonic component.

10-7. Grid-leak Bias

It was mentioned above that a class C amplifier requires a bias of from one and one-half to four times the value of cut-off bias. There are several methods of obtaining class C bias. The first method that we shall discuss is known as GRID-LEAK BIAS. You will recall that grid-leak bias is used in the self-biased oscillator. (refer back to paragraph 9-6) Fig.10-3 shows the r-f amplifier, V_2, employing grid-leak bias. R_1 is the bias resistor and C_1 is the bias condenser. Before the signal from the previous stage is applied to the grid of the amplifier tube, the bias on the grid is zero. However, when a signal is applied, a grid bias voltage develops across R_1. Let us see how this comes about: On the positive half of the incoming signal, the grid is driven positive with respect to the cathode. This causes a flow of grid current which charges up condenser C_1. On the negative half of the signal, the condenser discharges through R_1. The discharge current that flows through R_1 develops a d-c voltage across R_1. Condenser C_1 which is effectively in parallel with R_1 tends to keep this voltage constant. Since the current enters R_1 at the top, (the grid side) the top part of the resistor is negative with respect to the bottom part. The top of the resistor is connected to the grid. Therefore, the grid is negatively biased with respect to the cathode.

The amount of grid-leak bias that is developed depends upon the strength of the signal. This may sometimes be a serious disadvantage. If for some reason the signal or excitation is lost, the bias will disappear and the plate current may rise to excessively high values.

10-8. Fixed Bias

Another method of obtaining bias for class C amplifiers is through the use of a "C" battery. A "C" battery is just an ordinary battery used for biasing purposes. The negative terminal of the "C" battery is connected to the grid, and the positive terminal is connected to the cathode. This, of course, makes the grid negative with respect to the cathode. An r-f by-pass condenser is usually shunted across the battery to complete the r-f path around the battery. The amount of battery voltage to be used for a particular tube can be found by consulting a transmitting tube manual.

10-9. Combination Grid-leak, Cathode Bias

A third method of obtaining bias is shown in fig.10-5 This method is a combination of grid leak and cathode bias. R_1 provides most of the bias voltage. R_2 is placed in the circuit to act as a protective bias in case the input signal to the stage should fail. Upon loss of grid leak bias, the increased plate current will flow through R_2 developing a heavy bias voltage which will in turn limit the plate current to a safe value. R_2 will not cause any appreciable loss of plate voltage, since its value is small. It will simply serve to bias the tube should the grid leak bias disappear.

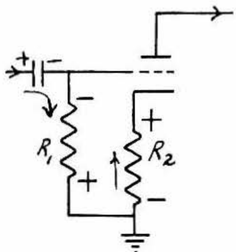


Fig.10-5.

10-10. Grid-leak and Battery Bias

The fourth method of obtaining bias for an r-f amplifier is shown in fig.10-3. This method is a combination of grid-leak and battery bias. Again, most of the bias voltage is obtained from the voltage drop across the grid leak resistor. The battery is connected in the circuit simply as a means of keeping some bias voltage on the tube in the event that the grid-leak bias drops to zero. The transmitting tube is thus protected against damage due to excessive plate current flow.

10-11. Power Supply Bias

The last biasing method that we will discuss is power supply bias. The only difference between this system and the battery bias system is that the battery has been replaced by a well-regulated negative power supply. If the excitation to the stage fails, the bias is not affected, and the plate current does not rise to dangerous values. This method is quite popular in the more expensive transmitters.

10-12. Neutralization

Examine the r-f amplifier of fig.10-6. Note that the tank circuit L_2C_2 is not only the plate tank circuit of the oscillator, but can also be considered as the grid tank circuit of the r-f amplifier. Notice that the portion of the schematic of fig.10-6 inside the dotted line is exactly the same as a tuned-plate, tuned-grid oscillator.(refer to lesson 9, fig.9-10) This portion of the circuit will oscillate just like a tuned-plate, tuned-grid oscillator unless certain precautions are taken. An oscillating r-f amplifier is very undesirable. An amplifier is only supposed

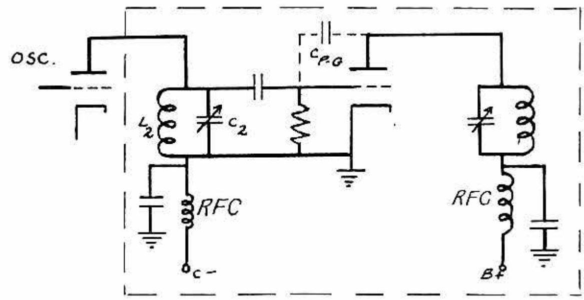


Fig.10-6. Oscillatory circuit in an unneutralized RF amplifier.

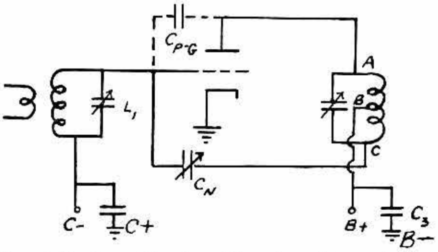
to amplify and not to oscillate. An oscillating amplifier has poor frequency stability. Antenna variations are directly coupled back to the oscillating amplifier, and all sorts of spurious radiations will result. Spurious radiations differ in frequency from the desired r-f transmission. They are radiated with the desired frequency transmission and cause interference with stations on nearby frequencies.

There are two general methods of preventing an r-f amplifier from oscillating. One is to use a tetrode or pentode instead of a triode. As you have previously learned, the addition of a screen grid reduces the grid-plate capacitance. It would therefore be very difficult for a tetrode or pentode to oscillate since there would be no feedback through the grid-plate capacitance as we have in a triode. Most high powered r-f amplifying tubes, however, are triodes, and therefore we do have the problem of preventing oscillations from taking place. Therefore, precautions must be taken when triodes are used as r-f amplifiers. This brings us to the second method of preventing an r-f amplifier from oscillating.

10-13. Plate Neutralization

We realize that as long as we use a triode, we will have feedback from the plate circuit to the grid circuit through the interelectrode plate-grid capacitance. We must in some manner cancel out or neutralize this feedback if we are going to prevent oscillations. The remedy is to connect an external condenser into the circuit to NEUTRALIZE this feedback. Fig.10-7 shows a neutralized triode r-f amplifier. Condenser C_N is the neutralizing condenser, and

$C_{P\text{-}G}$ is the grid to plate interelectrode capacity. Notice that the B+ is fed to the plate through a center-tap on



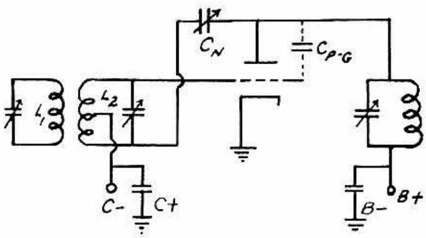


Fig.10-7. Plate Neutralization. Fig.10-8. Grid neutralization.

the plate coil. The center-tap is placed at r-f ground (zero) potential through condenser C_3. The plate r-f voltage with respect to ground is the voltage across the top half of the coil; it is the voltage between A and B. This voltage feeds energy back to the grid and tends to make the amplifier oscillate. The r-f voltage between points B and C is the neutralizing voltage, and is equal to the plate r-f voltage. Because potentials at opposite ends of a coil are 180° out of phase with each other, the plate r-f voltage is 180° out of phase with the neutralizing voltage. If C_N is made to equal $C_{P\text{-}G}$, the neutralizing voltage will cause a voltage to be fed back to the grid which will be equal and opposite to the voltage fed back by $C_{P\text{-}G}$. The two voltages will cancel each other out, and the amplifier will no longer oscillate. The above system of neutralization is called PLATE NEUTRALIZATION or HAZELTINE NEUTRALIZATION. We can recognize it by the fact that C_N is connected between the bottom of the plate coil and the control grid. This is the system used in fig.10-3 and 10-7.

10-14. Grid Neutralization

Fig.10-8 shows another system of neutralization. It is called GRID NEUTRALIZATION or RICE NEUTRALIZATION. In this case, the grid coil is split and C_N is connected between the bottom of the grid coil and the plate. The operation of the neutralization process in this system is similar to the plate neutralization system. The neutralizing voltage fed back from the plate to the bottom of the grid coil will cancel out the voltage fed back from the plate to the top of the grid coil by the grid to plate capacitance.

10-15. Criss-Cross Neutralization

Fig.10-9 shows a third system of neutralization. This is the system used to neutralize an r-f amplifier stage consisting of two triodes in push-pull. It is called CRISS-CROSS NEUTRALIZATION or BALANTINE NEUTRALIZATION. The plate of tube A is joined with the grid of tube B through a neu-

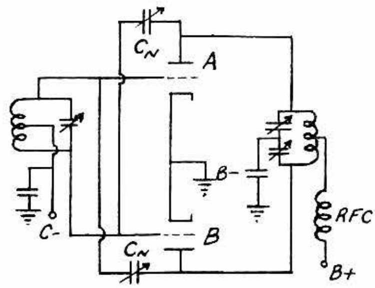


Fig.10-9. Criss-cross neutralization.

tralizing condenser; the plate of tube B is joined with the grid of tube A through another neutralizing condenser. If you examine the circuit of fig.10-9, you will see that criss-cross neutralization is really a double Hazeltine system.

10-16. <u>Steps in Neutralizing an r-f Amplifier</u>

The previous paragraphs describe the theory of neutralization. It is important, however, to know the actual practical steps in neutralizing an r-f amplifier of a transmitter. There are two methods in general use today. The first method is as follows:

1.- Remove the plate voltage from the stage to be neutralized. This is very important since it is impossible to neutralize an amplifier with the plate voltage applied.

2.- The stage preceding the stage to be neutralized should have its power on and should be properly tuned to the oscillator frequency. The filament voltage of the stage being neutralized should be on.

3.- The grid and plate tank circuits of the stage being neutralized should now be tuned to resonate with the signal coming from the preceding stage. This is done by tuning the grid and plate tank condensers for a maximum indication of the r-f indicator which is coupled to the plate tank circuit. The r-f indicator may be a neon bulb or a flashlight bulb connected to a small loop of wire. We can also use a thermocouple ammeter which is connected in series with the plate tank circuit. If a thermocouple ammeter is used, care should be taken not to overload the meter. It is a sensitive instrument that is easily damaged. Any coupling between an indicating instrument and plate tank coil should be made as loose as possible.

4.- The neutralizing condenser or condensers are then adjusted until the r-f indicator shows that the r-f energy in the plate tank circuit is at a minimum.

5.- Repeat steps 3 and 4 to make sure that the stage is as completely neutralized as possible.

The second method used to neutralize a triode r-f amplifier is as follows:

1.- Remove the plate voltage from the stage to be neutralized. Keep the filament voltage on.

2.- Tune the preceding stages so that there is excitation (a signal input) to the stage to be neutralized.

3.- Insert a d-c milliammeter in the grid circuit if one is not already present.

4.- Rock the plate tuning condenser of the stage to be neutralized back and forth, and observe the grid meter. If the grid meter varies, the stage is not neutralized. Then adjust the neutralizing condenser until rocking of the plate tank condenser no longer causes the grid meter to vary.

It is not always possible to neutralize an amplifier completely. Therefore, if you neutralize an amplifier by using the first method, do not always expect a zero reading of the r-f indicator. It is quite likely that there is stray inductive or capacitive coupling between the stage being neutralized and a preceding stage. The neutralizing condenser cannot cancel this out. It is also possible that there is insufficient neutralizing capacity or too much stray capacity within the stage itself. Proper wiring and parts layout would remedy this situation to a great extent.

10-17. Frequency Multipliers*

It is not always desirable to have the oscillator of a transmitter generate the frequency which is to be radiated. In order for a crystal controlled oscillator to produce a high frequency, the crystal must be ground very thin. Since a thin crystal can crack easily, it is a good idea to operate the oscillator at a low frequency and to step up the frequency by means of special r-f amplifiers. These special r-f amplifiers are called FREQUENCY MULTIPLIERS.

Frequency multiplication is made possible by operating a vacuum tube on the non-linear portion of its characteristic curve. As a result, harmonic distortion is

*Do not confuse the output of a frequency multiplier with PARASITIC OSCILLATIONS. The latter are UNWANTED oscillations not occuring at wanted operating frequencies.

developed in the plate circuit. As you have already learned, harmonic distortion results in the generation of new frequencies. These new frequencies are multiples of the original or fundamental frequency. In other words, if we feed 1000 kc into the grid circuit of an amplifier which is operated to give strong harmonic distortion, the plate circuit will contain 1000 kc, 2000 kc, 3000 kc, 4000 kc, etc. The 1000 kc is known as the fundamental, 2000 kc is the second harmonic, 3000 kc is the third harmonic, etc.

Ordinarily, harmonic distortion is to be avoided in an amplifier circuit, because distortion alters the waveshape of the original signal. However, when frequency multiplication is required, the signal is deliberately distorted to form strong harmonics. The desired harmonic frequency is then selected with a properly tuned plate circuit. In other words, the plate tank circuit is made resonant to the desired harmonic frequency.

In order to develop strong harmonic distortion, the frequency multiplier tube is heavily biased; even more so than a class C amplifier. The bias voltage may be as high as 10 times the value of cut-off bias. However, this large grid bias requires very strong grid excitation or drive. The signal must be large enough so that the positive peaks of the signal can overcome the large negative grid bias voltage. The plate current consists of positive pulses, but the inertia, or flywheel effect, of the plate tank circuit will make up the remaining portion of the sine wave of the harmonic frequency peaks.

A unique method of obtaining frequency doubling is to connect up two amplifiers in PUSH-PUSH. In a push-push circuit, the grids are connected in the conventional push-pull arrangement (at opposite ends of a tank circuit). The plates, however, are connected in parallel across a tank circuit which is tuned to double the frequency of the grid input signal. The output of a push-push arrangement is rich in even harmonic components. The complete C.W. transmitter of fig.10-14 contains a FREQUENCY DOUBLER (tube V_2). We call it a frequency doubler because the plate tank circuit is tuned to the second harmonic of the fundamental. If the plate tank were tuned to three times the fundamental, we would call it a FREQUENCY TRIPLER. Note that there is no neutralizing condenser in the frequency multiplier even though a triode is being used. This is because the plate and grid circuits of a frequency multiplier are tuned to different frequencies and there is no danger of oscillation due to feedback. Other characteristics of a frequency multiplier not mentioned in previous paragraphs are as follows:

1.- The plate current flows for approximately 90° or one quarter of the time of an input cycle.

2.- The plate efficiency of the frequency multiplier is lower than that of a straight class C amplifier.

3.- The plate tank circuit has a high impedance to the harmonic frequency to which it is tuned (high L to C ratio).

10-18. Coupling Between Stages

There are three types of stage to stage coupling used in transmitters. The first type is called CAPACITY COUPLING and is shown in fig.10-3. It is similar to the resistance capacity coupling that is used in audio amplifiers. Capacitive coupling is the simplest and least expensive method of coupling. It consists merely of a coupling condenser which transfers the r-f voltage from the plate of one tube to the grid of the next. Sometimes condenser C_c is tapped down on L_1 for impedance matching purposes. The disadvantage of capacity coupling as compared to the other coupling methods is that undesired harmonics are easily transferred from stage to stage.

Fig.10-8 shows a second method of coupling between stages. It is called INDUCTIVE COUPLING. The r-f voltage is magnetically, or inductively, coupled from L_1 to L_2. Inductive coupling is more expensive than capacitive coupling since it requires two tuned circuits. It also requires additional tuning. The advantage of inductive coupling is that the addition of a tuned grid circuit results in increased gain and power output.

The third method of coupling r-f from stage to stage is called LINK COUPLING. Link coupling is a very efficient form of coupling and is often used between stages, or between the final stage and the antenna. Fig.10-14 shows the doubler (V_2) and the power amplifier (V_3) link coupled. The actual link coupling consists of a pair of wires with a loop of two or three turns at either end. The chief advantage of this form of coupling is that two stages which are physically some distance from each other can be coupled. Capacitive or inductive coupling methods could not be used in such a case since long wires cause heavy losses at high frequencies. Long leads have sufficient inductive reactance at high frequencies to build up a counter-e-m-f and cut down the signal strength to the next stage. In link coupling, however, no counter-e-m-f is induced in the long leads since the current in one leg at a certain instant is opposite in direction to the current in the other leg at the same instant. The resulting magnetic fields are out of phase, and therefore cancel each other. The result is that no back e-m-f or inductive reactance is created, and the signal is coupled to the next stage without loss.

Notice that each loop is coupled to its respective coil at a point of low r-f potential. This is the point where B+ or C− is connected to the tank circuit. B+ and C− are at zero r-f potential because the power supply filter condensers have a negligible impedance to ground at r-f. Coupling from points of low r-f potential prevents unwanted harmonics from being transferred through the stray capacitive coupling that exists between the tank coils and the link coils.

10-19. Keying the Transmitter

At the beginning of this lesson we learned that the telegraph key is used to start and stop the operation of a C.W. transmitter. This causes radio waves to be sent out by the antenna in the form of dots and dashes. The telegraph key is merely a switch which opens and closes a circuit or circuits in a transmitter.

While keying may at first thought seem simple, there are many considerations which make it a very important subject for study. These considerations concern not only the simple act of forming dots and dashes by keying, but also the undesired effects that may result from interrupting the operation of the transmitter.

A good keying system should fulfill three requirements:

1.- There should be no radiation of energy from the antenna when the key is open. (key up)

Some energy may get through to the antenna during keying spaces (when the key is open). The energy that is radiated during key-up is called BACKWAVE. A C.W. signal containing backwave is very difficult to read because a weak signal is heard in the receiver during the space interval between dots and dashes. This signal may be almost as loud as the code reception. A pronounced backwave often results when the keying is done in the amplifier stage feeding the antenna. Backwave may also be caused by incomplete neutralization of the final stage. This allows energy to get to the antenna through the grid-plate capacitance of the tube. A third cause of backwave may be the possible magnetic pickup between the antenna coupling coils and one of the low power stages. Backwave can generally be eliminated by shielding, by proper neutralization, and by rearranging the tank circuits to eliminate unwanted coupling.

2. The keying system should allow the radiation of full power output when the key is closed. (key down)

3. The code output should be free of clicks.

When power is applied or removed from a circuit very suddenly, as is the case when a transmitter is keyed, the large amounts of energy that are thus released will surge back and forth and will result in damped oscillations. The damped oscillation will cause interference in nearby receivers. Interference will be present in the form of clicks or thumps even though the receivers are tuned to different frequencies from that of the transmitter. KEY CLICK FILTERS are used in the keying system of radio transmitters. A typical key click filter is shown in figures 10-10 and 10-14. The inductance, L, causes a slight lag in the current which builds up gradually instead of instantly when the key is closed. C and R are connected in series across the key to absorb the spark which tends to occur when the key is opened. The condenser charges up and prevents a spark from jumping the gap formed by the open key. When the key is closed, the condenser discharges through R, thereby dissipating the energy of the charged condenser.

10-20. Methods of Keying

Keying takes place in either the oscillator or amplifier stages of the transmitter. A number of different keying systems are in use today. Fig. 10-11 illustrates PLATE KEYING. Plate keying may be used in the oscillator

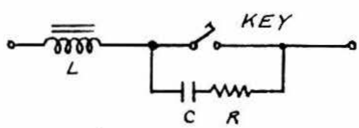


Fig. 10-10. Key click filter.

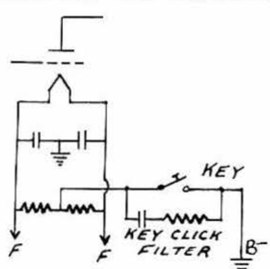


Fig. 10-11. Plate keying.

or amplifier stages. When the key is open, no plate current can flow, and the tube does not operate. When the key is closed, the tube operates and the transmitter sends out r-f. The key may be used to control the plate current of one tube or several tubes. Plate keying is usually accomplished in the power amplifier circuit in transmitters which use a crystal controlled oscillator.

In larger transmitters, the ordinary hand key cannot accomodate the large plate current flow without excessive arcing. The high plate voltage may also make it too dangerous to operate a hand key in the plate circuit. Therefore, some indirect method of stopping and starting the plate current is called for. Fig.10-12 shows a relay system for indirectly controlling the plate current. When

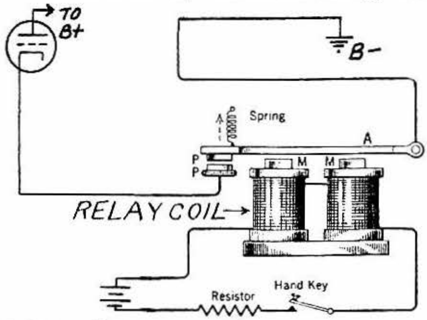


Fig.10-12. Indirect keying using relay.

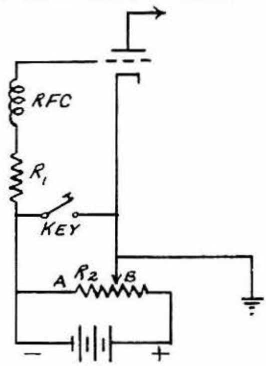


Fig.10-13. Blocked-grid keying.

the key is closed, a current from the battery flows through the relay coil. The magnetic field about this coil draws the metal arm, A, towards it. The metal arm moves towards the coil, M, against the tension of the spring, S. As the arm is drawn to M, the relay contact points make contact and the plate current circuit is now complete. When the key is opened for a code space, the coil de-energizes and allows the contact points to be drawn apart by the tension of the spring.

A second method of keying is known as TRANSFORMER-PRIMARY KEYING. In this method, the key is simply inserted in the primary of the high voltage plate transformer which supplied B+ voltage to the stage or stages to be keyed. When the key is depressed, the primary circuit is completed and current will flow through it. The primary current will induce a voltage in the secondary which in turn will be rectified as a high B+ voltage and applied to the plate of the keyed stage. When the key is opened, the primary current will be interrupted and the plate voltage of the keyed stage will drop to zero.

A third, and widely used method of keying is called BLOCKED-GRID KEYING. In this method, a high negative bias is applied to the grid of the stage to be keyed. This bias is sufficient to cut off plate current completely, even with excitation applied to the grid. Fig.10-13 illustrates the method of blocked-grid keying. R_1 is the normal grid-leak resistor. R_2 is a voltage dividing resistor across which the entire voltage is placed. When the key is up, the large negative voltage across the AB portion of R_2 is applied to the grid. This voltage is large enough to cut the tube off completely regardless of the size of the input signal. The stage is therefore inoperative and there is no output from the transmitter. When the key is depressed, the blocking bias across AB is shorted out; and the only bias in the stage is the grid-leak bias. This is the normal bias for the stage, and the transmitter now radiates its normal output.

10-21. A Typical C.W. Transmitter

Fig.10-14 is a schematic of a typical MEDIUM POWER C.W. TRANSMITTER that can be used by amateurs. We will now proceed to discuss in detail the characteristics of this transmitter. The typical C.W. transmitter illustrated consists of two power supplies, an oscillator, a frequency doubler, and an r-f push-pull amplifier. Let us first discuss the power supplies.

10-22. Power Supplies

You will notice that there are TWO power supplies in this transmitter instead of one. The oscillator and first r-f amplifier (doubler) connect to one power supply; and the power amplifier connects to the second power supply. The reason for having a separate power supply for the oscillator is to prevent the oscillator from becoming unstable. If the oscillator and the final amplifier were to have a common power supply, any load changes which occur in the amplifier would be fed to the oscillator through the common supply. These load changes would cause the voltage on the elements of the oscillator to change. This in turn would cause the frequency of the oscillator to vary. An oscillator whose frequency drifts or varies is very undesirable because it causes fading at the receiver end and interference on adjacent frequencies.

One of the requirements for good frequency stability in a transmitter is a well-regulated power supply. A well-regulated power supply consists of a choke input filter and a bleeder. The rectifier tube is usually of the mercury vapor type for two reasons:

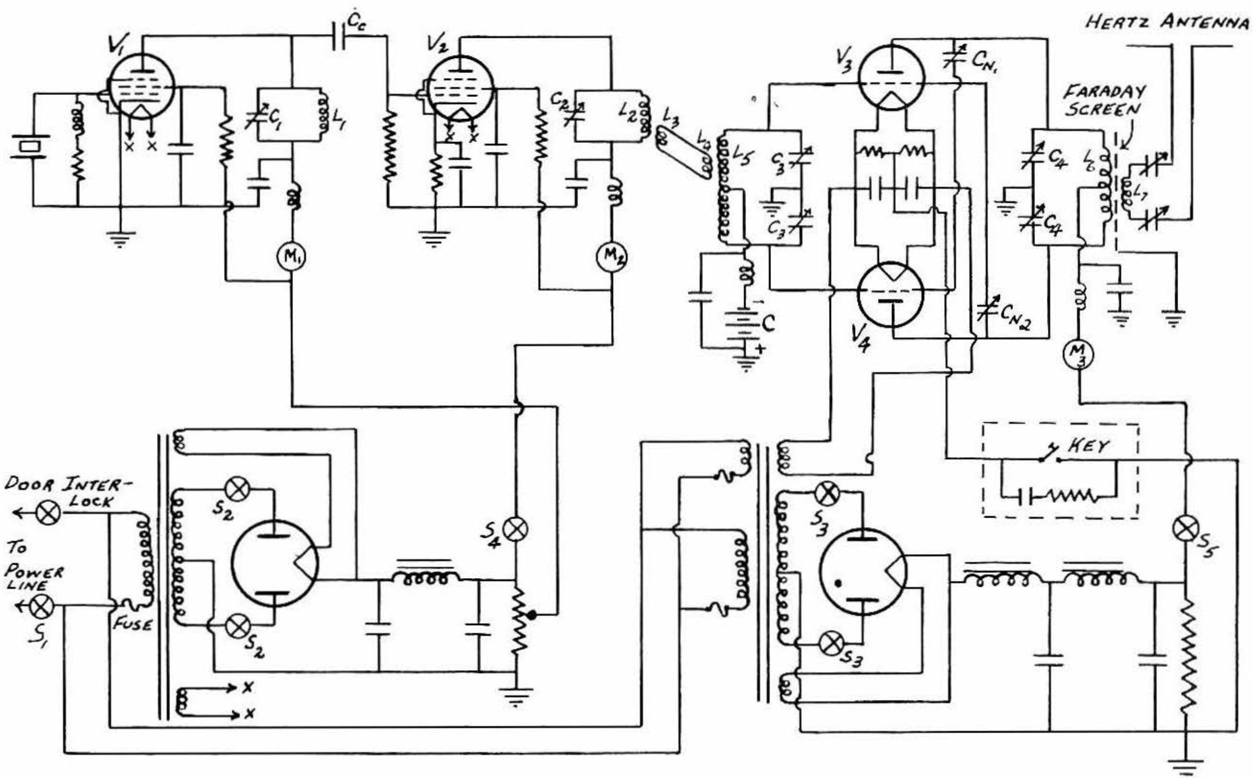


Fig.10-14. Complete C-W transmitter.

