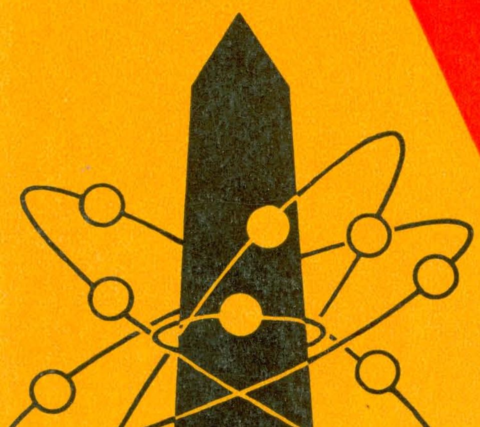
No. 170-4

basic electronics

by VAN VALKENBURGH, NOOGER & NEVILLE, INC.

VOL. 4

TRANSMITTERS
TRANSMISSION LINES & ANTENNAS
CW TRANSMISSION & AMPLITUDE MODULATION



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by VAN VALKENBURGH,
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VOL. 4

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PREFACE

The texts of the entire Basic Electricity and Basic Electronics courses, as currently taught at Navy specialty schools, have now been released by the Navy for civilian use. This educational program has been an unqualified success. Since April, 1953, when it was first installed, over 25,000 Navy trainees have benefited by this instruction and the results have been outstanding.

The unique simplification of an ordinarily complex subject, the exceptional clarity of illustrations and text, and the plan of presenting one basic concept at a time, without involving complicated mathematics, all combine in making this course a better and quicker way to teach and learn basic electricity and electronics.

In releasing this material to the general public, the Navy hopes to provide the means for creating a nation-wide pool of pre-trained technicians, upon whom the Armed Forces could call in time of national emergency, without the need for precious weeks and months of schooling.

Perhaps of greater importance is the Navy's hope that through the release of this course, a direct contribution will be made toward increasing the technical knowledge of men and women throughout the country, as a step in making and keeping America strong.

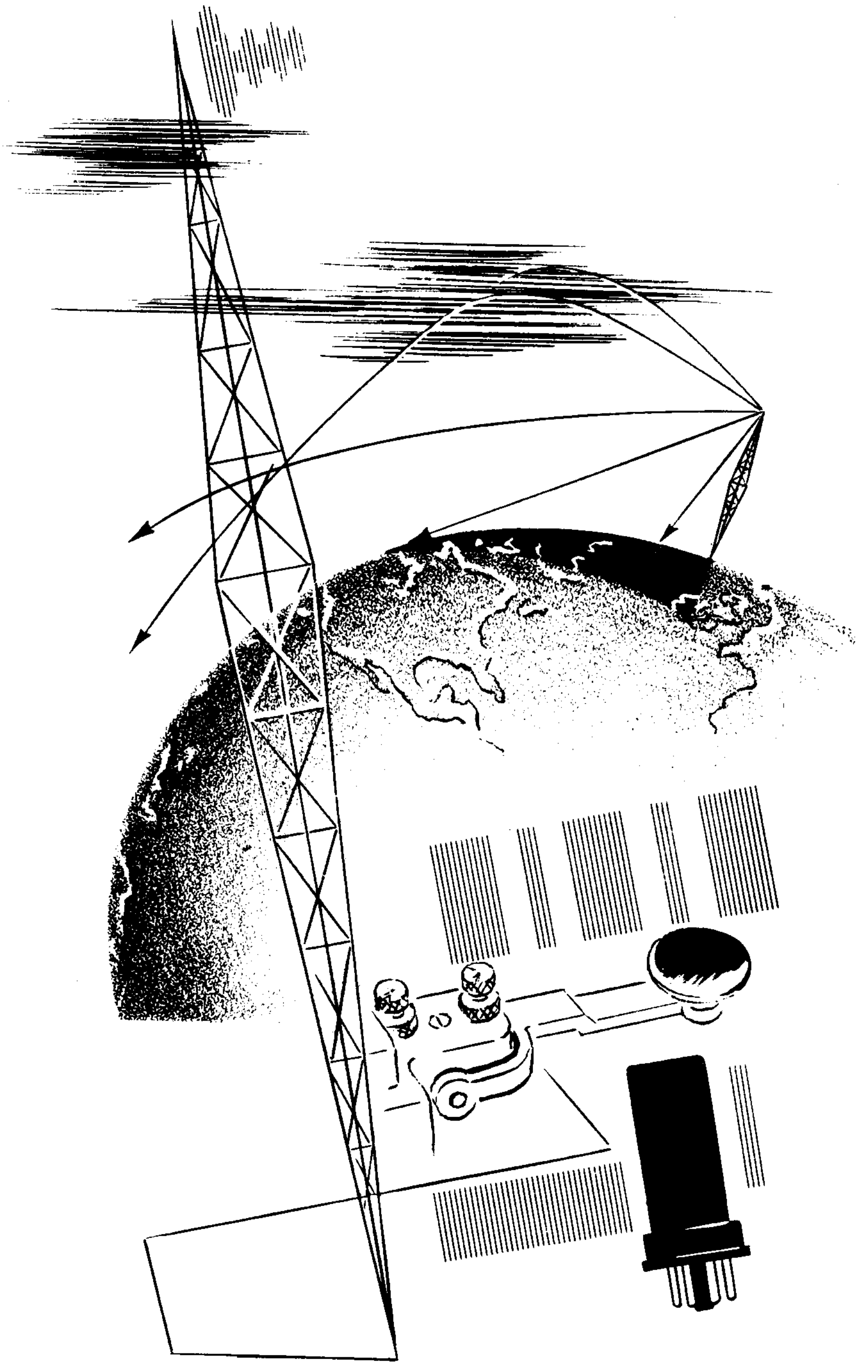
Van Valkenburgh, Nooger and Neville, Inc.

New York, N. Y.

February, 1955

TABLE OF CONTENTS

VOL. 4 — BASIC ELECTRONICS

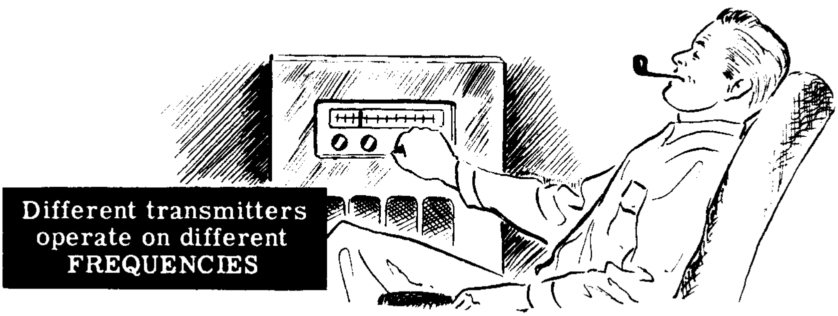


Transmitters

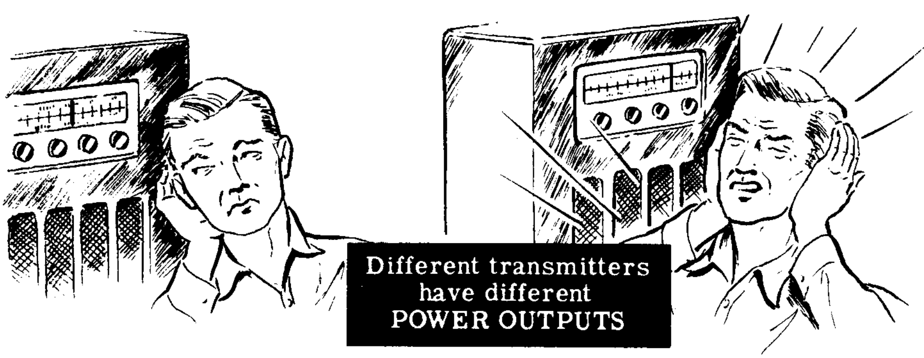
What You Know About Transmitters

Probably very few of you have had any direct experience with transmitters. To many of you, the word itself may be unfamiliar. However, you have referred many times to one type of transmitter—a radio station.

When you listen to a radio, the sounds you hear travel to the radio receiver through the air. If someone were to ask you how those "sounds" happened to be in the air, you would probably say, "A radio station broadcasts them."



There are other things you already know about transmitters from your experience with radio sets. You know that "changing stations" is also called "tuning." From this, you realize that different transmitters operate at different frequencies. You select the station you want to listen to by tuning your radio to the frequency of that station.

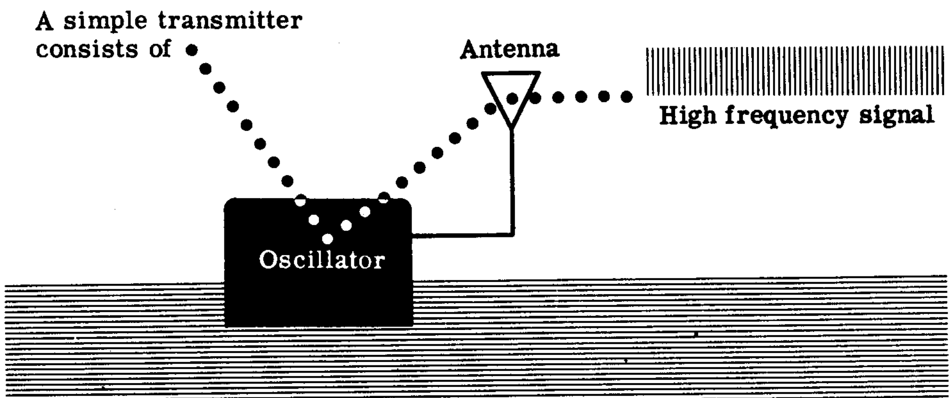


You have also noticed that some stations come in stronger than others. If different transmitters at equal distances away have different power outputs, the station whose transmitter has the largest power output will be heard the loudest. Also, if there are two stations whose transmitters have the same power output, you will hear more loudly the station that is closer to your radio set.

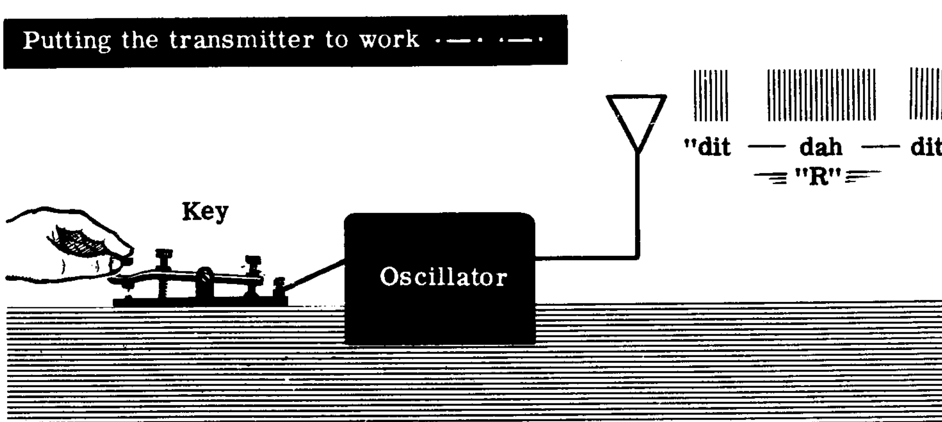
You see that you really knew some things about transmitters even if you never heard the word before.

A Simple Transmitter

The simplest transmitter consists of an oscillator which generates a high frequency signal. The oscillator—and the type of oscillator doesn't matter—could be connected to an antenna to make up a complete transmitter. The antenna in this case would radiate a signal which is constant in amplitude and of the same frequency as the oscillator.



If your home radio set picked up the constant-amplitude signal from such a transmitter, you would hear nothing at all. If a special type of radio received this signal, a constant audio tone would be heard. In either of these cases, no message could be "read" from the incoming signal—such a signal is said to contain "no intelligence." To add intelligence to the signal, the oscillator would be turned on and off with a key to produce dots and dashes.



A signal of this type contains intelligence since a message can be obtained from it. The radio would produce a sound somewhat like "dit-dah-dit" which a radio operator understands as the letter "R."

A Simple Transmitter (continued)

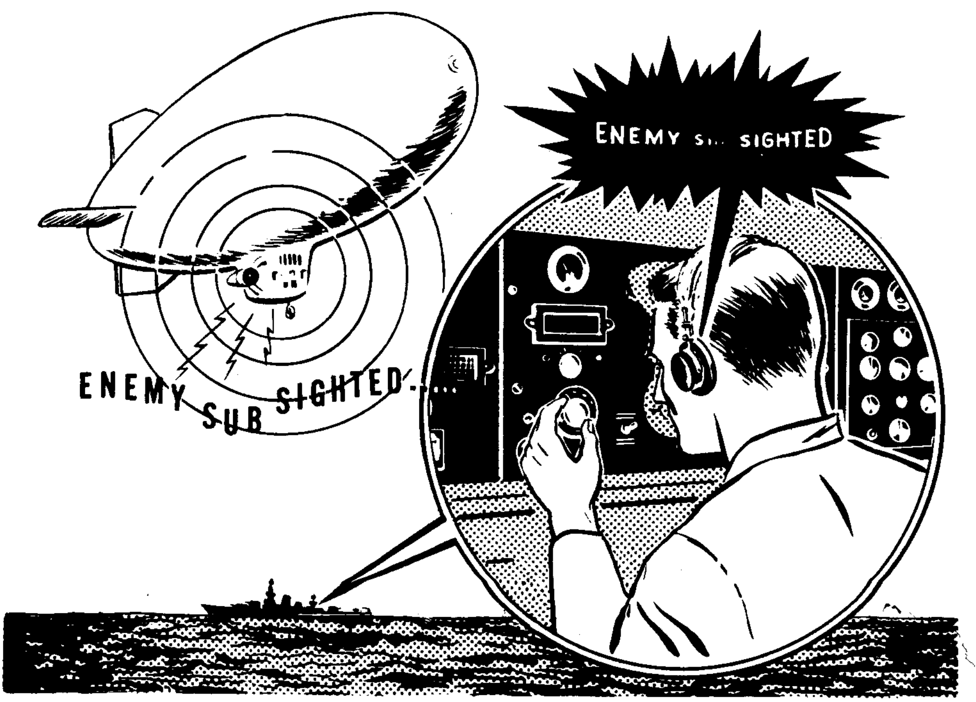
Almost every transmitter contains more than just an oscillator. There are two main drawbacks to connecting the oscillator directly to the antenna. The first is that the power output would be limited because there are no stages of RF amplification between the oscillator and the antenna to build up the strength of the RF signal. Power output is important because it determines the distance over which the transmitted signal can be picked up by the receiver.

The other consideration is frequency stability. An oscillator from which a large amount of power is drawn has a tendency to drift in frequency. A drift in the frequency of the transmitted signal would mean that a portion of the message would be lost by the operator trying to receive it.

For these reasons—poor frequency stability and low power output—oscillators are not connected directly to an antenna.

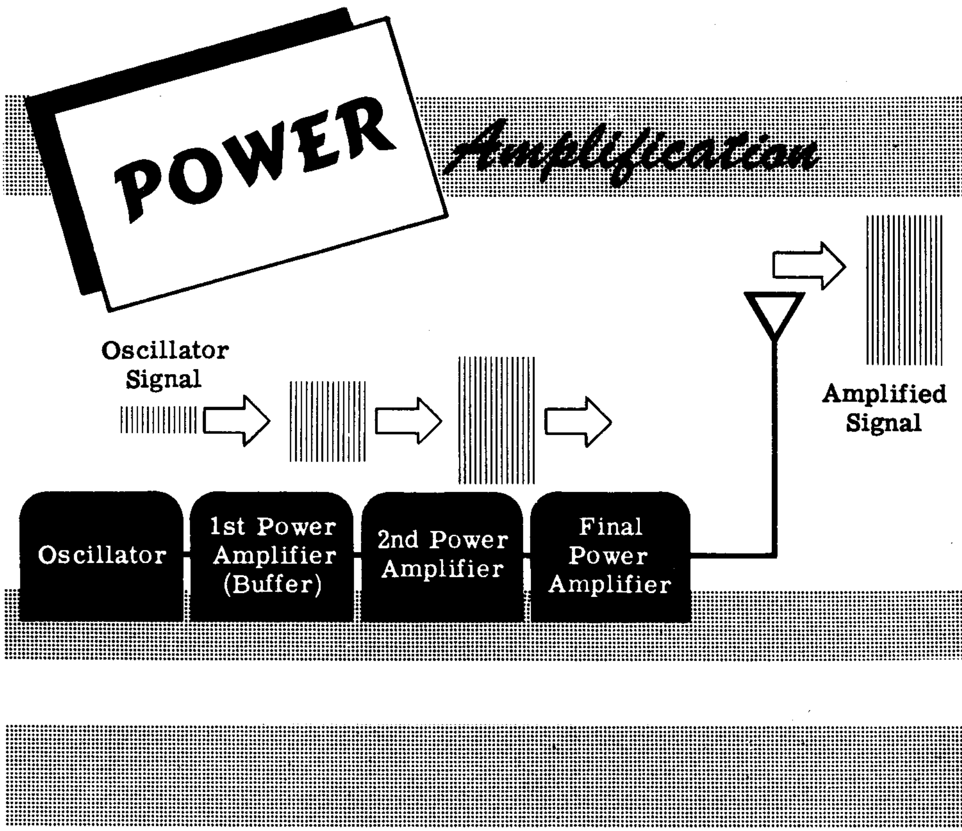
Frequency Drift and Low Power Output

result in poor reception....



A Simple Transmitter (continued)

To overcome the limitations of connecting an oscillator directly to the transmitting antenna, one or more stages of amplification are connected between the oscillator and the antenna. The stage which is connected to the antenna is usually called the "final power amplifier." The other stages of amplification are known by several names. Sometimes they are referred to as the "first and second power amplifiers," and sometimes as "intermediate power amplifiers." In addition, the first power amplifier, since it serves to isolate the oscillator from variations of load, is also called a "buffer" amplifier.



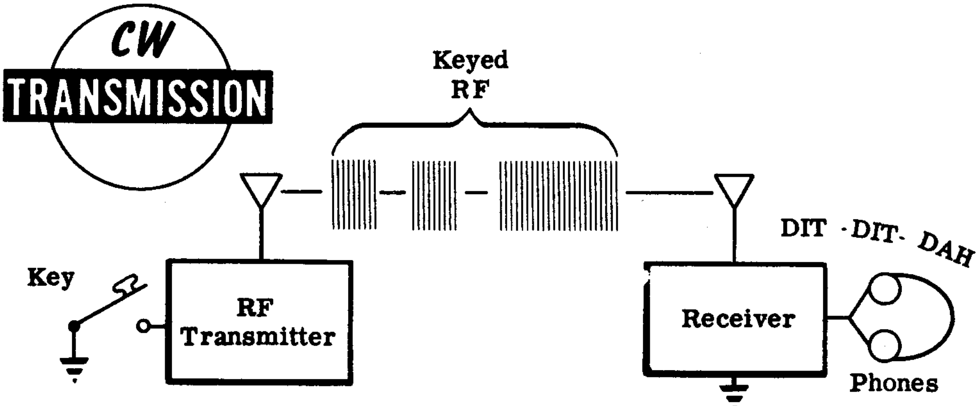
The RF signal is generated in the oscillator circuit and is amplified by the first and second power amplifiers which drive the final power amplifier. The powerful signal from the final power amplifier is fed to the antenna which radiates the signal into space.

As has been said, the RF signal by itself does not contain any intelligence. However, several things may be done to it so that it will contain or carry a message. Because of this, the RF signal is commonly referred to as "the carrier wave"—it is not, of itself, the message, but it can carry a message to some distant point.

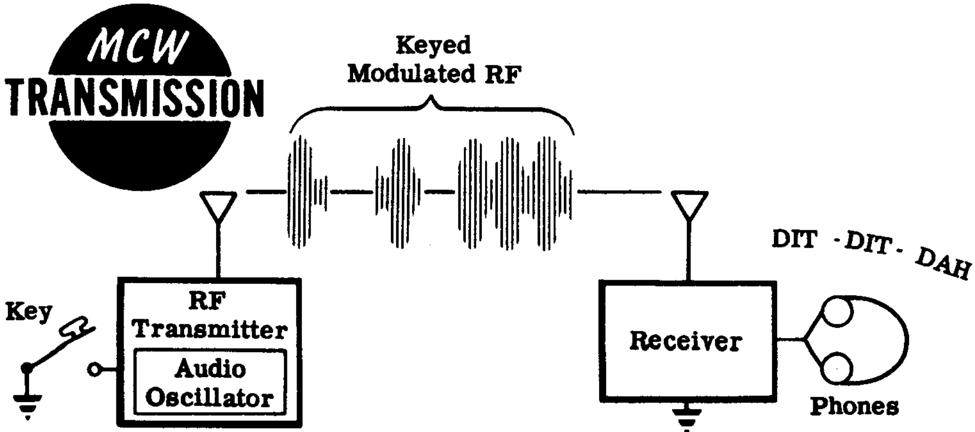
Keyed Transmission

A transmitted signal may contain a message in several forms such as code or voice. The process by which the carrier wave is changed so that it can carry a message is called "modulation." Every communication transmitter needs modulation because the carrier by itself (unmodulated) cannot be interpreted as having any meaning.

In most transmitters the message is transmitted either in code or by voice. The most common types of code transmission are continuous wave (CW) and modulated continuous wave (MCW). In CW transmission the RF to the antenna is interrupted or turned on and off with a hand key so that the carrier is radiated as dots and dashes. CW is used primarily for long distance communication. A special receiver is needed to receive CW.

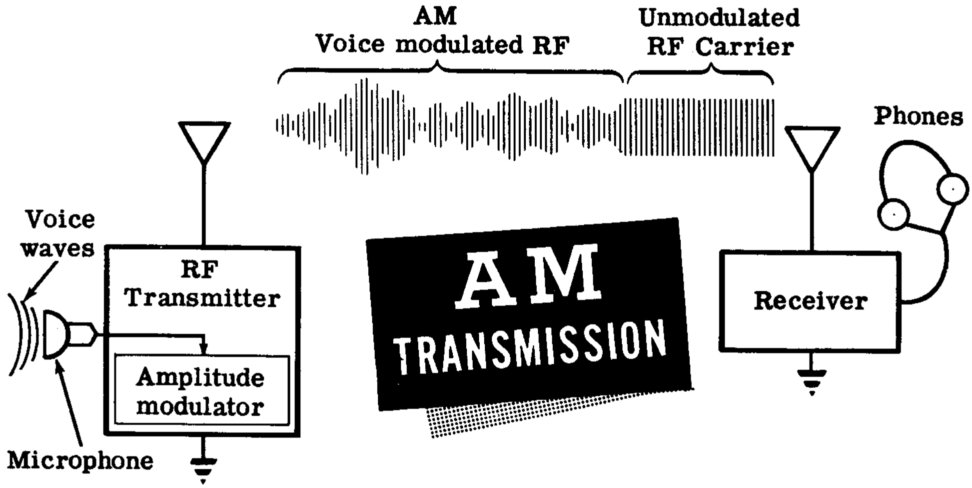


In MCW transmission a constant amplitude audio frequency is superimposed on the carrier. The carrier is then turned on and off with a key just as in CW transmission. Any receiver with the proper frequency range can receive MCW. MCW transmission is used mostly for emergency communication.

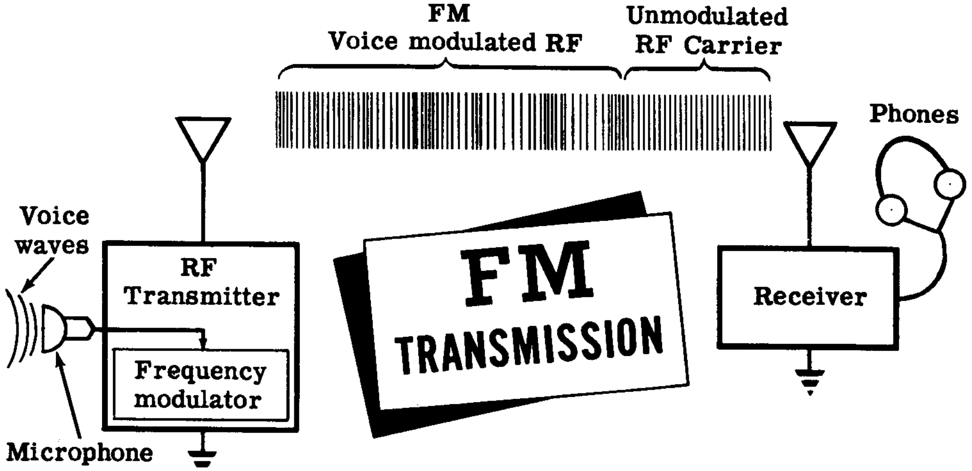


Voice Transmission

Voice transmission is also of two types. In the most common type of voice transmission used the amplitude of the carrier is varied in the same manner as the amplitude of the voice signal. This is called "amplitude modulation" (AM) and is the type of transmission used in the standard radio broadcast.



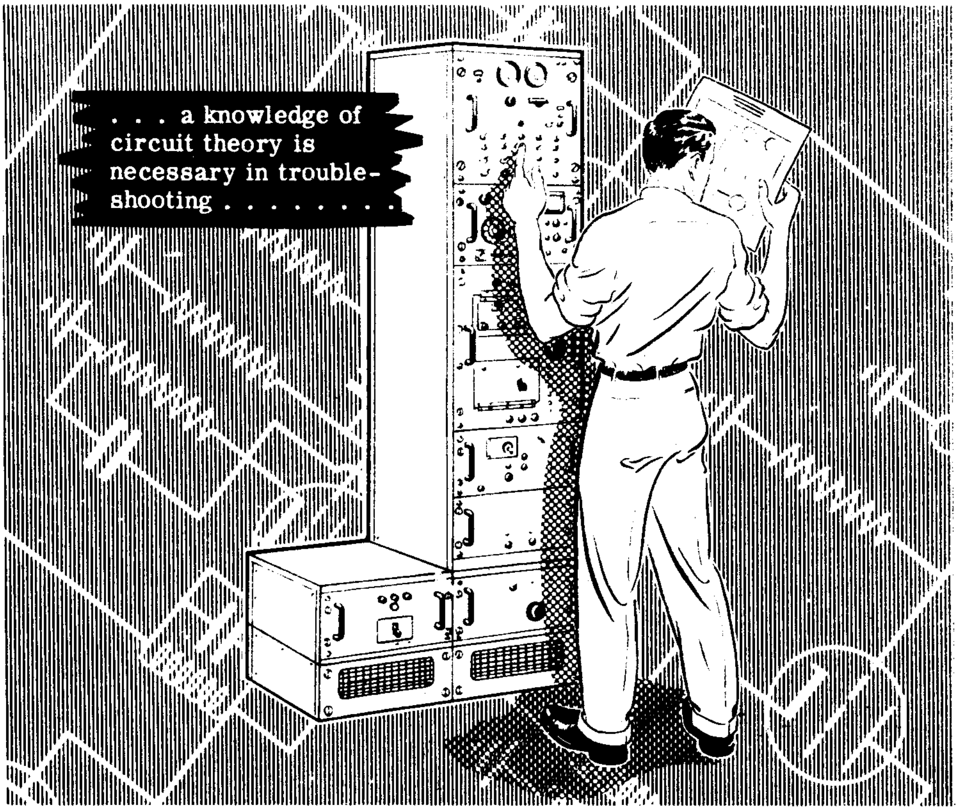
The other type of voice transmission, which is being used more and more, is called "frequency modulation" (FM). Here the frequency of the carrier is shifted back and forth at a rate equal to the frequency of the voice signal. FM transmission is comparatively free from "static" interference, is used in place of AM when the latter may be difficult to receive.