1. A mercury vapor rectifier tube has a constant voltage drop regardless of load current changes. This improves the voltage regulation.

2. The mercury vapor tube is capable of supplying the large load current requirements of the transmitter. For a review of power supplies refer to lesson 5.

For purposes of safety, a DOOR INTERLOCK SWITCH is used. The door interlock switch shuts off the power to the transmitter when the transmitter door is open. The operator is thereby protected from contact with high voltages inside the transmitter. Notice that the transformer primaries are fused. The fuses protect the various parts of the power supply from damage due to short circuits or overloads. These fuses also prevent power line shut-offs by blowing out before the main power line fuses blow. There is a main on-off switch which turns on filament power for all tubes. Switches S_2 and S_3 in the plate circuit of the rectifier tubes allow the high voltage to be turned on after the mercury vapor rectifiers have had sufficient time to warm up. Switches S_2 and S_3 in the off-position put the transmitter in "stand-by"

10-23. Oscillator and Frequency Doubler

The oscillator in the illustrated C.W. transmitter is a conventional pentode crystal controlled oscillator. M_1 is a milliammeter which is placed in the plate circuit to measure plate current and to tune the plate tank circuit to resonance with the crystal frequency. Plate tank tuning is indicated by a dip reading (minimum reading) on M_1 (refer to lesson 9, paragraph 9-18). The energy from the oscillator is capacity coupled to the frequency doubler through C_c . The frequency doubler is an r-f stage which is tuned to twice the oscillator frequency in the plate circuit. Since it is located between the oscillator and the final amplifier, it is called a buffer stage. It isolates the oscillator from the final amplifier and thereby improves the oscillator frequency stability. Notice that there is no neutralization of the frequency doubler. There are two reasons for this. As we mentioned previously, frequency multipliers do not require neutralization since the grid and plate circuits are tuned to different frequencies. Also, since the tube used is a tetrode, the grid-plate capacitance is very small and the plate to grid feedback will therefore be negligible. Neutralization of a tetrode is only necessary at very high frequencies.

The bias for the frequency doubler stage is a combination of grid-leak bias and cathode bias. Most of the bias voltage comes from the grid-leak resistor; the cathode bias is simply protective bias. The reason for the protective cathode bias is as follows: Among other things, grid-leak bias depends upon the excitation voltage coupled from the preceding stage. If the oscillator were to stop oscillating, there would be no excitation voltage applied to the r-f amplifier. The bias would consequently drop from its high negative value to zero, and would cause the plate current to rise to a value high enough to damage the tube. This is a very serious disadvantage of grid-leak bias. The cathode bias that you see in the diagram is a protective bias. It provides for a minimum bias when the grid-leak bias fails. As the plate current rises, the cathode bias also rises.

10-24. <u>R-F Power Amplifier</u>

The buffer amplifier is coupled to the final r-f amplifier by a link coupling system as shown in fig.10-14. Link coupling may be used between any two stages as well as between the final amplifier and antenna. (refer to paragraph 10-17) The output stage is coupled to a simple half-wave antenna (called a Hertz antenna) by means of a tuned line.

The r-f power amplifier is connected in push-pull. The advantages to be gathered from push-pull operation are as follows:

1.- Even harmonics are cancelled out in the plate circuit reducing the possibility of serious second harmonic radiation. (refer to lesson 8, paragraph 8-14)

2.- The power output is higher than the power output of a single-ended amplifier.

3.- There is no need to re-neutralize when the transmitter is tuned from one frequency output to another.

Notice that the r-f power amplifier employs:

1.- criss-cross neutralization

2.- battery bias in the grid circuit

3.- key and key-click filter in series with the center-tap return of the filament transformer to ground.

10-25. <u>The Faraday Shield</u>

One way of reducing undesirable radiation of harmonic frequencies is by including a FARADAY SHIELD between the tank coil of the power amplifier and the antenna coupling circuit. In fig.10-14, the Faraday shield reduces the harmonic transfer of energy through the stray capacity that exists between the inductively coupled coils, L_6 and L_7 . The faraday shield is actually a mesh of metal strips which is grounded to the chassis of the transmitter.

10-26. The Directly Heated Power Amplifier

Most high power transmitting tubes (see tubes V_3 and V_4 of fig.10-14) are directly heated triodes using a-c for filament power. A directly heated filament presents a problem as far as the return path for the plate and grid circuits are concerned. If we were to connect B— and the bottom of the grid circuit to one side of the filament, the output of the amplifier would have a 60 cycle hum superimposed on the r-f. The hum modulation would be radiated and picked up by the receiver as undesirable noise. To prevent hum modulation, the equivalent center point is connected through the key to ground as the return path for the plate and grid circuits. (See fig. 10-14). This can also be done by grounding the center tap of the transformer.

10-27. Tuning the Transmitter

It is very important that the amateur radio operator know how to put a transmitter into operation. We will use the C.W. transmitter of fig.10-14 to describe the complete procedure in tuning and operating the transmitter.

We will assume that all the switches are open and that the transmitter has not been used for some time. With the power plug plugged into a 110 a-c wall socket, we proceed in the following manner:

1. The main switch S_1 is closed to allow the filaments of all the tubes in the transmitter to heat up.

Since the rectifier tubes are of the mercury-vapor type, the filaments of these rectifiers must be heated for several minutes before voltage is applied to the rectifier plates.

2. After the filaments have heated up for a few minutes, switch no.2 is closed. Switch no.2 is a double pole single throw switch which applies a-c voltage to the plates of the rectifier tube of the oscillator-buffer power supply. The oscillator tube now has plate voltage and is ready to be tuned.

3. We tune the oscillator by varying condenser C_1 and observing meter M_1 for the characteristic crystal oscillator dip. (the tuning procedure for an oscillator was described in lesson 9, paragraph 9-18) The oscillator plate tank circuit is now resonant to the crystal frequency and offers maximum impedance to plate current flow.

4. By closing switch no.4, we apply B+ voltage to the plate of the buffer-doubler stage. This stage is now ready for tuning.

5. The plate of the buffer-doubler stage is tuned by adjusting C_2 until the plate milliammeter, M_2, dips. (reads a minimum) The tuned circuit, C_2L_2, is now resonant to the second harmonic of the oscillator frequency.

6. The push-pull power amplifier stage is now ready to be neutralized. We use either of the two methods of neutralization described in detail in paragraph 10-15. Neutralizing condensers N_1 and N_2 are adjusted at the same time.

7. Switch no.3 is closed next. This applies a-c voltage to the plates of the high voltage rectifier. However, the high B+ voltage is still not applied to the power amplifier stage. With switch no.5 still open, the plate tuning condenser is turned to the approximate resonant point as indicated by a marked line on the plate tuning dial. This mark had been previously recorded under operating conditions as being the point of resonance for the plate tank circuit. We can now close switch no.5 and be assured that the plate tank is close enough to resonance to prevent excessive plate current flow at the instant the key is closed. Upon closing switch no.5, depress the key, and immediately adjust C_4 for a minimum reading on M_3.

8. The dummy antenna (not shown) is next hooked up to L_7 and the last stage is then retuned for a minimum reading of M_3.

9. The dummy antenna is removed and the actual antenna is hooked up to the transmitter. C_1, C_2, C_3, and C_4 are retuned slightly, and the transmitter is now ready for operation.

PRACTICE QUESTIONS - LESSON 10

(For answers, refer to back of Study Guide, Section III)

10-1.* The purpose of using a center-tap return connection on the secondary of a transmitting tube's filament transformer is to:

a. allow the filaments to heat up
b. permit power output
c. prevent modulation of the r-f by the a-c filament supply
d. prevent radiation of spurious harmonics

10-2.* A separate power supply is used for the oscillator stage of a transmitter;

a. Because the filaments require a separate heating source
b. because a lower B voltage is required
c. to prevent frequency instability due to load variations being fed back through a common power supply.
d. to increase the frequency band-width radiated due to a common power supply

10-3.* The principle advantage of a screen-grid type r-f amplifier tube over a triode of equal output rating is;

a. it does not require neutralization
b. it has more gain
c. it has higher interelectrode capacity
d. the need for lower operating voltages

10-4.* Describe the adjustment procedure for proper neutralization in a radio-frequency power amplifier using an r-f indicator coupled to the plate tank circuit

10-5.* A triode radio-frequency power amplifier must be neutralized;

a. to increase power output
b. to prevent self-oscillations
c. to eliminate second harmonic radiation
d. when used as a frequency doubler

10-6.* The result of operating an unneutralized r-f triode power amplifier would be;

a. decreased output
b. spurious radiation
c. a decrease in harmonic content
d. varying load condition

10-7.* One of the characteristics of an r-f frequency doubler amplifier is <u>not</u>;

a. high negative grid bias
b. large excitation signal
c. high impedance plate circuit tuned to twice the excitation frequency
d. low impedance plate circuit tuned to the same frequency as the excitation voltage

10-8.* Where is link coupling applicable in a transmitter?

10-9.* The purpose of a faraday shield between the output circuit of an r-f power amplifier and antenna coupling system is;

a. to eliminate ueed for neutralization
b. to reduce undesirable harmonic radiation
c. to eliminate need for antenna tuning
d. to prevent 60 cycle modulation of the carrier

10-10.* What are the output circuit conditions for obtaining optimum power output from an r-f power amplifier?

10-11.* A power output r-f amplifier <u>should not</u>

a. be coupled to the antenna system
b. have minimum plate current at resonance
c. couple high harmonics to antenna
d. be matched to the output circuit impedance

10-12.* The plate current of a radio-frequency power amplifier at resonance;

a. is a minimum
b. is a maximum
c. does not change
d. increases slightly over non-resonance

10-13.* Draw a simple schematic diagram of two r-f amplfier stages using triode tubes, showing the neutralizing circuit, link coupling between stages, and between output and antenna system, and a keying connection in the negative high voltage lead including a key-click filter.

10-14.* Draw a simple schematic diagram of a plate-neutralized final triode r-f stage coupled to a Hertzian antenna, showing the antenna system and a faraday screen to reduce harmonic radiation.

10-15.* The principle purpose of using door interlock switches is to;

a. eliminate the need of turning off transmitter
b. act as an on-off switch
c. protect equipment against mishandling by incompetent personnel
d. prevent personnel from being accidentally shocked by dangerous voltages when cage to transmitter is open.

10-16.* The circuit condition which <u>will not</u> minimize harmonic components in the output circuit of an r-f amplifier is;

a. low L/C ratio
b. improper neutralization
c. push-pull operation
d. proper bias voltage

10-17.* The most useful operating characteristic of a push-push amplifier is that it;

a. can be used as frequency doubler
b. cancels even harmonics
c. does not have to be neutralized
d. has high efficiency

10-18.* The principle disadvantage to using a grid-leak as the only source of bias in a class C r-f power amplifier is;

a. poor efficiency
b. varying bias voltage
c. it distorts output
d. loss of excitation will drop bias to zero, resulting in heavy plate current

10-19.* Draw a simple schematic diagram of a radio-frequency doubler stage driving a neutralized push-pull amplifier using triodes, showing the methods of interstage coupling and indicating the relative resonance frequencies of the grid and plate circuits.

SECTION III LESSON 11

THE MODULATED TRANSMITTER

11-1. Introduction

In the previous lesson we learned how a C.W. transmitter operates. Communication by means of C.W. code transmission is known as RADIOTELEGRAPHY. The disadvantage of radiotelegraphy transmission is that the radio operator must know code. In order that operators who are not familiar with code be able to send and receive messages directly, the transmission of speech is necessary. The transmission of audio (speech) by means of radio communication is known as RADIOTELEPHONY.

A radiotelephone transmitter consists of a C.W. transmitter (minus the telegraph key) plus an audio frequency amplifier system. The audio frequency system amplifies the audio signals and superimposes them on the r-f signal that is generated by the r-f oscillator. The process of superimposing the audio on the r-f is known as MODULATION. The r-f signal is called a CARRIER since it "carries" the audio through space to the receiving antenna.(refer back to the introduction to transmission and reception at the beginning of lesson 9)

11-2. Amplitude Modulation

There are several methods of modulating a carrier. The method which interests us as amateurs is called AMPLITUDE MODULATION.

In amplitude modulation, the modulating frequency is the intelligence (voice or music) which is to be transmitted through space to receivers many miles away. The modulating frequency is audio and, by itself, cannot be transmitted. A radio-frequency wave, however, is capable of being transmitted through space. If we combine or mix an audio-frequency wave with a radio-frequency wave in a special mixing circuit, we obtain an r-f output which contains the audio and can be transmitted. Fig.11-1 illustrates a voice modulated radio-frequency wave whose amplitude varies according to the amplitude of the audio wave. (Thus the term "amplitude modulation") The frequency of this variation is the same as the audio modulating frequency. (The abbreviation for amplitude modulation is a-m) An a-m wave is therefore a radio-frequency wave which contains in its amplitude variations the audio or intelligence which

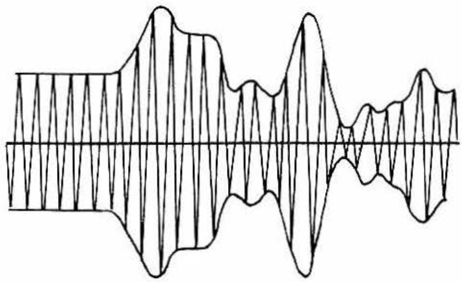


Fig.11-1. Radio wave modulated with voice.

we desire to transmit.

11-3. The A-M Transmitter

A block diagram of a typical amplitude modulated radiotelephone transmitter is shown in fig.11-2. Above each block is drawn the waveshape of the voltage output of that particular stage. With the aid of these waveshapes and the block diagram layout, we shall discuss the operation of the radiotelephone transmitter.

To begin with, the oscillator stage generates a radio-frequency voltage called the carrier. Following the oscillator, is the buffer-amplifier stage which amplifies the output of the oscillator and isolates the oscillator from the power amplifier. The final stage is the power amplifier which delivers energy to the antenna. Notice that the output waveshape of the final r-f stage does not resemble the input waveshape from the buffer. The r-f waveshape has been altered by modulation. This brings us to the modulation or audio section. The microphone converts the sound that is to be transmitted into electrical

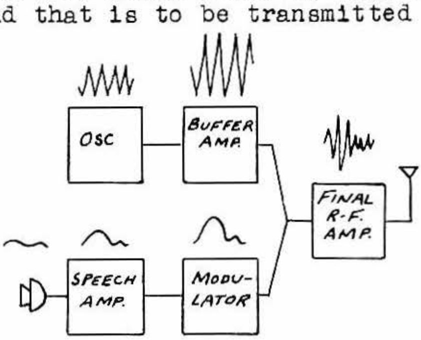


Fig.11-2. Block diagram of amplitude-modulated transmitter.

variations. The weak output of the microphone is fed into an audio amplifier (speech amplifier). The output of the speech amplifier drives an audio power amplifier called a MODULATOR. The modulator injects the audio signals into the r-f power amplifier to produce the modulated r-f output.

11-4. Percentage of Modulation

The method by which the audio signal is actually injected into the r-f amplifier will be discussed later on. We will now explain the term "amount of modulation" as expressed in a percentage number.

It is possible to modulate with a large audio voltage or with a small audio voltage. A large modulating voltage causes a large variation in the peaks of the r-f carrier which results in a large percentage of modulation. A small audio voltage causes a small variation in the peaks of the r-f carrier which results in a low percentage of modulation. By examining the waveshape of a modulated carrier, it is possible to determine the numerical percentage of modulation.

For example, fig.11-3 illustrates a carrier 100% modulated. Notice that the highest peak of the modulated wave

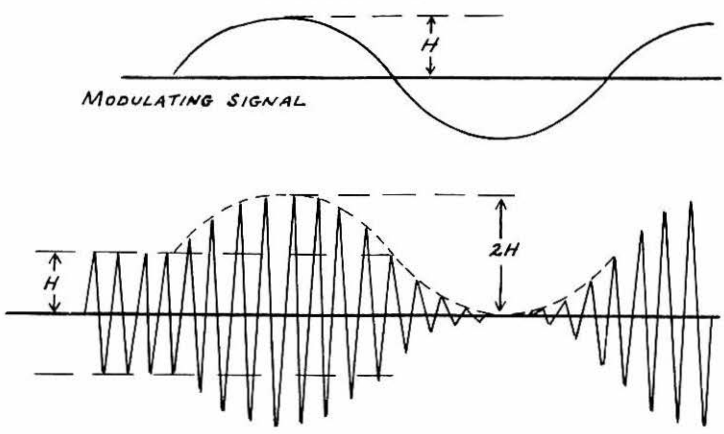


Fig.11-3. 100 per cent amplitude modulation.

is exactly twice as high as the peak of the carrier before modulation. Also notice that the minimum point of the modulated signal is at zero amplitude. In other words, the peaks of the carrier, modulated, vary 100% above and below the peaks of the unmodulated carrier. This is the condition for 100% modulation. Fig.11-4 shows an example of 50% modulation. The carrier of fig.11-4 is the same in amplitude as the carrier of fig.11-3. The modulating signal of fig. 11-4 is, however, half the amplitude of the modulating signal of fig.11-3. The maximum peak of the modulated signal

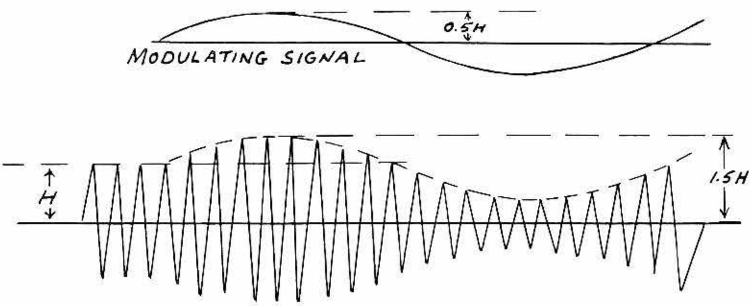


Fig.11-4. 50 per cent amplitude modulation.

is one and one-half times the peak of the unmodulated carrier, and the minimum peak is one half times the peak of the unmodulated carrier. In other words, the peaks of the modulated carrier vary 50% above and below the peaks of the unmodulated carrier.

If the carrier level is kept the same, and the modulating signal is increased above that of fig.11-3, we get the wave shown in fig.11-5. This illustration is the waveshape of an OVERMODULATED carrier. During the interval labeled "C", there is actually no output from the antenna.

The 100% modulated carrier of fig.11-3 is theoretically the most desirable in terms of reception. A 100% modulated signal produces the strongest possible undistorted signal at the receiver end. The 50% modulated carrier of fig.11-4 is considered an UNDERMODULATED signal. An undermodulated signal produces an undistorted but weak signal at the receiver end. The overmodulated carrier of fig.11-5 is highly undesirable since it results in a distorted signal at the receiver end. Overmodulation also produces spurious radiation which causes interference with transmitters operating on nearby frequencies.

11-5. Side Bands

The waveshapes of figures 11-3 and 11-4 are actually the result of a combination of several frequencies. It is not possible to tell, merely by looking at a waveshape, what frequencies are combined to give it the shape that it has. However, these frequencies can be determined by a

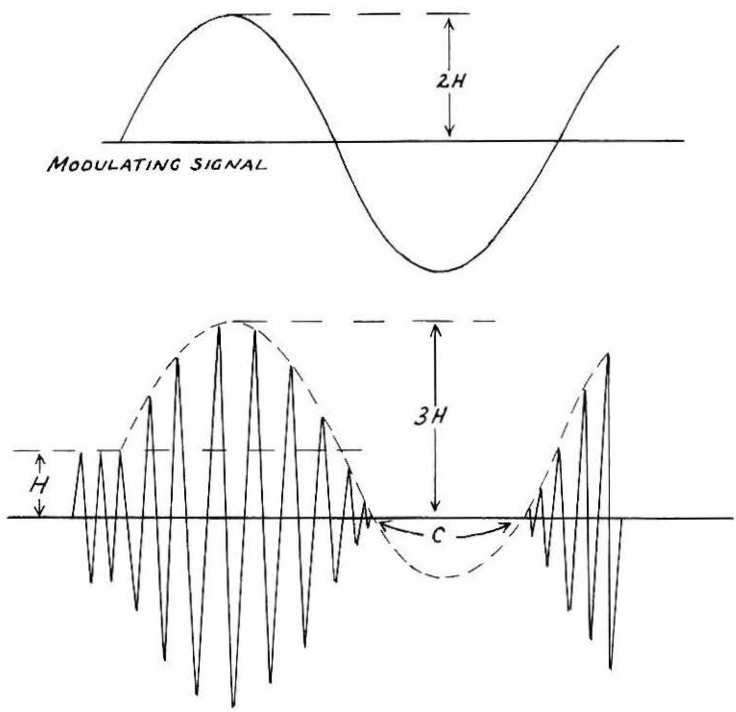


Fig.11-5. Over-modulation.

complicated mathematical analysis. For example, it has been determined that when a 1kc audio-frequency modulates a 1000 kc carrier the resultant signal will be a complex modulated wave containing the following component frequencies:

1 kc } 1000 kc }	-	the original frequencies
1001 kc	-	the sum of the original frequencies
999 kc	-	the difference of the original frequencies

Whenever any two frequencies combine by modulation, the resultant waveshape will contain the original frequencies plus the sum and difference of the original frequencies. These new sum and difference frequencies are known as SIDE BAND FREQUENCIES or simply SIDE BANDS. In the above example, the 1001 kc component is known as the UPPER SIDE BAND. The 999 kc component is known as the LOWER SIDE BAND. If the audio frequency had been 2 kc, the upper side band would have been 1002 kc, and the lower side band would have been 998 kc. The higher the audio modulation frequency, the farther both side bands are removed from the carrier frequency.

When speech or music is used to modulate a carrier, many audio modulating frequencies are present. Each audio frequency will produce an upper side band frequency and a lower side band frequency. Therefore, speech or music modulation generates a wide band of frequencies. The difference in kilocycles between the uppermost side band and lowest side band is called the BAND WIDTH of the modulated carrier. The band width of a carrier is equal to twice the highest audio modulating frequency used. For example, if the carrier is 1000 kc, and the highest audio modulating frequency is 5 kc, the band width is 10 kc (1005 kc - 995 kc)

11-6. Power in the Side Bands

If the modulator of a radiotelephone transmitter were turned off, the carrier would continue to be radiated as C.W. transmission by the r-f section of the transmitter. As soon as the modulator is turned on, the carrier is amplitude modulated and the side band frequencies come into existance. Since the modulated wave contains frequencies in addition to the carrier, there must be more power in the modulated wave than in the unmodulated wave. The additional power is supplied by the modulator stage, and is contained in the side bands of the transmission.

11-7. Methods of Modulation

In the last few paragraphs we have discussed the general principles of amplitude modulation. We are now ready to study exactly how the audio signal is superimposed onto the carrier.

There are many different methods of amplitude modulation. The most common method is to apply the audio-frequency modulating voltage to the plate of one of the r-f amplifiers. This popular method is known as PLATE MODULATION. If the audio-frequency modulating voltage is applied to the control grid of the r-f amplifier, we have what is called GRID MODULATION. If a pentode power amplifier is modulated by applying the audio-frequency modulating voltage to the suppressor grid, we have SUPPRESSOR MODULATION. SCREEN GRID MODULATION and CATHODE MODULATION can be similarly accomplished by applying the audio-frequency modulating voltage to the screen and cathode electrodes respectively. In other words, the method of modulation is determined by the electrode of the r-f amplifier tube to which the audio frequency modulating voltage is applied.

Since there are several r-f amplifier stages in a transmitter, a transmitter designer has his choice as to which stage shall be modulated. Modulating the final r-f stage of a radiotelephone transmitter is known as HIGH-LEVEL MODULATION. The term is derived from the fact that the modulation takes place at the highest power level of the transmitter. If the modulation process takes place in a stage preceding the final stage, the system is known as LOW-LEVEL MODULATION. In low-level modulation, the r-f amplifiers which follow the modulated stage are operated as linear or class A amplifiers, rather than class C. A class C amplifier will distort the audio component of the modulated signal, whereas a class A amplifier will amplify all signal frequencies without distortion. If the audio component of the modulated wave is distorted, the receiver will in turn reproduce a distorted audio signal. In high-level modulation, the final r-f amplifier is always operated as a class C amplifier. High-level modulation is the most efficient modulating system, and is also much more popular than low-level modulation.

Most commercial and amateur transmitters use either plate or control grid high-level modulation. We will discuss these two systems in detail.

11-8. Plate Modulation

There are several methods of plate modulation. The simplest method of plate modulation is illustrated in fig. 11-6. The audio-frequency output of the modulator stage is coupled through transformer, T, to the plate circuit of of the power amplifier. Transformer T is called the modulation transformer. The audio voltage across the secondary, S, of the modulation transformer is in series with the B+ voltage which is applied to the plate of the r-f power amplifier stage. Fig. 11-7A shows the audio voltage.

When the audio voltage causes the top of the transformer secondary, S, to go positive with respect to the bottom, the audio voltage and the power supply voltage will aid each other in series. The plate voltage of the r-f amplifier stage will therefore be the sum of the power supply voltage and the audio voltage. Fig. 11-7B shows the rise in the r-f amplifier plate voltage above the B+ value during the positive alternation of the audio. Since the plate power input to the stage is directly dependent upon the plate voltage, the plate power input will increase during the positive audio alternation. An increase in

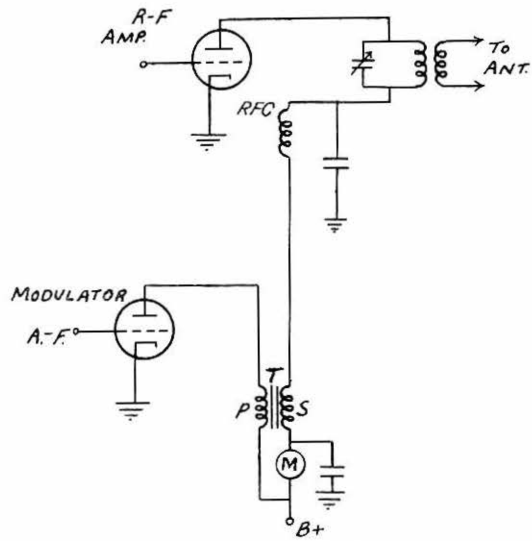


Fig.11-6. Transformer-coupled modulator circuit.

plate power input will in turn cause the useful power output to increase. The r-f output therefore rises during the positive half of the audio cycle. Fig.11-7C illustrates the r-f output voltage waveform before the modulating audio voltage is applied, and the resulting increase in amplitude of the r-f during the positive peaks of modulation.

During the negative half of the audio cycle, the top of the transformer secondary, S, is negative with respect to the bottom. Now the audio voltage and the power supply voltage are in series opposing. The two voltages therefore buck each other, and the plate voltage of the r-f amplifier is the difference between the two voltages. Fig. 11-7B shows the drop in the r-f amplifier plate voltage below the B+ value during the negative alternation of the audio. The drop in plate voltage causes the plate power input to decrease, which in turn causes the useful power output to decrease. Fig.11-7C shows the resulting decrease in amplitude of the r-f during the negative peaks of the audio. Fig.11-7C also shows the r-f output over a few cycles. Fig.11-1 illustrates the r-f output from a transmitter that has been modulated by speech or music which is a complex audio signal.

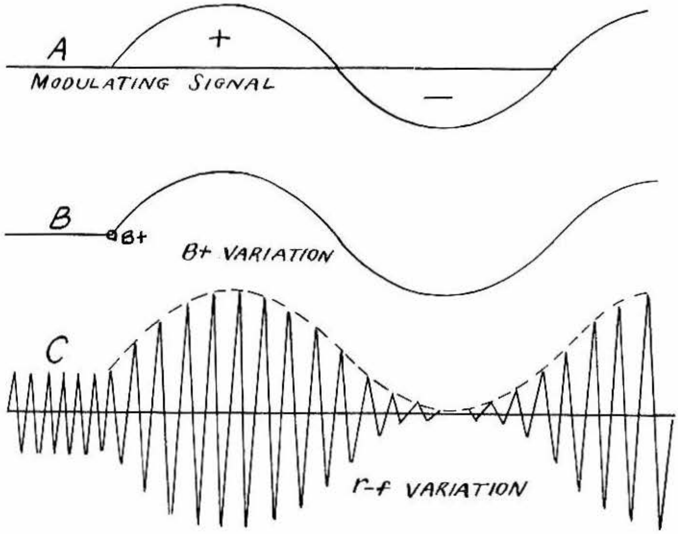


Fig.11-7. Amplitude Modulation.

11-9. Plate Current in Plate Modulation

In Fig.11-6,"M" is a d-c milliammeter which measures the d-c plate current of the modulated r-f stage. During normal modulation (100% or under), the d-c plate current REMAINS CONSTANT. If the percent modulation does not increase beyond 100%, there will be no distortion of the r-f wave. The instantaneous increase in plate current will therefore be exactly the same as the instantaneous decrease in the plate current. Therefore, the average plate current change is zero. The d-c plate current meter therefore reads the same plate current when the power r-f amplifier stage is either modulated or unmodulated.

11-10. The Push-Pull Modulator

The single ended (one tube) modulator stage of fig. 11-6 is operated class A so that there will be no distortion of the amplified modulating signal. The disadvantage of a one tube class A amplifier is that it operates at low efficiency. A low efficiency tube cannot always deliver the power that is required of a modulator stage. A push-pull amplifier which is capable of delivering more power than a single tube is therefore to be preferred. Fig.11-8 illustrates a push-pull modulator circuit.

The push-pull modulator may be operated either class A or class B depending upon the power output requirements.

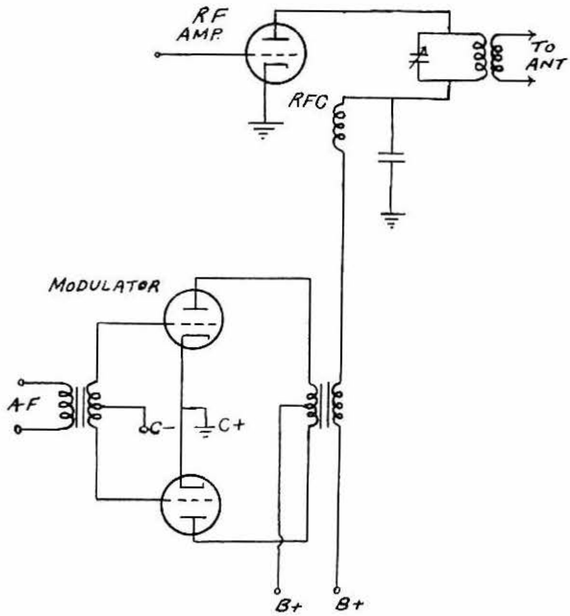


Fig.11-8. A push-pull modulator circuit.

A class B push-pull amplifier requires a large driving power applied to its grid circuit. The positive peaks of the grid signal usually drive the grid into grid current. Flow of grid current causes power to be dissipated in the grid circuit. The driver stage must be able to supply the power dissipated in the grid circuit.

A push-pull amplifier operated class A does not operate in the grid current region, and therefore requires very little grid driving power from the driver stage. The class A push-pull amplifier amplifies the audio modulating voltage without distortion. The class B modulator introduces a certain amount of distortion into the modulating signal.

11-11. Power Relations in a Plate Modulated Transmitter

We can summarize the power relations that exist in a class C modulated power amplifier by stating that the power required to generate the carrier wave is supplied from the r-f amplifier d-c plate supply, while the power required to generate the side bands is supplied by the modulator. The amount of modulating power required to modulate a transmitter depends upon three factors. First of all, it depends upon the type of modulation that is being used (plate modulation, grid modulation, etc.). Secondly, it depends upon the percentage of modulation. Thirdly, it depends upon the nature of the audio that is doing the modulating.

In order to modulate a carrier 100% with a pure sine wave of audio frequency, the audio output power of the modulator stage must be equal to one half of the input power to the r-f stage. For example, if the unmodulated plate power input to the final r-f power amplifier stage is 200 watts, (refer to lesson 6, paragraph 6-8 for discussion of plate power input) the modulator power output should be 100 watts for 100% modulation. The power input to the r-f power amplifier stage has been increased by 50% ($\frac{100}{200} \times 100 = 50\%$) from 200 to 300 watts. If speech or music is used to modulate the carrier, the output modulator power that is required need be only one fourth of the r-f input power. In the above example, the average modulator power output for speech modulation would be 50 watts. ($\frac{1}{4}$ of $200 = 50$) This insures that the peaks of the speech modulation do not over-modulate the r-f power amplifier. The power input to the r-f power amplifier is increased by 25% ($\frac{50}{200} \times 100 = 25\%$) from 200 to 250 watts.

An examination of fig. 11-3 will show that the peak modulated r-f output voltage during 100% modulation is <u>twice</u> as high as the unmodulated output carrier voltage. This is also true for the plate current. The r-f power amplifier when modulated must therefore be capable of handling peak voltages and currents that are twice as great as unmodulated voltages and currents. Since 100% modulation increases the power to the modulated r-f stage by 50%, the plate losses (refer to lesson 6, paragraph 6-9) are increased by 50%. The r-f stage must be capable of handling this extra loss. A transmitter which is therefore designed for both C.W. and phone operation is adjusted for a lower plate voltage, with a resulting lower carrier power, in phone operation.

For 100% pure sine wave modulation, the modulator supplies an amount of power to the r-f amplifier equal to 50% of the power output of the r-f amplifier unmodulated. The total power increase in the modulated carrier is therefore 50%. This 50% increase in power is contained in the side bands. The side bands contain one third of the total modulated carrier power for 100% modulation. For example, if the unmodulated carrier power is 200 watts, the 100% modulated carrier power would be 300 watts. (50% increase in power). The increased 100 watts of power is contained in the side bands. <u>The side bands therefore contain $\frac{100}{300}$ or one third of the total modulated carrier power.</u>

11-12. Grid Modulation

Plate modulation requires a large amount of audio modulating power. Grid modulation, in comparison, requires very little audio modulating power.

Grid modulation operates by varying the bias to the grid of the r-f power amplifier in accordance with the audio modulating voltage. The varying bias in turn causes the power output of the r-f power amplifier to vary.

Grid modulation is illustrated in fig.11-9. The primary of the modulation transformer T_2, is connected to the plate of the modulator. The secondary of T_2 is in series

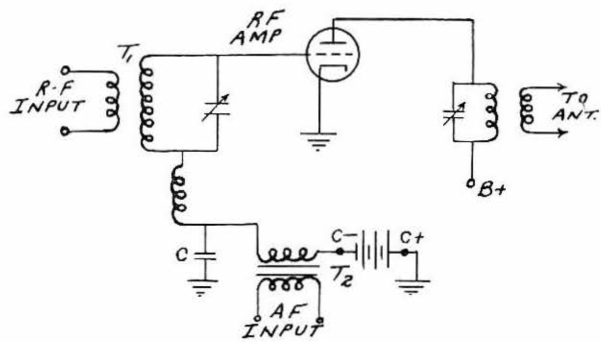


Fig.11-9. Grid modulation.

with the grid bias power supply of the r-f amplifier. The grid bias power supply can either be supplied by a battery or a rectifier type power supply. The audio modulation varies the voltage across the secondary of transformer T_2 in polarity and in amplitude. This varying voltage adds to or subtracts from the bias supply, resulting in a varying bias voltage on the grid of the r-f power amplifier. The varying bias causes a varying r-f output which is the modulated carrier. The purpose of condenser C is to by-pass the r-f around the secondary of the modulator transformer.

The last audio or modulator stage must be operated as a class A amplifier if fidelity of reproduction is to be maintained. The comparatively low output of a class A audio amplifier is sufficient for grid modulation because low power is required to vary the grid bias of the r-f amplifier. The modulated carrier power of a grid modulated transmitter is about one quarter of the output of a similar plate modulated transmitter. Because of the low efficiency and low power output, grid modulation is seldom used.

11-13. A Typical Radiotelephone Transmitter

Fig.11-10 illustrates a simple low power plate modulated radiotelephone transmitter. The power supplies have been omitted from the diagram for the sake of simplicity.

V_1 is a triode crystal controlled oscillator, and V_2 is the modulated r-f amplifier. The details of the operation of these two stages have been adequately covered in lesson 10. We will now discuss the audio section in detail.

V_3, the speech amplifier, is a high gain pentode which amplifies the weak audio voltage output of the high impedance crystal microphone. The output of V_3 is resistance coupled to a medium gain triode, V_4, through R_6, the audio volume control. The setting of R_6 will determine the average percentage modulation of the carrier. The output of V_4 is transformer coupled by T_1 to V_5 and V_6. T_1 is called an interstage transformer. It serves to match the impedance of the plate of V_4 to the grids of V_5 and V_6. V_5 and V_6 may be operated in class AB push-pull. Class AB is commonly used since it exhibits efficiency and fidelity characteristics which are midway between class A and class B operation. T_2 is the modulation transformer which couples the modulator stage to the r-f power amplifier.

The function of the resistors and condensers which have not been discussed are given below:

R_1 - Grid return resistor
R_2, R_7, R_9 - Cathode bias resistors
C_1, C_5, C_7 - Cathode by-pass condensers
C_2 - Screen by-pass condenser
R_4 - Screen dropping resistor
R_3 - Plate load resistor
C_4 - Coupling condenser
R_5, R_8 - Plate decoupling or isolating resistors
C_3, C_6 - Plate decoupling or isolating condensers.

11-14. Checking for Percent of Modulation

For maximum undistorted radiation of energy into space, a properly adjusted transmitter should be operated

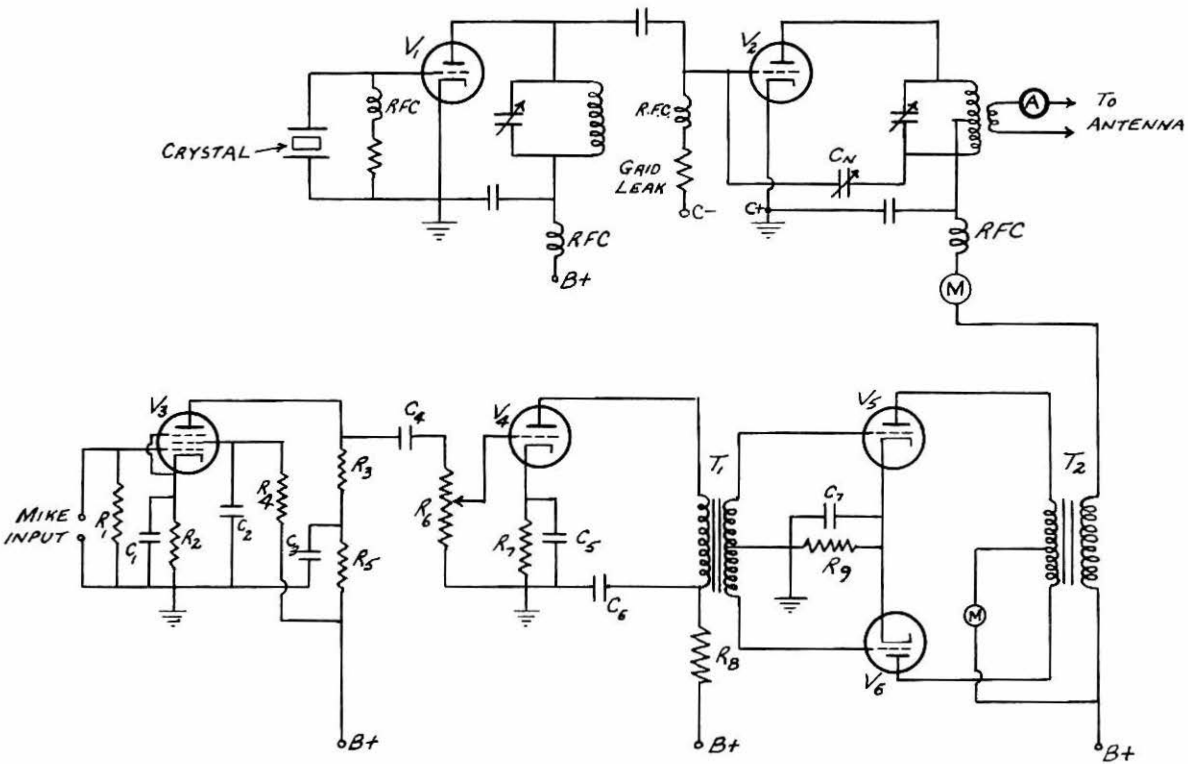


Fig.11-10; A typical radio telephone transmitter.

at 100% modulation. It is therefore important to be able to determine the point of 100% modulation of a transmitter.

A very simple method of determing the point of 100% modulation is to observe the d-c plate current meter in the r-f stage which is being modulated. The modulator output is adjusted up to the point where the needle of the plate current meter just begins to flicker. When this occurs, we are modulating at approximately 100%. It was previously pointed out that there should be no variation in the plate current reading of a modulated r-f amplifier that is properly adjusted. A slight movement of the d-c plate current meter indicates that the peaks of the speech modulation are driving the r-f power amplifier stage slightly above 100% modulation. This slight overmodulation at the peak can be tolerated.

Another check on the proper point of 100% modulation is to observe the r-f ammeter in the antenna circuit. (see fig.11-10) When the transmitter is modulated, power is added to the carrier. The total output power is increased by 50% from the unmodulated to the 100% modulated condition (pure sine wave modulation). The antenna current should therefore rise approximately 22% from the unmodulated to the 100% modulated condition. If a pure sine wave audio note is not available to check for this 22% rise, the operator should whistle or hum a steady note into the microphone to simulate a pure sine wave note. If the antenna current meter reads 100 ma with the transmitter unmodulated, the meter reading should increase about 22% to 122 ma with the transmitter modulated 100% (22% of 100 ma = 22 ma).

A third way of checking modulation is by means of an instrument called a PEAK MODULATION MONITOR. The peak modulation monitor simply indicates when we are overmodulating. It does not tell us the percentage of modulation. Fig.11-11 shows a peak modulation monitor hooked up to a transmitter.

The monitor consists of a diode and a milliammeter in series across the modulation transformer. When overmodulation occurs, the plate voltage of the r-f amplifier becomes negative with respect to ground during the negative peaks of the modulating wave. (During this time the output of the transmitter drops to zero as indicated by interval "C" of fig.11-5) When the plate of the r-f amplifier is negative with respect to ground, the diode will conduct because the cathode of the diode is connected to the plate of the r-f amplifier, and the plate of the diode is connected to ground. This diode current will flow through the milli-

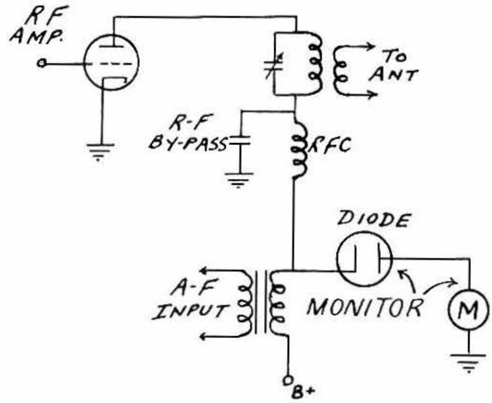


Fig.11-11. Peak modulation monitor connected to transmitter.

ammeter indicating a condition of overmodulation.

The fourth way to check modulation is by means of an instrument called the OSCILLOSCOPE or OSCILLOGRAPH. This instrument shows the graph or waveshape of the particular voltage waveform to be checked. By means of the oscilloscope we can tell the approximate percentage of modulation, as well as a condition of overmodulation.

There are two ways in which the oscilloscope can be connected to the modulated r-f amplifier to check modulation. Fig.11-12 shows one method.

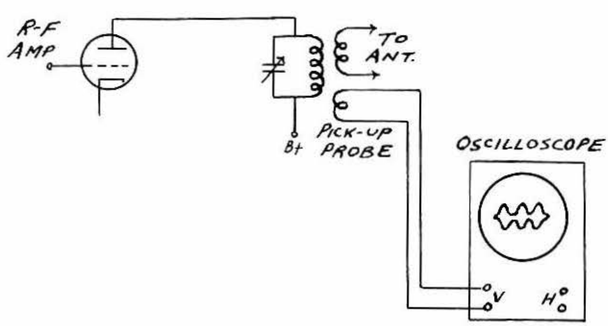
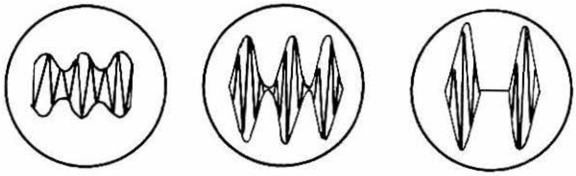


Fig.11-12. Checking percentage modulation.

The output of the transmitter is coupled directly to the vertical plates of the oscilloscope. The internal sweep of the oscilloscope is turned on. Fig.11-13 illustrates three possible patterns that would be seen on the screen of the oscilloscope for three different conditions of modulation. It is assumed that the modulating voltage



A. 50% modulation. B. 100% modulation. C. Over-modulation.
Fig.11-13. Wave-envelope modulation patterns on the oscilloscope.

is a pure sine wave. Fig.11-13A shows the waveshape for 50% modulation. Fig.11-13B shows 100% modulation, and fig. 11-13C shows overmodulation.

The second method of using a oscilloscope to check modulation is illustrated in fig.11-14.

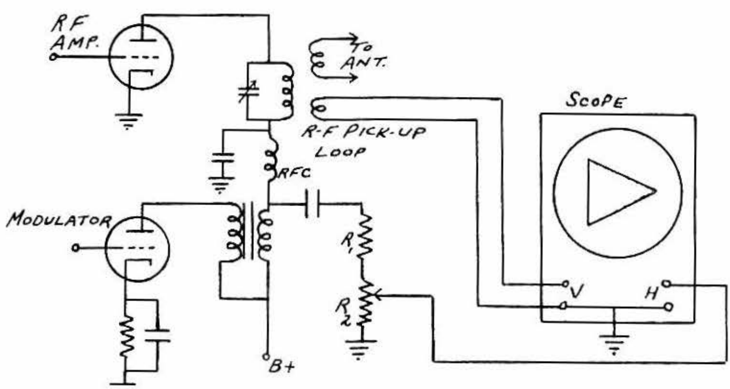
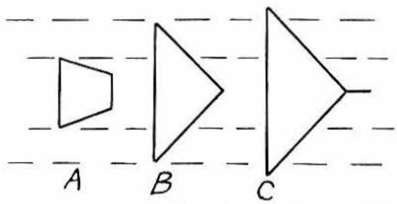


Fig.11-14. Trapezoidal modulation patterns on oscilloscope.

The transmitter output is coupled to the vertical plates of the oscilloscope. The audio output of the modulator is connected to the horizontal deflecting plates. The internal sweep of the oscilloscope is turned off. As the amplitude of the audio signal applied to the horizontal deflecting plates varies, the r-f output of the transmitter also varies. This produces on the screen a wedge-shaped pattern called a TRAPEZOID. Fig.11-15 illustrates three trapezoidal patterns for three different conditions of modulation. Fig.11-15A shows the pattern for 50% modulation; fig.11-15B shows the pattern for 100% modulation; and fig.11-15C shows the pattern for overmodulation.



A. 50% modulation. B. 100% modulation. C. Over-modulation.
Fig.11-15. Trapezoidal modulation patterns on oscilloscope.

11-15. Factors Causing Decrease in Antenna Current During Modulation

We pointed out in paragraph 11-14 that the antenna current should rise about 22% when the transmitter is being modulated. Sometimes the operator may find that the antenna current drops during modulation when it should be increasing. The operator should then immediately check the transmitter for one or more of the following troubles:

1. insufficient r-f excitation to the modulated amplifier.
2. insufficient bias on the grid of the modulated amplifier.
3. heavy overloading of the modulated class C, r-f amplifier
4. defective tube
5. poor voltage regulation of a power supply common to both the modulator and the r-f amplifier.
6. faulty or insufficient capacity of output filter condenser in power supply of r-f amplifier

The decrease in antenna current during modulation is known as DOWNWARD MODULATION.

11-16. Types of Transmission

There are various types of transmissions that are used in radio communication. The two methods that we have studied are; 1) continuous wave transmission in which the carrier is keyed according to the telegraph code. 2) amplitude modulating transmission in which the carrier is amplitude modulated with audio. The Federal Communications Commission has classified these and other types of emission according to letters and numbers as follows:

Type A0: is the steady unmodulated emission of a C.W. transmitter. It is used only in special cases, such as radio beacon stations.

Type A1: TELEGRAPHY: is the keyed emission of a C.W. transmitter. It can only be picked up by special receivers.

Type A2: MODULATED TELEGRAPHY: is the keyed emission of a transmitter whose carrier is modulated by a pure audio note. It can be picked up by an ordinary receiver.

Type A3: RADIOTELEPHONY: is the emission of a transmitter whose carrier is modulated by voice, music, etc. An example of this type is the familiar broadcast transmitter.

Type A4: FACSIMILE: is the emission of a transmitter whose carrier is amplitude modulated by frequencies obtained by scanning a still picture or printed page.

Type A5: TELEVISION: is the emission of a transmitter whose carrier is amplitude modulated by frequencies obtained by scanning scenes, pictures, people, etc.

PRACTICE QUESTIONS - LESSON 11

(For answers, refer to back of Study Guide, Page 269)

11-1.* Draw the trapezoidal type patterns showing 50% modulation and overmodulation as they would appear on the screen of an oscilloscope.

11-2.* Draw a simple schematic diagram of a peak modulation monitor.

11-3.* The average plate current in an amplitude modulated r-f amplifier should;

a. increase
b. remain constant
c. decrease
d. increase on the positive peaks, and decrease on the negative peaks.

11-4.* A class B modulator as compared to a class A modulator requires;

a. larger excitation voltage
b. lower excitation voltage
c. no power to drive the grid
d. zero bias operation

11-5.* If the grid bias supply of a class B modulator was suddenly short circuited;

a. the plate current would increase to excessively high values
b. grid current would increase
c. overmodulation would result
d. output power of the carrier would be in the side bands.

11-6.* The ratio of modulator sine wave power output to class C amplifier unmodulated plate power input is;
a. 100% b. 25% c. 125% d. 50%

11-7.* The ratio of modulator speech power output to class C amplifier unmodulated plate power input is;
a. 125% b. 100% c. 25% d. 50%

11-8.* Define amplitude modulation.

11-9.* What are side band frequencies?

11-10.* A downward deflection of the antenna r-f current meter during modulation might indicate;

a. sufficient r-f excitation to the modulated stage
b. proper filament emission of the modulated stage
c. excellent voltage regulation of power supply common to both modulator and r-f stage
d. insufficient bias on grid of modulated stage

11-11.* Show by a diagram the sinusoidal modulation envelope of an amplitude modulated wave at;

a. 50% modulation
b. 100% modulation
c. overmodulation

11-12.* What undesirable effects result from frequency modulation of an amplitude modulated carrier wave?

11-13.* What is a safe procedure for removing an unconscious person from contact with a high voltage circuit?