What You Will Learn About Transmitters

At this point in your study of electronics, you could not go up to a transmitter front panel and use it efficiently. However, after you have gone through this section the terminology and also the function of the various controls and indicators will be clear to you.

In order to understand the various transmitters found in equipment, whether in sonar, radar, communications equipment, etc., you first will need to understand how basic transmitter circuits operate. The three-stage RF transmitter you will learn about in this section is the key to understanding other transmitter circuits you will work with. When you know what each circuit in this basic transmitter does and how it should operate correctly, you will have the foundation to work with nearly any type transmitter in whatever equipment it may be found.



The type of amplifier most commonly used in transmitter circuits is the tuned Class "C" power amplifier. You will study the operation of this circuit first. Then you will see how Class "C" amplifiers are used in a typical three-stage transmitter. From here you will go into a study of transmission lines, antennas and coupling circuits which together help to get the signal into the air.

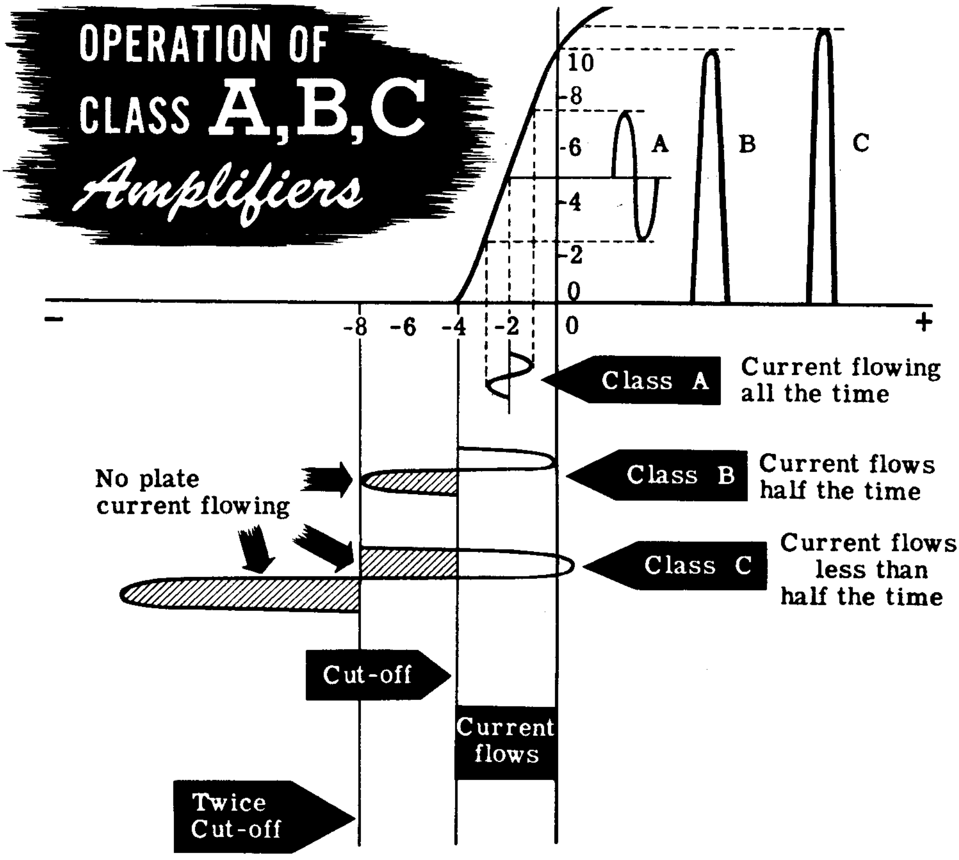
Review of Classes of Operation

You remember from your study of amplifiers that there are three main types of vacuum tube operation—Class A, Class B, and Class C.

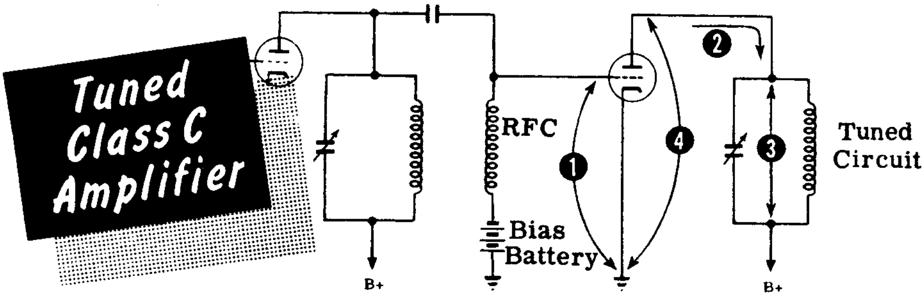
In Class A operation, the grid is biased near the midpoint of the linear portion of the plate current - grid voltage curve. The AC signal on the grid causes the grid voltage to vary above and below the bias value. The current variations are proportional to the grid voltage since the grid voltage swing does not go beyond the linear portion of the curve. Plate current flows throughout the entire AC cycle since the grid voltage does not bring the tube into cut-off.

In Class B operation, the grid is biased at or near its cut-off value. The AC signal drives the tube into cut-off for approximately half of the cycle. Thus the tube conducts for about 180 degrees of the cycle and is cut off during the other 180 degrees of the cycle.

In Class C operation—the type of operation with which you will be most concerned in your study of transmitters—the grid is biased considerably beyond cut-off. The tube remains cut off for most of each AC cycle and current flows in the tube only when the AC signal increases the grid voltage above cut-off. The plate current therefore flows in pulses as shown.

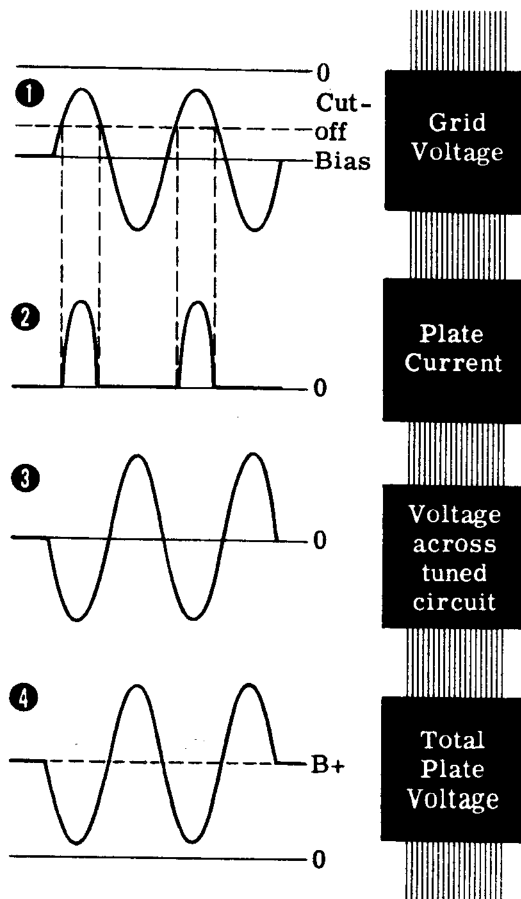


Tuned Class C Amplifiers



The operation of a Class C amplifier will become clear when you analyze what happens in a tuned amplifier such as the one shown in the schematic diagram. An AC signal is developed across the tuned circuit in the plate of the previous stage. This voltage also appears across the RF choke (RFC) in the grid circuit of the tuned Class C amplifier stage. The DC bias provided by the bias battery causes the tube to operate Class C.

The pulses of tube current which flow as a result of this type of operation deliver a "kick" to the tuned circuit in the plate. This "kick" makes the tuned circuit oscillate, and it fills in the part of the cycle during which plate current has stopped. For a review of how oscillations are kept going in a tuned circuit, refer to the section on oscillators, Volume 3.



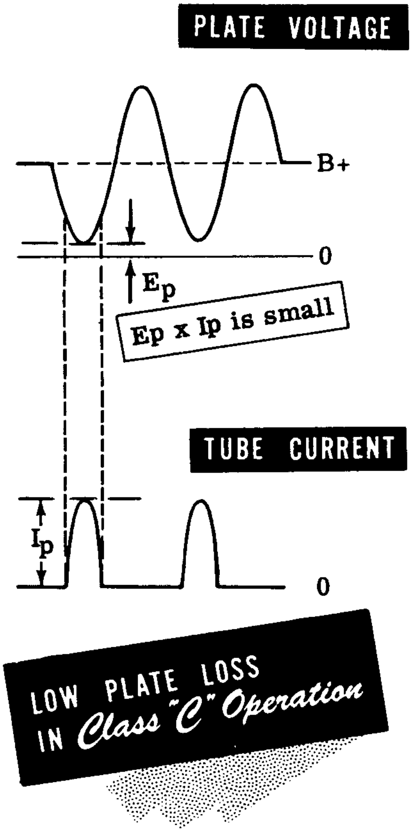
The plate voltage is the difference between the B+ voltage and the AC voltage across the tuned circuit. When the pulse of plate current flows, the voltage at the plate end of the tuned circuit goes negative and subtracts from the B+ voltage. When the voltage across the tuned circuit reverses and goes positive at the plate end, it adds to the B+ voltage. As a result, the plate voltage wave form varies above and below the B+ voltage level as shown.

Tuned Class C Amplifiers (continued)

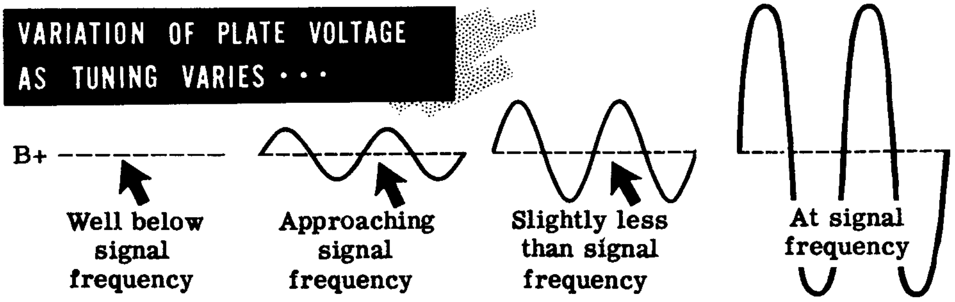
The reason why tuned Class C amplifiers are universally used in high powered transmitters is because of their high efficiency of operation which results in a maximum of radiated power.

The power we supply to an amplifier is always greater than the power we get out of it. Some power is used up by the tube and the rest appears as useful output in the load. The power used up by the tube equals its plate voltage times its plate current.

Since the plate current of a Class C amplifier flows during less than half the cycle, the average plate current is less than in Class A or B operation. Therefore less power is used up by the tube and more power can get to the output. This makes the Class C amplifier more efficient and therefore more desirable for use in a transmitter.



If the tuned circuit in the plate is not tuned to the frequency of the input signal, then the voltage across it will be lower—in proportion to how much it is mistuned. The further off it is tuned, the less power will appear across it and the more power will be dissipated by the tube itself. Then the efficiency of the amplifier is lower, the tube heats up more, and the power output is lower.

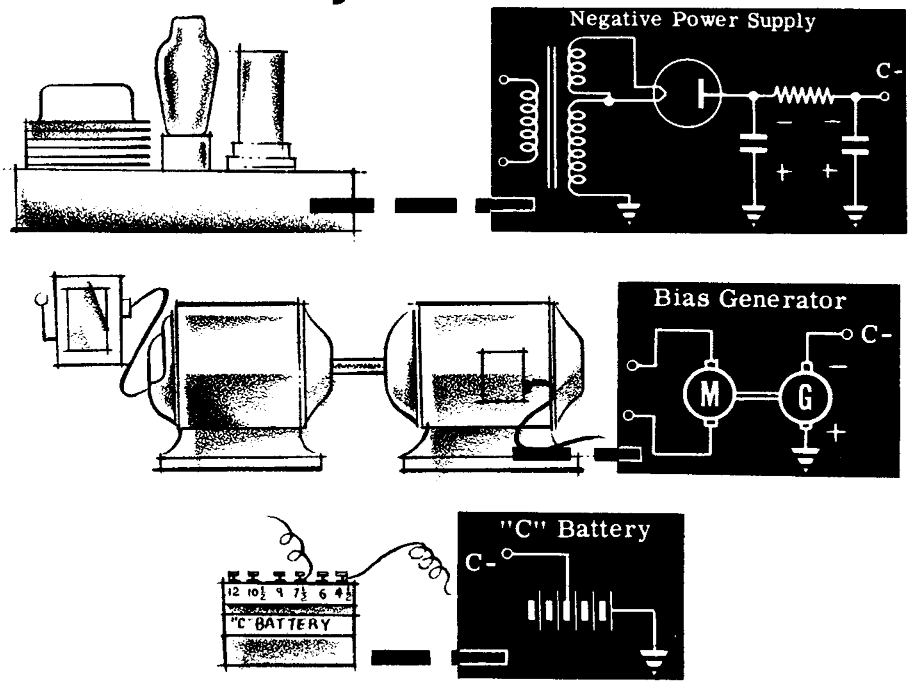


Fixed Bias

The term "fixed bias" describes any method of obtaining bias in which the bias remains fixed as the strength of the input signal varies.

Fixed bias may be obtained from a negative power supply, from a motor-generator set, with a negative DC output, or from a battery. Each of these methods will keep the grid at a constant negative DC voltage which will not vary regardless of the strength of the signal input. The fixed negative bias is called "C-" just as the positive supply voltage is called "B+."

Fixed Bias may be obtained from...



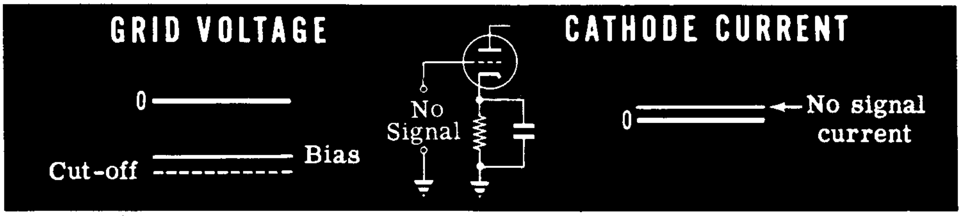
One of the advantages of fixed bias is that the tube remains cut off under no signal conditions.

The disadvantage of fixed bias is that the gain of the amplifier remains constant so that if the grid signal varies in amplitude, the output will similarly vary. This is not desirable in a transmitter because the output to the antenna must remain constant in amplitude if the radiated signal strength is to remain constant. If the bias could be made to vary as the signal input to the amplifier varies, the amplifier output could be maintained practically constant.

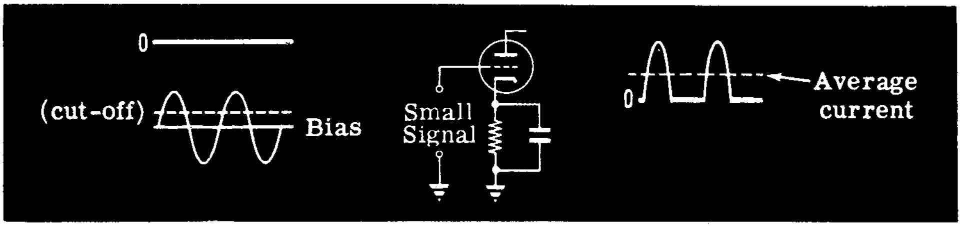
Self-bias

The term "self-bias" describes any grid bias which results from the current flow in the vacuum tube that is being biased. You are already familiar with the two methods that are commonly used to provide self-bias.

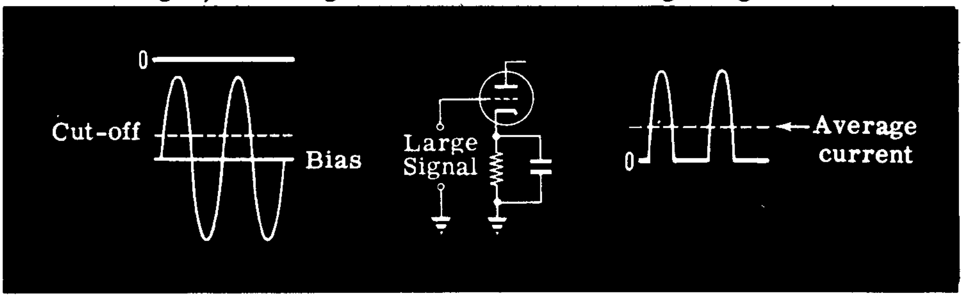
A resistor placed in the cathode circuit makes the cathode more positive than ground and therefore makes the grid more negative than the cathode. The bias voltage developed across this resistor is equal to the average current times the size of the resistor. If a large cathode resistor is used, the bias voltage will be large. This resistor can be made large enough to cause the bias to approach cut-off when there is no signal on the grid.



When there is a signal applied to the grid, the cathode current will increase on the positive half-cycles, and become zero (cut-off) on the negative half-cycles. The average current will be increased and the bias will increase.



If a larger signal is applied to the grid, the current will be larger during the positive half-cycles of voltage but will remain zero during the negative halves. Thus, the average tube current increases as the grid signal becomes larger, resulting in increased bias for larger signals.



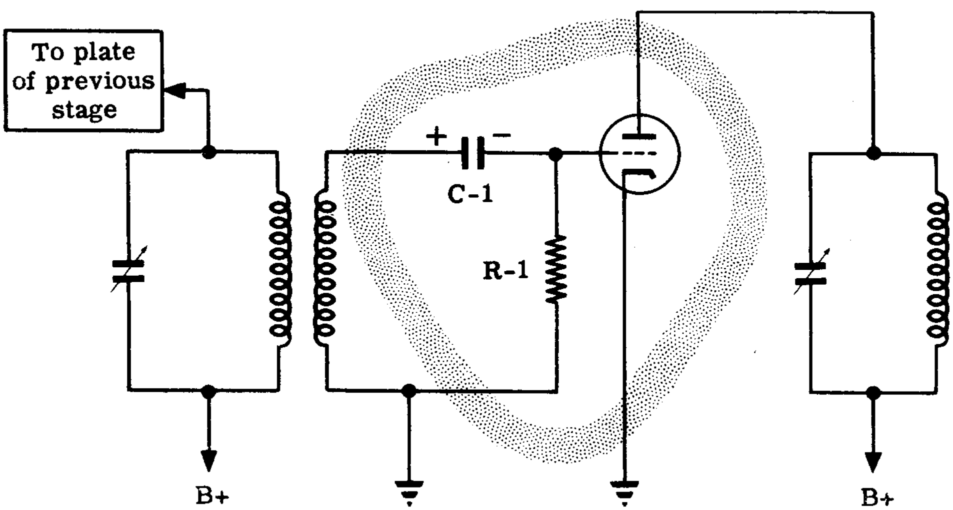
This effect of bias varying with signal strength tends to stabilize the amplitude of that portion of the grid signal above the cut-off level. As a result the amplitude of the current pulses in the plate will not vary as much as their corresponding grid signals vary. Because of the above mentioned effect, self-bias tends to produce amplitude stability of the plate signal and, therefore, is sometimes called "automatic bias." Cathode bias is not common in high-powered transmitter circuits.

Self-bias (continued)

A very common type of self-bias arrangement found in transmitters makes use of the current that flows from the cathode to the grid at the positive peaks of the signal input. This is called "grid-leak bias."

Class C Amplifier with

Grid-leak Bias



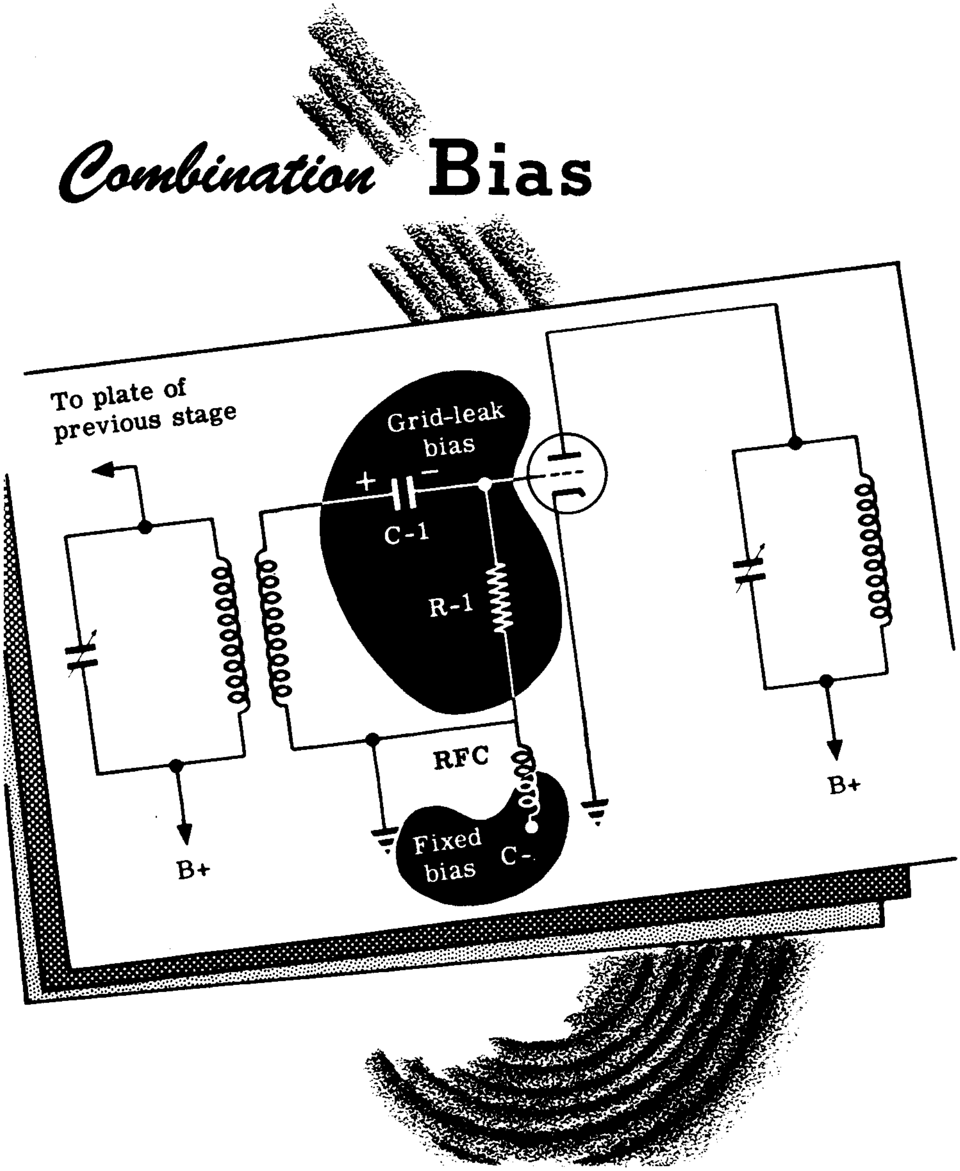
Whenever the signal drives the grid positive, the grid draws current and charges up capacitor C-1 to make the grid negative. Resistor R-1 provides a path for C-1 to discharge slightly between the pulses of grid current flow.

The main advantage of this type of bias is that it develops a voltage whose amplitude depends upon the strength of the input signal. If the input signal increases, the grid will draw more current and the bias will become more negative. After the new value of bias has become established, the peaks of this larger signal will not drive the grid very much more positive than a weaker signal would. Thus, the peaks of the larger signal will cause about the same amount of plate current to flow as the peaks of a smaller signal. In this way, grid-leak bias provides for amplitude stability.

The main disadvantage of grid-leak bias is that it depends entirely upon the presence of a signal in order to develop any bias voltage, and therefore doesn't protect the tube when there is no signal on the grid. If the oscillator of a transmitter stopped oscillating for any reason, the grid-leak arrangement in the amplifiers would not develop any bias since the grid would not, under these conditions, be driven positive. The transmitting tube would draw a very large current with zero bias and would burn out in a short time.

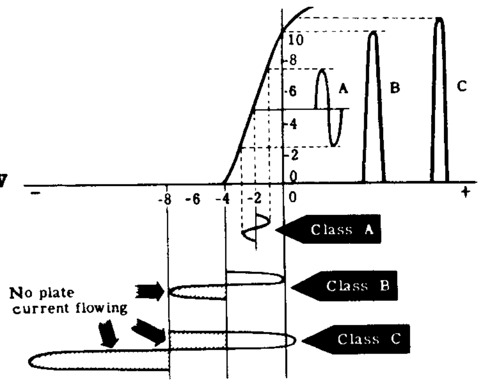
Combination Bias

The most common bias arrangement in transmitters is a combination of fixed bias and grid-leak bias. The fixed bias is sufficient to limit the current to a low value or even to cut-off in the absence of a signal. When a large enough signal is present to drive the grid positive, grid-leak bias is developed which stabilizes the amplitude of the output. Thus combination bias protects the tube and stabilizes the output.

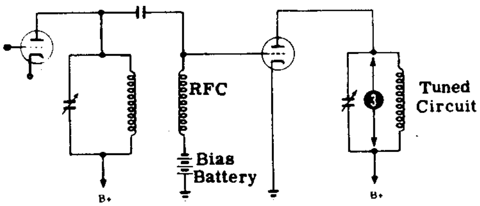


Review of Class C Amplifiers

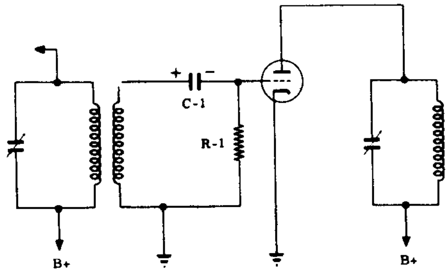
CLASS C OPERATION—The grid of the vacuum tube is biased well below cut-off so that plate current flows only in pulses.