SECTION III LESSON 12

ANTENNAS, FREQUENCY METERS, TYPES OF TRANSMISSION

12-1. Antenna Radiation

Once the r-f signal has been generated in the transmitter, some means must be provided for radiating this r-f energy into space. The transmitting antenna provides the link or impedance matching device between the output stage of the transmitter and space. This energy, in the form of an electric field, travels through space and cuts across a receiving antenna, inducing a voltage in it. If the receiver is tuned to the same frequency as the transmitter, the signal will be received and heard.

12-2. Principles of Radiation

The currents flowing in the antenna, due to the excitation from the transmitter, set up magnetic and electrostatic fields which are pushed out from the antenna and fly off into space in all directions. The two fields moving through space as an electromagnetic wave contain the carrier and side band energy, and as such have quite definite characteristics. These characteristics are:

1) The wave has a very definite frequency which is equal to the carrier frequency of the transmitter.

2) The wave travels through space at a constant velocity regardless of the frequency at which it is being transmitted. This velocity is 186,000 miles per second or 3×10^8 meters per second. $3\text{x}10^8 = 300{,}000{,}000$

3) The wave has a certain wave length which is defined as the distance between adjacent peaks, or the distance the wave travels through space during one cycle of the antenna current. The wave length is measured in meters and is given the symbol "L". $L =$ wavelength in meters.

4) An equation which ties together wavelength, frequency, and velocity of an electromagnetic wave is given below:

$$V = FL$$

where: V is the velocity of the electromagnetic wave in free space which is constant. $V = 3 \times 10^8$ meters per second.

F is the frequency of the wave in cycles per second.

L is the wavelength in meters.

If the frequency is in kilocycles per second, the formula becomes:

$$2. \quad F\ (kc) \times L\ (meters) = 300{,}000$$

If we wish to solve for the wavelength, the formula becomes:

$$3. \quad L\ (meters) = \frac{300{,}000}{F\ (kc)}$$

If we wish to solve for the frequency, the formula becomes:

$$4. \quad F\ (\text{in kc per second}) = \frac{300{,}000}{L\ (meters)}$$

For Example:

a) Find the wavelength of the distress frequency, 500 kc?

Solution:

Use formula no.3

$$L\ (meters) = \frac{300{,}000}{F\ (kc)} = \frac{300{,}000}{500} = \underline{\underline{600\ meters}}$$

b) Find the wavelength of the frequency 1500 kc?

Solution:

Use formula no.4

$$L\ (meters) = \frac{300{,}000}{F\ (kc)} = \frac{300{,}000}{1500} = \underline{\underline{200\ meters}}$$

c) Find the frequency of the signal whose wavelength is 300 meters?

Solution:

Use formula no.4

$$F\ (kc) = \frac{300{,}000}{L\ (meters)} = \frac{300{,}000}{300} = \underline{\underline{1000\ kc}}$$

d) Find the frequency of the signal whose wavelength is 500 meters?

Solution:

Use formula no.4

$$F\ (kc) = \frac{300{,}000}{L\ (meters)} = \frac{300{,}000}{500} = \underline{\underline{600\ kc}}$$

Radio waves today are designated in frequency rather than in wavelength; as for example you talk about a 30 megacycle carrier frequency, rather than a 10 meter carrier wavelength. However, wavelength figures are very convenient in the discussion of antenna systems because the wavelength gives some indication of the actual physical dimension of the wires. For example, a half wave antenna for 10 meter transmission is 5 meters long, or converting to yard units; 5½ yards.

12-3. Fundamental Antenna Considerations:

Fig.12-1 shows an antenna or wire connected to an r-f source. The alternating current travels out from point A and along the wire until it reaches point B. Since point B

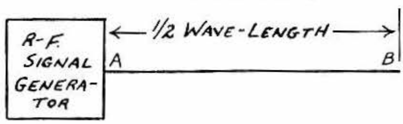


Fig.12-1. Half-wave antenna.

is free, the wave cannot continue farther and bounces back, or is reflected, from this point. The distance an r-f wave travels during the period of one cycle is known as the wavelength. If the wave is to travel exactly the length of the wire and back, during the period of one cycle, it is evident that the wire must be equal in length to one half the wavelength of the voltage being applied. The wire is then said to be resonant to the frequency of the applied voltage. During the negative alternation of the r-f generator, electrons will move along the wire away from point A towards point B. The electrons are stopped and accumulate at point B, which represents a high voltage point. During the positive alternation of the r-f power source, electrons move away from point B and crowd together at point A, which also represents a high voltage point. In the center of the antenna there is at all times a maximum movement of electrons causing a high current or a low voltage point. Very little voltage will appear, therefore, at the center of the antenna, and no current will flow at the ends. Fig.12-2 illustrates the voltage and current distribution on a fundamental half wave antenna. This representation of a voltage and current distribution is known as a standing wave pattern. The points of minimum current and minimum voltage are known as current and voltage nodes respectively. An antenna is said to be resonant when there exist standing waves of voltage and current along its length. Since the waves traveling back and forth in the antenna reinforce each other, a maximum radiation of electro-magnetic waves into space results. When there is no resonance (no standing waves), the waves tend to cancel each other, thus dissipating their energies in the form of heat loss, rather than utilizing them to radiate the radio waves. Therefore, a resonant antenna connected to an r-f generator can dissipate power because some of the energy leaves the antenna in the form of radiation.

12-4. Antenna Impedance

Since voltage and current vary along the length of the antenna, a definite impedance value must be associated with each point along the antenna. The impedance varies according to the relative crowding of the electrons as the ends are approached. The impedance existing at any point is simply the voltage at that point divided by the current at that point. Thus, the lowest impedance occurs where the current is highest; and the highest impedance occurs where the current is lowest.

12-5. Practical Transmitting Antennas

Most practical transmitting antennas come under one of two classifications, Hertz antennas or Marconi antennas. A Hertz antenna is operated some distance above the ground, and may be either vertical or horizontal. A Marconi antenna operates with one end grounded. (usually through the output of the transmitter or the coupling coil at the end of the feed line) Hertz antennas are generally used at higher frequencies, above about 2 megacycles, while Marconi antennas are used at lower frequencies.

12-6. The Hertz Antenna

A Hertz antenna is any length of wire far enough from ground so that it will not be influenced by grounded objects. Therefore, its physical length will directly determine the wavelength to which it will tune. A short length antenna will be resonant to a short wavelength or a high frequency; a long length antenna will be resonant to a long wavelength or low frequency. Therefore, the resonant frequency of a Hertz antenna can be changed by varying its physical length. This is true because an antenna acts like a resonant circuit. Fig.12-3 illustrates a center fed

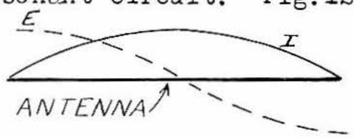


Fig.12-2. Distribution of voltage and current on half-wave antenna.

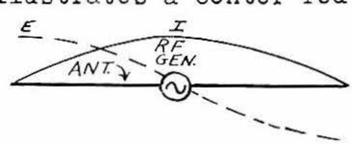


Fig.12-3. Center-fed Hertz antenna.

Hertz half-wave antenna. As the center of a half-wave antenna is a high current point, we say that the antenna is current fed by the the transmitter. The impedance at the center of this Hertz antenna is about 73 ohms. The impedance rises uniformly towards each end of the antenna where it is about 2400 ohms.

12-7. The Marconi Antenna

If the lower half of a half-wave Hertz antenna is replaced by a conducting plane such as illustrated in fig.12-4, no disturbance is caused in the propagated wave from the upper half. The remaining quarter-wave will continue to

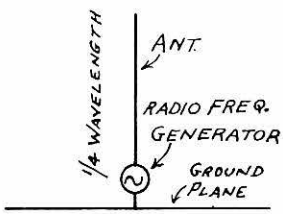


Fig.12-4. Marconi antenna.

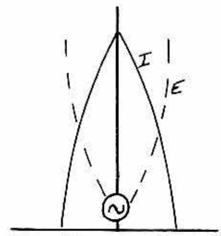


Fig.12-5. Distribution of voltage and current in a Marconi antenna.

radiate much in the same manner as a half-wave antenna, provided a large and extensive conducting plane is present (such as a good ground). The ground connection actually makes up the other half of the antenna's electrical length; you can look at it from the viewpoint that the antenna proper provides one-quarter wavelength, and the ground, or earth, supplies the additional one-quarter wavelength. A practical form of such a radiating system is the Marconi antenna, in which the lower terminal of the generator is connected to ground, and the earth's surface serves as the required extended conducting plane. The current and voltage distributions along the antenna length are as shown in fig.12-5. Notice that the generator feed point is still a high current, low impedance point as in the case of the ungrounded Hertz antenna. Since the Marconi antenna is only one-quarter wavelength in length, it is one-half the physical length of a Hertz antenna, and therefore, is more practical for mobile operation.

12-8. Antenna Loading

Since an antenna acts like a resonant circuit, it is resistive at its resonant frequency, and reactive at nonresonant frequencies. The antenna operates most efficiently when it presents a resistive load to the generator, in other words, when it is resonant. If the physical length of the antenna is too long at the wavelength which it is to radiate, it will act as an inductive load on the generator. We say that the electrical length of the antenna is too long. In this case, the electrical length of the antenna can be decreased by means of loading the antenna with a lumped capacitive reactance which will counterbalance the effective inductive reactance of the antenna. The result is that the antenna is made to present a resistive load to the generator. Similarly, if the electrical length of the generator is too short, it will present a capacitive load to the generator resulting in inefficient radiation. Loading the antenna with an inductance of the right value will resonate the antenna.

To summarize: 1) When an antenna is too long, it acts as an inductive load and requires a series condenser to effectively shorten it.

2) When an antenna is too short, it acts as a capacitive load and requires a series inductance to effectively lengthen it.

3) Increasing the electrical length of an antenna will decrease its resonant frequency.

4) Decreasing the electrical length of an antenna will increase its resonant frequency.

12-9. Radiation Resistance

The action of the antenna as a resistance and as a power dissipator has resulted in a term called the RADIATION RESISTANCE. It is defined as that value of resistance which, if substituted for the antenna and connected in its place, would dissipate the same amount of power in heat as the antenna dissipates in radiation. As you can see, this is a rather fictitious term, since the antenna is not a resistance, but is simply acting like one. The radiation resistance at the center of a half-wave Hertz antenna is 73 ohms. For a Marconi antenna, the radiation resistance is roughly 37 ohms, or about half that of the Hertz. The radiation resistance can be used to determine the power input into an antenna by using the formula $P = I^2R$ where I is the antenna current at the antenna input, and R is the radiation resistance. P is the power input to the antenna in watts.

12-10. Dummy Antenna

When a transmitter is being tuned up for optimum operation, the antenna should be coupled to the final stage in order to insure correct settings of plate voltage and current. (since the antenna is the load on the final stage) Coupling an antenna during the adjustment period is forbidden by law, since radiation will result which may cause interference. Most stations get around this difficulty by utilizing a dummy antenna which is nothing more than a resistive load of the correct power dissipation coupled to the tank coil of the final output tube in the same manner as the antenna is later to be coupled. An incandescent bulb of the proper wattage can readily be used. The brilliance of the lamp will give a rough idea of the transmitter power output. The peak brilliance of the lamp will indicate to the operator when the transmitter is tuned for maximum power output.

12-11. Tuning Indicator for the Antenna Circuit

The thermocouple ammeter is the standard antenna tuning indicator. The antenna circuit is tuned so that the ammeter reads a peak of r-f antenna current. Auxiliary methods employ neon bulbs or low voltage incandescent lamps which can be connected to a loop of wire of several inches in diameter; the bulbs are then loosely coupled to the antenna inductor. The lamps will glow with a maximum brilliance when the antenna is tuned to resonance.

12-12. Fading

A signal picked up by a receiver may sometimes fade in and out of hearing. This variation in signal strength is due to the interaction between two signals at the receiving antenna which vary in and out of phase with each other. These two signals are: 1) the directly received signal from the transmitter 2) the same signal which has traveled to the receiver from a reflecting object. One way to overcome fading is to have two receiving antennas placed some distance away from each other, with both feeding into the same receiver. Such a system is known as a diversity antenna receiving system.

12-13. Protecting Station Equipment from Static Charge and Lightning Discharge on Antenna

During an electric storm an antenna may be hit by lightning which can damage the station equipment. A means must be provided to safely by-pass the lightning discharge to ground. What is usually done is to connect spark gaps of large current carrying capacity between the antenna and ground. The spark gap will provide an effective by-pass for the lightning surge. If an antenna is capacity coupled to the output of the transmitter, static charges of high potential may build up on the antenna because there is no direct leakage path to ground. In this case, static drain coils having a high reactance at the radiating frequency are connected from the base of the antenna to ground. They serve as the discharge path for any static charge on the antenna.

12-14. The Measurement and Determination of Frequency

The FCC states that a station must maintain its exact operating frequency so that stations do not interfere with each other. Therefore, one of the most important duties of the transmitting engineer is to keep his station exactly on frequency. The FCC assigns definite frequencies or bands of frequencies to the various transmitting services. Operating "off frequency" represents a serious offense, and must be avoided. It is therefore very important to be able to measure the frequency of a transmitter. The instrument which is used to measure frequency is called a frequency meter.

We will now discuss several frequency meters in detail:

12-15. The Absorption type Frequency Meter or Wavemeter

A high "Q" tank circuit is resonant to only one frequency. If this tank circuit is placed in the vicinity of an r-f field, it will absorb energy from this field and start to oscillate if the resonant frequency of the tank circuit is equal to the frequency of the radiation. This is the principle of the absorption type wavemeter. The circuit is illustrated in fig.12-6.

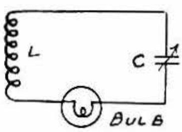


Fig.12-6. Frequency meter.

The absorption type wavemeter consists of a rigidly constructed, accurately calibrated coil and a variable condenser combination. The coil is usually interchangeable with other coils to permit measurements to be taken over a large portion of the radio frequency spectrum. The resonance indicator may be a flash light bulb for high intensity r-f fields. A highly sensitive resonance indicator is a thermocouple ammeter which is placed in series with the tank circuit. A thermocouple ammeter can be used in place of the bulb. At resonance, the tank circuit will absorb maximum energy from the radiation, and therefore, the circulating current in the series resonant loop will be at a maximum as indicated on the ammeter or bulb. A set of calibration charts are provided with the instrument. These charts relate the dial reading of the instrument in terms of frequency. A separate chart is provided for each coil.

If we wish to determine the output frequency of a transmitter, the wavemeter, with the proper coil in place, is brought near the output tank coil of the transmitter. A knob which is geared to the condenser, C, and the dial is turned rapidly until a reading is noted on the bulb or ammeter. The dial is read, and reference made to the calibration chart to determine the frequency of that particular dial setting.

A precaution to be followed in using the wavemeter is to place the instrument as far away as possible from the radiating source, consistent with a readable indication. The reason for this is that we do not want the wavemeter to change the operation of the radiating source by mutual coupling reaction.

12-16. Percentage Error

Suppose you want to determine the frequency of your transmitter using your absorption type wavemeter. You would turn the tuning knob of your wavemeter until the indicating device indicates that the wavemeter is resonant to the transmitter frequency. At this point you would stop and take a reading of the dial to determine the frequency. The reading that you get is not 100% accurate. There is a certain percentage error involved in the reading. This error involved in the reading is due to a number of factors. One factor is that it may be difficult to read the dial with complete accuracy. Another is error due to the limitations of the mechanical gearing system of the wavemeter. There may be some slack in the gears. Another factor is caused by the slight inaccuracies in the variable condenser due to the limitations in manufacturing. All these factors contribute to a certain percentage error in a wavemeter reading. All wavemeters have their maximum percentage error listed under their characteristics. For example, a wavemeter is listed as having a maximum percentage error of 0.50%. What is the error involved in cycles at a reading of 1000 kc?

Solution: The error in cycles per second is plus or minus 0.50% of 1000 kc or:

$$\frac{0.50}{100} \times 1000 \text{ kc} = 5 \text{ kc} = \underline{\underline{\pm 5000 \text{ cps}}}.$$

The error in the reading $\pm$ 5000 cps means that the actual frequency may be anywhere between 995 kc and 1005 kc.

12-17. Error Calculations When Using the Wavemeter

Suppose you wish to operate your transmitter close to the high frequency end of the 3500 - 4000 kc amateur band. You set your wavemeter dial to read 4000 kc, and adjust your transmitter frequency until the wavemeter reads. Are you absolutely sure that the radio transmitter is radiating at 4000 kc. You cannot be sure if you remember that the wavemeter reading has a tolerance which means that there is a definite percentage error involved when a dial reading is indicated on a wavemeter. Returning to our example, if the wavemeter dial reads higher than the actual radiating frequency you have nothing to worry about. However, if the dial reads lower than the actual radiating frequency (dial reading indicates 4000 kc), you are operating outside the band and are liable to be penalized by the FCC. If the wavemeter has a possible error of 0.60% at a reading of 4000 kc, you should adjust the transmitter frequency to the wavemeter dial reading 3976 kc.

$$0.60\% \text{ of } 4000 \text{ kc} = 24 \text{ kc}$$
$$4000 - 24 = 3976 \text{ kc}$$

You can now be sure that if the wavemeter reading is low, the transmitter is in error by no more than 24 kc. (To be exact: 0.60% of 3976 = 23.86 kc.

Therefore, the most that the transmitter would be off from 3976 kc would be 3976 ± 23.86 or 3999.86 kc.

Problems:

1.- Using a frequency meter with a possible error of 0.75%, on what whole number kilocycle frequency nearest the low frequency end of the 14,000 - 14,400 kc band could a transmitter safely be set?

Solution: The low frequency end of the band is 14,000 kc.

$$0.75\% \text{ of } 14{,}000 \text{ kc is } \frac{.75}{100} \times 14{,}000 = 105 \text{ kc}$$

The transmitter should be set at:

$$14{,}000 \text{ kc} + 105 \text{ kc} = \underline{\underline{14{,}105 \text{ kc}}}$$

2.- Using a frequency meter with a possible error of 0.75%, on what whole number kilocycle frequency nearest the high frequency end of the 14,000 - 14,400 kc band could a transmitter safely be set?

Solution: The high frequency end of the band is 14,400 kc.

$$0.75\% \text{ of } 14{,}400 \text{ kc is } \frac{.75}{100} \times 14{,}400 = 108 \text{ kc}$$

The transmitter should be set at:

$$14{,}400 \text{ kc} - 108 \text{ kc} = \underline{\underline{14{,}292 \text{ kc}}}$$

12-18. The Heterodyne Frequency Meter

The Heterodyne Frequency Meter is a rigidly constructed, accurately calibrated oscillator and detector. For stability, the oscillator is usually of the electron-coupled type. The oscillator is continuously variable, and therefore, is not crystal controlled. An additional crystal oscillator can be incorporated in the frequency meter to check and calibrate the heterodyne oscillator at the crystal check points. Fig.12-7 illustrates a combination heterodyne frequency meter and monitor. The frequency meter incorporates a detector circuit into which is fed two r-f signals. They are: 1) the transmitter signal

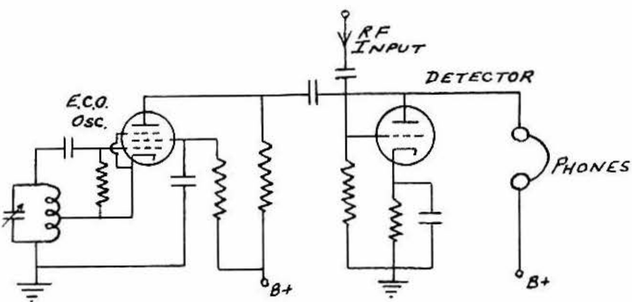


Fig.12-7. Combination heterodyne frequency meter and monitor.

picked up by an antenna circuit. 2) the signal from the heterodyne oscillator. These two signals mix in the grid of the detector, and produce a beat note, or difference frequency. If the beat note is in the audio range, it will be heard in the head sets.

To check the transmitter frequency, vary the frequency of the heterodyne oscillator frequency until the beat note becomes a zero beat. At zero beat, the transmitter and oscillator are producing exactly the same frequency. The frequency may now be read off directly from the frequency meter dial.

A number of precautions to be observed in the use of the heterodyne type of frequency meter are as follows:

1) The heterodyne oscillator must be calibrated against the crystal oscillator check points for frequency accuracy.

2) When battery operated, check A and B battery voltages; as a change in battery voltage will affect the oscillator frequency.

3) Allow warm-up period before using.

PRACTICE QUESTIONS - LESSON 12

(For answers, refer to back of Study Guide, Page 270)

12-1.* Draw an antenna system connected to a Hertz antenna.

12-2.* The usual means for protecting amateur station equipment from damage by charges of atmospheric electricity (static) on the antenna system is to;

a. connect a large size condenser from the top of the antenna to ground
b. connect a static drain coil
c. shunt the antenna with a low value resistance
d. disconnect the coupling system from the antenna when not in use.

12-3.* A transmitter is protected against damage from lightning by;

a. connecting spark gaps from the antenna base to ground
b. shorting the antenna
c. shunting the antenna with a low value resistance
d. opening up the antenna circuit

12-4.* Using a frequency meter with a possible error of 0.75%, on what whole number kilocycle frequency nearest the high frequency end of the 3500 - 4000 kc amateur band could a transmitter safely be set?

12-5.* Using a frequency meter with a possible error of 0.75%, on what whole number kilocycle frequency nearest the low frequency end of the 7000 - 7300 kc amateur band could a transmitter safely be set?

12-6.* Draw a schematic diagram of a combination heterodyne frequency meter and monitor.

12-7.* Using a frequency meter with a possible error of 0.75%, on what whole number kilocycle frequency nearest the low frequency end of the 14,000 - 14,400 kc band could a transmitter safely be set?

12-8.* Using a frequency meter with a possible error of 0.75%, on what whole number kilocycle frequency nearest the high frequency end of the 14,000 - 14,400 kc band could a transmitter safely be set?

12-9.* A precaution to be observed in the use of the battery operated heterodyne frequency meter is to;

a. check the crystal frequency
b. check the oscillator with a standard frequency
c. check the A and B battery voltages
d. check the tube filaments

12-10.* A precaution to be observed in the use of the absorption type frequency meter is to;

a. loosely couple the frequency meter to the oscillator tank circuit
b. calibrate the frequency meter
c. check the B voltage of the frequency meter
d. zero-beat the output of the wavemeter

SECTION III LESSON 13

THE RADIO RECEIVER

13-1. Functions of a Radio Receiver

Up to this point, we have covered the principles of the amplitude modulated transmitter in great detail. To complete the picture, we must consider the problem of the reception of radio waves by the radio receiver.

The radio receiver must be able to perform the following functions:

1.- pick up radio frequency signals radiated by transmitters.

2.- tune to one desired signal and reject the remaining signals.

3.- amplify the desired radio frequency signal using radio frequency amplifiers.

4.- detect or demodulate the desired signal (separate the audio intelligence from the radio frequency carrier)

5.- amplify the detected audio signal and drive a speaker with it.

13-2. The One Tube Radio Receiver

Fig.13-1 illustrates a block diagram of a one tube radio receiver.

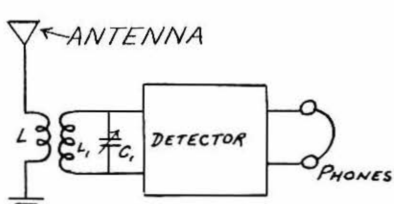


Fig.13-1. A simple one-tube receiver.

The antenna picks up any radiated signals that may be present in its vicinity, and couples them to the tuned circuit, $L_1 - C_1$. The function of the tuned circuit is to select the station that is desired to be heard, and at the same time to reject the unwanted signals. This is accomplished by varying condenser, C_1, until the tuned circuit is resonant to the desired frequency. For a review of the theory of a tuned circuit refer to lesson 3, paragraph 25 on series resonance. Once the signal has been selected, it is necessary to extract the audio-frequency intelligence from the radio-frequency carrier. This job is done by the detector, or demodulator, stage. The audio is then applied to the head phones.

13-3. The Tuned Radio-Frequency Receiver

A radio signal diminishes in strength at a very rapid rate after it leaves the transmitting antenna. Therefore, it is seldom possible to use a detector circuit alone to obtain any useful output from the few microvolts of signal available at the receiving antenna. To remedy this, it is desirable to amplify the r-f signal before it is detected. This is done by the use of an r-f amplifier. The r-f amplifier, like the detector, is provided with one or more tuned circuits, so that it amplifies only the desired signal. The addition of an r-f amplifier to the receiver gives not only greater sensitivity (ability to receive weak signals), but also greater selectivity (ability to separate signals). Audio amplifier stages usually follow the detector to amplify the audio signals before they are applied to the reproducer. The complete receiver, consisting of radio-frequency amplifiers, detector, and audio amplifiers, is called the tuned radio frequency receiver, or as it is more commonly called, the t-r-f receiver.

A block diagram of a t-r-f receiver, showing the signal passing through the receiver, is illustrated in fig. 13-2.

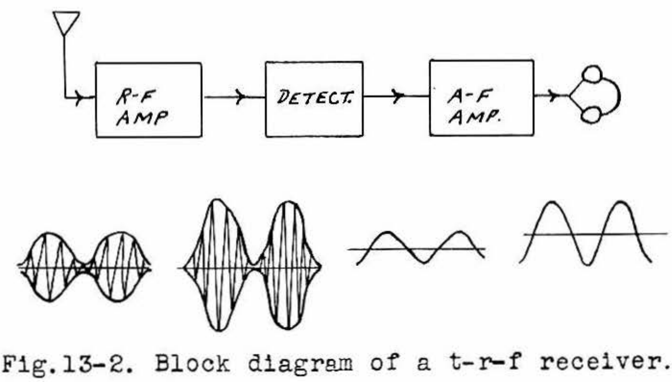


Fig.13-2. Block diagram of a t-r-f receiver.

13-4. The R-F Amplifier

The r-f amplifier, as indicated previously, gives us the desired selectivity and sensitivity required for satisfactory reception. Fig.13-3 illustrates an r-f stage of amplification. The important operating characteristics of

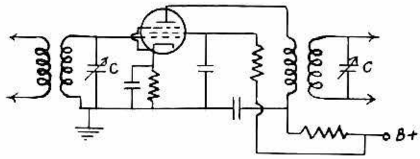


Fig.13-3. R-f stage of a t-r-f receiver.

the amplifier shall be discussed at this point:

1.- The r-f amplifier tube is biased to operate as a class A voltage amplifier. A class A audio voltage amplifier differs from a class A r-f amplifier in that it does not have a tuned circuit and amplifies only audio frequencies. On the other hand, the r-f amplifier has a tuned circuit which enables it to tune in, or select, only one signal frequency. Since this r-f amplifier operates class A, its fidelity is excellent.

2.- The r-f amplifier tube is always a pentode which has very low interelectrode capacities. If a triode with its high interelectrode capacities were used as an r-f amplifier, there would be sufficient feedback from plate to grid at radio frequencies to cause the circuit to break into oscillations.

3.- As in the audio amplifier, self-bias is almost always employed by using a cathode biasing resistor and a cathode by-pass condenser.

4.- The r-f transformer consists of a primary coil and a secondary coil. The secondary coil is designed to cover the desired frequency range when tuned by the tuning condenser, C , which is connected across the secondary. Most r-f amplifier receivers use two or three r-f stages preceding the detector, with each stage tuned to the same frequency. It is therefore more convenient to have all of the tuning capacitors mounted on a common shaft so that all stages can be tuned simultaneously. These condensers are called ganged variable condensers. When these tuning circuits are ganged, the coils and the capacitors must be identical. This is necessary in order that all the circuits will tune to the same frequency for any dial setting. Since it is hardly likely that all the coils and condensers of the tuned circuits will be identical, (due to irregularities in manufacturing, and the effects of stray capacity) the tuned circuits will not all tune to the same frequency; and decreased selectivity will result. These small differences are compensated for by providing small trimmer condensers across each tuning capacitor. These trimmers are adjusted by means of a screw-driver so that each circuit may tune to the same frequency. This process is known as alignment. When all the stages tune to identical frequencies at all dial settings they are said to be tracking; and maximum gain and selectivity will be obtained from the receiver.

13-5. A-F Amplifiers

Since the signal output of a detector stage in a tuned radio-frequency amplifier (t-r-f) receiver is low, it is usual to have at least one stage of a-f amplification. The output of the first a-f amplifier may be further amplified if necessary, depending on the requirements of the receiver.

13-6. Capabilities of a t-r-f Receiver

Although the t-r-f receiver will give satisfactory results when covering the medium frequency band, such as the broadcast band, it has several disadvantages which makes it impractical for use in high frequency and multi-band receivers. The chief disadvantage of the t-r-f receiver is that its selectivity does not remain constant over its tuning range. When a tuned circuit is made variable, as it must be in a t-r-f receiver, selectivity will decrease as the receiver is tuned to the high end of the band. If it were possible to design a receiver in which the selective circuits were fixed tuned, these circuits could very easily be designed for high gain and selectivity for the particular frequency at which they are to operate. This desirable effect is accomplished in the SUPERHETERODYNE RECEIVER.

13-7. Theory of Superheterodyne Action

The important difference between the t-r-f receiver and the superheterodyne receiver is that in the t-r-f the r-f signal is amplified at the frequency of the signal, while in the superheterodyne receiver the r-f signal is amplified at a new, lower, fixed frequency called the INTERMEDIATE FREQUENCY. The intermediate frequency (IF), though much lower in frequency than the original signal, retains all the modulation characteristics of the original signal. By amplifying this lower fixed frequency, it is possible to use circuits which are more selective and capable of greater amplification than the circuits used in t-r-f receivers.

13-8. The Heterodyne Principle Generating a Fixed I-F

In our study of the transmitter, we discussed the process of modulation which is the mixing of two signals together to produce new frequencies called side bands. (refer to lesson 11, paragraph 5). In the superheterodyne receiver, the intermediate frequency is similarly generated by a mixing process called frequency conversion or HETERODYNING. The intermediate frequency in this case is the difference frequency.. Suppose we were to mix a 1000 kc signal and a 1450 kc signal in a special mixing circuit. The output of the mixing circuit will contain the original frequencies (1000 kc and 1450 kc), the sum of the frequencies (2450 kc), and the difference frequency (450 kc). If the two original frequencies were varied by the same amount, the output difference frequency would remain fixed at 450 kc. For example, if the two frequencies were increased by 1000 kc, so that they became 2000kc and 2450 kc respectively, the difference frequency would still be 450 kc. So long as the two frequencies vary up or down by the same amount, the difference frequency (the I-F) will always remain fixed at 450 kc. If a modulated carrier is beat against a pure r-f frequency, the modulation frequency will still remain present and unchanged in amplitude in the difference, or intermediate, frequency. For example, if a 1000 kc signal with a 400 cycle audio modulation is beat against a 1450 kc signal, the beat frequency will be a 450 kc r-f wave with a 400 cycle audio modulation envelope. The process of mixing two frequencies to obtain a constant difference or intermediate frequency is utilized in the superheterodyne receiver.

13-9. The Superheterodyne Receiver

The block diagram of a typical superheterodyne receiver, showing the signal passing through, is illustrated in fig.13-4. The received modulated r-f signal is first

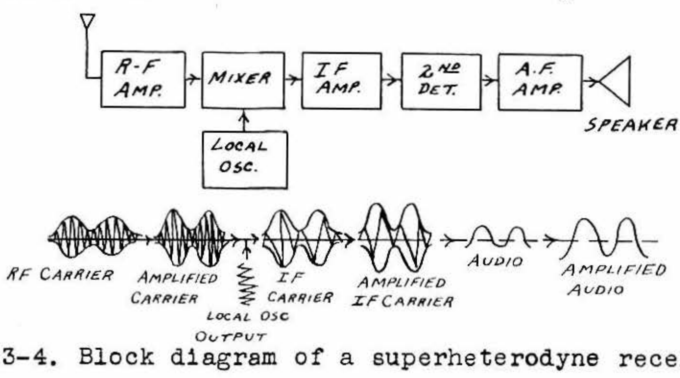


Fig.13-4. Block diagram of a superheterodyne receiver.

passed through an r-f amplifier. A locally generated unmodulated r-f signal is then mixed with the carrier frequency in the mixer stage. The mixer is called a converter, and sometimes a first detector. This mixing action produces two new modulated r-f signals in the output of the mixer, the sum and the difference, in addition to the original signals. It is the difference, or intermediate frequency, in which we are interested. A fixed tuned circuit in the plate of the mixer will reject all frequencies except the I-F frequency to which it is tuned. This new I-F frequency contains all the modulation characteristics of the original signal; but it is much lower in frequency. The intermediate frequency is usually set at some definite value. The frequency of the local oscillator must differ from that of the signal being received by an amount equal to the intermediate frequency. Thus, as the r-f amplifier of the receiver is tuned to signals of various frequencies, the local oscillator must be tuned simultaneously, so that its frequency is always separated from that of the signal by the same amount. For example, if the I-F is 450 kilocycles, a commonly used frequency, and the range of the receiver is from 500 to 1600 kc, the oscillator would have to operate over a range of either 950 (450 + 500) to 2050 (450 + 1600) kilocycles or 50 (500 - 450) to 1150 (1600 - 450) kilocycles. Whether the oscillator frequencies are higher or lower than the signal, the difference is still 450 kc. The intermediate frequency is then amplified in one or more fixed tuned stages called intermediate-frequency amplifiers, and is then fed into the second detector where it is detected, or demodulated. The detected signal is amplified in the a-f amplifier, and then fed to the headset or loudspeaker. The reason why the detector is called the second detector is because the mixer tube is sometimes called the first detector. Because of this, the superheterodyne is sometimes called a double detector receiver. At this point, in order that you don't lose sight of the essential reason for designing the superheterodyne receiver, reread chapter 13-6, "Capabilities of a t-r-f receiver."

13-10. Frequency Conversion

The combined circuits of the oscillator stage and mixer stage form the frequency converter of the superheterodyne receiver. There are a large number of possible combinations of tubes and circuits which may be employed for frequency conversion.

The most popular circuits employ the Hartley, the Electron Coupled, or the Armstrong type of oscillator. The major requisite is stability rather than high output. The frequency of the oscillator is controlled by the coil constants, and the variable condenser which is ganged to the mixer tuned circuit.

The two most important types of conversion circuits are:

1.- A separate oscillator and mixer as illustrated in fig.13-5.

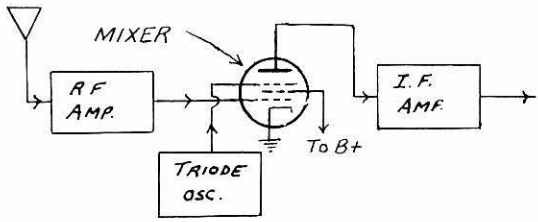


Fig.13-5. The pentode mixer

2.- Pentagrid converter: This circuit employs a single tube combining the oscillator and frequency mixer in the same envelope. The basic circuit of the pentagrid converter is illustrated in fig.13-6. The cathode and the first two grids represent the oscillator section of the pentagrid converter tube.

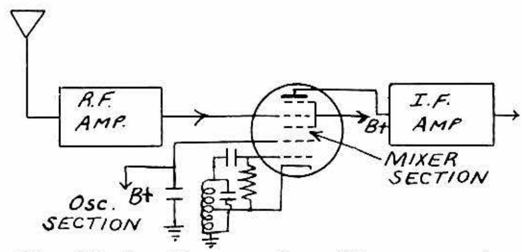


Fig.13-6. The pentagrid converter.

13-11. I-F Amplifiers

The intermediate-frequency amplifier is a high gain circuit permanently tuned to the frequency difference between the local oscillator and the incoming signal. Pentode tubes are generally used as I-F amplifiers because of their high gain and low interelectrode capacities. The I-F section consists of one or more I-F stages, with each stage adjusted to tune to the I-F frequency. Since all incoming signals are converted to the same frequency by the frequency converter, the I-F amplifier operates at only one frequency. The tuned circuits may, therefore, be permanently adjusted for maximum amplification and desired selectivity. It is in the I-F voltage amplifier that practically all of the voltage amplification and selectivity of the superheterodyne are developed.

13-12. The Wave Trap

Broadcast receivers sometimes experience interference from a nearby amateur transmitter. The interfering station is usually heard in the background over the entire tunable band of the receiver.

One way of reducing this interference is to place a tuned circuit in the antenna system which will either bypass the interfering station to ground, or else offer a high impedance to this frequency, and prevent it from being developed across the antenna primary coil. The circuit used for this purpose is called a WAVE TRAP. Fig.13-7 illustrates a shunt rejector wave trap. The parallel circuit consisting of L and C is tuned until the interfering station frequency disappears. The parallel resonant circuit is a very high impedance at the interfering frequency. It

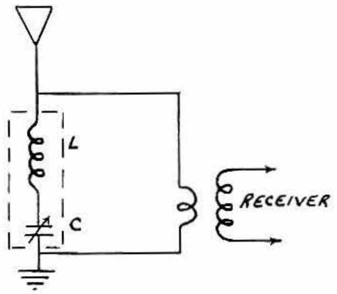


Fig.13-8. Series wave trap.

thus blocks this signal from entering the antenna coil primary. Fig.13-8 is a diagram of a series wave trap. L and C are connected in a series circuit which is bridged across the primary of the antenna coil. The circuit is adjusted by varying condenser C until the interfering station is eliminated. The wave trap acts as a short circuit at the interfering frequency, by-passing the signal to ground.

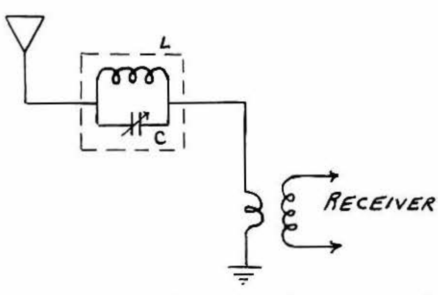


Fig.13-7. Shunt-rejector wave trap.

PRACTICE QUESTIONS - LESSON 13

(For answers, refer to back of Study Guide, Section III)

13-1.* Draw a schematic diagram of a filter for reducing amateur interference to broadcast reception, consisting of a series tuned circuit connected in shunt with the d-c receiver input to by-pass the interfering signal and a parallel tuned (trap) circuit in series with the receiver input to reject the interfering signal.

13-2. The function of the detector is to;

a. amplify the signal
b. demodulate the carrier
c. excite the speaker
d. by-pass the a-f

13-3. Increasing the number of tuned circuits in a receiver will;

a. increase the power output
b. increase the selectivity
c. decrease the sensitivity
d. improve fidelity

13-4. The disadvantage of a t-r-f receiver is that;

a. sensitivity decreases towards high end of band
b. sensitivity decreases towards low end of band
c. selectivity decreases towards high end of band
d. it has poor fidelity

13-5. The intermediate frequency;

a. is the difference frequency between the carrier frequency and the local oscillator frequency
b. is always ½ the local oscillator frequency
c. depends upon the station tuned in
d. is twice the carrier frequency

13-6. If a superheterodyne receiver is tuned to 880 kc, and the intermediate frequency is 456 kc, the local oscillator frequency is;

a. 1760 kc
b. 440 kc
c. 912 kc
d. 1336 kc

13-7. Fixed tuned i-f stages means;

a. high fidelity
b. variable i-f
c. high selectivity, high gain
d. constant power output

13-8. A pentagrid converter is;

a. a mixer oscillator tube
b. an r-f amplifier
c. an a-f amplifier
d. an audio power amplifier

13-9. The object of frequency conversion in a superheterodyne is to;

a. change the oscillator frequency
b. double the i-f
c. obtain a fixed i-f
d. increase the fidelity

13-10. The way in which to eliminate broadcast interference by amateur transmission is to;

a. tune to another channel
b. use a directional antenna
c. use a wave trap
d. increase the i-f

RULES AND REGULATIONS GOVERNING AMATEUR RADIO SERVICE

The government of the United States does not license or interfere in any way with the RECEPTION of standard broadcast or short wave programs. Anyone can own and operate a radio receiver without a license. However, in the case of radio transmission, the situation is entirely different. All transmitting stations, whether Amateur or Commercial, are licensed by the Federal Communications Commission (FCC). Consequently, all operators of transmitting equipment must be licensed.

There are various rules and regulations which govern the operation of all radio transmissions. It is important that the radio amateur be familiar with the general rules and regulations of Communications as well as those rules which apply specifically to Amateur Radio. The examinations for the Amateur Operators licenses contain questions based on the provisions of treaties, statutes, and regulations affecting amateurs. Because it is important to know the laws regarding amateur radio transmission, we are reproducing excerpts from the FCC rules that apply to the radio amateur service.

Violation of the rules and regulations of the Federal Communications Commission can result in a maximum penalty of up to $500.00 for each day during which the offense occurs. The penalty can also include suspension of the operator license and revocation of the station license.

CLASSES OF AMATEUR LICENSES AND ELIGIBILITY

1. AMATEUR EXTRA CLASS: Any citizen of the United States who has held an amateur operator license for a period of two years or more, excluding licenses of the Novice and Technician Classes.
2. ADVANCED CLASS: (previously Class A) Any citizen who has held for a period of a year or more an amateur operator license, excluding licenses of the Novice and Technician Classes. New Advanced Class Licenses were not issued after Dec. 1952. However, Advanced Class or Class A licenses may be renewed as set forth in Section 12.27.
3. GENERAL CLASS: (previously Class B) Any citizen.
4. CONDITIONAL CLASS: (previously Class C) Any citizen

whose residence and station location are more than 75 miles air line distance from the nearest location at which General Class examinations are held at intervals of not more than three months; or who is shown by a physician's certificate to be unable to appear for the examination because of protracted disability; or who is shown to be in the Armed Forces of the United States and is unable to appear (as certified by his Commanding Officer) for the examination at the time and place designated by the FCC; or who at the time of filing, furnishes sufficient evidence of temporary residence outside the continental limits of the United States, its territories or possessions (for a continuous period of at least 12 months) irrespective of the provisions for this class.

5. TECHNICIAN CLASS: Any citizen of the United States.

6. NOVICE CLASS: Any citizen of the United States except a former holder of an amateur license of any class issued by any agency of the United States Government, military or civilian.

12.23 PRIVILEGES OF AMATEUR OPERATOR LICENSES.

AMATEUR EXTRA CLASS. All authorized amateur privileges including such additional privileges in the communication and technical phases of the art which the FCC may consider as appropriately limited to the holders of this class of license.

ADVANCED CLASS. All amateur privileges except those which may be limited to holders of the Amateur Extra Class license.

GENERAL AND CONDITIONAL CLASSES. All authorized amateur privileges except those which may be reserved to the holders of the Amateur Extra Class license.

TECHNICIAN CLASS. All authorized amateur privileges in the 50-54 Mc. band, the 145-147 Mc. portion of the 144-148 Mc. band and in the amateur bands above 220 Mc.

NOVICE CLASS. Those amateur privileges as designated and limited as follows:

(a) The d.c. plate power input to the vacuum tube or tubes supplying power to the antenna shall not exceed 75 watts.

(b) Only the following frequency bands and types of emission may be used, and the emissions of the transmitter must be crystal-controlled:

(1) 3700 to 3750 kilocycles, radiotelegraphy using only

type A1 emission in accordance with the geographical restrictions set forth in Section 12.111.

(2) 7150 kc. to 7200 kc., radiotelegraphy using only type A1 emission.

(3) 21.10 mc. to 21.25 mc., radiotelegraphy using only type A1 emission.

(4) 145 to 147 mc., radiotelegraphy using A1 and A2 emission; radiotelephone using A3 and FM emission.

12.25 AVAILABILITY OF OPERATOR LICENSE - The original license of each operator shall be kept in the personal possession of the operator while operating an amateur station. When operating an amateur station, at a fixed location, however, the license may be posted in a conspicuous place in the room occupied by the operator. The license shall be available for inspection by an authorized Government official whenever the operator is operating an amateur station, and at other times, upon request made by an authorized representative of the Commission, except when such license has been filed with application for modification or renewal thereof, or has been mutilated, lost or destroyed, and application has been made for a duplicate license in accordance with 12.26. Photo copies of the license can be made but cannot be used in lieu of the original as required by this section.

12.26 DUPLICATE LICENSE - Any licensee applying for a duplicate license to replace an original which has been lost, mutilated, or destroyed, shall submit with the application the mutilated license or a statement setting forth the facts regarding the manner in which the original license was lost or destroyed. If, subsequent to receipt by the licensee of the duplicate license, the original license is found, either the duplicate or the original license shall be returned immediately to the Commission.

12.27 RENEWAL OF AMATEUR OPERATOR LICENSE (a) An amateur operator license, except the Novice Class, may be renewed upon proper application stating that the applicant has lawfully accumulated a minimum total of either 2 hours operatime time during the last 3 months, or 5 hours operating time during the last 12 months of the license term. Such "operating time", for the purpose of renewal, shall be counted as the total of all that time between the entries in the station log showing the beginning and end of transmissions as required in

Section 12.136(a), both during single transmissions and during a "sequence of transmissions" as herein provided. The application shall, in addition to the foregoing, include a statement that the applicant can send by straight key, semi-automatic key or electronic key, and receive by ear, in plain language, messages in the International Morse Code at the speed of not less than that which was originally required for the class of license being renewed.

(b) The novice class license will not be renewed.

(c) The applicant shall qualify for a new license by examination if the requirements of this section are not fulfilled.

(d) The renewal and/or modification (change of address, etc.) application of the amateur operator license shall be on FCC Form 610 and must be accompanied by the applicant's license. Unless the Commission directs otherwise, each application for the renewal of the license shall be filled only during the last 60 days of the license term or within a grace period of one year after the expiration date of the license. During the one year grace period, the expired license is not valid. Any license issued upon the basis of an application filed during the grace period will not be back-dated to the date of expiration of the license being renewed, but will be dated currently. In any case in which the licensee has, in accordance with the Commission's Rules, made timely and sufficient application for renewal of the license, no license with reference to any activity of a continuing nature shall expire until such application shall have been finally determined. A license for modification only will be dated to expire on the same date as the license being modified, in accordance with Section 12.29.

12.28 WHO MAY OPERATE AN AMATEUR STATION - An amateur station may be operated only by a person holding a valid amateur operator license, and then only to the extent provided for by the privileges granted under the license. When an amateur station is used for telephony or radioteleprinter transmissions, the station licensee may permit any person to transmit by voice or teleprinter, provided during such transmission, call signs are announced as prescribed by Section 12.82 and a duly licensed amateur operator maintains actual control over the emissions, including turning the carrier on and off for each transmission and signing the station off after communication with each station has been completed.

12.29 LICENSE TERM. Amateur operator licenses are normally valid for a period of 5 years from the date of issuance of a new or renewed license, except the Novice Class which is normally valid for a period of 1 year from the date of issuance. Duplicate or modified licenses shall bear the same date of expiration as the licenses for which they are duplicates or modifications of.

12.42 EXAMINATION ELEMENTS. Examination for amateur operator privileges will comprise one or more of the following examination elements:

Element 1 (A) - Beginner's Code Test. Code test at five (5) words per minute.

Element 1 (B) - General Code Test. Code test at thirteen (13) words per minute.

Element 1 (C) - Expert's Code Test. Code test at twenty (20) words per minute.

Element 2 - Basic Amateur Practice. Amateur radio operation and apparatus, including radiotelephone and radiotelegraph.

Element 3 (A) - Basic Law. Rules and regulations essential to beginner's operation, including sufficient elementary radio theory for the understanding of those rules.

Element 3 (B) - General Regulations. Provisions of treaties, statutes, and rules and regulations affecting all amateur stations and operators.

Element 4 (B) - Advanced Amateur Practice. Advanced radio theory and operation as applicable to modern amateur techniques including, but not limited to, radiotelephony, radiotelegraphy, and transmissions of energy for measurements and observations applied to propagation, for the radio control of remote objects and for similar experimental purposes.

12.43 EXAMINATION REQUIREMENTS. Applicants for original licenses will be required to pass examinations as follows:

(a) Amateur Extra Class: Elements 1(C), 2, 3(B) and 4(B)
(b) General Class: Elements 1(B), 2 and 3(B)
(c) Conditional Class: Elements 1(B), 2 and 3(B)
(d) Technician Class: Elements 1(A), 2 and 3(B)
(e) Novice Class: Elements 1(A) and 3(A)

12.44 MANNER OF CONDUCTING EXAMINATIONS.

a. The examinations for Extra and General Classes of Amateur operator licenses will be conducted by an authorized Commission employee or representative at locations and at times specified by the Commission. The examinations for Conditional Class, as well as Technician and Novice Class licenses, will be conducted in accordance with the provisions of paragraph (c) of this section. The examinations for Conditional Class will be available only under one or more of the following conditions:

(1) If the applicant's actual residence and proposed amateur station location are more than 75 miles airline distance from the nearest location at which examinations are conducted by an authorized Commission employee or representative at intervals of not more than 3 months for amateur operator licenses; or

(2) If the applicant is shown by physician's certificate to be unable to appear for examination because of protracted disability, or

(3) If the applicant is shown by certificate of the commanding officer to be in the armed forces of the United States at an Army, Navy, Air Force or Coast Guard station and, for that reason, to be unable to appear for examination at the time and place designated by the Commission; or

(4) If the applicant demonstrates by sufficient evidence that his temporary residence is for a continuous period of at least 12 months outside the continental limits of the United States, its territories or possessions, irrespective of other provisions of this paragraph.

b. A holder of a Technician or Novice Class license obtained on the basis of an examination under the provisions of paragraph (c) of this section is not required to be re-examined when changing residence and station location to within a regular examination area, nor when a new examination location is established within 75 miles of such licensee's residence and station location.

c. Each examination for Conditional Class license, or for Technician or Novice Class license under special conditions, set forth in paragraph (a) of this section, shall be conducted and supervised by not more than two volunteer examiners, whom the Commission may designate or permit the applicant to select (not more than one examiner for the code test and not more than one examiner for the complete written examination). In the event the examiner for the code test is selected by the applicant, such examiner shall be the holder of an Extra Class, Advanced Class, or General Class of amateur operator license or shall have held, within the 5 years prior to the date of the examination, a commercial radiotelegraph operator license issued by the Commission or within that time shall have been employed in the service of the United States as the operator of a manually operated radiotelegraph station. The examiner for the written test shall be at least 21 years of age.

12.46 EXAMINATION CREDIT. An applicant for a higher class of amateur operator license who holds a valid amateur operator license issued upon the basis of an examination by the Commission will be required to pass only those elements of the higher class examination that were not included in the examination for the amateur license held when such application was filed. However, credit will not be allowed for licenses issued on the basis of an examination given under the provisions of Section 12.44(c).

An applicant for any class of amateur operator license, except the Extra Class, will be given credit for the telegraph code element if within 5 years prior to the receipt of his application by the Commission he held a commercial radiotelegraph first or second class operator license, issued by the Federal Communications Commission.

No examination credit, except as herein provided, shall be allowed on the basis of holding or having held any amateur or commercial operator license.

12.48 GRADING: Code tests are graded as "passed" or "failed" separately for sending and receiving tests. Failure to pass the required code test for either sending or receiving will terminate the examination.

Seventy-four percent is the passing grade for written examinations. For the purpose of grading, all elements, other than element 4(B), required in qualifying for a particular license will be considered a single examination, and element 4(B) will be considered as a separate examination.

12.50 CODE TEST PROCEDURE: The code test required of an applicant for amateur radio operator license, in accordance with the provisions of Sections 12.42 and 12.43 of these rules, shall determine the applicant's ability to transmit by hand key (straight key, or if supplied by the applicant, any other type of hand operated key such as a semi-automatic or electronic key) and to receive by ear, in plain language, messages in the International Morse Code at not less than the prescribed speed, free from omission or other error for a continuous period of at least 1 minute during a test period of 5 minutes, counting five characters to the word, each numeral or punctuation mark counting as two characters.