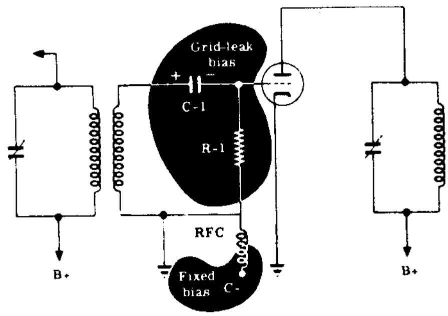
TUNED CLASS C AMPLIFIERS—Used in transmitters because they are very efficient when tuned to the frequency of the input signal.



GRID-LEAK BIAS—Depends on grid current and varies as the strength of input signal changes.



COMBINATION BIAS—A combination of fixed and grid-leak bias most commonly used in transmitters.

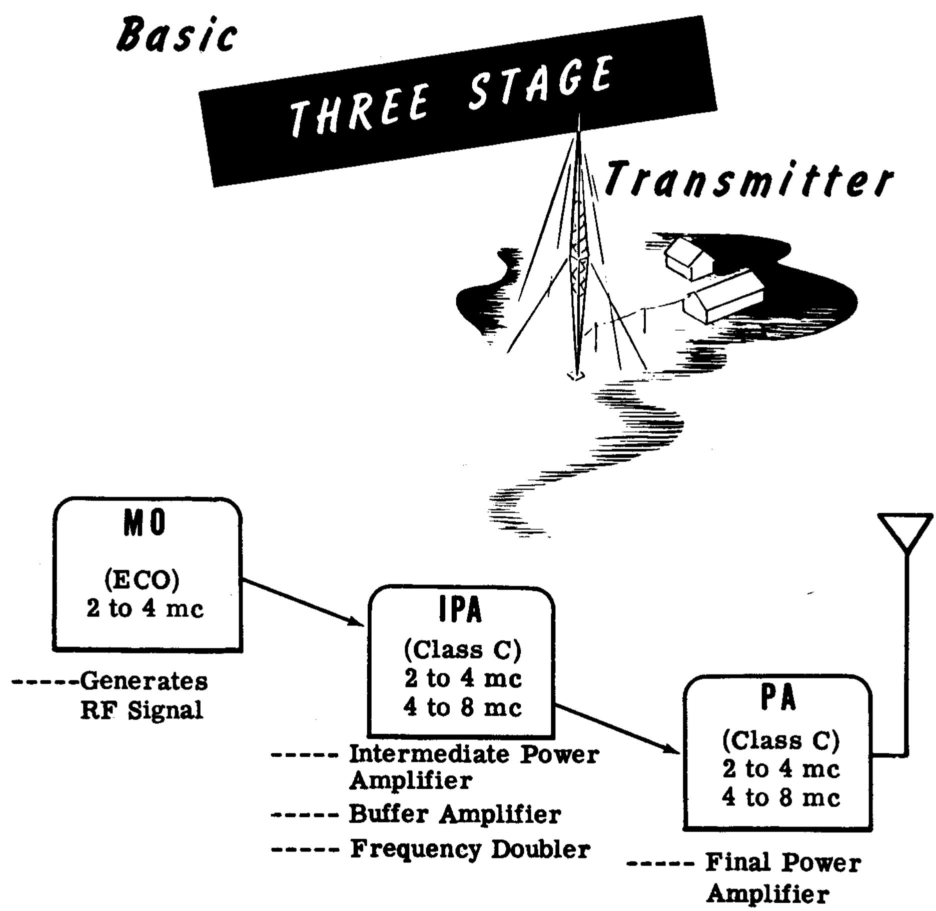


The Three Basic Circuits

A block diagram of a basic three stage transmitter is shown below. All three stages are operated Class C for high efficiency. The ECO master oscillator (MO) generates the RF signal which can be varied, for example, from 2 to 4 megacycles.

The intermediate power amplifier (IPA) amplifies the RF signal and isolates the master oscillator from the final power amplifier to improve frequency stability. The IPA is therefore called a "buffer amplifier." The IPA may also act as a frequency doubler to double the oscillator frequency. The operation of a frequency doubler will be explained later. The output frequency of the IPA can therefore vary from 2 to 4 or 4 to 8 megacycles.

The final power amplifier (PA) generates a large amount of power output and delivers it to the antenna, usually at the same frequency as its grid signal.



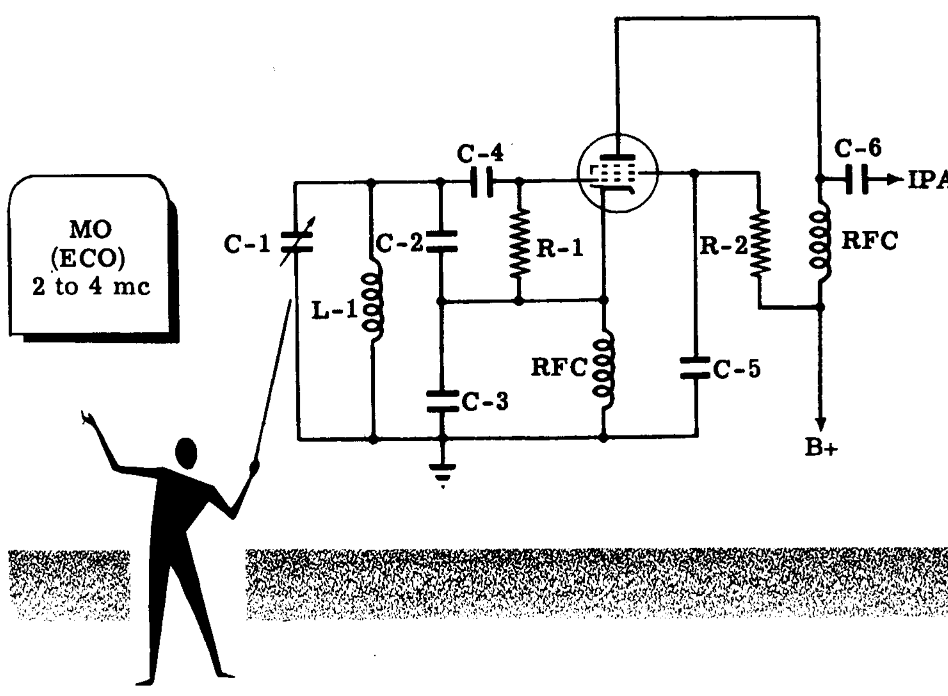
The Oscillator

The purpose of the electron-coupled master oscillator is to generate a stable RF signal which can be varied over a given range.

The ECO operates as follows: The oscillator section of the ECO is composed of the grid and screen circuits and is a Colpitts oscillator. The oscillator frequency is determined by the grid-screen tank circuit consisting of L-1, C-1, C-2 and C-3. The screen, which acts as the plate of the oscillator section, is coupled to the tank circuit through the RF bypass capacitor, C-5. Grid-leak bias is developed across R-1 by the discharge of C-4. The RF choke in the cathode circuit provides a low resistance DC path to ground for the cathode. However, the high reactance of the choke to RF does not allow RF to flow through it. The RF must flow through C-3 (the feedback capacitor) to the cathode. The screen dropping resistor, R-2, drops the screen voltage to the correct value. The RF oscillations generated in the oscillator section of the ECO are electron-coupled to the plate through the flow of plate current. The RF choke in the plate lead acts as a high impedance for the RF signal and serves the same purpose as the plate load resistor in an audio amplifier. The RF coupling capacitor, C-6, passes the signal to the grid of the IPA.

Master Oscillator (ECO)

...Generates RF Signal



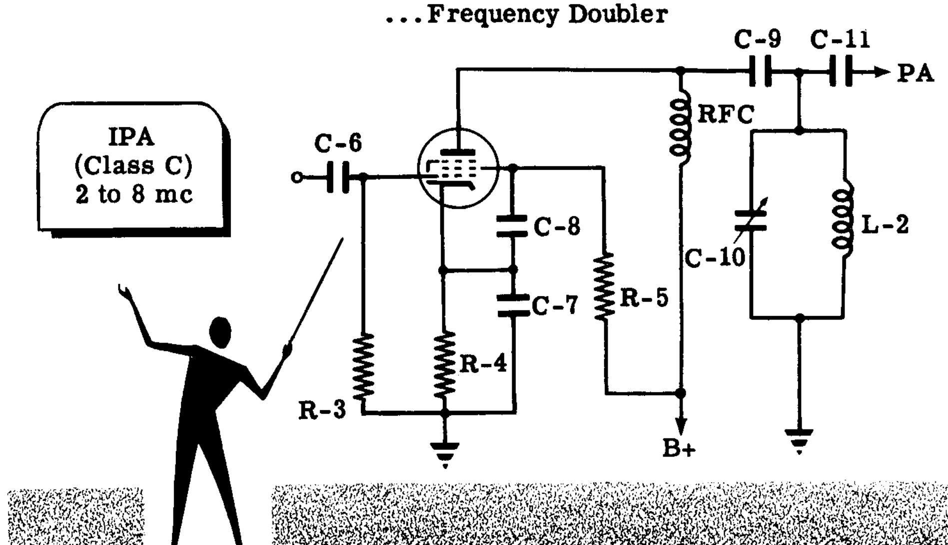
The Intermediate Power Amplifier

The purpose of the intermediate power amplifier is to isolate the oscillator for improved frequency stability and to amplify the RF signal in order to drive the power amplifier efficiently. The IPA also serves to increase the tuning range, if desired, by doubling or tripling the generated frequency in its plate tank circuit.

The operation of the IPA is essentially as follows: A combination of grid-leak and cathode bias is provided by R-3, C-6 and R-4, C-7 respectively. Resistor R-5 drops the screen voltage to the correct value. The screen by-pass capacitor, C-8, is returned directly to the cathode rather than to ground. This provides a more direct path back to the cathode for any RF variations on the screen. The RF coil in the plate lead acts as a high impedance for the RF signal and serves the same purpose as the plate load resistor in an audio amplifier. C-9 is a coupling capacitor which passes the RF to the tank circuit and at the same time blocks the DC. The plate tank circuit,C-10 and L-2,can be tuned to the IPA grid signal, in which case the IPA is said to operate "straight through," or the tank circuit can be tuned to twice the grid signal frequency, and in this case the IPA is called a "doubler." When the IPA doubles, the isolation between the grid and plate circuits is improved and as a result there is less chance of the IPA breaking into oscillation. Doubling has another advantage in that it raises the carrier frequency while permitting the oscillator to operate at a lower frequency where it will be more stable. Capacitor C-11 couples the RF to the grid of the power amplifier.

Intermediate Power Amplifier (IPA)

...Intermediate Power Amplifier
...Buffer Amplifier
...Frequency Doubler



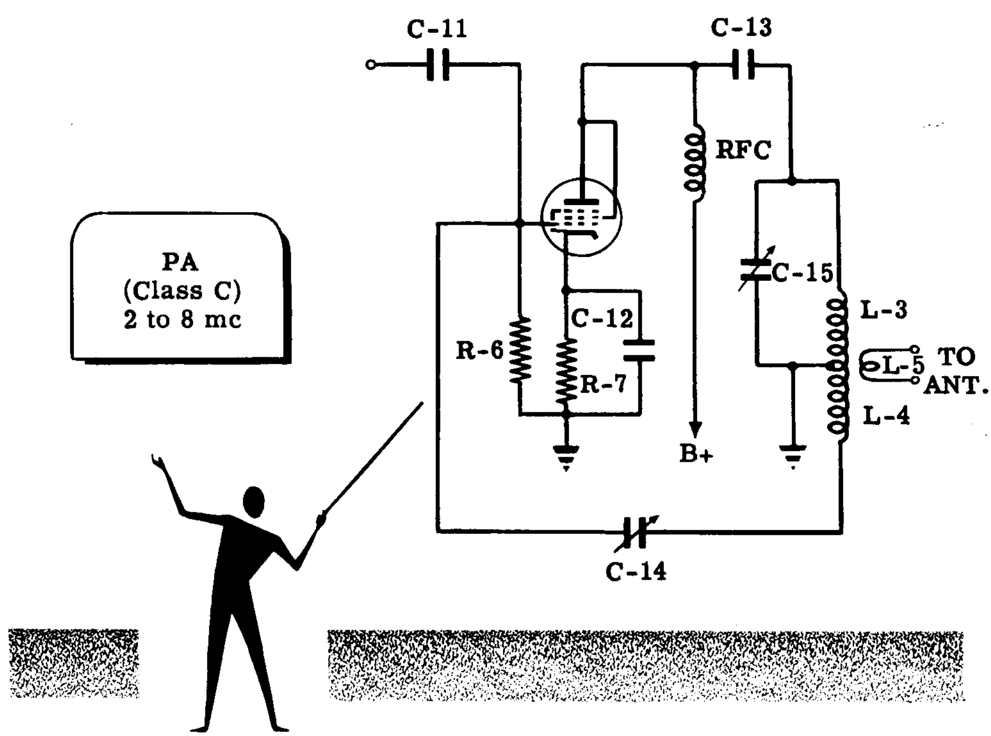
The Power Amplifier

The purpose of the power amplifier is to increase the power of the RF signal so that it can be radiated by the antenna. The PA usually operates straight through for good efficiency. Only in unusual cases does the PA act as a doubler.

The PA operates as follows: Capacitor C-11 couples the RF from the output of the IPA to the grid of the PA. Here as in the IPA there is a combination of grid-leak and cathode bias provided by R-6 and C-11; and R-7 and C-12, respectively. The RF choke while providing a DC path from plate to B+ also acts as a high impedance plate load for the RF signal. C-13 couples the RF to the tuned circuit and blocks the DC.

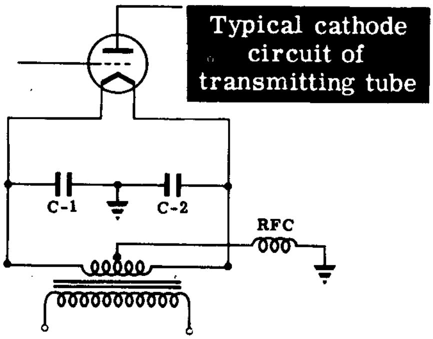
The plate tank circuit C-15, L-3 is tuned to the grid signal frequency and a high RF voltage is developed across it. The high powered RF signal in the plate tank is coupled by coil L-5 to the antenna for radiation. Coil L-4 couples some energy back to the grid through capacitor C-14, called a "neutralizing capacitor." The purpose of the neutralizing circuit will become apparent shortly.

The Final Power Amplifier (PA)

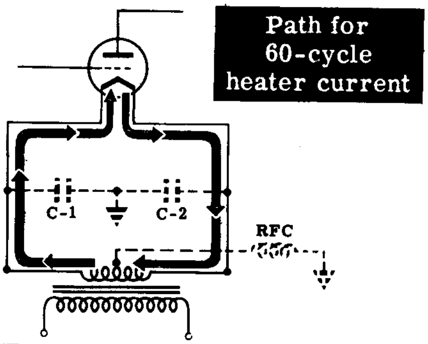


Transmitting Tube Filament Circuit

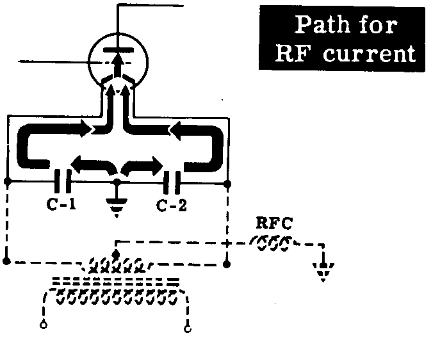
Transmitting tubes used in many transmitters usually have directly heated cathodes which are capable of supplying the large current requirements. Tungsten cathodes are commonly used because of their relatively long life. However, the use of directly heated tubes complicates the wiring of the cathode circuit slightly, as shown.



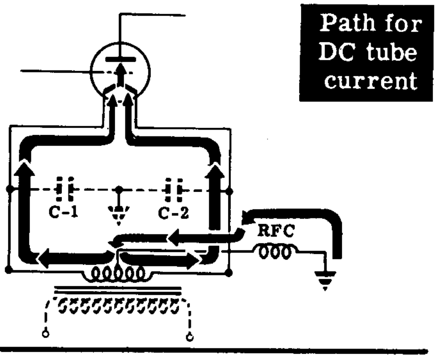
The filament is connected across a secondary winding of a filament transformer. This secondary winding is center-tapped to prevent the 60-cycle filament voltage from appearing in the plate signal of the tube.



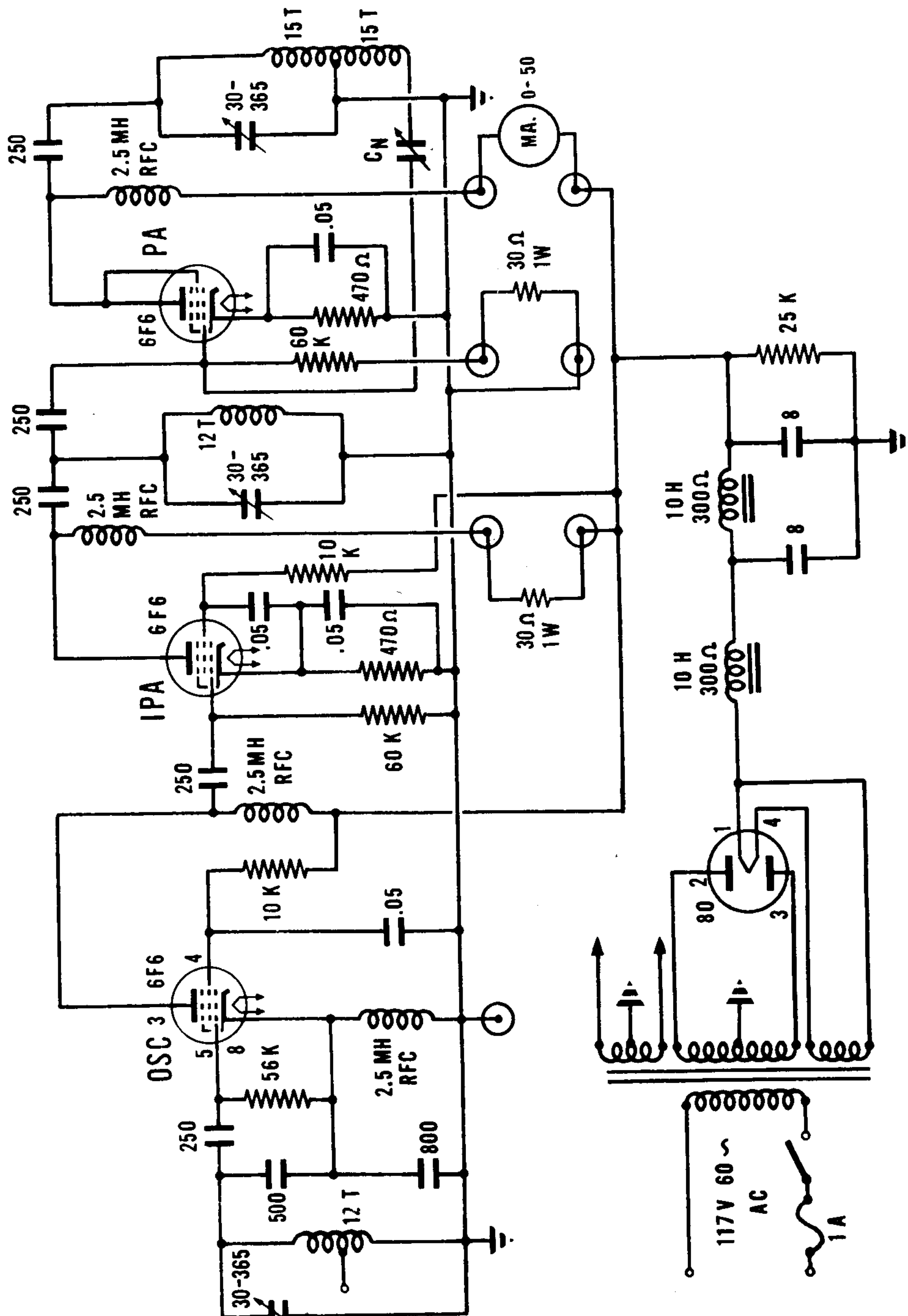
The center tap of the transformer is connected to ground through the RF choke to keep the RF current from flowing in the transformer winding. The RF current gets to the filament through C-1 and C-2.



The DC tube current flows through the RF choke, divides in going through the filament transformer winding and arrives at the filament. Because the DC current divides, both ends of the filament are at the same DC potential. If one side were less positive than the other, more plate current would be drawn from that side. Since the two sides of the filament are at the same potential, equal currents are drawn from each, resulting in longer life for the tube.



Complete Diagram of a Three Stage Transmitter

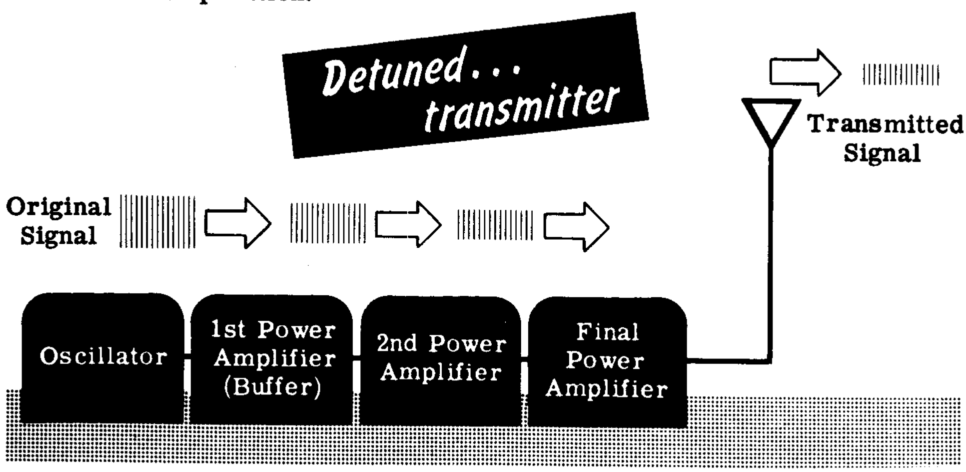


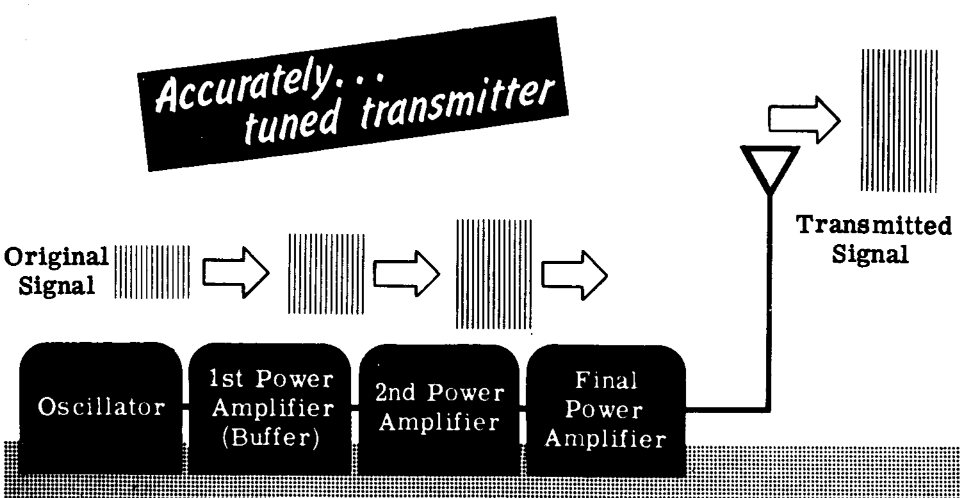
Purpose of Tuning

If a Class C amplifier is to operate efficiently, the plate tank circuit must resonate at the same frequency as the grid signal. If the tuning capacitor is variable, the plate circuit will be either on or off resonance depending upon the setting of the variable capacitor. Adjusting the variable capacitor to make the plate tank circuit resonate to the grid signal is called "tuning."

When a transmitter is detuned, a weak signal will be radiated and receivers tuned to the transmitter frequency may not pick up the signal.

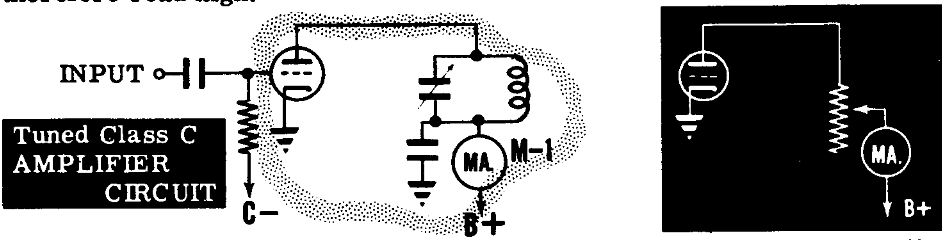
When a transmitter is tuned to a given frequency, all the tank circuits in the transmitter are tuned to resonate at this given frequency. The transmitter than radiates a stable signal at maximum efficiency and maximum power output. Tuning a transmitter is therefore the most important procedure in its operation.





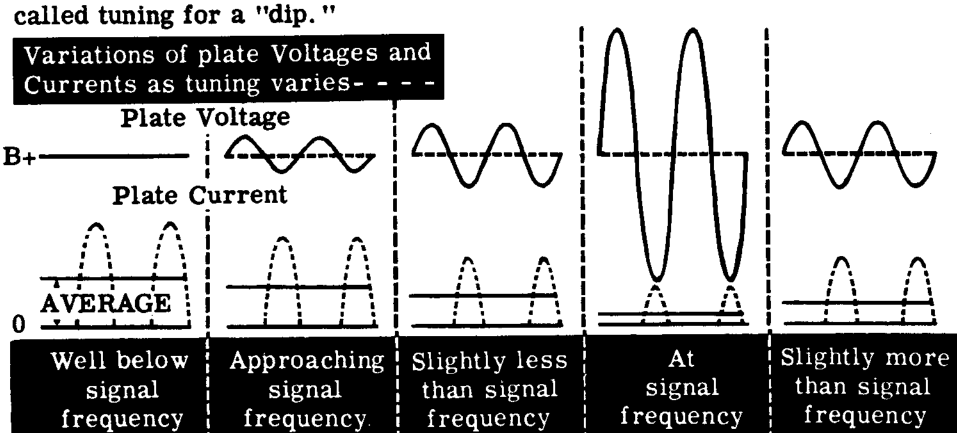
Tuning Methods

A tank circuit in series with the plate of a Class C amplifier can be compared to a rheostat in series with the plate. When the plate circuit is completely detuned, it acts just as if there were no resistance in the plate. As a result,plate voltage will always be equal to B+ and the pulses of plate current (when grid is driven above cut-off) will be large. The DC meter (M-1) which measures the average of the current pulses will therefore read high.