12.64 LOCATION OF STATION: (a) Every amateur station shall have a fixed transmitter location. Only one fixed transmitter location will be authorized and will be designated on the license for each amateur station, except that when remote control is authorized, the location of the remote control position, as well as the location of the remotely controlled transmitter, shall be considered as fixed transmitter locations and will be so designated on the station license. Unless remote control of the transmitting apparatus shall be authorized, such apparatus shall be operated only by a duly licensed amateur radio operator present at the location of such apparatus.

12.66 AUTHORIZED APPARATUS: An amateur station license authorizes the use under control of the licensee, of all transmitting apparatus at the fixed location specified in the station license which is operated on any frequency or frequencies allocated to the amateur service, and in addition, authorizes the use, under control of the licensee, of portable and mobile transmitting apparatus operated at other locations.

12.67 RENEWAL OF AMATEUR STATION LICENSE: An amateur station license may be renewed upon proper application filed not more than 60 days prior to date of expiration of such license or within a period of grace of one year after the expiration date of such license.

12.68 AVAILABILITY OF STATION LICENSE: The original license of each amateur station or a photocopy thereof shall be posted in a conspicuous place in the room occupied by the licensed operator while the station is being operated at a fixed location, or shall be kept in his personal possession. When the station is operated at other than a fixed location, the original station license or a photocopy thereof shall be kept in the personal possession of the station licensee (or a licensed representative) who shall be present at the station while it is being operated as a portable or mobile station. The original station license shall be available for inspection by any authorized Government official at all times while that station is being operated and at other times upon request made by an authorized representative of the Commission, except when such license has been filed with application for modification or renewal thereof, or has been mutilated, lost or destroyed, and application has been made for a duplicate license in accordance with 12.26.

12.81 ASSIGNMENT OF CALL SIGN: (a) The call signs of amateur stations will be assigned systematically by the Commission with the following exceptions:

1) A specific unassigned call sign may be reassigned to the most recent holder thereof;

2) A specific unassigned call sign may be assigned to a previous holder if not under license during the past 5 years;

3) A specific unassigned call sign may be assigned to an amateur organization in memoriam to a deceased member and former holder thereof;

4) A specific call sign may be temporarily assigned to a station connected with an event, or events, of general public interest;

5) An unassigned "two-letter call" (a call sign having two letters following the numeral) may be assigned to a previous holder of a "two-letter call".

12.82 TRANSMISSIONS OF CALL SIGNS: (a) An operator of an amateur station shall transmit the call sign of the station called or being worked and the call sign assigned the station which he is operating at the beginning and end of each transmission, and at least once every 10 minutes during every transmission of more than 10 minutes duration. In the case of stations conducting an exchange of several transmissions in sequence, with each transmission less than 3 minutes duration, the call signs of the communicating stations need be transmitted only once every 10 minutes of operation, as well as at the beginning and at the termination of the correspondence.

12.90, 12.91 REQUIREMENTS FOR PORTABLE AND MOBILE OPERATION-NOTICE OF OPERATION: Within the continental limits of the United States, its territories or possessions, an amateur station may be operated as either a portable or a mobile station on any frequency authorized and available for the amateur radio service. Whenever portable operation is, or is likely to be, for an over-all period in excess of 48 hours, away from the fixed transmitter location designated in the station license, the licensee shall give prior written notice to the FCC Engineer-

In-Charge of the radio inspection district in which such portable operation is intended. (This applies to operation on any amateur band). A new notice is required whenever there is any change in the particulars of a previous notice or whenever operation away from the authorized station continues for a period in excess of one year. The notice required for either portable or mobile operation shall state the station call sign, authorized fixed transmitter location, the name of the licensee, the date or dates of proposed operation and the contemplated portable station locations or mobile station's itinerary, as specifically as possible. Also, the address at which, or through which, the licensee can be readily reached. In the case of mobile operation, the official name, registry number or license number (including the name of the issuing state or territory, if any) of the aircraft, vessel or land vehicle in which the mobile station is installed and operated, must be given.

12.93 <u>SPECIAL REQUIREMENTS FOR NON-PORTABLE STATIONS</u>: (a) An amateur station that has been moved from the authorized permanent location to another permanent location may be operated for a period not exceeding four consecutive months at the latter location, but in no event beyond the expiration of the license unless timely application for renewal thereof has been filed in accordance with the provisions of Section 12.67 under the following conditions:

(1) Advance notice, in accordance with the provisions of section 12.91, shall be given to the Engineer in Charge of the radio district in which the operation is intended; and

(2) formal application for modification to change the permanent location shall be filed with the Commission within the above specified four month period.

(b) The licensee of an amateur station who changes residence temporarily, but retains a permanent residence associated with the fixed transmitter location designated in the station license, and moves his amateur station to a temporary location associated with his temporary residence, or the licensee-trustee for an amateur radio society which changes the normal location of its amateur station to a different and temporary location, may operate the station at such temporary location under the condition that: Notice, in accordance with the provisions of Section 12.91, shall be given to the Secretary of the Commission, Washington 25, D. C. and to the Engineer in Charge of the radio district in which the temporary operation is intended.

(c) When the station is operated under the provisions of this section, the portable identification procedures specified in Section 12.82 shall be used.

12.101 POINTS OF COMMUNICATIONS: An amateur station may be used to communicate only with other amateur stations, except that in emergencies or for test purposes it may also be used temporarily for communication with other classes of stations licensed by the Commission, and with United States Government stations. Amateur stations may also be used to communicate with any radio station other than amateur which is authorized by the Commission to communicate with amateur stations. Amateur stations may be used also for transmitting signals, or communications, or energy, to receiving apparatus for the measurement of emissions, temporary observation of transmission phenomena, radio control of remote objects, and for similar experimental purposes set forth in 12.106 of these rules. (Third party messages may be handled by amateur stations of different countries if such communication is authorized by a special agreement between the countries involved).

12.102 NO REMUNERATION FOR USE OF STATION: An amateur station shall not be used to transmit or receive messages for hire, nor for communication for material compensation, direct or indirect, paid or promised.

12.103 BROADCASTING PROHIBITED: Subject to the provisions of 12.106 of these rules, an amateur station shall not be used to engage in any form of broadcasting, that is, the dissemination of radio communications intended to be received by the public directly or by the intermediary of relay stations, nor for the retransmission by automatic means of programs or signals emanating from any class of station other than amateur. The foregoing provision shall not be construed to prohibit amateur operators from giving their consent to the rebroadcast by broadcast stations of the transmissions of their amateur stations, provided, that the transmissions of the amateur stations shall not contain any direct or indirect reference to the rebroadcast.

12.104 RADIOTELEPHONE TESTS: The transmission of music by an amateur station is forbidden. However, single audiofrequency tones may be transmitted for test purposes of short duration for the development and perfection of amateur radiotelephone equipment.

12.105 CODES AND CIPHERS PROHIBITED: The transmission by radio of messages in codes or ciphers in domestic and international communications to or between amateur stations is prohibited. All communications, regardless of type of emission employed, shall be in plain language except that generally recognized abbreviations established by regulation or custom and usage are permissible as are any other abbreviations or signals where the intent is not to obscure the meaning but only to facilitate communications.

12.111 FREQUENCIES AND TYPES OF EMISSION FOR USE OF AMATEUR STATIONS: Subject to the limitations and restrictions set forth in these rules, the following frequency bands are available for amateur use:

(1) 1800 to 2000 Kc. Use of this band is on a shared basis with the Loran system of radio navigation. In any particular area, the Loran system operates either on 1800-1900 Kc. or 1900-2000 Kc. In any area, the amateur service uses whichever bands, 1800-1825 and 1875-1900 Kc. or 1900-1925 and 1975-2000 Kc., which are not required for Loran in that area. For instance, in most Eastern states, the Loran system operates in the 1900-2000 kc. band and the amateurs have the use of the 1800-1825 Kc. and 1875-1900 Kc. bands. In most Western states, the Loran system uses the 1800-1900 Kc. band and the Amateurs use the 1900-1925 Kc. and the 1975-2000 Kc. bands. Type A1* or A3* emission is used in the 1800-2000 Kc. bands. The power used is 500, 200 or 50 watts, depending on the geographical area and the time of day. For exact information as to frequency and power in any particular state, write to the Federal Communications Commission.

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*The types of emission referred to in the amateur rules are as follows:

Type AØ - Steady, unmodulated, pure carrier.
Type A1 - Telegraphy on pure continuous waves.
Type A2 - Amplitude tone-modulated telegraphy.
Type A3 - Amplitude-modulated telephony.
Type A4 - Facsimile.
Type A5 - Television.
Type FØ - Steady, unmodulated pure carrier.
Type F1 - Carrier-shift telegraphy.
Type F2 - Audio frequency-shift telegraphy.
Type F3 - Frequency-or phase-modulated telephony.
Type F4 - F.M. facsimile.
Type F5 - F.M. television.

(2) 3500 to 4000 Kc. Type A1 emission may be used in the entire band. Carrier-shift-telegraphy may be used on 3500-3800 Kc. Type A3 emission may be used on 3800 to 4000 Kc. Narrow band frequency modulation and phase modulation may also be used in the 3800 to 4000 Kc. portion of the band. The frequencies of 3900 to 4000 Kc. are not available to stations located within the following United States possessions in Region III as defined in the Atlantic City, 1947, Radio Regulations: Baker, Canton, Enderbury, Guam, Howland, Jarvis, Palmyra, American Samoa and Wake Islands. The phone part of this band may be used by all amateurs except those of the Novice and Technician Classes. See Page 246 for the Novice use of this band.

(3) 7000 to 7300 Kc. Type A1 emission may be used on the entire band. Carrier-shift-telegraphy may be used in the 7000 to 7200 Kc. portion of the band. Type A3 emission and narrow band frequency or phase modulation may be used in the 7200 to 7300 Kc. portion of the band.

(4) 14000 to 14350 Kc. Type A1 emission may be used in the entire band. Carrier-shift-telegraphy may be used in 14000 to 14200 Kc. Type A3 emission or narrow band frequency or phase modulation for radiotelephony may be used in the 14200 to 14350 Kc. portion of the band.

(5) 21000 to 21450 Kc. Type A1 emission may be used in the entire band. Carrier-shift-telegraphy may be used on 21000 to 21250 Kc. Type A3 emission may be used on 21250 to 21450 Kc.

(6) 28.0 to 29.7 Mc. Type A1 emission may be used in the entire band. Type A3 emission may be used on 28.5 to 29.7 Mc. Special FM emission (using carrier shift or other FM techniques) may be used on 29.0 Mc. to 29.7 Mc.

(7) 50.0 to 54.0 Mc. Type A1 emission may be used in the entire band. Types AØ, A2, A3, A4 and narrow band F1, F2, F3 emissions on 51.0 to 54.0 Mc. Types FØ, F1, F2 and F3 emissions may be used on 52.5 to 54.0 Mc.

(8) 144.0 to 148.0 Mc. Type A1 emission may be used in the entire band. Types AØ, A2, A3, A4, FØ, F1, F2 and F3 may be used on 144.0 to 147.9 Mc.

(9) 220 to 225 Mc. The entire band may be used for types AØ, A1, A2, A3, A4, FØ, F1, F2, F3 and F4 emission. The amateur service shall not cause harmful interference to the government radiopositioning service in this band. In portions of the States of Texas and New Mexico, the 220 to 225 Mc. band is not available for use by amateur stations engaged in normal

amateur operation between the hours of 0500 and 1800 local time, Monday through Friday inclusive of each week.

(10) 420 to 450 Mc. The whole band may be used for types AØ, A1, A2, A3, A4, A5, FØ, F1, F2, F3, F4 and F5 emission. In some areas of the Southeast and Southwest, the maximum DC plate power to the final shall not exceed 50 watts input. In this band, the amateur service shall not cause harmful interference to the government radiopositioning service.

(11) 1215 to 1300 Mc. The entire band may be used for types AØ, A1, A2, A3, A4, A5, FØ, F1, F2, F3, F4 and F5 emission. In this band, harmful interference to the government radiopositioning service is not allowed.

(12) 2300 to 2450 Mc., 3500 to 3700 Mc. and 5650 to 5925 Mc. These bands may use types AØ, A1, A2, A3, A4, A5, FØ, F1, F2, F3, F4, F5 and pulse emission. Operators in the frequency bands 2300 to 2450 Mc. and 5650 to 5925 Mc. are subject to such interference between 2400 and 2450 Mc. and between 5775 and 5925 Mc., respectively, as may result from emissions of industrial, scientific and medical devices on the frequencies 2450 and 5850 Mc. respectively. In these bands, the amateur service shall not cause harmful interference to the government radiopositioning service.

(13) 10,000 to 10,500 Mc. Types AØ, A1, A2, A3, A4, A5, FØ, F1, F2, F3, F4 and F5 emission may be used in this band. In this band, the amateur service shall not cause harmful interference to the government radiopositioning service.

(14) 21,000 to 22,000 Mc. and any frequency or frequencies above 30,000 Mc. Types AØ, A1, A2, A3, A4, A5, FØ, F1, F2, F3, F4, F5 and pulse emission may be used in the entire bands.

12.114 TYPES OF EMISSION: Type AØ emission, where not specifically designated in the bands listed in 12.111 of these rules, may be used for short periods of time when required for authorized remote control purposes or for experimental purposes. These limitations do not apply where type AØ emission is specifically designated.

The use of narrow band FM or phase modulation is subject to the conditions that the band-width of the modulated carrier shall not exceed the band-width occupied by an amplitude modulated carrier of the same audio characteristics, and that the purity and stability of such emissions shall be maintained in accordance with the requirements of 12.133 of these rules.

12.131 MAXIMUM AUTHORIZED POWER: Except on the 420 to 450 Mc. band and the 1800 to 2000 kc. band, each amateur transmitter may be operated with a power input not exceeding 1 kilowatt to the final stage.

An amateur station operating with a power input exceeding 900 watts on the final stage shall provide means for accurately measuring this power.

12.132 POWER SUPPLY TO TRANSMITTER: The licensee of an amateur station using frequencies below 144 megacycles shall use adequately filtered direct-current plate power supply for the transmitting equipment to minimize modulation from this source. (Operation above 144 Mc. does not require adequately filtered d-c plate power supply).

12.133 PURITY AND STABILITY OF EMISSIONS: Spurious radiation from an amateur station being operated with a carrier frequency below 144 megacycles shall be reduced or eliminated in accordance with good engineering practice. This spurious radiation shall not be of sufficient intensity to cause interference in receiving equipment of good engineering design including adequate selectivity characteristics, which is tuned to a frequency or frequencies outside the frequency band of emission normally required for the type of emission being employed by the amateur station. In the case of A3 emission, the amateur transmitter shall not be modulated to the extent that interfering spurious radiation occurs, and in no case shall the emitted carrier wave be amplitude-modulated in excess of 100 percent. Means shall be employed to insure that the transmitter is not modulated in excess of its modulation capability for proper technical operation. For the purposes of this section, a spurious radiation is any radiation from a transmitter which is outside the frequency band of emission normal for the type of transmission employed, including any component whose frequency is an integral multiple or submultiple of the carrier frequency (harmonics and subharmonics), spurious modulation products, key clicks and other transient effects, and parasitic oscillations. When using amplitude modulation on frequencies below 144 megacycles, simultaneous frequency modulation is not permitted and when using frequency modulation on frequencies below 144 megacycles, simultaneous amplitude modulation is not permitted. The frequency of the emitted carrier wave shall be as constant as the state of the art permits.

12.134 MODULATION OF CARRIER WAVE: Except for brief tests or adjustments, an amateur radiotelephone station shall not emit a carrier wave on frequencies below 51 megacycles unless modulated for the purpose of communication.

12.135 FREQUENCY MEASUREMENT AND REGULAR CHECK: The Licensee of an amateur station shall provide for measurement of the emitted carrier frequency or frequencies and shall establish procedure for making such measurement regularly. The measurement of the emitted carrier frequency or frequencies shall be made by means independent of the means used to control the radio frequency or frequencies generated by the transmitting apparatus and shall be of sufficient accuracy to assure operating within the amateur frequency band used.

12.136 LOGS: Each licensee of an amateur station shall keep an accurate log of station operation, including the following:

a) The date and time of each transmission. (The date need only be entered once for each day's operation. The expression "time of each transmission" means the time of making a call and need not be repeated during the sequence of communication which immediately follows; however, an entry shall be made in the log when signing off so as to show the period during which communication was carried on).

b) The signature of each licensed operator who manipulates the key of a radiotelegraph transmitter or the signature of each licensed operator who operates a transmitter of any other type and the name of any person not holding an amateur operator license who transmits by voice over a radiotelephone transmitter. The signature of the operator need only be entered once in the log, in those cases when all transmissions are made by or under the supervision of the signatory operator, provided a statement of that effect also is entered. The signature of any other operator who operated the station shall be entered in the proper space for that operator's transmission.

c) Call sign of the station called. (This entry need not be repeated for calls made to the same station during any sequence of communication, provided the time of signing off is given).

d) The input power to the oscillator, or to the final amplifier stage where an oscillator-amplifier transmitter is employed. (This need be entered only once, provided the input power is not changed).

e) The frequency band used. (This information need be entered only once in the log for all transmissions until there is a change in frequency to another amateur band).

f) The type of emission used. (This need be entered only once until there is a change in the type of emission).

g) The location of the station (or the approximate geographical location of a mobile station) at the time of each transmission. (This need be entered only once provided the location of the station is not changed. However, suitable entry shall be made in the log upon changing the location. Where operating at other than a fixed location, the type and identity of the vehicle or other mobile unit in which the station is operated shall be shown).

h) The message traffic handled. (If record communications are handled in regular message form, a copy of each message sent and received shall be entered in the log or retained on file at the station for at least one year).

12.37 RETENTION OF LOGS: The log shall be preserved for a period of at least one year following the last date of entry. The copies of record communications and station log required by 12.136 shall be available for inspection by authorized representatives of the Commission.

12.151 ADDITIONAL CONDITIONS TO BE OBSERVED BY THE LICENSEE: In all respects not specifically covered by these regulations, each amateur station shall be operated in accordance with good engineering and good amateur practice.

12.152 RESTRICTED OPERATION: a) If the operation of an amateur station causes general interference to the reception of transmissions from stations operating in the domestic broadcast service when receivers of good engineering design including adequate selectivity characteristics are used to receive such transmissions, and the fact is made known to the amateur station licensee, the amateur station shall not be operated during the hours from 8 P.M. to 10:30 P.M., local time, and on Sunday for the additional period from 10:30 A.M. until 1:00 P.M. local time, upon the frequency or frequencies used when the interference is created.

b) In general, such steps as may be necessary to minimize interference to stations operating in other services may be required after investigation by the Commission.

12.156 OPERATION IN EMERGENCIES: (DISTRESS CALLS AND DISTRESS COMMUNICATIONS HAVE ABSOLUTE PRIORITY OVER ALL OTHER COMMUNICATIONS). In the event of widespread emergency conditions affecting domestic communication facilities, the Commission may confer with representatives of the amateur service and others, and if deemed advisable, declare that a state of general communications emergency exists, designating the area or areas concerned, and specify the amateur frequency bands, or segments of such bands for use only by amateurs participating in emergency communication within the affected area. It shall be incumbent upon each amateur station in such area to observe the following restrictions for the duration of such emergency:

a) Transmissions other then those relating to relief work or other emergency service, such as amateur station networks can provide, shall not be made within the designated emergency bands. Incidental calling, testing and working, including casual conversation or remarks not pertinent or necessary to constructive handling of the emergency situation shall be prohibited.

b) The Commission may designate certain amateur stations to assist in promulgation of its emergency announcement, to police the designated amateur emergency communications bands and to warn non-complying stations observed to be operating therein. The operators of these observing stations shall report fully to the Commission, the identity of any stations failing to comply, after notice, with any of the pertinent provisions of this section. Such designated stations will act in an advisory capacity when able to provide information on emergency circuits. Individual policing transmissions shall refer to this section of the rules by number (12.156) and shall specify briefly and concisely the date of the Commission's declaration and the area and nature of the emergency. Policing observer stations shall not enter into discussions with other stations beyond the furnishing of essential facts relating to the emergency.

c) The special conditions imposed under the provisions of this section shall cease to apply only after the Federal Communications Commission, or its authorized representative, shall have declared such general state of communications emergency to be terminated; however, nothing in this paragraph shall be deemed to prevent the Federal Communications Commission from modifying the terms of its declarations from time to time as may be necessary during the period of a communications emergency, or from removing those conditions with respect to any amateur frequency band or segment of such band which no longer appears essential to the conduct of the emergency communications.

12.157 OBSCENITY, INDECENCY, PROFANITY: No licensed radio operator or other person shall transmit communications containing obscene, indencent or profane words, language or meaning.

12.158 FALSE SIGNALS: No licensed radio operator shall transmit false or deceptive signals or communications by radio or any call letter or signal which has not been assigned by proper authority to the radio station he is operating.

12.159 UNIDENTIFIED COMMUNICATIONS: No licensed radio operator shall transmit unidentified radio communications or signals.

12.160 INTERFERENCE: No licensed radio operator shall willfully or maliciously interfere with or cause interference to any radio communication or signal. (The penalty for violation of this rule is as follows: A fine of up to $500 for each day during which the offense occurs, and suspension of the operator's license. In case the interference is in connection with distress communications, the penalty may be a maximum fine of $10,000 or imprisonment up to two years, or both, and the revocation of the station license).

12.161 DAMAGE TO APPARATUS: No licensed radio operator shall willfully damage, or cause or permit to be damaged, any radio apparatus or installation in any licensed radio station.

12.162 FRAUDULENT LICENSES: No licensed radio operator or other person shall obtain or attempt to obtain, or assist another to obtain or attempt to obtain, an operator license by fraudulent means.

PRACTICE QUESTIONS - LESSON 14

(For answers - refer to back of Study Guide - Page 270)

14.1* What radio messages have priority over all other communications?

14.2* What is the penalty for willful or malicious interference with other radio communications?

14.3* What is the FCC rule regarding emission of unmodulated carriers by amateur stations?

14.4* On what amateur bands is portable operation permitted without prior notification to the inspector of the district in which such operation is contemplated?

14.5* What third party messages may be handled between amateur operators of different countries?

14.6* What is the function of the amateur stations that have been designated by the FCC to assist the FCC during a state of Communications emergency?

14.7* When does a state of emergency affecting amateur communications become effective and when is it terminated?

14.8* What amateur bands are affected and what frequencies are reserved for emergency calling when a state of communications emergency has been proclaimed by the FCC?

14.9* On what frequencies may a licensee holding Class B amateur privileges operate an amateur radiotelephone station? Class B means General Class.

14.10* What is the FCC regulation regarding transmission of music by an amateur radiotelephone station for testing purposes?

14.11* What is the highest modulation percentage of an amateur radiotelephone transmitter permitted by FCC regulations and under what condition may it be employed?

14.12* What power input should an amateur station use for a particular communication when the maximum legal input is 1 kw.?

14.13* On what amateur bands is portable operation permitted only when prior notification has been given to the FCC Engineer in charge of the district in which such operation is contemplated?

14.14* On what amateur bands is adequately-filtered direct current plate power supply required for operation of an amateur transmitter?

14.15* On what amateur bands is adequately-filtered d-c plate power supply NOT required for operation of an amateur transmitter?

14.16* What is the maximum permissible plate power input to the final stage of an amateur transmitter and under what circumstances may it be used?

14.17* Give the meaning of the following "Q" signals: QRK, QRM, QRT, QRX, QSA, QSY, QSZ.

14.18* What are the rules and regulations regarding obscenity, indecency, profanity, false signals and malicious interference?

STUDY GUIDE SECTION III

Section III is the most important section of the course for the following reasons:

1. 50% or more of the license examination questions are based upon the material in this section.
2. It contains detailed discussion of transmitter theory and operation which is of major importance to an amateur radio operator.
3. It contains government rules and regulations concerning amateur radio operation which every amateur is required to know.

You must, therefore, study Section III very carefully. making sure that you understand every lesson thoroughly and can answer without difficulty the practice questions before you proceed to take the FCC-type examination.

It is suggested that before you take the official license examination, you should go over all of the practice questions of the course, as well as all FCC type examinations. If you find that you have forgotten an answer or simply cannot answer the question, go back to the lesson material and review those points on which you are hazy. Only in this way will you build up your confidence to successfully pass the license examination and gain your Radio Amateur's license.

A. LESSON 9 - OSCILLATORS

1. Make sure that you know the characteristics of the different crystal cuts.
   a) Review paragraph 9-16.
   b) Refer to practice questions 1, 3, 4.

2. You must be able to work out problems on crystals.
   a) Review paragraph 9-19.
   b) Refer to practice questions 9, 10, 11, 12.

3. Know the characteristics of crystal oscillators and their advantages over other type oscillators.
   a) Review paragraph 9-14
   b) Refer to practice questions 2, 5, 6, 7, 8.

4. Be able to draw the diagram of a crystal controlled oscillator.
   a) Refer to Fig. 9-13.
   b) Refer to practice question 8.

B. LESSON 10 - C.W. TRANSMITTERS

1. Be able to draw diagrams in answer to the following practice questions:

a) Question 13; the diagram in answer to this question is shown in Fig. 10-15.

b) Question 14; refer to the triode r-f amplifier of Fig. 10-15 and the antenna coupling system and antenna of Fig. 10-14.

c) Question 19; refer to Fig. 10-14.

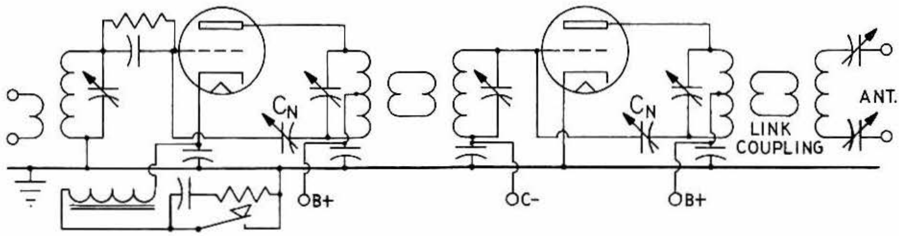


Fig. 10-15. Two-stage neutralized triode r-f amplifier.

2. You must be able to outline the adjustment procedure for neutralization.

a) Review paragraph 10-15.

b) Refer to practice question 4.

3. In order to answer question 10, review maximum power transfer as discussed in paragraph 3-38.

a) Optimum power output is the highest power output obtainable with small distortion and high efficiency. In the case of an r-f power amplifier, optimum power output is achieved when the output circuit impedance (in this case the antenna) is matched to the rated load resistance in the plate circuit.

4. Question 17 refers to the characteristics of a push-push amplifier. A push-push amplifier is similar to a push-pull amplifier in that the grid circuits of the two tubes are connected in push-pull. The plates, however, are connected in parallel. The most useful operating characteristic of a push-push amplifier is that only even harmonics of the signal are amplified in the plate circuits. The odd harmonics are cancelled out. Such a circuit can, therefore, be used as an even harmonic frequency multiplier such as a frequency doubler.

5. You should be able to answer every practice question contained in this lesson.

C. LESSON 11 - THE MODULATED TRANSMITTER

1. You should be able to draw the following diagrams:
   a) Trapezoidal patterns on the oscilloscope (Refer to Fig. 11-15 and practice question 1)
   b) Peak modulation monitor (Refer to Fig. 11-11 and practice question 2)
   c) Sinusoidal modulation envelope
      (Refer to Figs. 11-3, 11-4, 11-5)
      (Refer to practice question 11)

2. You should be familiar with the causes for a downward deflection of the antenna current meter during modulation.
   a) Refer to paragraph 11-15.
   b) Refer to question 10.

3. Question 12 refers to the effects of frequency-modulation on an amplitude-modulated carrier. In a poorly designed A-M transmitter, the carrier may shift frequency during operation because of instability in the oscillator (refer to paragraph 9-12 for causes of frequency instability). This frequency shift results in a frequency modulation of the carrier which causes spurious side-bands to be transmitted; these spurious side-bands cause interference with adjacent frequency transmissions.

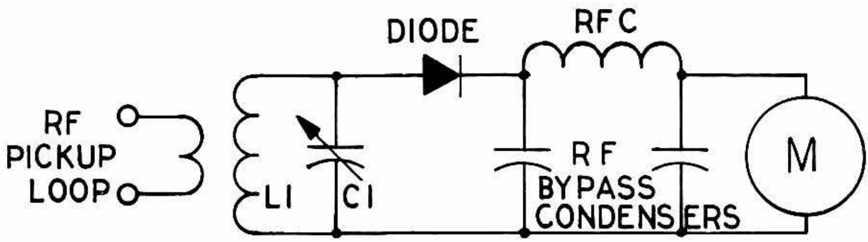


Fig. 11-16. Test equipment to detect carrier shift.

Fig. 11-16 (page 267) illustrates a piece of test equipment which may be used to detect carrier shift. Energy is injected into the tank circuit by means of an r-f pick-up loop which is securely fixed in position and loosely coupled to the output circuit of the transmitter. The tank circuit (L - C) is then tuned to the output frequency of the transmitter as indicated by a peak reading on the milliammeter. A decrease in the meter reading from the peak value indicates that the carrier has shifted in frequency. (Refer to practice question 14).

4. Question 13 refers to a safe procedure in removing an unconscious person from contact with a high voltage circuit. The first thing to do is to open the main switch of the high voltage power supply. This will remove the high voltage and the person can then be moved to safety.

5. Be sure that you can answer all of the practice questions in this lesson.

6. Paragraph 11-16 explains the meaning of the different types of transmitter emissions which are classified according to letter and number by the FCC. When types of emission are discussed in the amateur rules, they are always referred to by letter and number. (For example, emission A Ø or A4). You must know this letter-number classification of emission.

D. LESSON 12 - ANTENNAS, FREQUENCY METERS.

1. You should be able to draw the following diagrams:
   a) An antenna system connected to a Hertz antenna. (Refer to paragraph 12-6 for a discussion of the Hertz antenna). (Refer to Fig. 10-14).
   b) A schematic diagram of a combination heterodyne frequency meter and monitor (Refer to Fig. 12-7)

2. You should be familiar with the means for protecting a transmitter against lightning discharge and a build up of static charge on the antenna. (Refer to paragraph 12-13 and practice question 2 and 3).

3. You must be able to work out problems on error and tolerance calculations for the frequency meter. (Refer to paragraph 12-15, 12-16). Refer to practice questions 4, 5, 7, 8.

4. You should know the precautions in the use of the frequency meter. (Refer to paragraph 12-14, 12-17). Refer to practice questions 9, 10).

E. LESSON 13 - THE RADIO RECEIVER.

There are very few questions asked on the official examination concerning radio receivers. As an amateur radio operator, however, you should have a fairly good working knowledge of receiver theory and operation.

1. You should be able to draw a schematic of a series and shunt type wave trap. (Refer to paragraph 13-12). (Refer to Figs. 13-7, 13-8).

2. You will be better able to understand the important process of generating side-bands in transmission, if you can understand the theory of frequency conversion in the superheterodyne.

a) Re-read paragraphs 13-7 and 13-8, and then review once again paragraph 11-15 on side-bands.

F. <u>LESSON 14</u> - <u>RULES AND REGULATIONS OF THE AMATEUR RADIO SERVICE</u>

The practice questions for this lesson are of the essay type. Write out your answers in complete sentences, using as few words as necessary. After you have written out the answer, check back to the referred paragraph to see if you have answered the questions correctly. The official examination questions on law will be very similar in content to the practice questions. Therefore, it is very important for you to know the answers to all of the practice questions and to be able to write out the answers in short, simple sentences.

1. Refer to practice question 3.
   a) to summarize paragraph 12.111: Type AØ emission is allowed on all amateur bands above 144 Mc.

2. You should be familiar with all of the provisions of paragraph 12.156 "Operation in Emergencies".

3. Refer to practice question 9.

The holder of a General Class license may operate a radiotelephone station in all frequencies that the FCC has designated for phone use by amateurs.

4. Refer to practice question 11.
   a) The highest permitted modulation is 100%, and only when means have been employed to insure that the transmitter is not modulated in excess of 100%.

5. Refer to practice question 12.
   a) Use the minimum input necessary in order to maintain the desired communication.

ANSWERS TO PRACTICE QUESTIONS

LESSON 9

1. - d	4. - d	7. - c
2. - d	5. - a	8. - Fig. 9-13
3. - b	6. - b	9. - 28.003 Mc.

LESSON 10

1. - c	6. - b	11. - c	15. - d
2. - c	7. - d	12. - a	16. - b
3. - a	8. - ℙ 10-17	13. - fig. 10-15 (page 266)	17. - a
4. - ℙ 10-15	9. - b		18. - d
5. - b	10. -*S.G., B-3	14. - fig. 10-14, 10-15	19. - fig. 10-14

LESSON 11

1. - fig. 11-15	6. - d	11. - fig. 11-3, 4, 5
2. -fig. 11-11	7. - c	12. - *S.G., C-3
3. - b	8. - ℙ 11-2	13. - *S.G., C-4
4. - a	9. - ℙ 11-5	
5. - a	10. - d	

LESSON 12

1. - fig. 10-14	4. - 3970 Kc.	7. - 14, 105 Kc.
2. - b	5. - 7053 Kc.	8. - 14, 292 Kc.
3. - a	6. - fig. 12-7	9. - c
		10. - a

LESSON 13

1. - fig. 13-7, 8	4. - c	7. - c
2. - b	5. - a	8. - a
3. - b	6. - d	9. - c
		10. - c

LESSON 14

1. - 12.156	7. - 12.156 12.156 (c)	12. - S.G., F-5
2. - 12.160	8. - 12.156	13. - 12.91 (a)
3. - 12.114(a) 12.111 S.G. F-1	9. - 12.111 S.G., F-3	14. - 12.132
4. - 12.91(a)	10. - 12.104	15. - 12.132
5. - 12.101	11. - 12.133 S.G., F-4	16. - 12.131
6. - 12.156 (c)		17. - See Appendix IV
		18. - 12.157, 12.158, 12.160

ℙ is a symbol for the word paragraph
* S.G. stands for Study Guide

"FCC-TYPE" EXAMINATION - SECTION III

Mark in the space next to the number of the question on the answer sheet, the letter of the answer you think is correct.

1.- Radio messages having top priority are;
  a. relief or emergency messages
  b. ordinary calls
  c. ship to shore messages
  d. messages sent to foreign amateurs

2.- A desirable operating characteristic of an A cut crystal is;
  a. negative temperature coefficient
  b. high output capability
  c. positive temperature coefficient
  d. high frequency drift

3.- The maximum input power permitted to the final stage of a transmitter owned and operated by a Novice operator is;
  a. 50 watts
  b. 75 watts
  c. 100 watts
  d. 250 watts

4.- The penalty for willful interference with other radio communications is;
  a. restricting operating to the 20 meter band
  b. restricting operator to key operation
  c. fine and suspension of license
  d. restriction to local calls

5.- A state of emergency affecting amateur communications becomes effective;
  a. when an emergency occurs
  b. when so ordered by FCC
  c. at discretion of the operator
  d. 3 hours after emergency has started

6.- The following restriction applies to the holder of a Novice Class license;
  a. electron-coupled oscillator must be used
  b. grid modulation must be used
  c. crystal controlled oscillator must be used
  d. Rice neutralization must be used

7.- A 2050 kc low-drift crystal has a positive temperature coefficient of 3 cycles per megacycle per degree centigrade. If the temperature at the start of operations is 60 centigrade, what will be the oscillating frequency at 30° centigrade?

a. 2050.1845 kc b. 2049.8155 kc
c. 2050 kc d. 2031.55 kc

8.- A low drift crystal for the 28.5 - 29.7 Mc amateur band is calibrated to within 0.05% of its specified frequency. Desiring to operate as close to the lower band limit of 28.5 Mc as possible, for what whole number kilocycle frequency should you order your crystal, allowing 1 kc additional for temperature and circuit constant variations?

a. 28,516 kc b. 28,484 kc c. 28,984 kc d. 28,600 kc

9.- What amateur bands are reserved for emergency calling when an official state of emergency has been proclaimed by the FCC?

a. above 144 Mc
b. 1750 - 2050 kc and 3500 - 4000 kc
c. 27.16 - 27.43
d. 29.0 - 29.7 Mc

10.- The purpose of using a center-tap return connection on the secondary of a transmitting tube's filament transformer is to;

a. allow the filaments to heat up
b. permit power output
c. prevent modulation of the r-f by the a-c filament supply
d. prevent radiation of spurious harmonics

11.- What is the highest percentage modulation of an amateur radiotelephone transmitter permitted by the FCC?

a. 75% b. 50% c. 25% d. 100%

12.- A separate power supply is used for the oscillator stage of a transmitter;

a. because the filaments require a separate heating source
b. because a lower B+ voltage is required
c. to prevent frequency instability due to load variations being fed back through a common power supply
d. to increase the frequency band width radiated due to a common power supply

13.- A triode radio frequency power amplifier must be neutralized;

a. to increase power output
b. to prevent self-oscillations
c. to eliminate second harmonic radiation
d. when used as a frequency doubler

14.- What is the maximum permissible plate power input to the final stage of an amateur transmitter on all bands except 420 - 450 Mc?

a. 850 watts   b. 1000 watts   c. 10 kilowatts
d. 1000 kilowatts

15.- The result of operating an unneutralized r-f triode power amplifier is;

a. decreased output
b. spurious radiation
c. a decrease in harmonic content
d. varying load condition

16.- One of the characteristics of an r-f frequency doubler amplifier is <u>not</u>;

a. high negative grid bias
b. large excitation signal
c. high impedance plate circuit
d. low impedance plate circuit tuned to the same frequency as the excitation voltage

17.- What are the requirements for portable operation in excess of 48 hours from the fixed location?

a. maximum power output is limited to 500 watts
b. operation permitted only in the 10 meter band
c. prior notification to FCC engineer in charge of district
d. single side band transmission

18.- In order to obtain optimum power output from an r-f power amplifier;

a. the antenna system should be matched to the rated tube load impedance
b. a directional array antenna should be used
c. link coupling is required
d. class B push-pull operation should be employed

19.- A power output r-f amplifier <u>should not</u>;

a. be coupled to the antenna system
b. have minimum plate current at resonance

c. couple high harmonics to antenna
d. be matched to the output circuit impedance

20.- An amateur operating at 1 kilowatt, 100 percent modulated power output;

a. must get permission from FCC
b. is operating illegally
c. must have means of adequately checking percent modulation and power output
d. can only operate on certain bands

21.- The principle purpose of using door interlock switches is that they;

a. eliminate the need of turning off transmitter
b. act as an on-off switch
c. protect equipment against mishandling by incompetent personnel
d. prevent personnel from being accidentally shocked by dangerous voltages when cage to transmitter is open

22.- The circuit condition which <u>will not</u> minimize harmonic components in the output circuit of an r-f amplifier is;

a. low L/C ratio
b. improper neutralization
c. push-pull operation
d. proper bias voltage

23.- What is the meaning of "QRM"?

a. I am being interferred with
b. stop sending
c. the strength of your signal is___.
d. change to transmission on another frequency

24.- The most useful operating characteristic of a push-push amplifier is that it;

a. can be used as frequency doubler
b. cancels even harmonics
c. does not have to be neutralized
d. has high efficiency

25.- What is the meaning of "QSY"

a. I am being interferred with
b. stop sending
c. shift to transmission on another wave
d. I shall call you again immediately

26.- The average plate current in an amplitude modulated r-f amplifier should;

a. increase
b. remain constant
c. decrease
d. increase on the positive peaks, and decrease on the negative peaks

27.- The usual means for protecting amateur station equipment from damage by charges of atmospheric electricity (static) on the antenna system is to;

a. connect a large size condenser from the top of the antenna to ground
b. connect a static drain coil
c. shunt the antenna with a low value resistance
d. disconnect the coupling system from the antenna when not in use

28.- A class B modulator as compared to a class A modulator requires;

a. larger excitation voltage
b. lower excitation voltage
c. no power to drive the grid
d. zero bias operation

29.- Using a frequency meter with a possible error of 0.75%, on what whole number kilocycle frequency nearest the high frequency end of the 3500 - 4000 kc amateur band could a transmitter safely be set?

a. 3975 kc b. 3960 kc c. 3970 kc d. 4030 kc

30.- If the grid-bias supply of a class B modulator was suddenly short-circuited;

a. the plate current would increase to excessively high values
b. grid current would increase
c. overmodulation would result
d. output power of the carrier would be in the side bands

31.- Using a frequency meter with a possible error of 0.75%, on what whole number kilocycle frequency nearest the low frequency end of the 14,000 - 14,400 kc band could a transmitter safely be set?

a. 14,000 kc
b. 13,895 kc
c. 14,200 kc
d. 14,105 kc

FINAL "FCC-TYPE" EXAMINATION

Mark in the space next to the number of the question on the answer sheet, the letter of the answer that you think is correct.

1.- A tetrode has;
  a. one grid   b. two grids
  c. three grids   d. four grids

2.- Power is measured by ;
  a. a voltmeter   b. an ammeter
  c. a wattmeter   d. an ohmmeter

3.- The second harmonic of 150 cycles is;
  a. 75 cycles   b. 150 cycles
  c. 300 cycles   d. 450 cycles

4.- The DC power input to the plate of a tube having a plate voltage of 750 volts and a plate current of 50 milliamperes is;
  a. 3,750 watts   b. 37,500 watts
  c. 375 watts   d. 37.5 watts

5.- The DC power input to the plate of a tube having a plate voltage of 500 volts and a plate current of 60 milliamperes is;
  a. 30 watts   b. 560 watts
  c. 300 watts   d. 3000 watts

6.- Radio messages having top priority are;
  a. third party messages
  b. ship to shore messages
  c. relief or emergency messages
  d. messages sent to foreign amateurs

7.- The purpose for a filter in a power supply is;
  a. to get rid of the excess DC
  b. to take the place of the rectifier tube
  c. to increase the output voltage
  d. to smooth out the AC ripple component

8.- A tetrode is superior to a triode as a radio frequency amplifier because of;
  a. lower plate resistance
  b. increased cathode emission
  c. reduced possibility of oscillation
  d. increased grid resistance

9.- A choke input filter;
  a. gives increased output voltage
  b. provides the best output current
  c. provides the best voltage regulation
  d. lowers the ripple frequency

10.- An important step in neutralizing an rf amplifier is;
  a. remove the plate voltage of the stage to be neutralized
  b. remove the filament voltage of the oscillator
  c. remove the plate coil
  d. lower the plate voltage

11.- Maximum plate dissipation means;
  a. maximum current to the filament
  b. maximum current the plate can absorb
  c. maximum heat the plate can safely radiate in watts
  d. maximum power output of the tube

12. If a transformer were connected to a source of DC;
  a. the primary current would be zero
  b. the secondary current would exceed the normal rating
  c. rectification would be easier
  d. excessive current would flow in the primary

13. The output ripple frequency of a full wave rectifier connected to a source of 60 cycle AC is;
  a. 30 cycles b. 60 cycles
  c. 120 cycles d. 240 cycles

14. Neutralization of a triode rf amplifier is necessary in order to prevent;
  a. self oscillation b. reduced amplification
  c. loss of power d. damped oscillation

15. A state of emergency affecting amateurs becomes effective;
  a. when so ordered by the FCC
  b. when an emergency occurs
  c. at the discretion of the amateur
  d. 3 hours after the emergency has started

16. A shorted filter condenser;
  a. causes the power supply current to drop
  b. causes the plate of the rectifier tube to become red hot
  c. causes the choke to short
  d. reduces the ripple frequency

17.- Frequency modulation of an amplitude modulated wave;
   a. causes no output signal
   b. doubles the output power
   c. causes spurious side bands and interference
   d. causes undesired harmonics

18.- Push-pull operation;
   a. introduces harmonics into the grid circuit
   b. improves the signal strength
   c. cancells the third harmonic
   d. eliminates the second harmonic in the plate circuit

19.- An electron-coupled oscillator;
   a. has very good frequency stability
   b. has very good efficiency
   c. has low output power
   d. is more stable than a crystal-controlled oscillator

20.- Optimum power output from an rf amplifier can be obtained;
   a. when the stage is a frequency doubler
   b. when the output circuit impedance matches the tube load impedance.
   c. when the plate impedance is equal to the grid load impedance.
   d. when the plate circuit is slightly off resonance

21.- The purpose of a Faraday shield is;
   a. to reduce power supply interference
   b. to reduce self oscillation
   c. to take the place of a lightning arrestor
   d. to reduce undesirable radiation of harmonics

22.- An advantage of a mercury vapor rectifier over a high vacuum rectifier is NOT;
   a. better voltage regulation
   b. low internal voltage drop
   c. a critical inverse peak voltage rating
   d. a relatively high current rating

23.- Full wave rectification is better than half wave rectification because;
   a. its output is easier to filter
   b. its output contains a lower ripple frequency
   c. a choke input filter may be used
   d. a swinging choke may be used

24.- The purpose of using a center-tap on the secondary of a transmitting tube's filament transformer is;

a. to prevent overheating of the transformer
b. to obtain half the secondary voltage
c. to prevent modulation of the carrier wave by the AC filament supply
d. to prevent interference by radiation of harmonics

25.- A 28 Mc crystal has a positive temperature coefficient of 200 cycles per degree centigrade and is started in operation at 45 degrees centigrade. What will the oscillating frequency be at 75 degrees centigrade?

a. 28.600 Mc. b. 34 Mc.
c. 28.006 Mc. d. 27.004 Mc.

26.- A crystal for the 28-29.7 Mc. band is guaranteed to be accurate to within 0.05% of its specified frequency. If you desire to operate as close as possible to the lower end of the band, for what whole number frequency in kilocycles should you order your crystal? Allow an additional 1 kc for temperature and circuit constant variations.

a. 28.150Mc. b. 28.14 Mc.
c. 28.5 Mc. d. 28.015 Mc.

27.- Using a frequency meter with a possible error of 0.5%, on what whole number kilocycle frequency nearest the high end of the 7000-7300 kc band could a transmitter safely be set?

a. 7277 kc b. 7323 kc
c. 7023 kc d. 7263 kc

28.- An amateur Novice Class license is good for;

a. 6 months b. 1 year
c. 3 years d. 5 years

29.- The owner of a Novice Class license may <u>not</u> operate his station in the following bands:

a. 3700 - 3750 kc. b. 21.10 mc. - 21.25 mc.
c. 28.5 mc. - 29.7 mc. d. 145 mc. - 147 mc.

30.- The owner of a General Class license may <u>not</u> operate a radiotelephone station in the following band:

a. 1800 kc. - 2000 kc. b. 28.0 mc.- 28.5 mc.
c. 28.5 mc. - 29.7 mc. d. 50.0 mc.- 54.0 mc.

31.- What is the FCC regulation regarding the transmission of music by an amateur station?

a. it is permitted only on frequencies above 28 Mc.
b. it is permitted only during the hours of 6AM-11AM
c. it is permitted only on frequencies above 116 Mc.
d. it is not permitted

32.- The ratio of modulator sine wave power output to class C amplifier unmodulated plate power input is;

a. 100% b. 25% c. 125% d. 50%

33.- The ratio of modulator speech power output to class C amplifier unmodulated plate power input is;

a. 125% b. 100% c. 25% d. 50%

34.- A precaution to be observed in the use of the battery operated heterodyne frequency meter is to;

a. check the crystal frequency
b. check the oscillator with a standard frequency
c. check the "A" and "B" battery voltages
d. check the tube filaments

35.- A downward deflection of the antenna r-f current meter during modulation might indicate;

a. sufficient r-f excitation to the modulated stage
b. proper filament emission of the modulated stage
c. excellent voltage regulation of power supply common to both modulator and r-f stage
d. insufficient bias on grid of modulated stage

36.- A precaution to be observed in the use of the absorption type frequency meter is to;

a. loosely couple the frequency meter to the oscillator tank circuit
b. calibrate the frequency meter
c. check the B+ voltage of the frequency meter
d. zero beat the output of the wavemeter

37.- The penalty for willful or malicious interference with other radio communication is;

a. a fine of up to $50 per day
b. a maximum of one year suspension of license
c. no penalty during peace time
d. a fine up to $10,000, up to 2 years imprisonment

38.- When removing an unconscious person from contact with a high voltage circuit, the first thing to do is to;

a. attempt to move person
b. call a doctor
c. open main switch of high voltage power supply
d. try to revive person

39.- The meaning of QRT is;
   a. I am being interfered with
   b. shift frequency
   c. transmit each word or group twice
   d. stop transmission

40.- The highest modulation percentage permitted is;
   a. 50%   b. 75%
   c. 100%   d. 125%

41.- The maximum power input to the final stage is;
   a. 100 watts   b. 500 watts
   c. 1000 watts   d. 10 kilowatts

42.- The value of the bias voltage of figure 1 is;
   a. 6.25 volts   b. 5 volts
   c. 1.25 volts   d. 50 volts

43.- The value of R_2 is;
   a. 60,000 ohms   b. 60 ohms
   c. 6000 ohms   d. 300 ohms

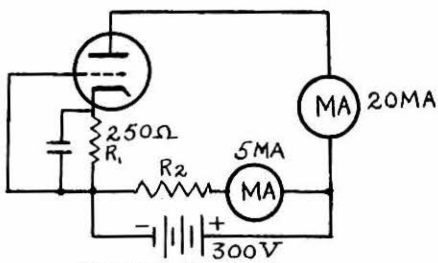


Figure 1

44.- Draw a diagram of a crystal-controlled oscillator using a pentode. Indicate the polarity of the supply voltages

45.- Draw a diagram of a full wave power supply. Show a filter circuit for best regulation and a bleeder resistor providing two different output voltages. Give approximate values of the filter components.

NOVICE FINAL EXAMINATION

1. A power supply filter eliminates:

   a. D.C. b. A.C. and D.C.
   c. the A.C. ripple d. R.F.

2. A detector stage:

   a. removes noise from the signal
   b. extracts audio from a modulated carrier
   c. resembles an R.F. amplifier stage
   d. is located between the mixer and I.F. stage

3. Attenuation means:

   a. boosting b. reducing
   c. distorting d. amplifying

4. In order to prevent R.F. from going to a certain point, we use:

   a. an I.F. Choke b. a resistor
   c. an oscillator d. an R.F. Choke

5. A filter choke :

   a. is used to oppose audio signals
   b. filters out D.C.
   c. is used in amplifiers to filter out harmonics
   d. filters out A.C. hum in a power supply

6. A device that is used to oppose the flow of audio frequency currents while allowing D.C. to pass is called:

   a. an audio trap b. an audio transformer
   c. an audio frequency choke d. a D.C. choke

7. The maximum permissible percentage of modulation of an amateur radiotelephone station is:

   a. 75% b. 50% c. 105% d. 100%

8. The holder of a Novice Class license may operate an amateur radiotelephone station in the following band:

   a. 145 mc - 147 mc b. 147 mc - 149 mc
   c. 28.5 mc - 29.7 mc d. 26.9 mc - 27.2 mc

9. F.M. stands for:

a. frequency monitoring
b. fundamental
c. frequency modulation
d. fading motorboating

10. A.M. stands for:

a. amplitude modulation
b. American measure
c. amplitude
d. amplitude megacycle

11. The abbreviation for kilocycle is:

a. Kl.
b. Ke
c. Ki
d. kc

12. The unit of inductance is the:

a. ohm
b. farad
c. henry
d. joule

13. Continuous Wave is abbreviated by:

a. CW
b. CN
c. CS.WV.
d. CU

14. Eastern Standard Time is abbreviated by:

a. E.T.
b. E.S.T.
c. E.T.S.
d. E.P.M.

15. GMT stands for:

a. General Motors Times
b. General Marine Tuner
c. Gradual Mean Transformer
d. Greenwich Mean Time

16. A.C. is changed to D.C. by means of:

a. a rectifier
b. a transistor
c. a filter
d. a transformer

17. Modulation is the process whereby:

a. the high audio tones are attenuated
b. audio is superimposed on an R.F. carrier
c. R.F. is superimposed on an A.F. carrier
d. image interference is eliminated

18. An amplifier stage is one which:

a. increases the D.C. component of the signal
b. extracts audio from an R.F. carrier
c. boosts the low frequency components of an audio signal
d. increases the strength of the signal that is applied to the control grid.