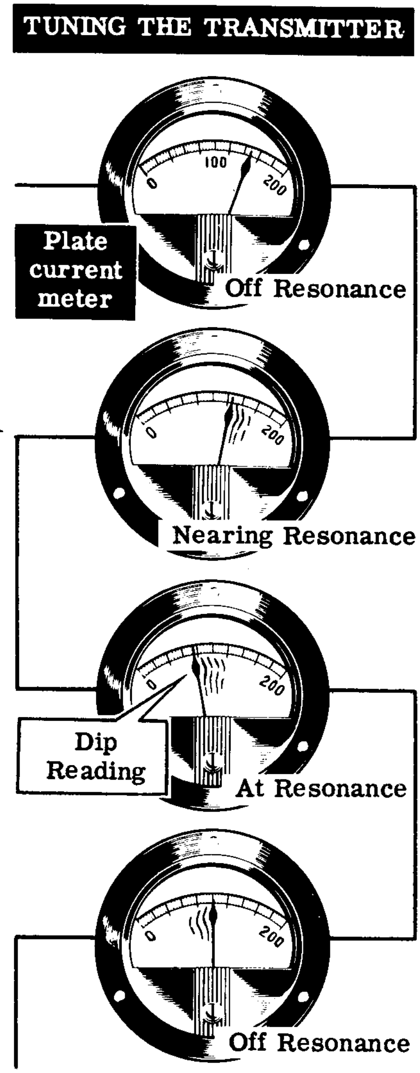
As the tuning is varied so that the resonant frequency of the tank circuit comes closer to the grid signal frequency, the impedance of the plate circuit rises above zero. Now a signal voltage appears across this impedance. Just as in an ordinary amplifier, when the grid signal is positive the plate voltage drops because of the voltage drop across the plate load resistor. Since the plate voltage is now lower than before (lower than B+) during the time the grid is driven above cut-off, the pulses of plate current will be lower in amplitude, and therefore their average value will be less. When the plate tank is tuned to the grid signal, the plate impedance is at its highest point and therefore the voltage drop across this impedance is at its highest point. As a result,the plate voltage (the difference between B+ and the load voltage) is at its lowest point. Since the plate voltage is at its lowest point (during the time the grid is above cut-off),the plate current pulses and therefore the average plate current will be at their lowest point.

A minimum DC plate current reading is therefore an indication that the plate tank is tuned to the grid signal frequency. When a plate tuned circuit is tuned for a minimum reading on the plate current meter, it is called tuning for a "dip."



Tuning Methods (continued)

The first step in tuning a transmitter is to set the oscillator to the desired frequency. This may be done by using a standard frequency meter which is calibrated and set to the desired frequency. The output of the oscillator in the transmitter (called the "master oscillator") is then zero-beat with the frequency meter at which point the master oscillator is set to the desired frequency.



The next stage to be tuned is the stage which follows the master oscillator. This can be done by observing the plate current for a minimum indication when the plate circuit is tuned to the master oscillator frequency. Initially this stage is detuned and the plate current is at a fairly high value.

As the tuning control is rotated, no change in the milliammeter reading will be noticed until the tuned circuit frequency is near the oscillator frequency. When the current starts to "dip," the control should be rotated slowly.

The current will continue to decrease as the tuning control is rotated until a minimum value occurs. This is the dip reading.

Continuing to rotate the control in the same direction will detune the circuit and the current will rise again.

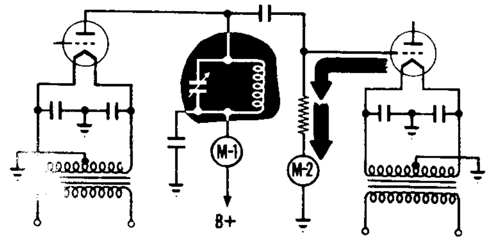
When the current is observed to be rising, the control should be turned in the opposite direction until it is set for minimum current. At this point, the tuned circuit is at the same frequency as the signal frequency and the output of the stage is maximum.

The plate tank circuits of the other stages can be tuned in exactly the same way.

Tuning Methods (continued)

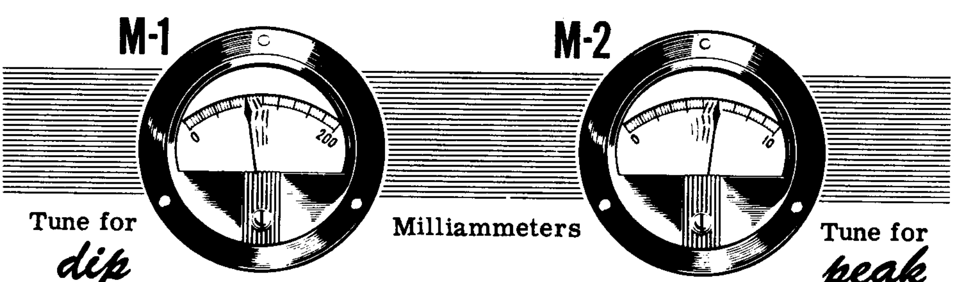
In addition to the plate current meter, there is another meter which indicates correct tuning of the plate circuit. This meter is in the grid circuit of the following stage and is labeled M-2 in the diagram below.

When the plate circuit is tuned to the frequency of the input signal, the voltage developed across the circuit is greatest and the output from that amplifier stage is greatest. The larger the output from that stage, the greater is the signal to the grid of the following stage.



The grid of the following stage will draw current whenever the input signal drives the grid positive. The larger the signal input, the greater will be the flow of current from the cathode to the grid. Since the signal input to the grid will be greatest when the plate circuit of the previous stage is accurately tuned, the grid will draw maximum current and milliammeter M-2 (which measures the average grid current) will indicate a maximum reading. Thus when the plate tank is accurately tuned, the plate current meter indicates a dip and the grid current meter of the following stage simultaneously registers a rise known as a "peak" reading.

Plate Current •• *decreases when* ••• Grid Current •• *increases*



If the grid circuit has fixed bias or combination bias, no grid current will be drawn until the signal is fairly large. This will happen some time after the plate current meter has started to dip. For this reason, the rising grid current indication is sharper than the decreasing plate current indication.

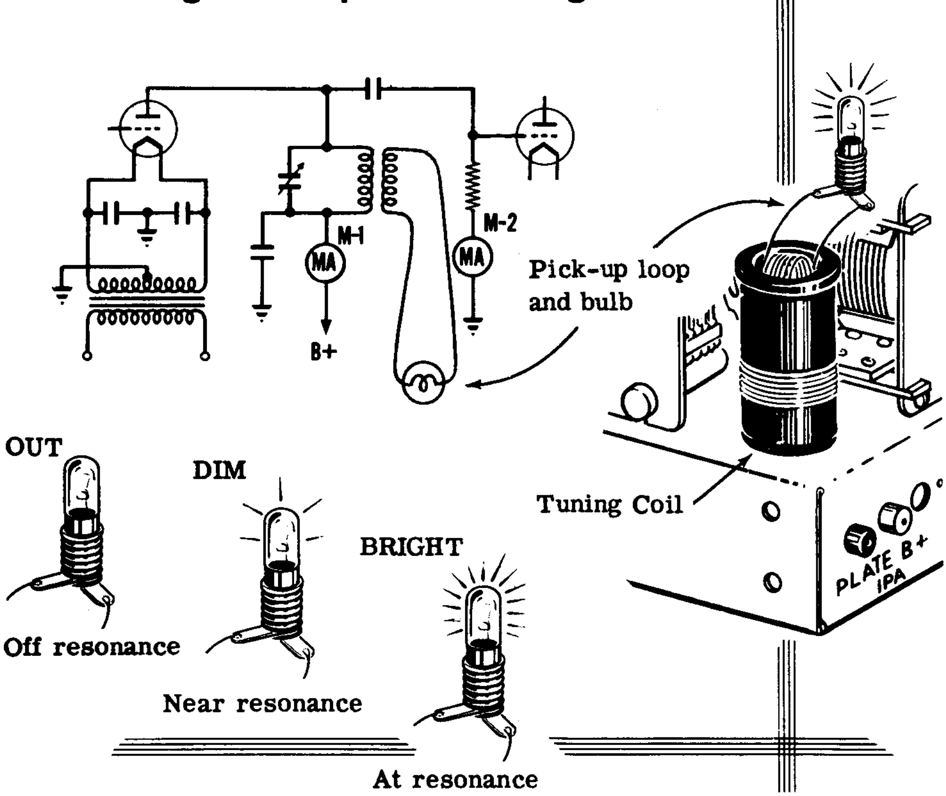
The normal procedure for tuning a stage which has a plate current meter and is followed by a stage which has a grid current meter, is to tune first for a minimum plate current. This indication is broader and less likely to be overlooked as you vary the tuning. After you have observed the plate current starting to decrease, you watch the grid current meter for a rise. The final adjustment will be for a rise in grid current. Since this is a sharper indication, tuning based on this indication will be more accurate.

Tuning Methods (continued)

When a plate tank circuit is tuned to the same frequency as the grid signal, the voltage across the tank is at its maximum. If another coil is transformer coupled to the coil of the tank circuit, the voltage induced in this coil will also be a maximum. This second coil can be connected to a pilot lamp which will glow if the induced voltage is large enough. If the tank circuit is detuned from the grid signal, the induced voltage in the lamp circuit will drop and the lamp will go out. The transformer coupled lamp is therefore a convenient means of tuning a tank circuit as the lamp is brightest when the tank circuit is tuned to the signal frequency.

This method of tuning is not as accurate as the current meter indications because the lamp circuit loads down the tank circuit and detunes it slightly. When using this method for tuning indication, the coupling must be kept as loose as possible to minimize the detuning effects on the plate tank circuit. The lamp method of tuning can be conveniently used on built up experimental transmitters in which the plate coils are accessible. In many transmitters this method cannot be used since the tuning coils are out of sight, and therefore tuning is done exclusively by current meter indications.

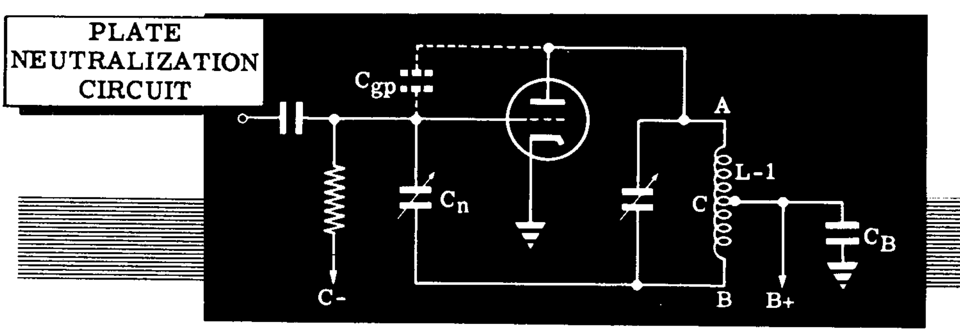
Using a lamp for tuning...



Neutralization

Sometimes a tuned Class C amplifier will act as a tuned-plate—tuned-grid oscillator at the resonant frequency of the tuned circuits. In this case, the interelectrode capacitance between plate and grid is large enough to provide the proper amount of feedback for sustained oscillations. This type of oscillation is most often encountered with triodes because of their large interelectrode capacities. Tetrodes and pentodes rarely have this problem of oscillations because their interelectrode capacities are very low. When triodes are used as RF amplifiers, it is possible to eliminate the above mentioned oscillations by a process called "neutralization." In neutralization a circuit is included in the amplifier which counteracts the feedback effect of the interelectrode grid to plate capacity.

Two circuits are used to neutralize the grid-to-plate capacitance and thereby reduce the possibility of oscillations. Each of these circuits accomplishes neutralization by feeding back a signal from the plate to the grid through a neutralizing capacitor. This signal is opposite in phase and equal in magnitude to the signal fed back through the grid-to-plate capacitance. These circuits are called "plate neutralization" and "grid neutralization" and get their names from the part of the circuit in which the feedback voltage is developed.



This is the circuit for plate neutralization. C_{gp} is the grid-to-plate capacitance represented in the schematic as a capacitor external to the tube. C_n is the neutralizing capacitor—that is, the capacitor through which the neutralizing signal is brought to the grid. The tuning coil, L-1, is center-tapped at point C, which is placed at RF ground by the RF bypass capacitor C_B. Since points A and B are at opposite ends of coil L-1, they are 180 degrees out of phase. Therefore the RF voltages measured at points A and B with respect to ground are 180 degrees out of phase and equal in amplitude (assuming point C is the exact center-tap).

The neutralizing capacitor, C_n, is connected between point B and the grid, while the interelectrode capacitance, C_{gp}, is connected between point A and the grid. Therefore the phase of the voltage fed from the plate to the grid through C_n is opposite to the phase of the voltage fed through the grid-to-plate capacitance and the voltages cancel. C_n is made variable so that the amplitude of the signal fed back through C_n can be made to balance out exactly that fed back through C_{gp}.

Neutralization (continued)

In the plate neutralization circuit just considered, both plates of the tuning capacitor and one plate of the neutralizing capacitor are at a high DC potential with respect to ground. Therefore,the rotor of the tuning capacitor must be insulated from ground. In many common types of tuning capacitors the rotor is common to the capacitor frame, and therefore an insulated mounting must be provided to keep the capacitor frame insulated from the chassis.

If a grounded rotor tuning capacitor must be used, the plate neutralization circuit can be modified so that no DC voltage is present on the rotor plate as illustrated below. In the schematic on the left, the rotor of the tuning capacitor is grounded. The tap on the coil is grounded for RF through the 0.05 mfd RF bypass capacitor. The tap is also connected to B+ through a radio frequency choke. Observe that only part of the coil from A to B is in the tuned circuit. The remainder of the coil from B to C is transformer-coupled to the A-B portion of the coil, and thus picks up RF for the neutralizing circuit.

In the other schematic the tuned circuit is capacity-coupled to the plate so that the DC plate current flows only through the radio frequency choke. One side of the tuning coil and tuning capacitor connect directly to ground, and the tuning and neutralizing circuits are completely isolated from DC.

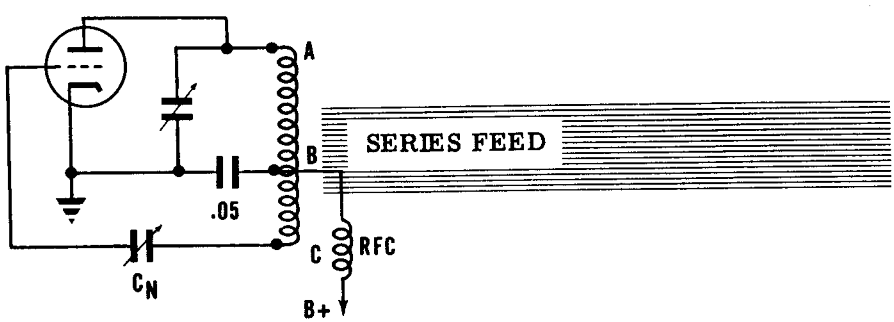
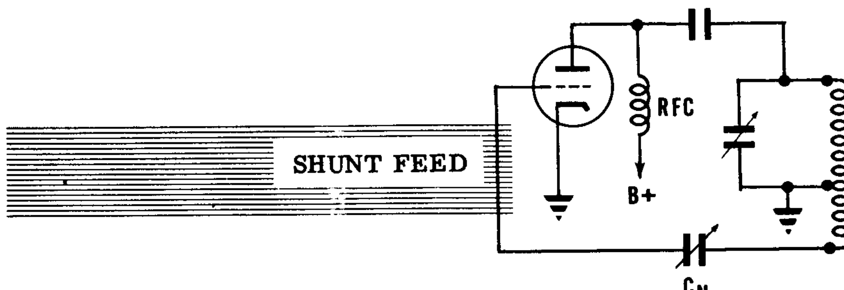
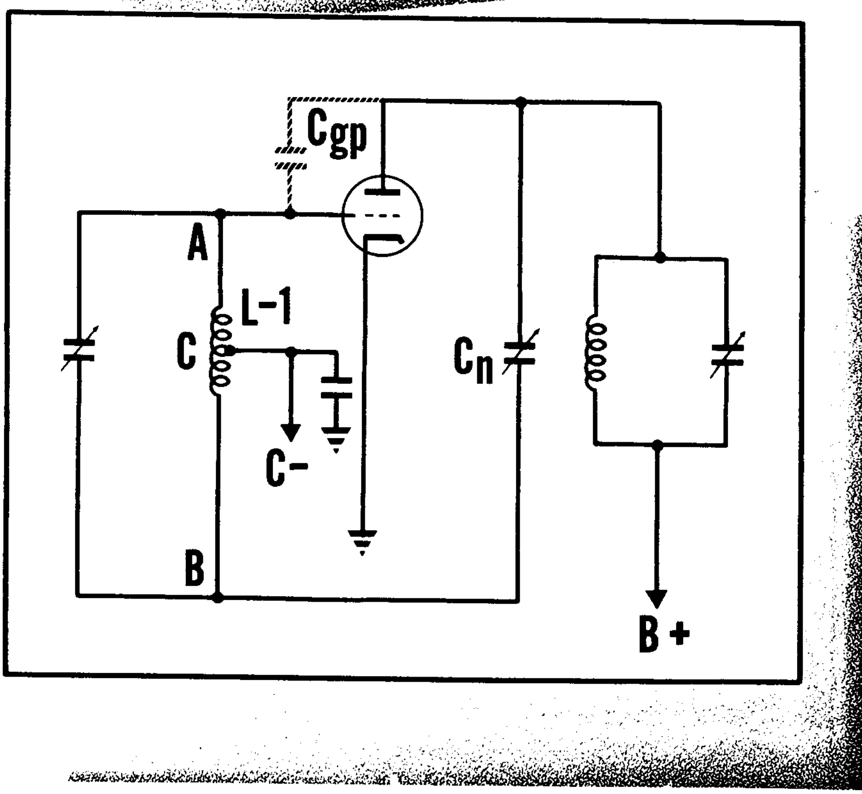


PLATE NEUTRALIZATION



Neutralization (continued)

Grid Neutralization Circuit



Another circuit which provides a means of neutralizing the grid-to-plate capacity is the grid neutralization circuit. In this circuit the neutralizing voltage is applied to end B of the center-tapped coil L-1 while the grid-to-plate feedback voltage is applied to end A of coil L-1. Since these two voltages are equal and of the same polarity, they cause currents to flow in the balanced grid tank circuit whose effects cancel each other. The result is that oscillations due to feedback cannot occur in the grid tank circuit and therefore the entire stage will not be able to oscillate. Therefore if C_n is adjusted to be equal to C_{gp}, the voltages coupled through these capacitors will cancel each other and the tube will not oscillate.

Once a neutralizing capacitor is adjusted for a particular tube, it will require only occasional checks. However, if the tube is changed for a new one, the neutralizing capacitor will need adjustment since the new tube will have a slightly different value of C_{gp}.

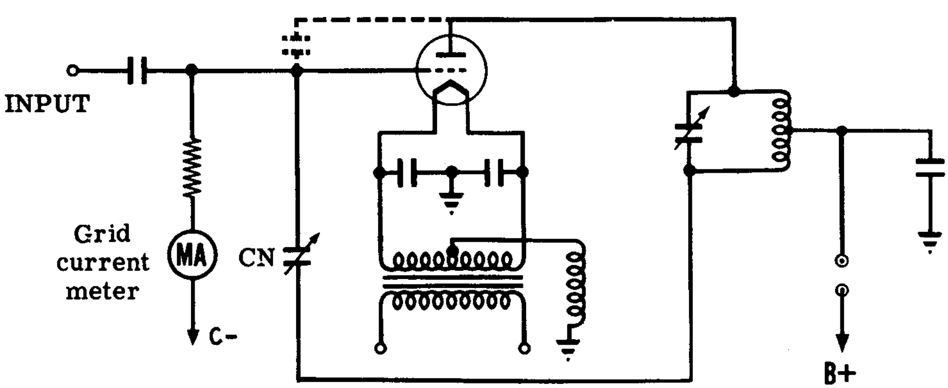
Neutralizing Procedures

The procedures for neutralizing are almost independent of the type of neutralizing circuit used. At the start of neutralization,the plate voltage is removed from the stage to be neutralized so that any signal present in the plate circuit is due to the interelectrode capacity coupling between the grid and plate.

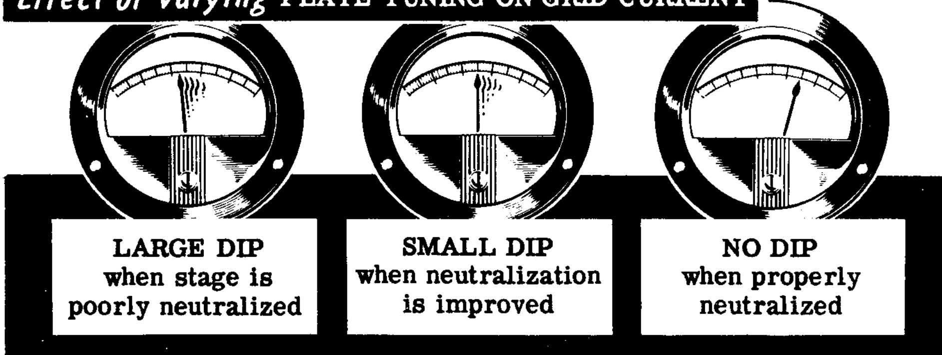
Then the master oscillator and those amplifier stages which precede the unneutralized stage are tuned. This will provide a strong signal to the grid of the unneutralized stage. The next step depends on the indicator used but it always results in the adjustment of the neutralizing capacitor until there is a minimum amount of energy transferred to the plate circuit.

If there is a grid current meter, the grid current can be used to indicate the correct adjustment of the neutralizing capacitor. When this capacitor is not properly adjusted, the grid current will dip as the plate circuit is tuned through resonance. When the circuit is properly neutralized, there will be no dip in the grid current when the plate circuit is tuned to resonance.

NEUTRALIZATION

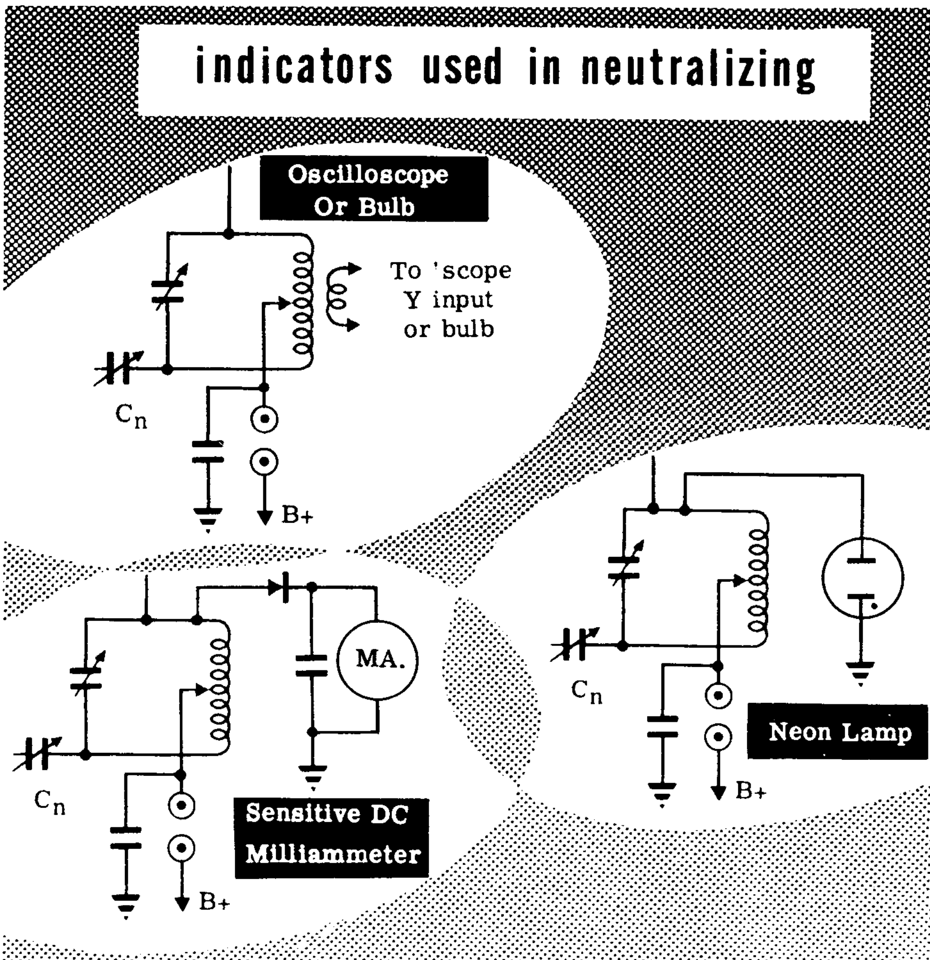


Effect of varying PLATE TUNING ON GRID CURRENT



Neutralizing Procedures (continued)

Other methods used to adjust the neutralizing capacitor make use of devices which can indicate the presence of RF energy in the de-energized plate circuit. Some devices which can be used for this purpose are the oscilloscope, a neon lamp, a small flashlight bulb or a sensitive DC milliammeter. The device chosen affects the accuracy of neutralizing but not the method of adjusting the neutralizing capacitor

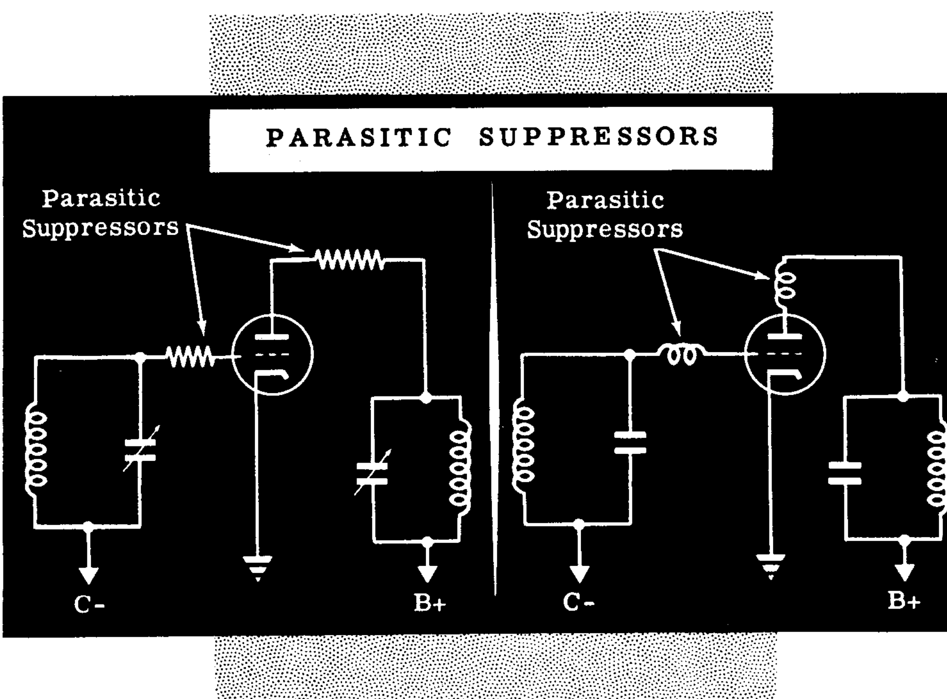


As before, the circuits in the transmitter that precede the unneutralized stage are tuned to provide a strong signal to that stage. The plate supply voltage is disconnected from the plate of the stage and when the plate is tuned to resonance,the indicator will show either a maximum current flowing in the tuned circuit or a maximum voltage across the tuned circuit. The plate circuit remains tuned to resonance and the neutralizing capacitor is adjusted until the voltage across (or the current in) the tuned circuit is a minimum as shown on the indicating device.

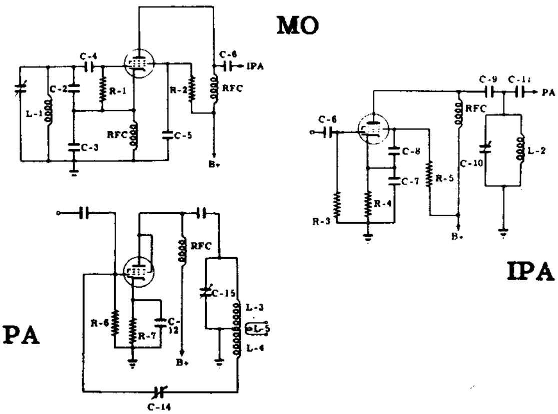
Parasitic Oscillations

In a transmitter which is operating correctly, the tuned Class C amplifiers serve only to amplify the RF generated by the master oscillator. Sometimes the inductance of wires in the circuit combine with stray capacities to form tuned circuits which are resonant to frequencies much higher than the desired transmitted frequency. These stray tuned circuits will often cause the amplifiers to oscillate at very high frequencies. These oscillations, called "parasitic oscillations," are transmitted together with the desired frequency. Parasitic oscillations are undesirable because they cause undue power losses and reduce the efficiency of the transmitter. In addition, they cause interference with other transmitters.

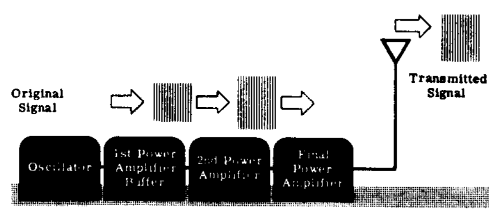
One way to eliminate parasitic oscillations is to improve the wiring by shortening leads and relocating components which may be in the parasitic oscillatory circuit. If this does not help, low value resistors or chokes of a few turns of wire should be connected directly to the grid and plate leads. These added components have very little effect on the amplification of the desired frequency. They do, however, isolate the grid from the stray tuned circuits to the point where the parasitic oscillations are eliminated. Components which are placed in a circuit to eliminate parasitic oscillations are called "parasitic suppressors." Very often parasitic oscillations can be eliminated only by completely rewiring a circuit.



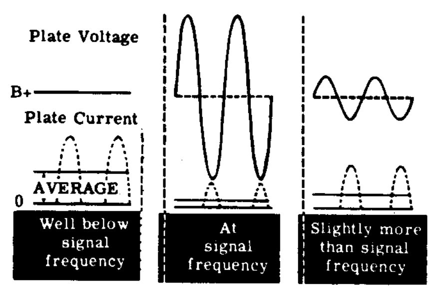
Review of the Three-Stage Transmitter



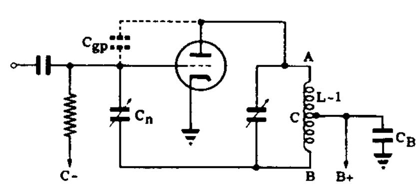
THE THREE STAGES—The master oscillator, intermediate power amplifier and final power amplifier make up the basic three-stage transmitter.



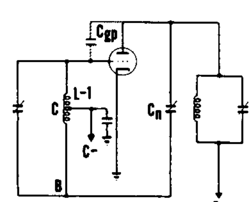
TUNING—For efficient operation, the plate tank circuit of the amplifier must resonate at oscillator frequency. Adjusting the variable capacitor to reach this condition is called "tuning."



TUNING METHODS—The plate circuit of each transmitter stage may be tuned by adjusting the variable capacitor for minimum DC plate current.



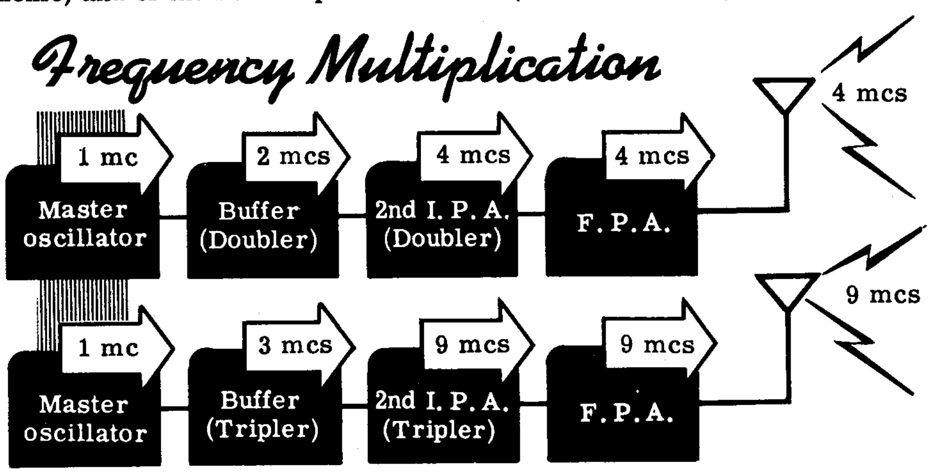
NEUTRALIZATION—Plate or grid neutralization circuits may be used to counteract the feedback effect of the grid to plate capacity in amplifiers using triodes.



Purpose of Frequency Multiplication

Up until now, it has been assumed that the plate-tuned circuit of an amplifier stage in a transmitter can be tuned only to the grid signal frequency, whatever that may be. For example, if the grid signal frequency is 1 mc, the plate circuit is also tuned to 1 mc.

If the grid signal is a pure sine wave, the plate circuit can be tuned only to the frequency of this sine wave (called the fundamental) and none other. It so happens that generated frequencies are very seldom pure; they usually contain harmonics of the fundamental frequency. This is especially true in transmitters where Class C amplifiers introduce many harmonics into the generated signal. For example, if the master oscillator (operating Class C) generates a 1 mc sine wave, that sine wave is rich in harmonics —it contains not only the fundamental (1 mc) but also the second harmonic (2 mc), the third harmonic (3 mc), etc. Therefore if a signal rich in harmonics is placed on the grid of a tuned amplifier, the plate can be tuned to any one of the harmonics that is present in the original grid signal. The process by which the input frequency to the grid is converted to a higher one in the plate by tuning to a harmonic of the fundamental is called "frequency multiplication." For example, if the output of the oscillator is 1000 kc, the output of the buffer amplifier might be 2000 kc (second harmonic) and of the next amplifier 4000 kc (fourth harmonic).



The reason that frequency multiplier circuits are used in transmitters is that an oscillator operates more satisfactorily at low frequencies. Therefore, if a high frequency is required, the oscillator operates at a low frequency and the multiplier circuits step up the oscillator frequency to the desired one.

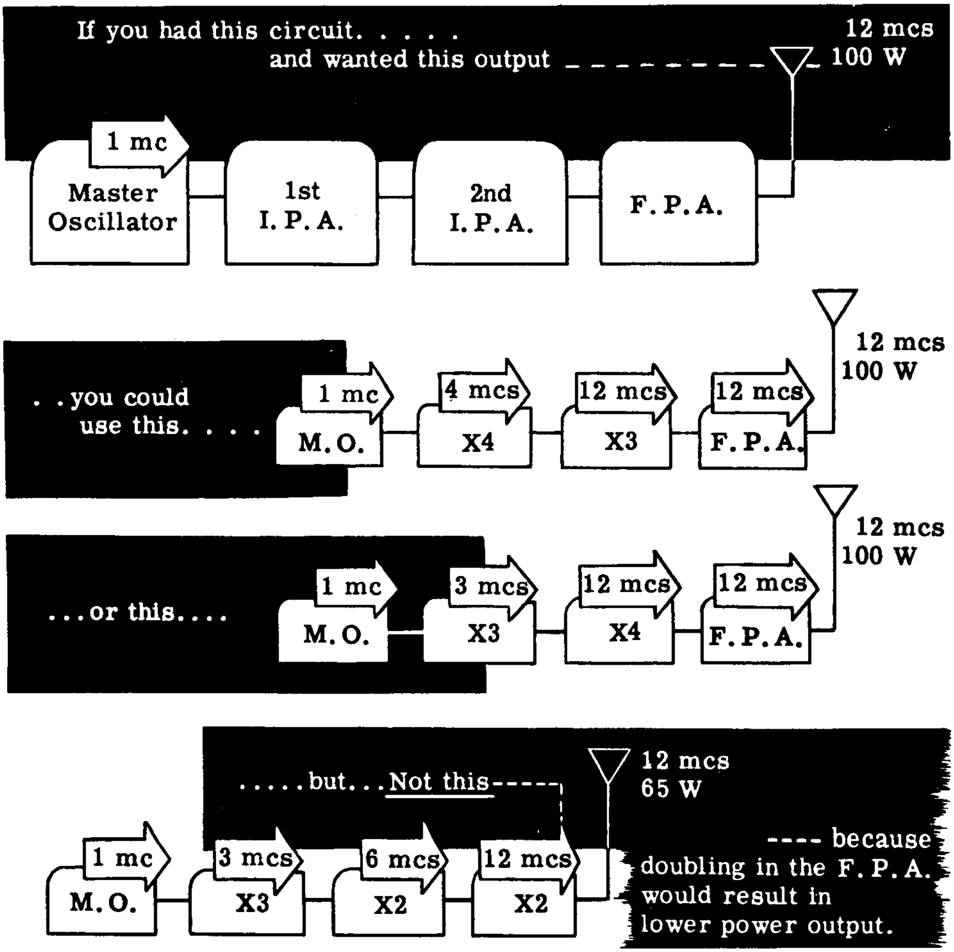
For very high frequencies, crystal oscillators are used to provide for good frequency stability. However, it is impractical to manufacture a crystal to vibrate at such high frequencies. Therefore, the crystal oscillator is operated at a much lower frequency and the desired output frequency is obtained by frequency multiplication.

The Final Power Amplifier

The maximum power which can be radiated from a transmitting antenna depends on the power output of the final power amplifier (FPA). If the final power amplifier has a power output of 100 watts, the antenna can radiate no more than 100 watts.

A frequency multiplier has a lower output than the same stage used as a straight frequency amplifier. If the final power amplifier which is capable of an output of 100 watts as a straight frequency amplifier were used as a doubler, its power output would be about 65 watts—as a tripler, 40 watts; as a quadrupler, 30 watts and so forth. As the multiplication of the frequency increases, the power output decreases.

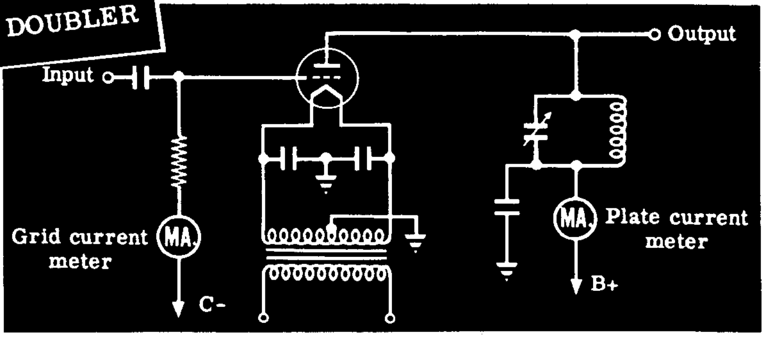
Because the power output of a transmitter depends to a great extent upon the output of the final power amplifier, the FPA is not operated as a frequency multiplier. Thus all the multiplication of the oscillator frequency must take place in the intermediate power amplifiers.



Frequency Doubling

Let's examine a typical doubler circuit—that is, one in which the output frequency is twice the input frequency—and see how it works.

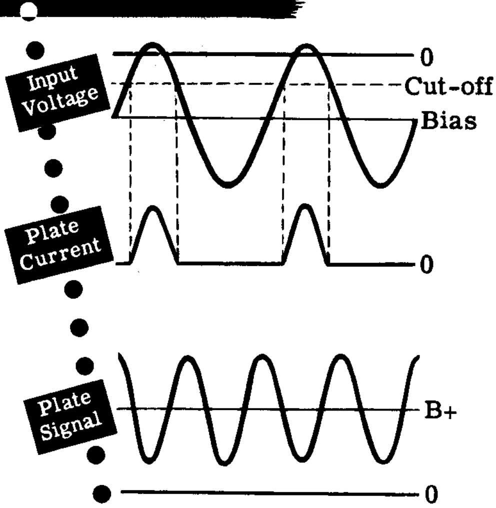
FREQUENCY DOUBLER



The circuit of a frequency doubler appears to be the same as that of an amplifier which operates at the input frequency. The only differences are that the plate circuit will be tuned to twice the input frequency and no neutralization is required since the input and output operate at different frequencies. This reduces the possibility of self-excited oscillations.

WAVE FORMS IN A TYPICAL DOUBLER CIRCUIT

The doubler circuit is operated Class C with the plate tank resonant to twice the grid signal frequency. The pulses of current at the same frequency as the input signal flow from the cathode to the plate, energizing the plate tank circuit and causing it to oscillate at twice the grid signal frequency. Between pulses of plate current, the tank circuit continues to oscillate.

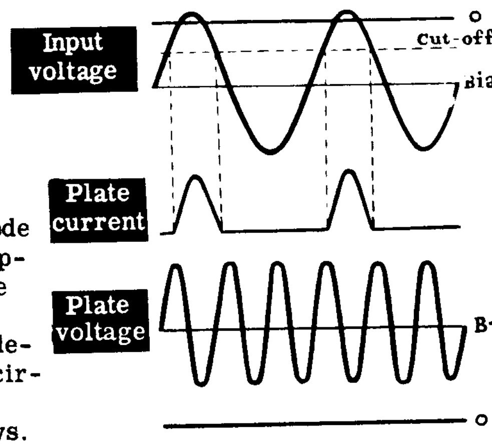


The reason the tuned circuit continues to oscillate is that the pulses of current always arrive at the same time during alternate cycles of the doubled frequency, thus energizing the tank circuit at the right time. When accurately tuned, the voltage across the doubler-tuned circuit is at a maximum and the voltage at the plate is at a minimum when current flows. Therefore, the indications for tuning to twice the frequency are the same as for tuning to the input frequency. The plate current meter will indicate a dip as the plate circuit is tuned to twice the input frequency. At the same time, the grid current meter will indicate a rise.

Frequency Tripling

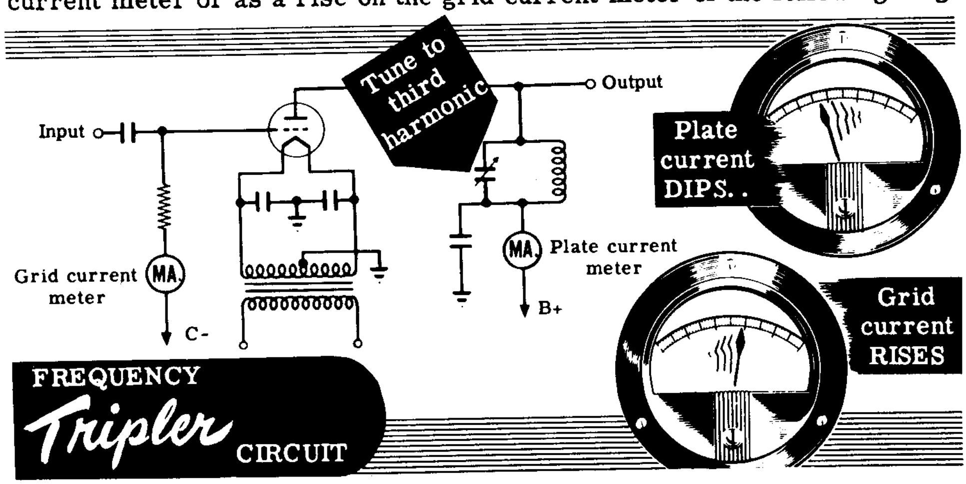
A frequency-tripling circuit, or more briefly a tripler, has an output frequency that is three times the input frequency. The appearance of the circuit is the same as that of a doubler or of an ordinary amplifier. Frequency tripling is accomplished by tuning the plate circuit of the tripler to the third harmonic of its input frequency.

Wave forms in a typical tripler circuit



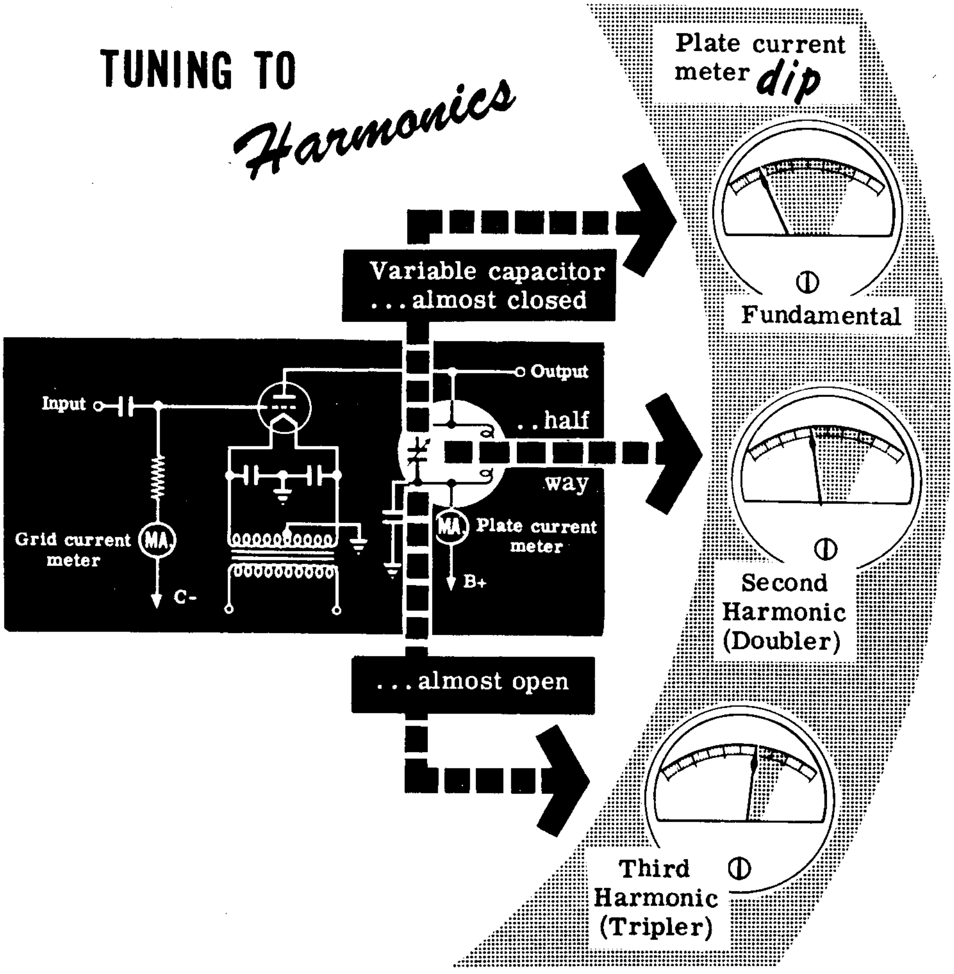
Pulses of current flow from cathode to plate—one pulse per cycle of applied signal. These pulses arrive at the tuned circuit during every third cycle of output voltage and deliver enough energy to the tuned circuit to sustain oscillations during those cycles when no current flows.

The same tuning indications hold for frequency doubling and tripling as for fundamental frequency amplification. When the circuit is tuned accurately to the third harmonic of the applied frequency, the voltage across the tuned circuit will be larger than if the circuit were poorly tuned. This will cause the voltage fed to the next stage to be larger, which results in more grid current. The larger voltage across the accurately tuned circuit causes the plate voltage to be at a low value when the tube conducts. This results in decreased plate current. Therefore the tuning of the plate circuit—whether it is tuned to the input frequency or to the second or third harmonic of the input frequency—can be indicated as a dip on the plate current meter or as a rise on the grid current meter of the following stage.



Tuning Indications

At this point the question arises "How can you tell to what frequency the plate tank circuit is tuned when the plate current meter indicates a dip reading?" The only way to tell is to use a frequency indicator such as a wavemeter, or a calibrated dial if the tuned circuit has been previously tuned. If you are working with an uncalibrated transmitter, the thing to do is to tune a stage, starting with the tuning capacitor fully meshed. The first dip indicates that the tank circuit is tuned to the fundamental. This can be checked with the wavemeter. As you continue decreasing the capacity, you come to a second dip (not as pronounced as the first one) which is the second harmonic. Again you can check the frequency with a wavemeter. Continue decreasing capacity and you may come to a third dip (provided the circuit constants are correct) which is not as pronounced as either the first or second dip. This dip indicates that the plate-tuned circuit is tuned to the third harmonic. Here too you can check the resonant frequency by using a wavemeter.

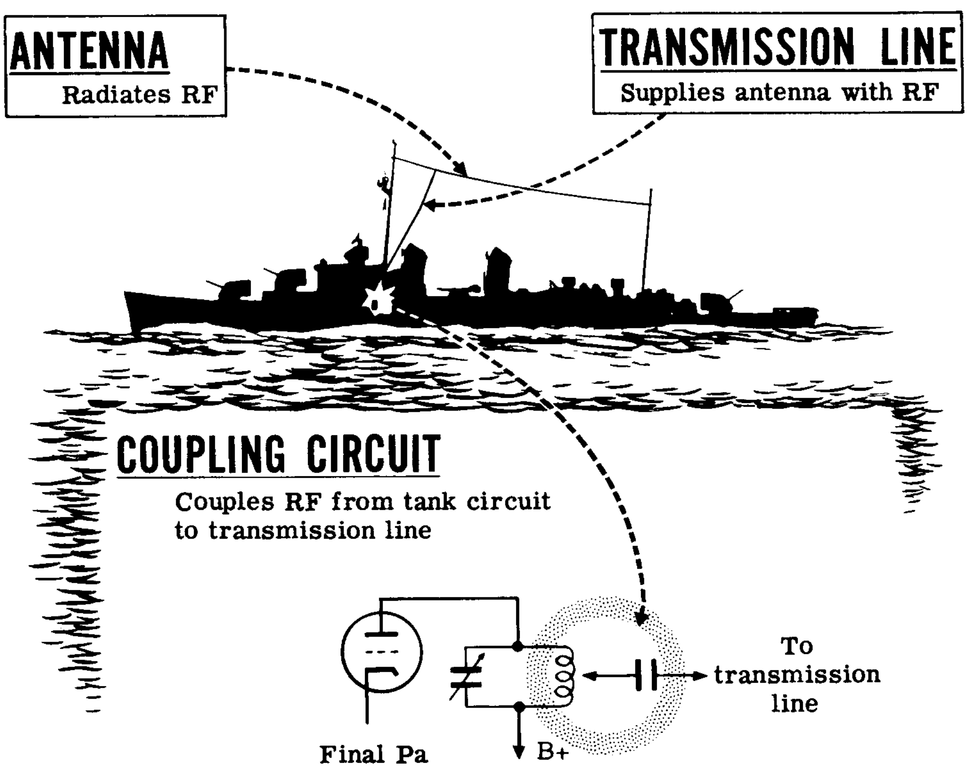


The Overall Transmitter

The end result of transmitter operation is the radiation of RF energy for great distances through space so that this energy can be detected by remote receiving antennas.

You have studied oscillator and Class C amplifier circuits whose function it is to generate and amplify RF energy. Other circuits are needed, in addition to the ones just mentioned, to transfer the amplified RF from the plate circuit of the final power amplifier to surrounding space. These additional circuits are transmission lines, antennas and coupling circuits. Just as a speaker in audio work transfers audio energy from electronic circuits into the air, so the antenna is the means of transferring RF energy from the electronic circuits into space. The transmission line is the conveyor or link between the transmitter and the antenna; and the coupling circuit connects the final power amplifier tank circuit to the transmission line.

HOW RF IS DELIVERED FROM TRANSMITTER TO SPACE

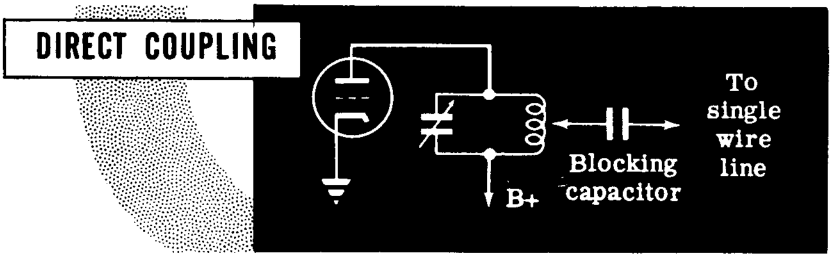


In this topic you will learn about transmission lines and coupling circuits —what they are like and how they do their job. Antennas will be discussed separately in the next topic.

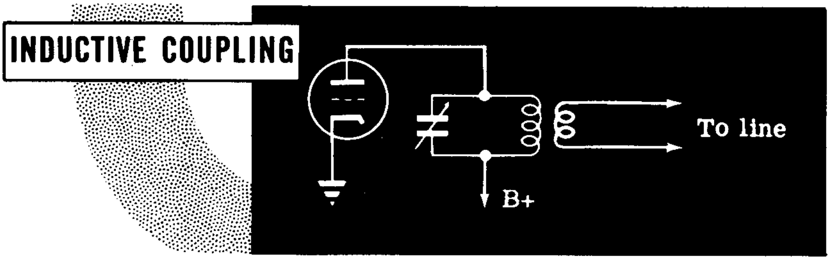
Coupling Circuits

A coupling circuit is used to transfer energy from the output of the transmitter to the transmission line which feeds the antenna. In doing its job of transferring energy, the coupling circuit isolates the antenna system from the high DC potentials present in the plate of the final power amplifier. The coupling circuit also determines the amount of coupling that is required for maximum power transfer from the plate tank circuit of the power amplifier to the line input.