19. What is the D.C. power input to a tube having a plate voltage of 750 V. and a plate current of 90 ma.

a. 63.3 W   b. 67.5 W   c. 67,500 W   d. 63,300 W

20. What is the D.C. power input to a tube having a plate voltage of 250 V. and a plate current of 40 ma.

a. 10 W   b. 100 W   c. 1 W   d. 6.25 W

21. Of the following percentages of modulation, which one would you consider to be one of overmodulation.

a. 50%   b. 75%   c. 100%   d. 110%

22. Of the following, which is not likely to be an effect of overmodulation:

a. distortion of the audio component of the carrier
b. radiation of spurious sidebands
c. drifting of the oscillator
d. interference with stations on nearby frequencies

23. Parasitic oscillations are:

a. oscillations at frequencies other than the desired output frequency
b. oscillations occuring at exactly twice the desired frequency
c. oscillations occuring at the receiver only
d. oscillations that take place in the audio section of the transmitter

24. Interference due to sparking at the telegraph key contacts can be eliminated by:
a. a spark suppressor   b. a resistor spark plug
c. a key-click filter   d. a spark gap device

25. A person without an operator license may operate an amateur transmitter:

a. if he sends at a code speed of less than 13 words per minute
b. if the transmitter's output doesn't travel more than 5 miles
c. if the transmitter is crystal controlled
d. a person without an operating license may not operate an amateur transmitter

26. Notice of portable or mobile operation must be given to the FCC inspector:

    a. at all times
    b. when the portable or mobile operation is to be for a period in excess of 48 hours.
    c. when the portable or mobile operation is to be for a period in excess of 24 hours.
    d. notice need not be given for portable or mobile operation

27. A Novice class operator may not operate an amateur radio station in the following band:

    a. 3700 kc - 3750 kc   b. 26.96 mc - 27.23 mc
    c. 50 mc - 54 mc   d. 145 mc - 147 mc

28. The maximum input power permited to the final stage of a transmitter, owned or operated by a Novice Class operator is:

    a. 50 W.   b. 75 W.   c. 100 W.   d. 1000 W.

29. The term of a Novice Class license is:

    a. 6 months   b. 1 year   c. 3 years   d. 5 years

30. A Novice Class license is renewable under the following conditions:

    a. upon application by the Novice operator
    b. if the Novice operator can show proof of still being able to pass the original examination
    c. proof must be given of 3 actual contacts with radio amateurs.
    d. the Novice Class license is not renewable under any conditions

31. The log of an amateur station must be preserved for:

    a. 6 months   b. 1 year   c. 2 years   d. 3 years

32. The log of an amateur station is:

    a. a special type of radio calender
    b. the rules and regulations of the FCC pertaining to the amateur operator
    c. a written record of transmissions made by the amateur operator
    d. a copy of the frequencies that an amateur can use under his class of license

33. An amateur station must be identified by its call sign:

a. at least once every 15 minutes during the transmission
b. at the beginning and end of each transmission and at least once every 10 minutes during a transmission
c. only at the beginning and end of each transmission
d. once every 20 minutes during a transmission

34. Spurious radiations from an amateur transmitter:

a. are permitted on all frequencies above 30 mc.
b. are forbidden on all amateur frequencies
c. must be reduced in accordance with good engineering practice on all frequencies below 144 mc.
d. are forbidden by Novice class operators

35. A frequency multiplier in a transmitter will:

a. increase the power of the fundamental frequency
b. increase the voltage of the fundamental frequency
c. increase the frequency in odd multiples
d. increase the frequency in multiples of 2, 3, 4, etc.

36. The method of frequency control required in a station licensed to the holder of a Novice Class license is:

a. automatic frequency control
b. crystal control
c. electron coupled oscillator must be used
d. monitor contron

37. An amateur shall establish a proceedure for measuring his carrier frequency:

a. when so ordered by the FCC
b. once a year
c. at regular intervals
d. when asked to do so by another amateur

38. The means by which an amateur measures his emitted frequency shall be:

a. sufficiently accurate to insure operation within the amateur band being used
b. accurate within 2% of the dial calibrations
c. accurate within 5% of the dial calibrations
d. crystal controlled

39. The transmission of improper language or false signals:

a. is permitted if the transmitter's output does not travel more than 5 miles in any direction
b. is permitted between the hours of 1 A.M. and 7 A.M.
c. there is no FCC rule regarding the transmission of improper language
d. is strictly forbidden at all times

40. Willful interference to other radio communication:

a. is prohibited
b. is permitted on frequencies above 144 mc
c. is permitted on frequencies above 420 mc
d. is permitted if the output power is under 50 W.

41. The second harmonic of 400 kc is:

a. 400 c   b. 800 c   c. 800 kc   d. 1200 kc

42. The third harmonic of 2 mc is:

a. 6 mc   b. 8 mc   c. 12 kc   d. 12 mc

43. A voltmeter measures:

a. current   b. amperes
c. electrical pressure   d. power

44. An ammeter measures:

a. current   b. voltage   c. amperes   d. ohms

45. Resistance is measured by:

a. an ammeter   b. a voltmeter
b. an ohmmeter   d. a wavemeter

46. Power is measured by:

a. a wattmeter   b. a voltmeter
c. an ohmmeter   d. a joulemeter

47. Electrical energy is measured by:

a. a watt-hour meter   b. a wavemeter
c. an ammeter   d. a voltmeter

48. One kilocycle is equal to:

a. 1000 cycles   b. 10,000 cycles
c. 1000 megacycles   d. 100,000 cycles

49. One megacycle is equal to:

a. 100,000 cycles   b. 1,000,000 cycles
b. 1,000 cycles   d. 100 kilocycles

APPENDIX I

RADIO ABBREVIATIONS

Group	Abbreviation	Meaning
Ampere	a, or amp	ampere
	μa	microampere
	ma	milliampere
Farad	fd	farad (rarely used alone)
	$\mu\mu$f	micromicrofarad
	μfd	microfarad
Frequency	f	frequency
	c, or	cycles
	cps	cycles per second
	kc	kilocycles per second
	Mc	Megacycles per second
Henry	h	henry
	μh	microhenry
	mh	millihenry
Impedance	X_L	inductive reactance (in ohms)
	X_C	capacitive reactance (in ohms)
Ohm	Ω (Omega)	ohm resistance
	M	megohm (one million ohms)
Volt	v	volt
Watt	w	watt
	p	power (in watts)
Current	a-c	alternating current
	d-c	direct current
Frequency	a-f	audio frequency
	r-f	radio frequency
	i-f	intermediate frequency
	t-r-f	tuned radio frequency
Miscellaneous	c-w	continuous wave
	a-m	amplitude modulation
	f-m	frequency modulation
	e-m-f	electromotive force (in volts)
	m-o-p-a	master-oscillator power-amplifier
	EST	Eastern Standard Time
	GMT	Greenwich Mean Time

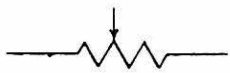
APPENDIX II

Table of Common Radio Symbols

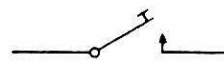
FIXED RESISTOR

VARIABLE RESISTOR

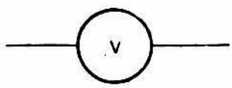
POTENTIOMETER



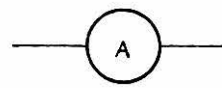
KEY



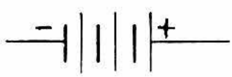
VOLTMETER



AMMETER

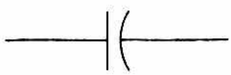


BATTERY

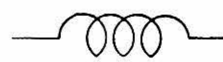


FUSE

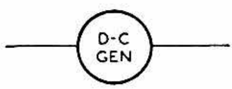
CAPACITOR



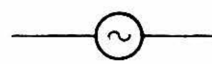
IRON CORE CHOKE COIL



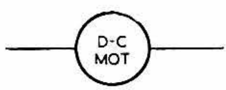
D-C GENERATOR



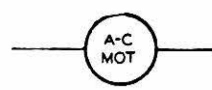
SOURCE OF ALTERNATING VOLTAGE



D-C MOTOR

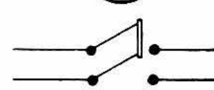


A-C MOTOR



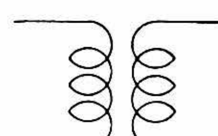
SINGLE POLE, SINGLE THROW SWITCH

DOUBLE POLE, SINGLE THROW SWITCH

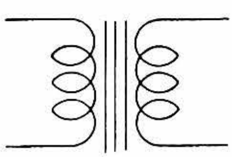


SINGLE POLE, DOUBLE THROW SWITCH

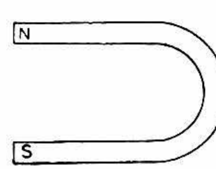
AIR CORE TRANSFORMER



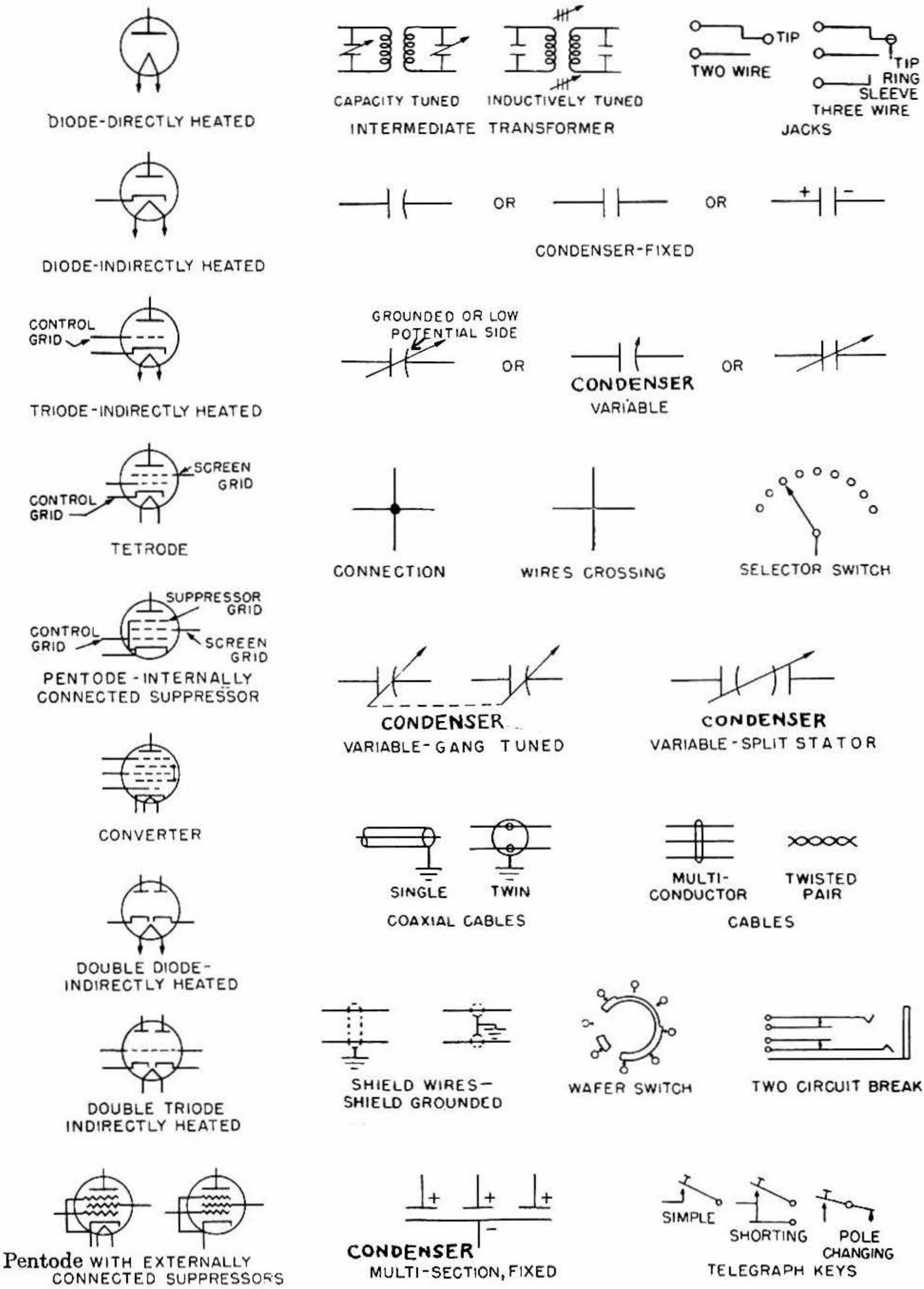
IRON CORE TRANSFORMER



HORSESHOE MAGNET



BAR MAGNET



DIODE-DIRECTLY HEATED
CAPACITY TUNED
INDUCTIVELY TUNED
INTERMEDIATE TRANSFORMER
TIP
TWO WIRE
TIP
RING
SLEEVE
THREE WIRE
JACKS
DIODE-INDIRECTLY HEATED
OR
OR
+
-
CONDENSER-FIXED
CONTROL GRID
TRIODE-INDIRECTLY HEATED
GROUNDED OR LOW POTENTIAL SIDE
OR
OR
CONDENSER
VARIABLE
SCREEN GRID
CONTROL GRID
TETRODE
CONNECTION
WIRES CROSSING
SELECTOR SWITCH
SUPPRESSOR GRID
CONTROL GRID
SCREEN GRID
PENTODE-INTERNALLY CONNECTED SUPPRESSOR
CONDENSER
VARIABLE-GANG TUNED
CONDENSER
VARIABLE-SPLIT STATOR
CONVERTER
SINGLE
TWIN
COAXIAL CABLES
MULTI-CONDUCTOR
TWISTED PAIR
CABLES
DOUBLE DIODE-INDIRECTLY HEATED
DOUBLE TRIODE INDIRECTLY HEATED
SHIELD WIRES-SHIELD GROUNDED
WAFER SWITCH
TWO CIRCUIT BREAK
+
+
+
-
Pentode WITH EXTERNALLY CONNECTED SUPPRESSORS
CONDENSER
MULTI-SECTION, FIXED
SIMPLE
SHORTING
POLE CHANGING
TELEGRAPH KEYS

APPENDIX III

RADIO FORMULAS

Ohm's Law: $I = \frac{E}{R}$ $E = IR$ $R = \frac{E}{I}$

Power: $P = EI$ $P = I^2R$ $P = \frac{E^2}{R}$

Resistors in Series: $R_T = R_1 + R_2 + R_3 \cdots\cdots$

TWO Resistors in Parallel: $R_T = \frac{R_1 \times R_2}{R_1 + R_2}$

Resistors in Parallel: $R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \cdots\cdots}$

Inductors in Series: $L_T = L_1 + L_2 + L_3 \cdots\cdots$

Inductors in Parallel: $L_T = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} \cdots\cdots}$

Inductive Reactance: $X_L = 2\pi fL$

Condensers in Parallel: $C_T = C_1 + C_2 + C_3 \cdots\cdots$

Condensers in Series: $C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \cdots\cdots}$

Capacitive Reactance: $X_C = \frac{1}{2\pi fC}$

Resonant Frequency of a Tuned Circuit: $f_r = \frac{1}{2\pi\sqrt{LC}}$

Characteristic Impedance of an Air Insulated Parallel Conductor Transmission Line: $Z = 276 \log \frac{b}{a}$

Standing Wave Ratio of a Transmission Line: $SWR = \frac{I_{max}}{I_{min}}$ or $\frac{E_{max}}{E_{min}}$

Wavelength of Radio Waves: $\lambda = \frac{300{,}000{,}000}{f}$

In the above formulas, I is current in Amperes, E is voltage in volts, R is resistance in ohms, P is power in watts, L is inductance in Henries, T stands for total, X_L is inductive reactance in ohms, f is frequency in cycles, C is capacity in farads, X_C is capacitive reactance in ohms, "a" is the radius of the conductor, "b" is the center to center distance between conductors.

APPENDIX IV

Table of Abbreviations to be Used in Radio Service

Abbreviation	Answer or Statement
QRK	The readability of your signals is... (1 to 5)
QRM	I am being interfered with.
QRT	Stop transmission.
QRX	Wait (or Wait until I have finished communicating with...) I shall call you again at...o'clock (or immediately)
QSA	The strength of your signals is (1 to 5)
QSY	Shift to transmission on another wave.
QSZ	Transmit each word or group twice.
QRJ	I cannot receive you. Your signals are too weak.
QRN	I am troubled by static.
QRO	Increase the power.
QRP	Decrease the power.
QRS	Transmit more slowly (...words per minute.)
QSB	The strength of your signals varies.
QSX	I am listening to... (call signal) on...kilocycles (or...meters.)
QUF	I have received the distress signal sent by...(call signal of the mobile station) at...(time)
QUM	The distress traffic is ended.

Appendix 5

STUDY MATERIAL FOR NOVICE LICENSE PREPARATION

Sec. 1. Introduction to radio - page 2
- Lesson 1. Paragraphs 1-1 to 1-12, 1-17. Practice questions 1, 2, 4, 5, 16, 17.
- Lesson 2. Paragraphs 2-1 to 2-11.
- Lesson 3. Paragraphs 3-1 to 3-4, 3-8, 3-15, 3-16, 3-32, 3-33. Practice questions 1, 2, 5, 12.
- Section 1 examination (page 70) Questions 1 to 5, 7 to 13, 19, 20.
- Study Guide Entire study guide - pages 66 to 69

Sec. 2.
- Lesson 4. Paragraphs 4-1 to 4-7, 4-9. All practice questions.
- Lesson 5. Paragraphs 5-1 to 5-8, 5-17, 5-19, 5-20. Practice question 7.
- Lesson 6. Paragraphs 6-1 to 6-3, 6-6, 6-8, 6-11, 6-13. Practice questions 4, 7 to 10, 15, 16.
- Lesson 7. Paragraphs 7-1, 7-2, 7-4, 7-18.
- Lesson 8. Paragraphs 8-1, 8-2, 8-6, 8-7, 8-15. Practice questions 3, 4, 5, 9.
- Section 2 examination (page 152) questions 2, 7, 9, 17.

Sec. 3. Introduction to transmission and reception (page 156).
- Lesson 9. Paragraphs 9-1, 9-15. Practice question 7.
- Lesson 10 Paragraphs 10-1 to 10-4, 10-17, 10-19.
- Lesson 11 Paragraphs 11-1 to 11-4, 11-16. Practice question 8.
- Lesson 12 Paragraphs 12-1, 12-2.
- Lesson 13 Paragraphs 13-1 to 13-3. Practice question 2.
- Lesson 14 Entire lesson.
- Section 3 examination (page 271) questions 1 to 6, 11, 14, 20.

Final examination questions 1 to 7, 9, 28, 29, 30, 37, 40.

Novice Final examination - Entire examination

Appendix 1, appendix 3 formula 1b, appendix 7- Q1,Q2,Q3,Q4.

Appendix 6

ANSWERS

Section 1 Examination - page 70

1. C	6. C	11. D	16. D	21. D	26. C
2. A	7. B	12. C	17. A	22. C	27. C
3. B	8. C	13. A	18. A	23. D	28. A
4. C	9. A	14. C	19. C	24. A	29. B
5. C	10. D	15. B	20. B	25. A	30. D

Section 2 Examination - page 152

1. C	6. A	11. C	16. C	21. A	26. C
2. C	7. C	12. A	17. B	22. D	27. C
3. D	8. D	13. B	18. B	23. A	28. A
4. C	9. A	14. A	19. C	24. D	
5.	10. D	15. A	20. C	25. B	

5a. 4.5 volts
5b. 75 volts
5c. 79.5 volts

Section 3 Examination - page 271

1. A	6. C	11. D	16. D	21. D	26. B	31. D
2. B	7. B	12. C	17. C	22. B	27. B	
3. B	8. A	13. B	18. A	23. A	28. A	
4. C	9. B	14. B	19. C	24. A	29. C	
5. B	10. C	15. B	20. B	25. C	30. A	

Novice Final Examination

1. C	8. A	15. D	22. C	29. B	36. B	43. C
2. B	9. C	16. A	23. A	30. D	37. C	44. A
3. B	10. A	17. B	24. C	31. B	38. A	45. C
4. D	11. D	18. D	25. D	32. C	39. D	46. A
5. D	12. C	19. B	26. B	33. B	40. A	47. A
6. C	13. A	20. A	27. B	34. C	41. C	48. A
7. D	14. B	21. D	28. B	35. D	42. A	49. B

Final Examination

1. B	8. C	15. A	22. C	29. C	36. A	43. A
2. C	9. C	16. B	23. A	30. B	37. D	44. Pg.170
3. C	10. A	17. C	24. C	31. D	38. C	45. Pg.98
4. D	11. C	18. D	25. C	32. D	39. D	
5. A	12. D	19. A	26. D	33. C	40. C	
6. C	13. C	20. B	27. D	34. C	41. C	
7. D	14. A	21. D	28. B	35. D	42. B	

APPENDIX VII

ADDITIONAL QUESTIONS

In early 1955 the FCC added new questions to the Novice and General Class examinations. The following questions and answers cover the information required for these new questions. Questions 1 through 4 are for the Novice examination. Question 4 and the remainder of the questions are for the General Class examination.

Q1. What is the purpose of an audio frequency choke?
A1. The purpose of an audio frequency choke is to oppose the flow of audio frequency currents while allowing direct current to flow.

Q2. What is the meaning of attenuation?
A2. Attenuation means to reduce in amount or amplitude.

Q3. What is the rule regarding eligibility for reexamination?
A3. An applicant who fails an operator examination may not take another one for such privileges within 30 days (except that this does not apply to an examination for a General Class license following an examination for a Conditional Class license).

Q4. What precautions should be taken to avoid the danger of shock from high-voltage electrical circuits?
A4. The following precautions should be taken: 1. Shut off power from circuits that you intend to work on. 2. Use bleeder resistors across the filter condensers in the power supply. 3. Do not allow high-voltage wires or circuits to be exposed where the operator or other person can come in contact with them.

Q5. What is meant by the "time-constant" of a resistance-capacity circuit?
A5. The "time-constant" is a number that is equal to the product of the resistance in ohms and the capacity in farads. It is the time in seconds that it takes for a condenser to charge up to 63% of the applied voltage.

Q6. What would happen if the primary of a 60 cycle power supply was connected to a DC source?
A6. With DC applied, there would be no inductive reactance in the primary of the transformer. The current flow would therefore be high and would damage the primary winding or blow the fuse.

Q7. What is the usual means for protecting amateur station equipment from damage by charges of atmospheric electrity on the antenna system?

A7. The usual means is an antenna grounding switch.

Q8. What is "skin effect"?

A8. "Skin effect" is the tendency of higher frequency currents to flow along the surface of the conductor. This is because of the reactance created on the inside of the conductor.

Q9. What effect does the Q of a circuit have on harmonic output?

A9. As the Q increases, the selectivity increases and the harmonic output decreases.

Q10. What are the relative bandwidths of type A1 and type A3 emissions? Of single sideband and double sideband amplitude-modulated emissions?

A10. Type A1 emission has no modulation and is therefore narrow in bandwidth - 100 cycles or less. The bandwidth of A3 emission depends upon the audio range used. The bandwidth is twice the limit of the audio frequencies. If the audio frequencies are limited to 3 kc. the bandwidth would be 6 kc.
The bandwidth occupied by double-sideband is twice that occupied by single-sideband.

Q11. What is the advantage of a high-pass filter at the input circuit of a Tv. receiver?

A11. The High-pass filter prevents the fundamental frequency of a transmitter from reaching the front end of the receiver and overloading it. It cuts out everthing below its cut-off frequency.

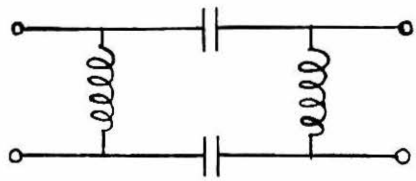
Q12. In the event of harmonic interference to a Tv. receiver, what is the advantage of a low-pass filter in the output circuit of an amateur transmitter?

A12. The low-pass filter reduces the output of harmonic frequencies that occur above the filter's cut-off point. This will eliminate the interference that falls in the Tv. bands.

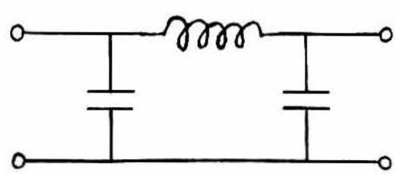
Q13. What is the Q of a resonant circuit?

A13. The Q of a resonant circuit is the gain of the circuit at the resonant frequency - in other words, a measure of the selectivity of the circuit. Numerically, it is the reactance of either the coil or the condenser divided by the resistance of the circuit at resonance.

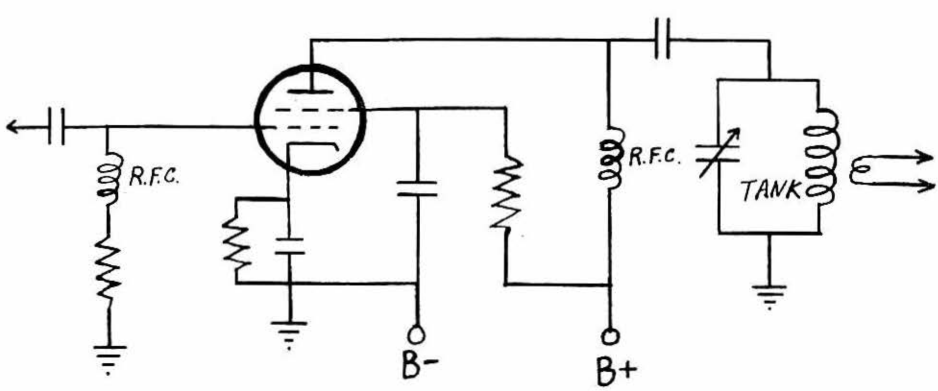
Q14. Draw a schematic diagram of a high-pass filter using a single, balanced, constant-k pi section.



Q15. Draw a schematic diagram of a low-pass filter using a single, unbalanced, constant-k pi section.



Q16. Draw a schematic diagram of an r.f. power amplifier stage using parallel feed.



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