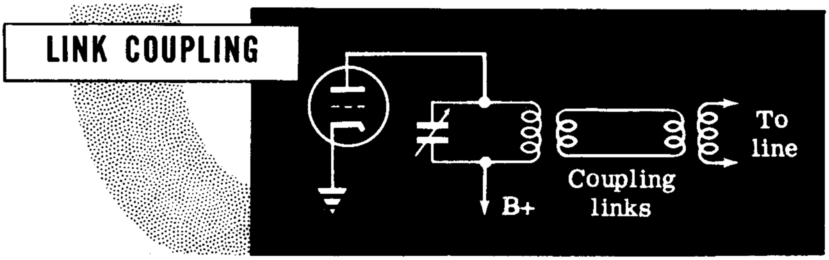
The simplest coupling circuit is direct coupling from the tank circuit to a single wire transmission line. A small capacitor is always placed at the input to the line to block the DC from the antenna. The coupling is adjusted by varying the tap on the plate tank coil.



Another simple coupling circuit is inductive coupling to the plate tank circuit with an untuned coil of a few turns. This type of coupling is used principally with flat lines (to be discussed later).



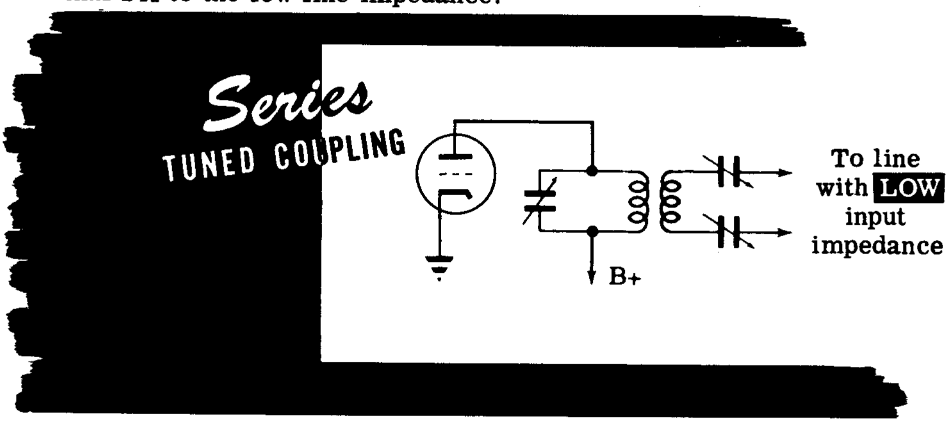
A system of untuned coupling called "Link Coupling" is used when the antenna coupling is remote from the plate tank circuit. The link consists of two pick-up coils of about two or three turns connected by wires and coupled to the plate tank and the antenna coupling circuit, respectively.



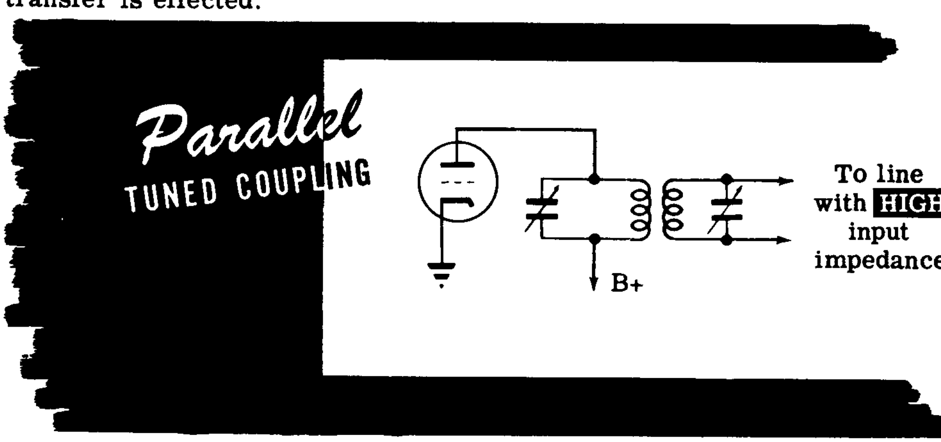
Tuned Coupling Circuits

A more commonly used type of coupling is tuned coupling in which the coupling circuit is tuned to the operating frequency. The advantage of tuned coupling is that it insures greater selectivity and minimizes the possibility of undesired frequencies being radiated. In addition, since the tuned coupler is almost always variable tuned it can compensate for changes in the impedance of the transmission line and thus insure maximum power transfer from the final power amplifier to the line at all times.

When the transmission line has a low input impedance, a series-tuned coupling circuit is used. Series tuning is called "current feed," and can match the final PA to the low line impedance.



When a transmission line has a high input impedance, parallel tuning, called "voltage feed," is used. Here the high impedance of the parallel tank circuit matches the high input impedance of the line, and maximum power transfer is effected.

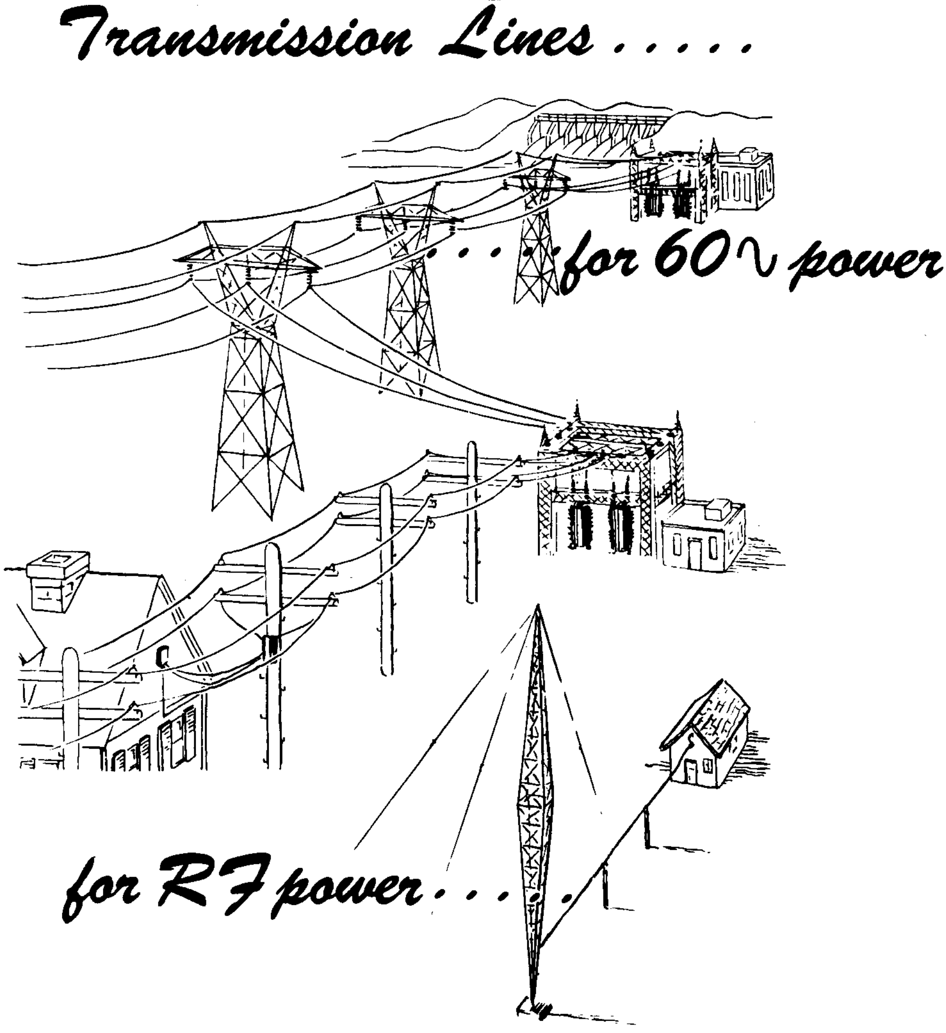


If the input impedance of the line is other than pure resistive, either of the above two tuned coupler circuits can be adjusted so that the reactance of the line is cancelled by the reactance of the tank circuit. This results in a pure resistive load, which is the requirement for maximum power transfer.

Transmission Lines

A transmission line provides a means of transferring electrical energy from one point to another. You know of at least one application of a transmission line in carrying 60 cycle power from the generator to the point of application.

In transmitters, transmission lines are similarly used to convey RF power from one point to another. For example, a transmission line is always used to carry RF power from the transmitter to the antenna when the antenna is some distance from the transmitter.



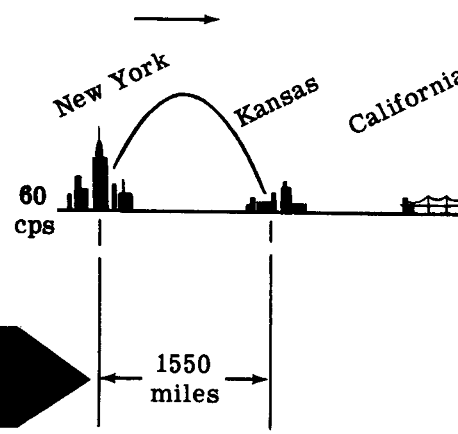
Transmission lines play an important part in the operation of a transmitter, not only to convey RF energy but also as circuit components.

Frequency and Wavelength

Before you learn the theory of transmission lines, you should understand something about the properties of a radiated wave—its velocity of propagation (how fast it travels), its frequency and its wavelength.

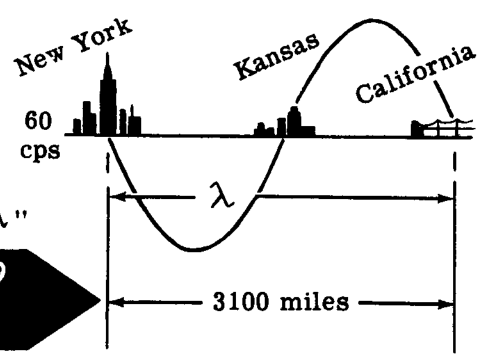
For purposes of simplicity consider an AC generator sending 60 cps energy along a transmission line from New York to California by way of Kansas. Assume that the rate of travel of the AC power is the same as the velocity of electromagnetic radiation in free space which is constant at 186,000 miles per second or 300,000,000 meters per second regardless of the frequency.

If the generator starts its generating action at the zero voltage point on the sine wave, after a half cycle has elapsed (1/120 of a second in time), the zero voltage point will have traveled a distance which can be determined by multiplying the velocity of the wave by the time duration for a half cycle. This distance equals about 1550 miles ($186,000 \times \frac{1}{120}$) which is approximately the distance from New York to Kansas.



DISTANCE TRAVELLED IN 1/120 OF A SECOND

When another half cycle or a total of a full cycle has elapsed (1/60 of a second), the zero voltage point will have traveled a distance of 3100 miles ($186,000 \times \frac{1}{60}$) which is the approximate distance from New York to California. This distance of 3100 miles is the wavelength of the 60 cycle AC, which is the distance that the wave travels during the time interval for one cycle. The symbol for wavelength is the greek letter " λ "



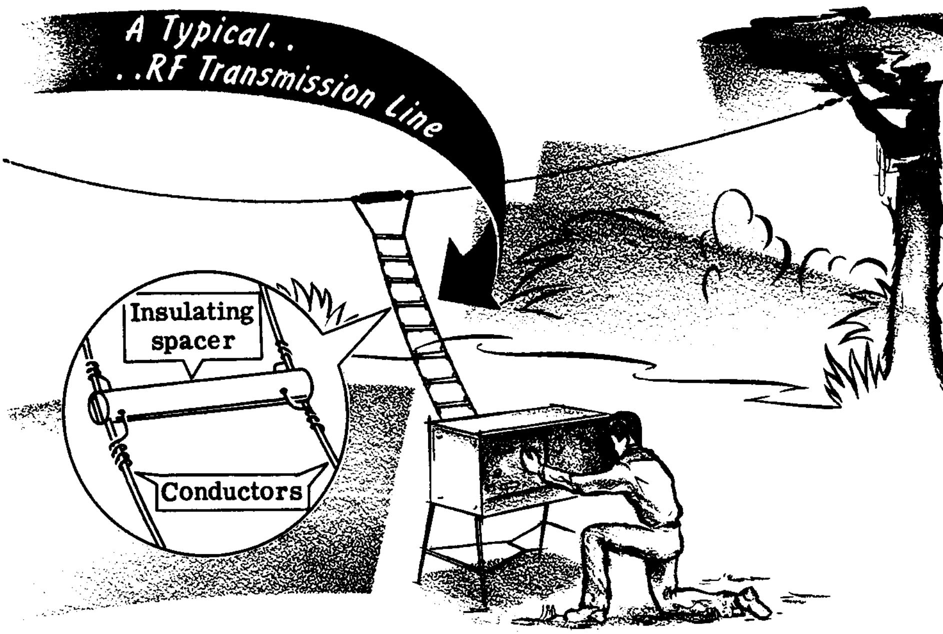
DISTANCE TRAVELLED IN 1/60 OF A SECOND

Similarly the wavelength of any frequency radiation can be determined by multiplying the constant velocity by the time for one cycle. Since the time for one cycle is equal to 1 divided by the frequency ($\frac{1}{f}$), the wavelength equals constant velocity over frequency ($\lambda = \frac{V}{f}$) or the velocity equals the frequency times the wavelength ($V = f\lambda$). Since V is constant, the higher the frequency, the lower the wavelength and vice versa.

From now on, transmission lines and antenna lengths will be defined in terms of wavelengths of the RF energy they are to radiate. For example, if an antenna is a half of a wavelength long it means that only one-half wavelength of the RF will be present on the antenna.

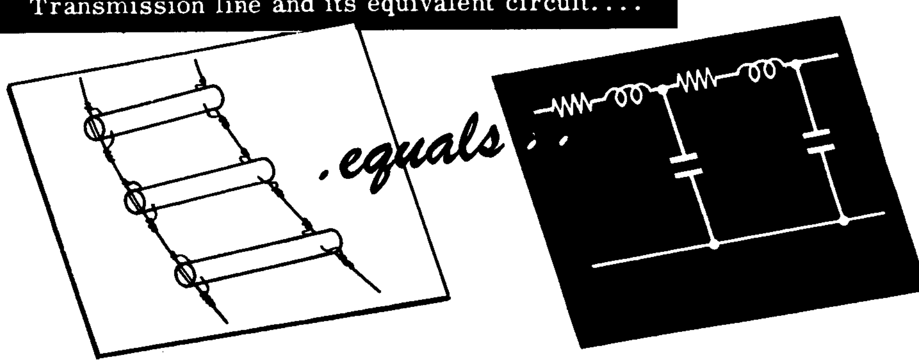
Equivalent Circuit of a Transmission Line

A typical transmission line used to convey RF energy from one point to another may consist of two parallel lengths of wire which are spaced apart at equal distances by insulating spacers as illustrated.



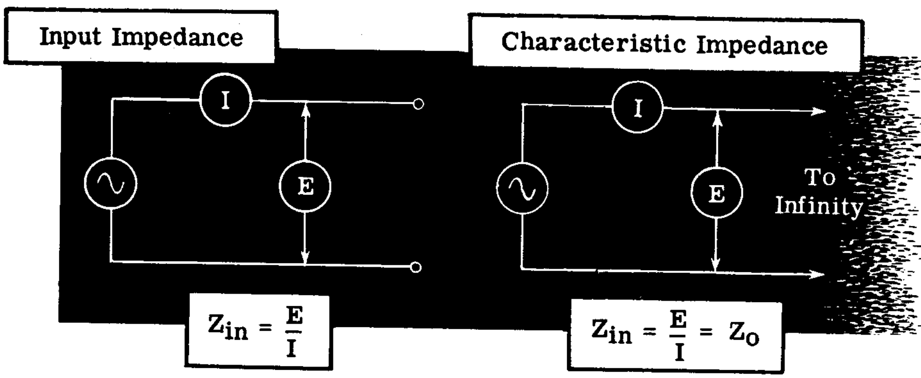
An RF transmission line will have a certain amount of resistance, capacitance and inductance along its length. The resistance is simply the resistance of the wire. The inductance is generated by the magnetic field (caused by current flow) expanding and collapsing along the entire length of the line, and the capacitance exists because the two conductors of the line act as plates of a capacitor separated by a dielectric (in the above case air). Since the line can be broken up into any number of small segments having equal amounts of inductance, capacitance and resistance, the entire line can be represented as consisting of a series of L, C, R networks connected as shown.

Transmission line and its equivalent circuit....

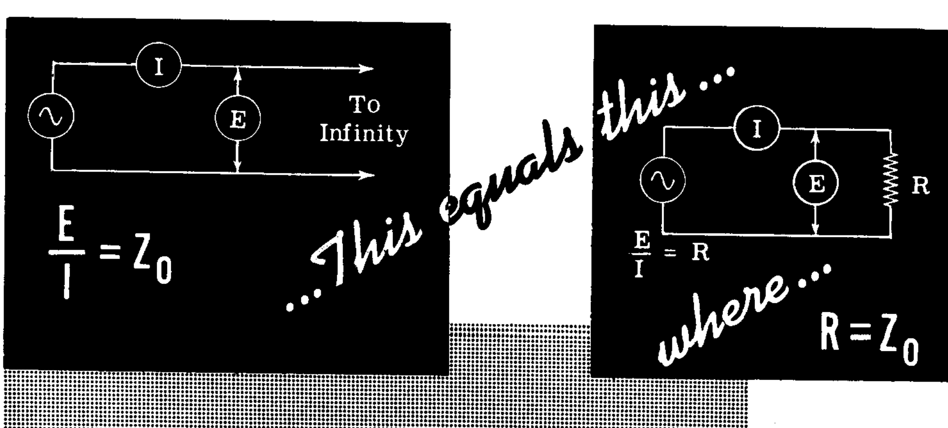


Characteristic Impedance

Suppose an RF generator is connected across a transmission line. The RF generator impresses a voltage across the line, which forces a current to flow. The amplitude of this current will be determined by the resistance, inductance and capacitance of the line, which together make up the line's impedance. If the magnitude of the input current is measured and divided into the input voltage, the input impedance (Z_{in}) of the line is obtained. If the line is infinitely long, this input impedance defines the characteristic impedance of the line. The symbol for characteristic impedance is Z_o.



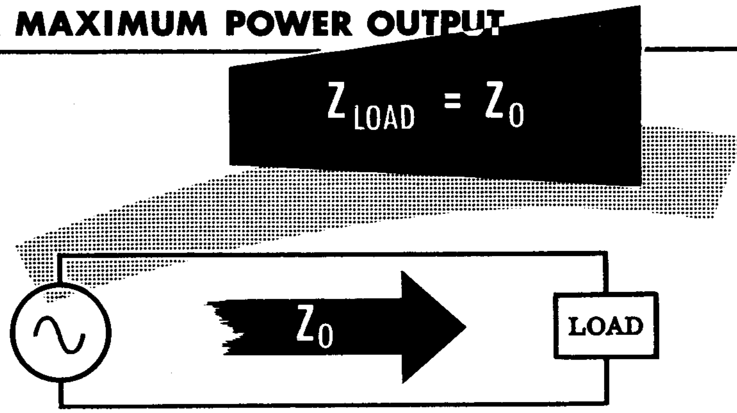
When a pure resistance loads down a generator, all of the power generated is dissipated by this resistance. Similarly when a generator sends electrical energy down an infinitely long transmission line, the electrical energy travels down the line indefinitely. In other words, all the electrical energy that the generator puts out is absorbed or dissipated by the infinitely long line. The infinite line therefore acts like a resistance equal in value to its characteristic impedance, Z_o. The infinite line can therefore be replaced by a resistance equal to its characteristic impedance and the generator will send the same amount of power into the resistance as it did into the infinite line.



Line Termination In Characteristic Impedance

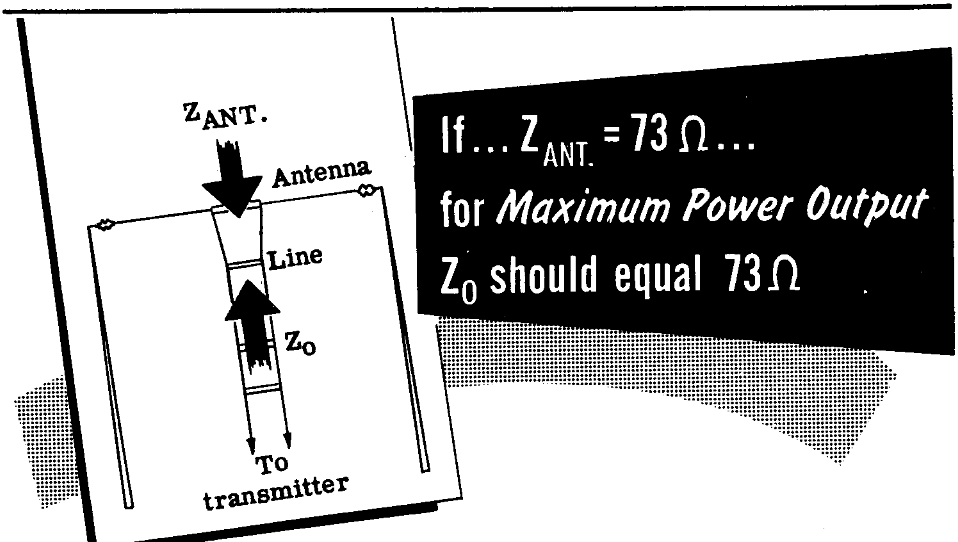
If a transmission line is terminated in a resistive load equal to its characteristic impedance, the load will absorb all the energy from the line that is applied to the input by the generator. This is the ideal condition of maximum power transfer.

. . . FOR MAXIMUM POWER OUTPUT



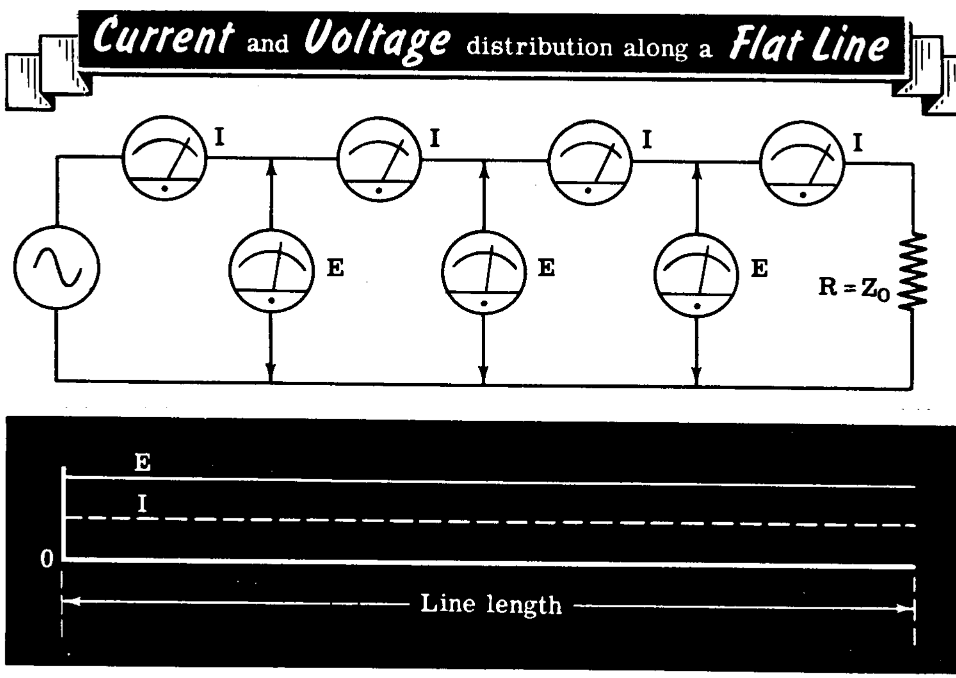
An example of getting maximum power transfer from a transmission line to a load is the case of a line feeding an antenna. If a certain type of antenna, called a "half-wave dipole," is used, the impedance at its center feed point is 73 ohms. Therefore in order to get maximum power transfer from the transmission line to the antenna, the characteristic impedance of the line should be 73 ohms or close to it. When this is the case, the line is said to be "matched" to the antenna.

. . . MATCHING LINE TO ANTENNA



Nonresonant and Resonant Lines

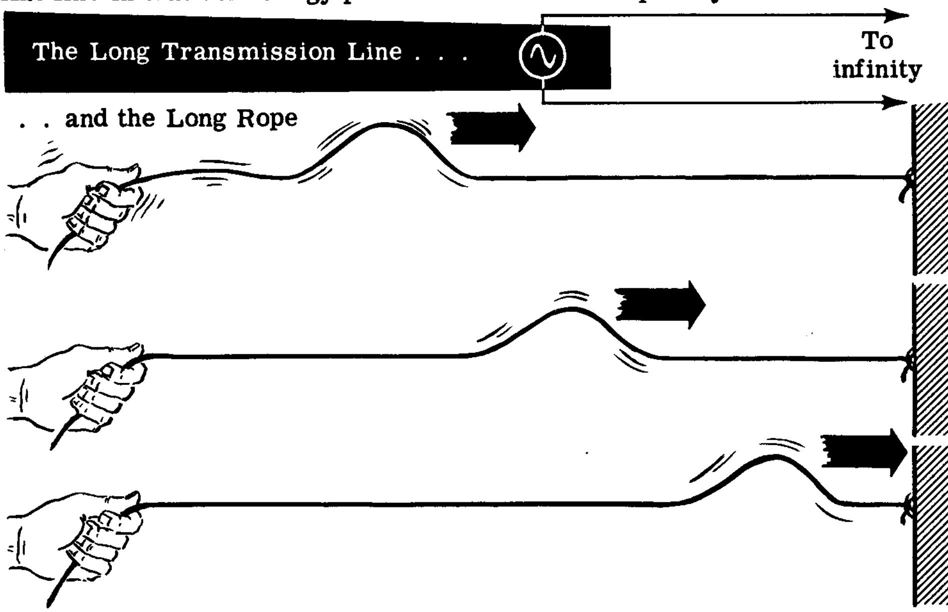
When a transmission line is matched to a load ($Z_{load} = Z_0$), the AC voltage measured across the line at any point is the same, discounting the slight voltage drops in the line due to its resistance. The current measured at any point in the line is also the same. This condition is shown in the illustration by equal readings on the RF voltmeters and ammeters placed along the length of the line. The effective voltage and current distribution along the line can be shown graphically by two straight lines indicating that the effective RF voltages and currents are equal all along the length of line. Such a line is called a "flat" line or nonresonant line. A transmission line will always be nonresonant if it is terminated in its characteristic impedance, which is the condition required for maximum power transfer.



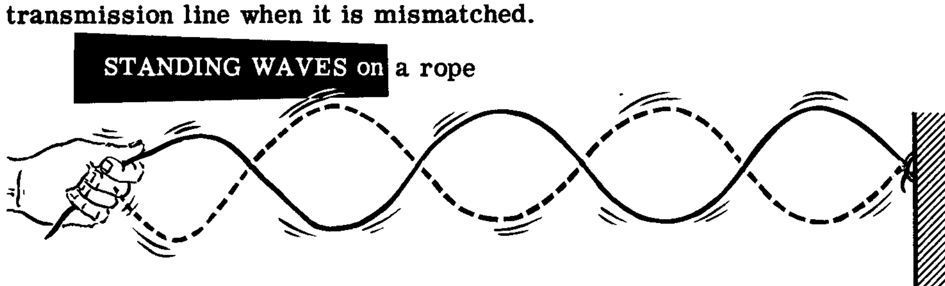
If a line is not terminated in its characteristic impedance it is said to be "mismatched," and all of the RF energy traveling down the line is not absorbed at the load end. The amount of energy absorbed depends upon how close the value of the load impedance is to the characteristic impedance of the line. Since the load of a mismatched line does not absorb all of the energy coming down the line, part of the energy which is not absorbed must be reflected back up the line. This energy which is reflected is called the "reflected wave." A mismatched line therefore has two waves flowing through it, the forward wave and the reflected wave. These two waves combine all along the line (now called a "resonant line") to form a resultant wave called a "standing wave."

Standing Waves on a Rope

To better understand how energy travels down a transmission line and how reflections generate standing waves on the line, consider a rope when one end is fastened to a wall while the other end is held in the hand. When the hand flicks the rope once, a vibration starts to travel down the rope. If the rope were infinitely long, the vibration would continue down the rope forever. This is equivalent to an infinite length of transmission line or a flat line in that the energy put into the line is completely absorbed.

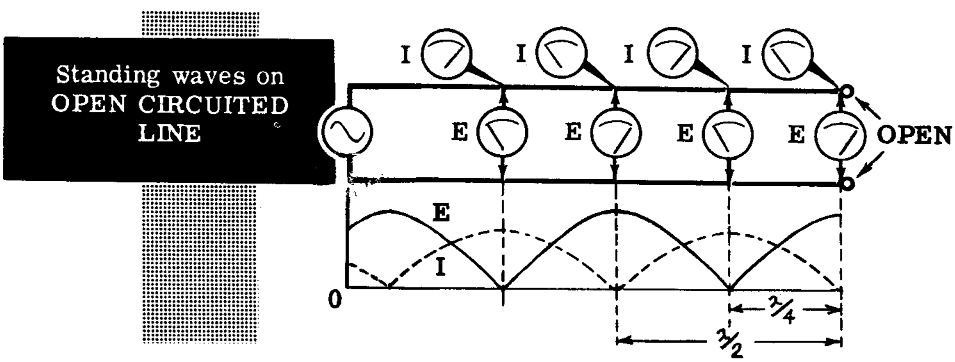


When the vibration traveling down the rope reaches the end attached to the wall, it is reflected back toward the hand. Similarly when a transmission line is mismatched, the electrical energy is reflected back toward the generator. If the hand vibrates the rope at a constant rate, the reflected vibrations combine with the oncoming vibrations to produce standing waves along the rope. At some points along the rope, the forward and reflected vibrations are in phase, reinforcing each other to produce vibration of large amplitude. At other points they are out of phase, thereby cancelling each other, and the rope appears to be motionless at these points. In a similar manner standing waves of voltage and current are formed on a transmission line when it is mismatched.

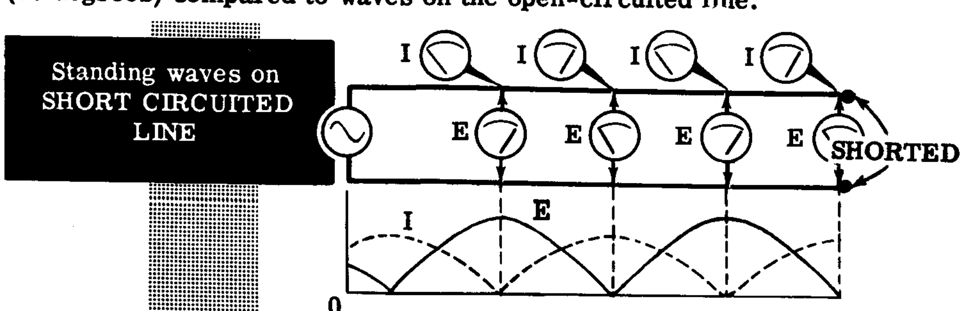


Open and Shorted Transmission Lines

When a transmission line is open at its end, the forward and reflected waves combine along the line to form points of varying effective voltage and current. At the open end, the effective voltage is a maximum and the effective current is zero. It is easy to see that the current must be zero at all times at the open end because it is an open circuit. Also since charges build up on the open ends, a large voltage difference will exist there. At half-wavelength distances from the open end, the voltage and current conditions will repeat themselves, and between these half-wave points the effective voltage and current readings will vary as a sine wave varies. The meter reading in the illustration shows the variations in the effective voltage and current along the length of the line at quarter-wavelength distances from the open end to the input. The wave forms shown are actually a plot of these voltage and current readings at different points along the line. The wave forms are called "standing waves". Observe that the standing waves cause the voltage and current to be zero at all times at certain definite points along the line. Notice that when the current is zero, the voltage is a maximum and when the voltage is zero, the current is maximum.

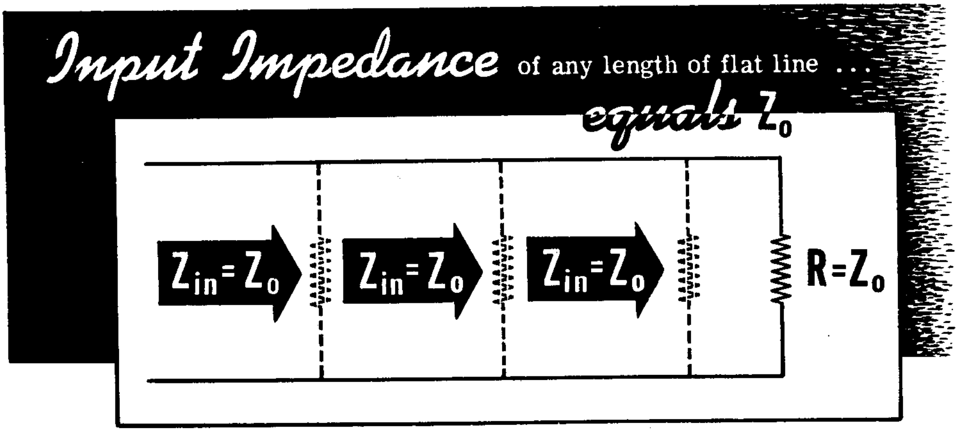


When the transmission line is shorted at its terminating end, the voltage at the open end must be zero because no voltage can exist across a short. Also the current at the short will be a maximum because the short provides a zero resistance path through which current can flow. Just as in the open-circuited line, these voltage and current conditions at the terminating end will repeat themselves at one-half wavelengths back from the short circuit. Observe that the standing waves on the short-circuited line have been displaced a distance equivalent to a quarter of a wavelength (90 degrees) compared to waves on the open-circuited line.

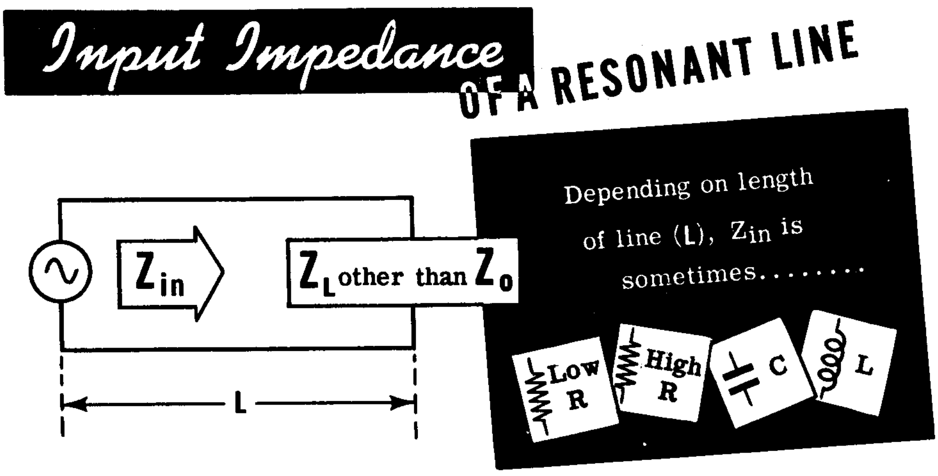


Input Impedance of a Line

In a transmission line terminated in its characteristic impedance, the voltage and current readings are the same all along the line. Therefore, the impedance anywhere along the line is constant and equal to its characteristic impedance. In other words, if you were to break off the line anywhere along its length and measure the impedance (Z_{in}) looking in towards the load end, the impedance value measured would always be the same and equal to the characteristic impedance, Z_0, which is resistive.



When a transmission line is terminated in other than its characteristic impedance, it becomes resonant and develops standing waves. The input impedance then varies with the length of the line because the effective values of the current and voltage vary along the length of the line. Also the reactance of the input impedance varies, being sometimes resistive, sometimes capacitive and sometimes inductive. Therefore, a resonant line has the characteristics of a resonant circuit which presents a resistive load at the resonant frequency and an inductive or capacitive reactance on either side of the resonant frequency.



Input Impedance of Short-Circuited Line

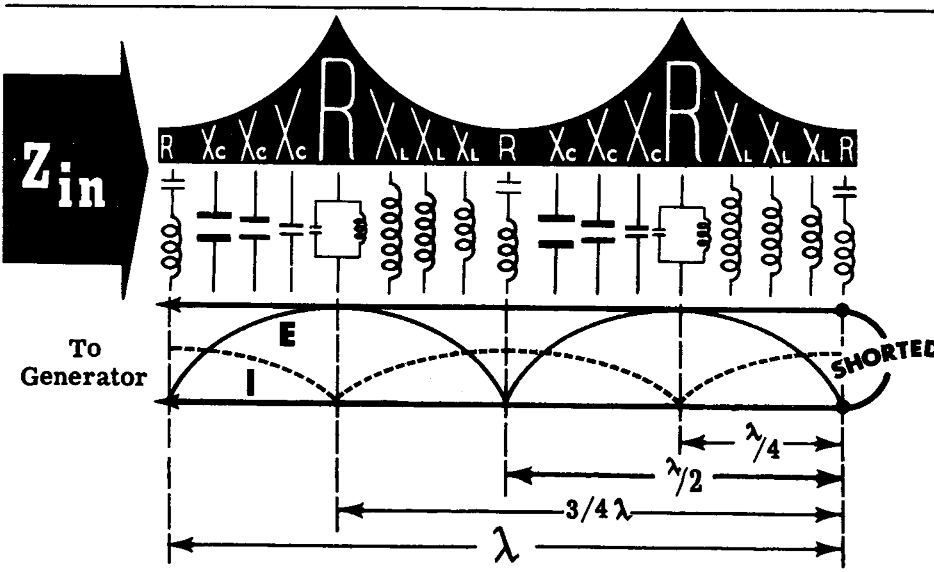
A short-circuited line appears as a very low resistance at the shorted end, since the voltage is minimum and the current is maximum. This low resistance is repeated every half wavelength back from the shorted end. Since the line is called "resonant", it is convenient to think of the low resistance points along the line as series-resonant circuits. For example, the input impedance at a half-wavelength section of shorted line is that of a series-resonant circuit. A quarter wavelength back from the shorted end, the current is minimum and the voltage is maximum. Therefore, this is a point of high resistance. This high resistance point is repeated every half wavelength back from the first high resistance point. The high resistance points can be considered to be parallel-resonant circuits just as the low resistance points are series-resonant circuits.

Between the high and low resistance points, the input impedance is either a capacitive reactance or an inductive reactance. From zero to a quarter wavelength back from the terminating short circuit, the input impedance is inductive. The inductive reactance is low in the vicinity of the short circuit and increases in magnitude as you approach the quarter-wave point. Exactly at the quarter-wave point, the impedance is a pure high resistance.

Between a quarter wavelength and a half wavelength, the input impedance is capacitive reactance. The capacitive reactance decreases as the half-wavelength point is approached until, at the half-wavelength point, the impedance is a pure low resistance.

The type and magnitude of the input impedance as seen at different points along the short-circuited line is illustrated below.

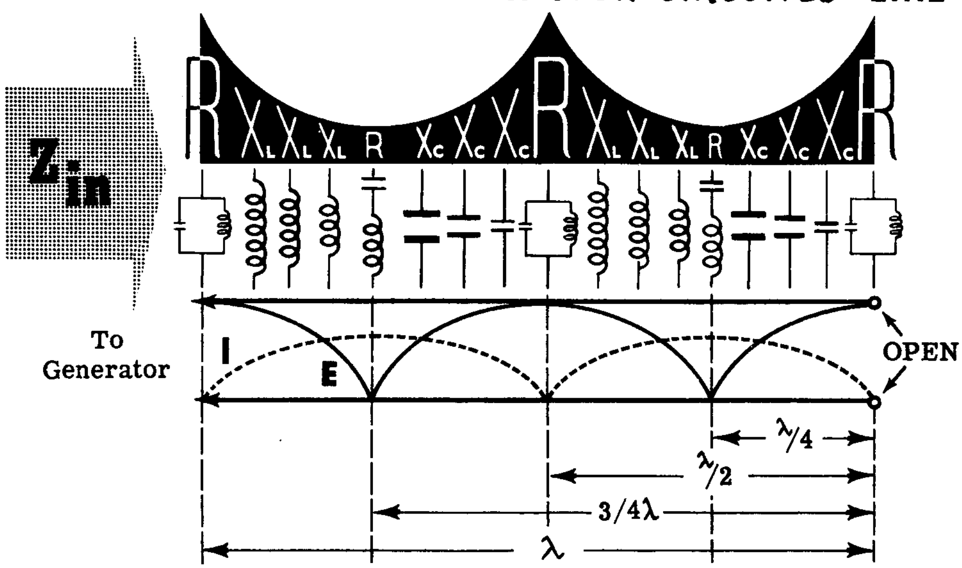
INPUT IMPEDANCE ALONG A *SHORT CIRCUITED* LINE



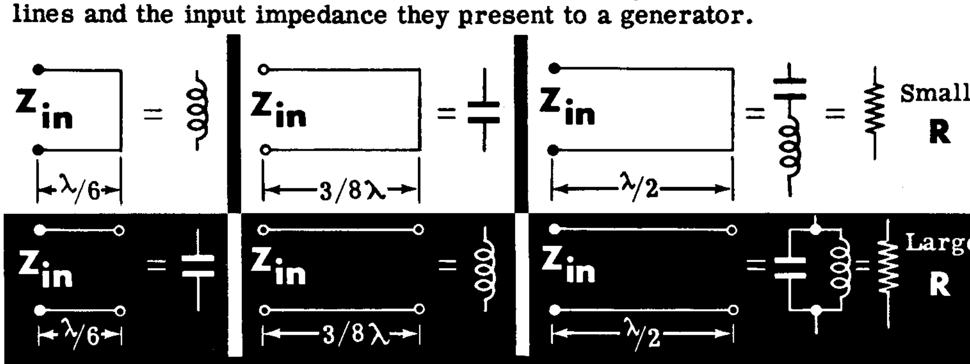
Input Impedance of Open-Circuited Line

In the open-circuited line, the terminating impedance (open circuit) is a high resistance and therefore acts like a parallel circuit. A quarter wavelength back the input impedance is a low resistance and therefore has the characteristics of a series-resonant circuit. Between zero and one-quarter wavelength back from the open circuit, the input impedance is capacitive, and between one-quarter and one-half wavelength the input impedance is inductive. If you compare the open- and short-circuited lines, you will observe that for a given wavelength back from the end, the reactances are opposite to each other; where one is capacitive the other is inductive and vice versa.

INPUT IMPEDANCE ALONG AN *OPEN-CIRCUITED* LINE



The following diagrams illustrate different lengths of open and shorted lines and the input impedance they present to a generator.



It is obvious from the above diagrams that the terminal conditions at the end of the line are the only factors which determine the type and magnitude of the input impedance at any point along the line.

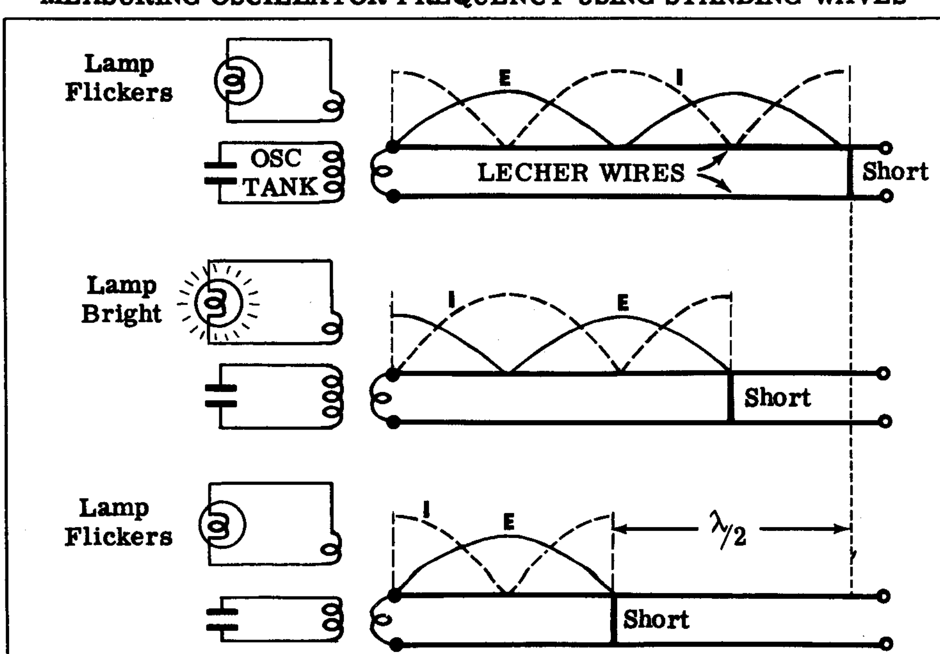
Frequency Measurement Using Standing Waves

Whenever standing waves exist on a transmission line, the adjacent peaks of voltage are always one-half wavelength apart as are the adjacent peaks of current. Similarly, adjacent zero points of voltage and current are also one-half wavelength apart. If the distance between two adjacent peaks of either voltage or current can be determined, the frequency of the RF can be calculated using the formula: frequency (in megacycles) = $\frac{5906}{D}$, where "D" is the measured distance in inches between adjacent peaks.

A standard procedure for determining the high frequency oscillations of an oscillator is to use a Lecher wire setup. A pilot lamp is coupled to the oscillator tank circuit until it glows. Then a short is placed across the open terminals of the Lecher wire and moved slowly back toward the oscillator until a point on the line is reached where the short reflects a short across the input to the line loading down the oscillator tank circuit. The oscillator does not generate as much power as before and the bulb's brightness dims. As the short continues to move down the line, the reflected short at the oscillator output disappears and the bulb comes back to its original brightness. Soon another point is reached where the short reflects a short across the oscillator output and again the bulb flickers. The number 5906 divided by the distance, in inches, between these two points gives the frequency of oscillations in megacycles.

$$F_{(mc)} = \frac{5906}{D(in)}$$

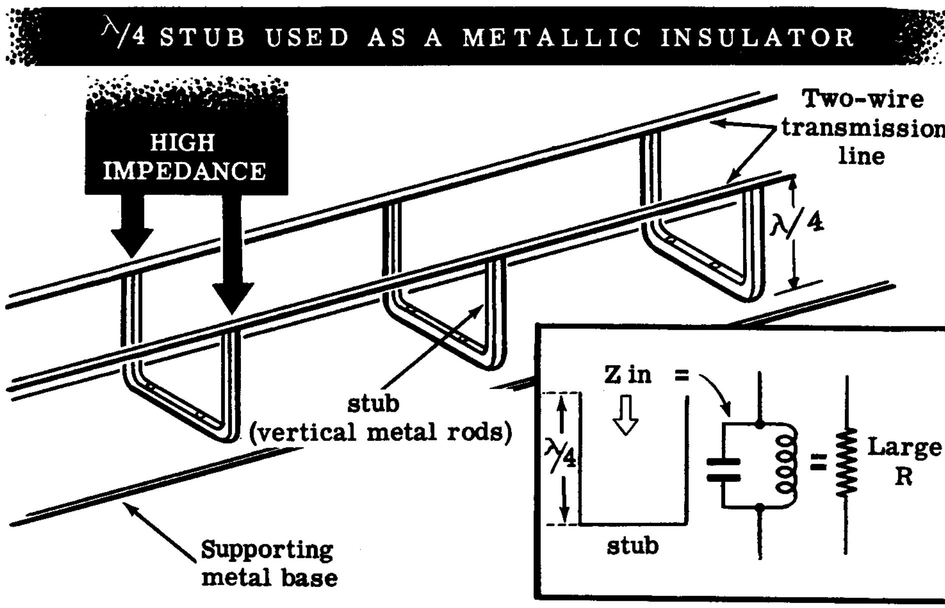
MEASURING OSCILLATOR FREQUENCY USING STANDING WAVES



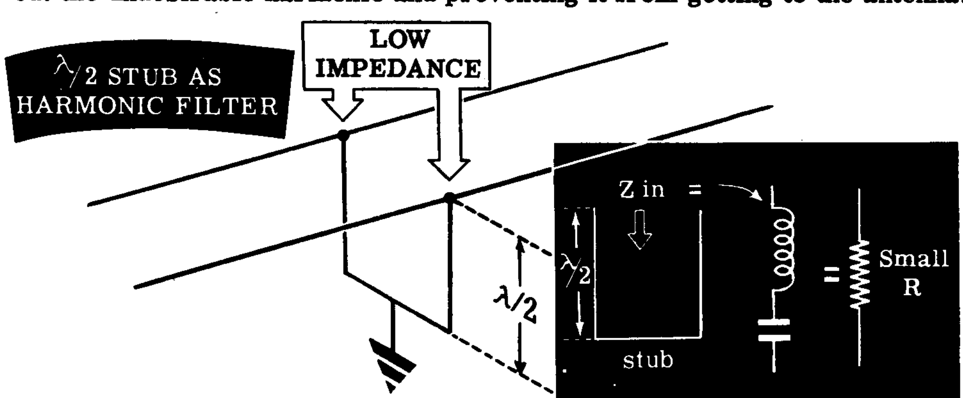
Applications of Transmission Line Principles

With your understanding of how transmission lines work, suppose you learn about a few of the many applications of transmission lines in electronic equipment.

A shorted quarter-wave transmission line, known as a "stub," will offer a very high impedance at its input. It can therefore be used as a metallic insulator to support a two-wire transmission line without shorting the line.



The shorted quarter-wave stub also makes a very effective filter for harmonic frequencies of the fundamental which one does not desire to transmit. For the fundamental frequency the stub is a high impedance as was shown above. For the second harmonic, the stub is now a half wavelength long and will act as a short circuit across the transmission line, shorting out the undesirable harmonic and preventing it from getting to the antenna.

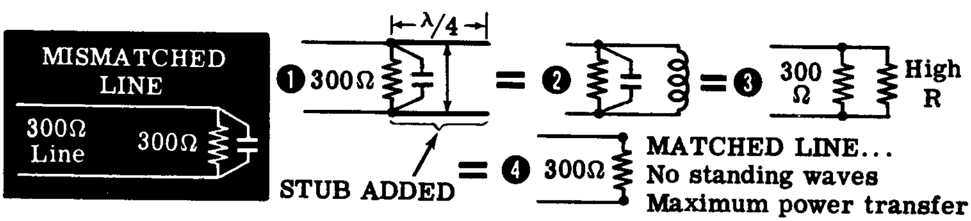


Applications of Transmission Line Principles (continued)

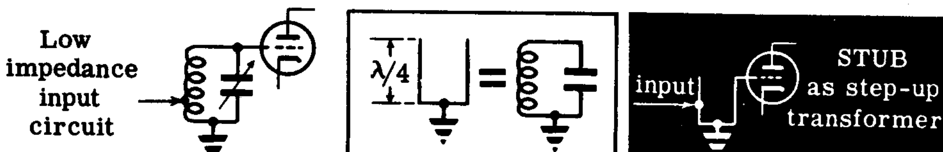
An important application of a short transmission line, or "tuned line section," as it is called, is to tune out the reactance of a load on a transmission line thus leaving the load resistive.

For example, suppose a 300-ohm line is feeding a load which looks like a 300-ohm resistance in parallel with a capacity. Since the load is not completely resistive, standing waves will exist on the line and maximum power transfer to the load will not be realized. If an inductance could be placed in parallel with the capacity, to effect a parallel-resonant circuit, the transmission line would look into the 300-ohm resistive component in parallel with the high resistance of the parallel-resonant circuit. Since the high resistance of the parallel-resonant circuit is so much greater than 300 ohms, the transmission line effectively sees only the 300-ohm resistance. The effect of the capacity has thus been cancelled out.

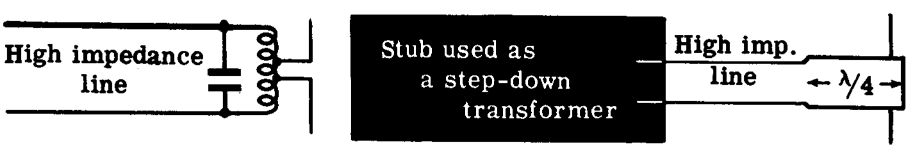
The way to introduce an inductance across the load is to place a quarter-wave shorted stub, with a movable shorting arm, across the load terminals. By moving the short so that the stub is less than a quarter wavelength long, the input reactance of the stub becomes inductive. The value of this inductance can be varied by means of the movable short until it cancels the capacity of the load, leaving the load resistive.



Quarter-waveline sections are also used as transformers or matching devices to connect circuits of unequal impedances. If a low impedance input circuit is to be connected to a high impedance grid circuit, the input circuit may be tapped down on the coil of a tank circuit as shown. If a tuned line is used, the input circuit can similarly be tapped down on the tuned line. This is an example of a tuned line used as a step-up transformer.



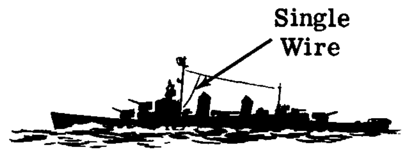
A quarter-wave stub can be used as a step-down transformer to match a high impedance line to a low impedance dipole antenna. The line is connected to the high impedance input of the stub and the antenna is connected near the low impedance shorted end of the stub.



Types of Transmission Lines

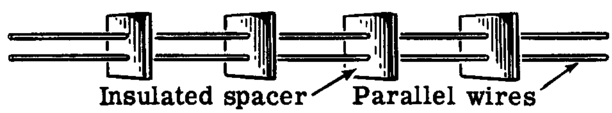
Many different types of transmission lines are employed in electronic applications. Each line has a certain characteristic impedance, current carrying capacity, insulation and physical shape to meet a particular requirement. Below are shown some of the most frequently used transmission lines.

A simple method of feeding an antenna from a transmitter is to use a single-wire transmission line with the ground return completing the circuit.



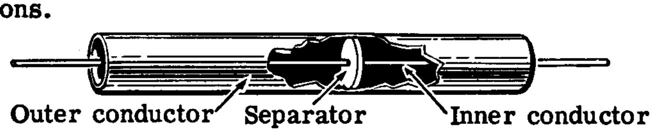
Another type of transmission line consists of two parallel wires which are maintained at a fixed distance from each other by insulated spacers. Since the line is not shielded, losses occur, due to radiation and absorption by metallic objects. The use of the line is therefore restricted to comparatively low-frequency transmission and it should be strung only in places where it will be away from metallic objects and out in the open.

TWO WIRE OPEN LINE



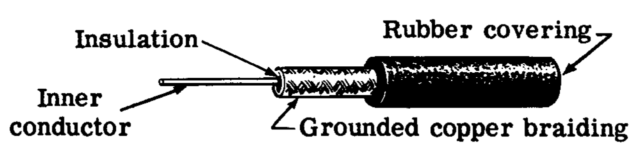
Some of the disadvantages of the two-wire open line are overcome in the concentric line which is made of a cylindrical copper tube with a thin conductor running full length through the center. The inner conductor is kept centered by spacers and the outer conductor is grounded to shield the inner conductor. Since the line is mechanically rigid, it can be used only for permanent installations.

CONCENTRIC LINE



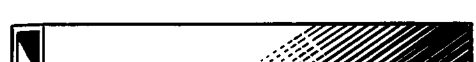
The inflexibility of the concentric line is overcome in the coaxial cable which consists of one or more inner conductors imbedded in an insulating material and covered with a grounded copper braid. The coaxial cable has much higher losses than the concentric line.

COAXIAL CABLE



At very high frequencies the losses in any of the above mentioned lines become excessive and wave guides must be used. Wave guides are made of round or rectangular hollow tubes.

WAVE GUIDE



Rectangular hollow tube

Demonstration—Transmission Lines

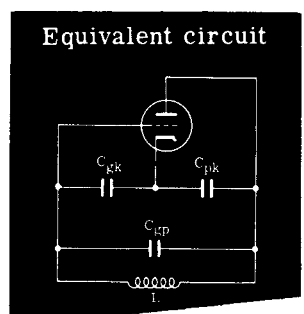
In this demonstration a high-frequency oscillator is going to feed Lecher wires on which standing waves will be generated. The presence of these standing waves will be shown with different types of pickup devices. You will also see that the current and voltage peaks are shifted a half wavelength when the end of the line is shorted. A procedure for determining the frequency output of an oscillator using Lecher wires will be demonstrated as will a method for determining the characteristic impedance of a transmission line.

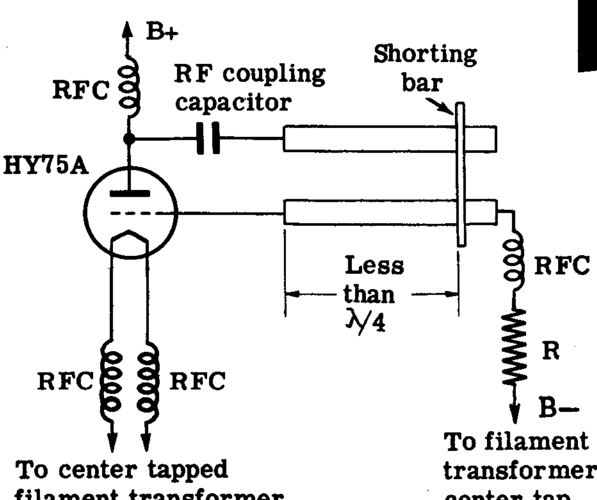
The transmitter used for this demonstration is a very high frequency tuned-line oscillator which will oscillate in the neighborhood of 160 megacycles. The oscillator is effectively a Colpitts oscillator with the tuned line acting as the coil of the tank circuit and the tube interelectrode capacities acting as the capacitor voltage divider network. The schematic and equivalent RF circuit of the oscillator are pictured below. The capacities represented in the equivalent circuit are the interelectrode capacities, and the inductance L is the input reactance of the less-than-a-quarter-wavelength short-circuited transmission line. The oscillator will always oscillate at the frequency for which the tuned line is less than a quarter-wavelength long. One of the pickup devices is an RF current meter whose circuit diagram appears below.

Schematic

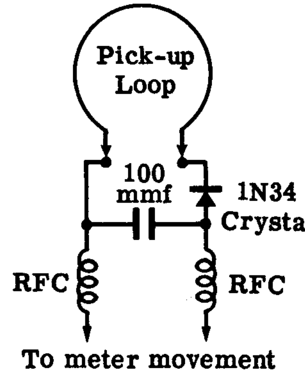
THE VHF *Oscillator*

Equivalent circuit





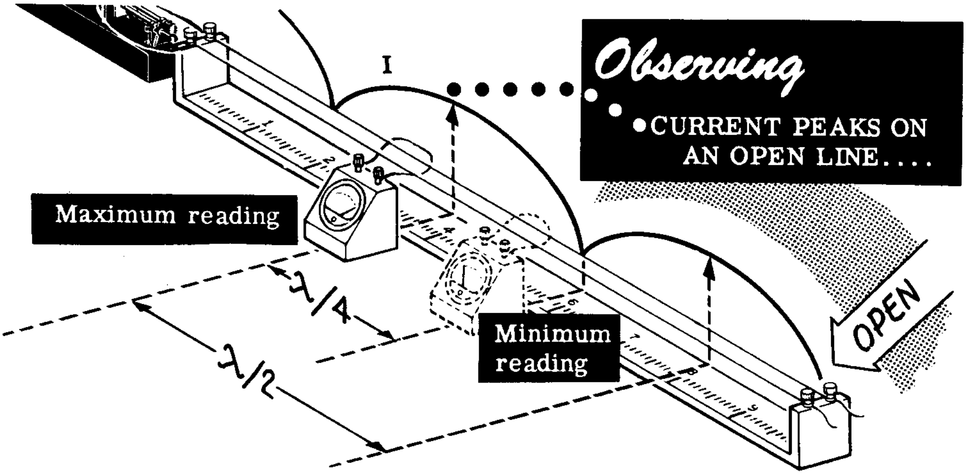
Circuit diagram of RF Current Meter



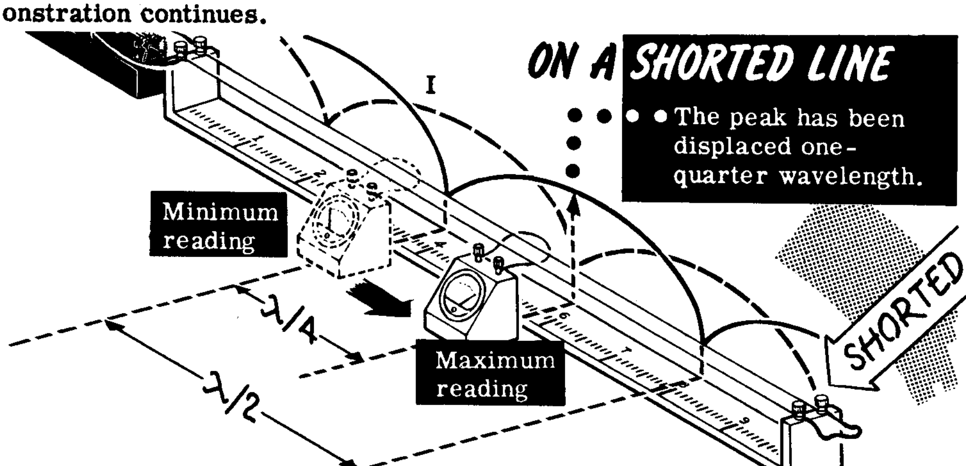
Demonstration—Transmission Lines (continued)

Next the instructor demonstrates the existence of standing waves along the open-ended Lecher wires, using various indicating devices.

The high frequency oscillator is turned on, and the Lecher wires are energized. The meter-type RF current indicator is moved underneath the wires, and the distance of the loop from the wires is adjusted so that the meter shows a maximum deflection. Then the meter is moved slowly along the length of the wire and the position of the maximum current points are noted. The distance between two adjacent current peaks is equal to one-half wavelength.



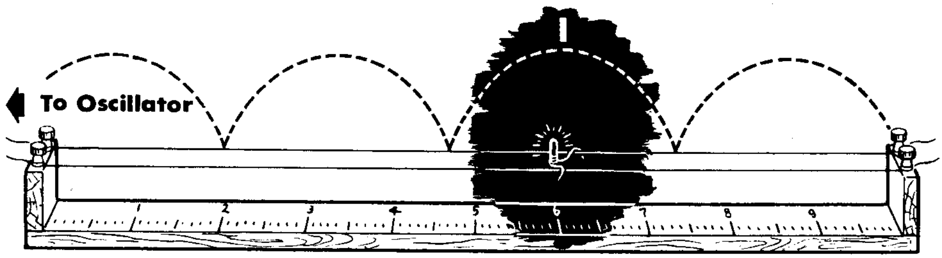
The meter indicator is placed at a point of maximum current, and the instructor shorts the open end of the line with a screwdriver. The reading drops immediately and the meter is moved to the new current peak which is a quarter wavelength away from the previous current peak position. The short has displaced the standing waves one-quarter wavelength from their position when the line was open. The short is removed and the demonstration continues.



Demonstration—Transmission Lines (continued)

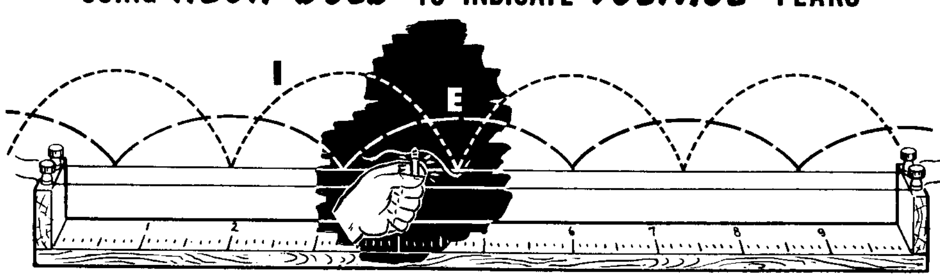
The position of current peaks can also be shown using a pilot light indicator. The pilot indicator is placed across the open-ended Lecher wires and slowly moved along their entire length. When a current peak is reached, the bulb lights. Observe that the bulb lights at the same point where the current meter had indicated current peaks.

USING *PILOT LIGHT* TO INDICATE *CURRENT* PEAKS



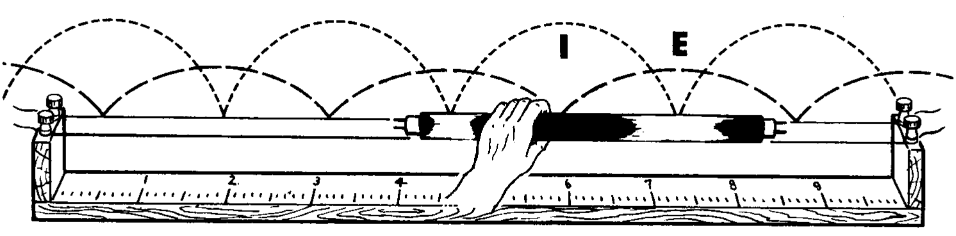
The voltage peaks can be found by using a neon bulb. The instructor holds the glass end of the bulb with his fingers and moves it along one wire, keeping a wire from the bulb in contact with the line at all times. The bulb remains out at the current peaks previously noted, but lights up between the current peaks, reaching maximum brilliance equidistant between two current peaks. The point of maximum brilliance is a voltage peak.

USING *NEON BULB* TO INDICATE *VOLTAGE* PEAKS



Both voltage and current peaks can be shown by using a long fluorescent light. The light areas are voltage peaks or current nulls.

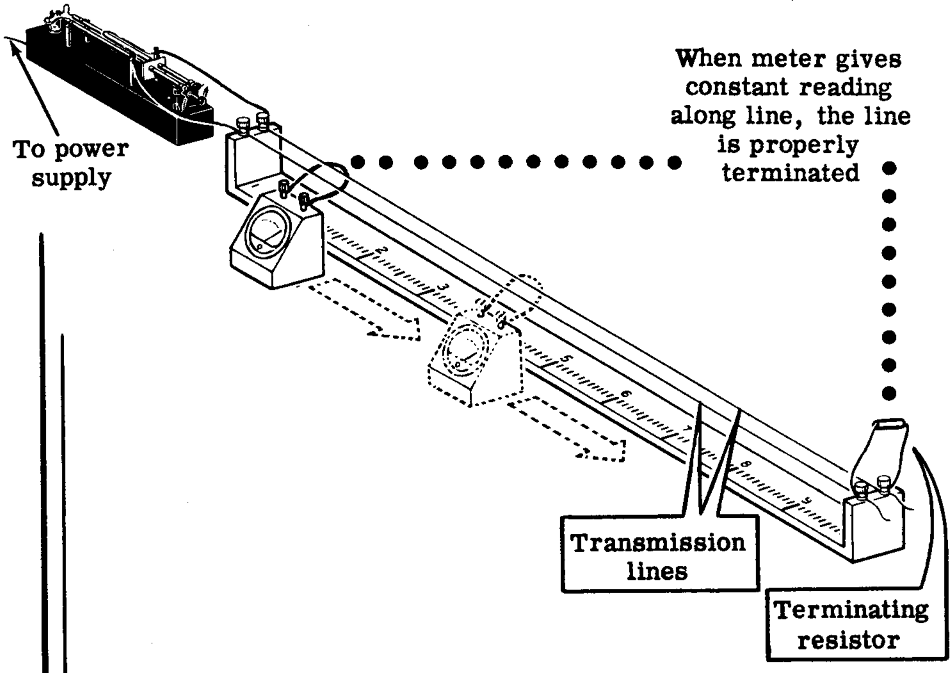
OBSERVING STANDING WAVES USING A *FLUORESCENT LIGHT*



Demonstration—Transmission Lines (continued)

When a transmission line is terminated in its characteristic impedance, no standing waves of voltage or current will exist on the line. Therefore the characteristic impedance of a line can be determined by placing different values of resistance across the line until the standing waves disappear or are reduced to a minimum. The value of the resistor which produces this result is equal to the line characteristic impedance.

The instructor turns on the high frequency oscillator and checks for standing waves on the line using the meter-type RF current indicator. As the meter indicator is moved along the line, the readings vary from a maximum to a minimum indicating the presence of standing waves. Next, each of the resistors in turn is connected across the line, and a check is made each time for the presence of standing waves. When the current indicator gives a practically constant reading along the entire length of the line, the value of the resistor connected across the end of the line is approximately equal to the line characteristic impedance.



Determining Characteristic Impedance of a Line

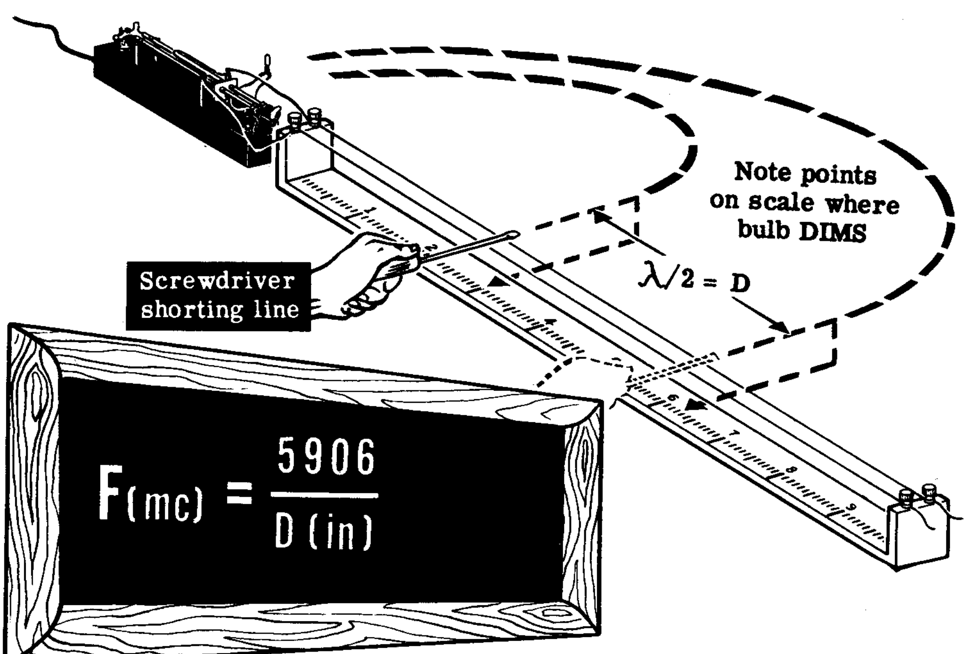
Demonstration—Transmission Lines (continued)

The instructor now demonstrates a procedure for determining the frequency of a high frequency oscillator using Lecher wires.

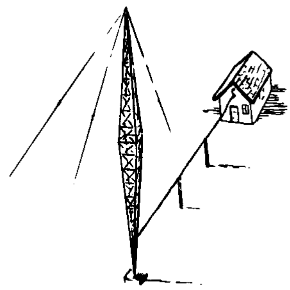
The pilot light and pickup loop are coupled to the oscillator tank circuit by placing the coil between the tuned line and the tuning rod so that the bulb lights. Then, holding a screwdriver by the insulated handle and with the metal shank at the input end, the instructor shorts out the line, and slowly moves the screwdriver toward the open end, keeping the line shorted. At a certain point the pilot light dims, indicating that the short is electrically a half wavelength away from the coupling loop and therefore is loading down the oscillator. This point is carefully noted and the instructor continues to move the screwdriver toward the open end. Again a point is reached when the light dims. This point is one-half wavelength away from the preceding point. The instructor using the formula $F = \frac{5906}{D}$ (where F is the frequency in megacycles and D is the distance in inches between the two points) calculates the oscillator frequency.

If the meter-type RF current indicator is used in place of the bulb, the correctly positioned shorted points will show up as a dip reading on the meter.

Determining Oscillator Frequency



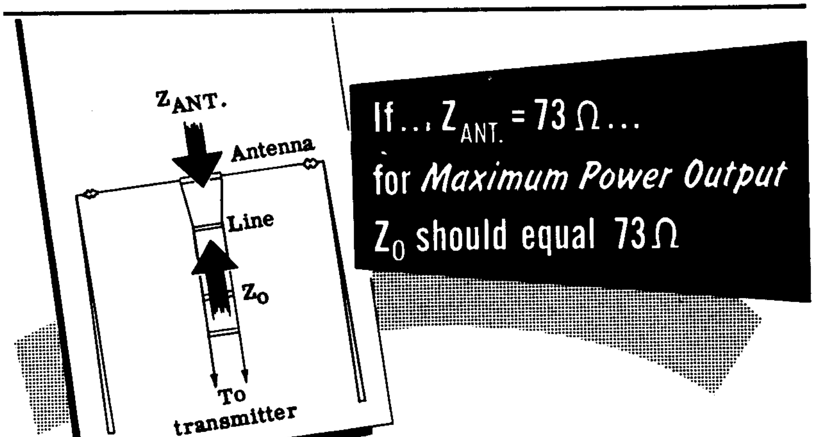
Review



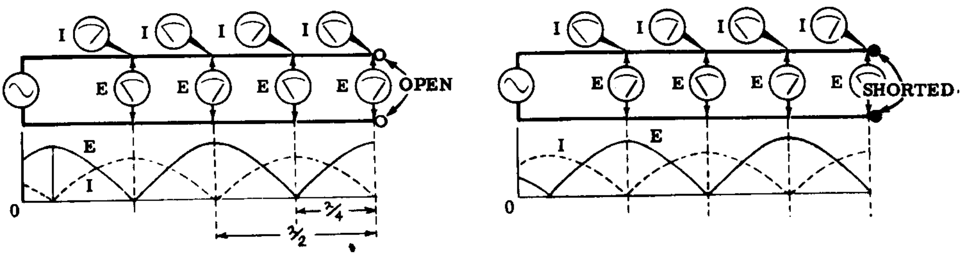
TRANSMISSION LINES — The purpose of a transmission line in a transmitter is to convey RF energy from the transmitter to the antenna. The characteristic impedance of the transmission line should match the input impedance of the antenna, if maximum power transfer to the antenna and therefore maximum radiated power is to be realized.

CHARACTERISTIC IMPEDANCE — A transmission line has a characteristic impedance (Z_0). If it is terminated in a load equal to its characteristic impedance, maximum power is transferred to the load and no standing waves exist on the line.

. . . MATCHING LINE TO ANTENNA



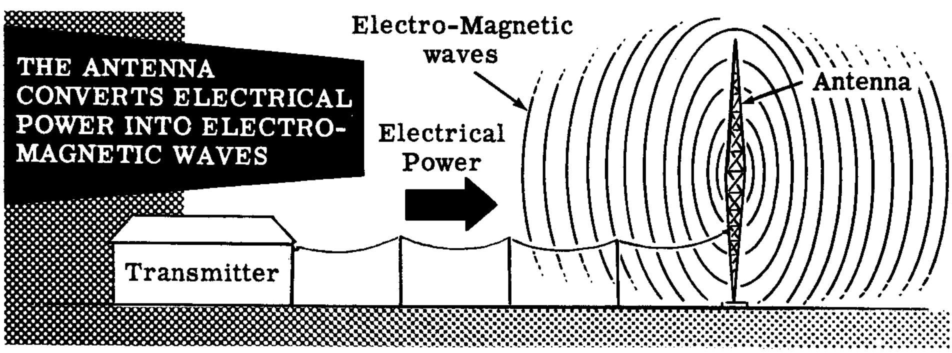
STANDING WAVES — When a transmission line is terminated in a load other than its characteristic impedance, some of the energy is reflected at the end of the line back towards the generator. The forward and reflected waves combine along the line to form standing waves. The voltage and current distribution along an open and shorted line are as shown.



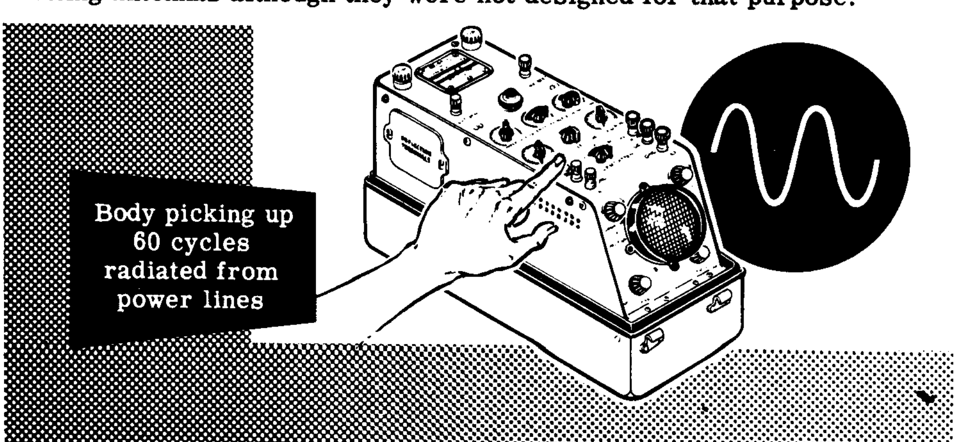
Purpose of an Antenna

The purpose of a transmitting antenna is to convert the power delivered by the transmission line into a wave called an "electromagnetic wave." This electromagnetic wave has the unique property of radiating through space without the aid of wires. All antennas work on the same principle—the antenna current generates an electromagnetic field which leaves the antenna and radiates outward as an electromagnetic wave.

The antennas you will be concerned with now are those which are designed as transmitting antennas. These will operate at much higher frequencies than the power lines and will be much more efficient. However, it is still the current which flows in the antenna that causes the electromagnetic field to be radiated.



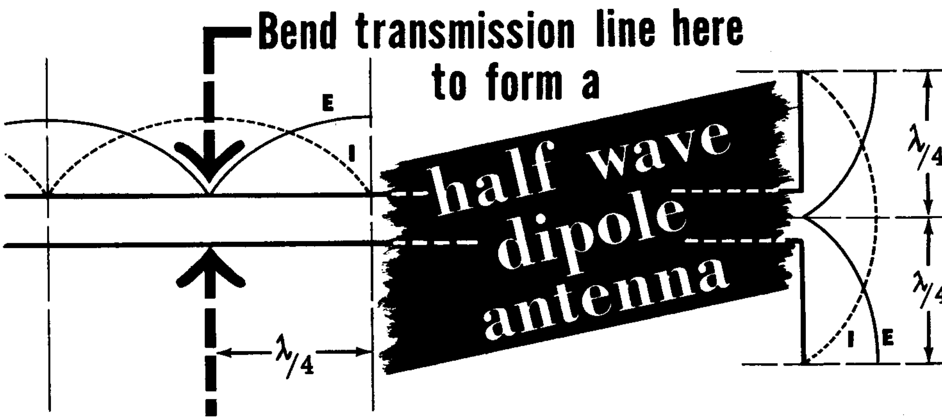
An interesting example of antenna action can be observed by touching your finger to the vertical input terminal of an oscilloscope. You will see a 60 cycle wave form on the 'scope screen which obviously must come from your body. What is actually happening is that your body is picking up 60 cycle electromagnetic waves which are radiated from the many power wires that carry 60 cycle current. The power lines are acting as transmitting antennas although they were not designed for that purpose.



How an Antenna Works

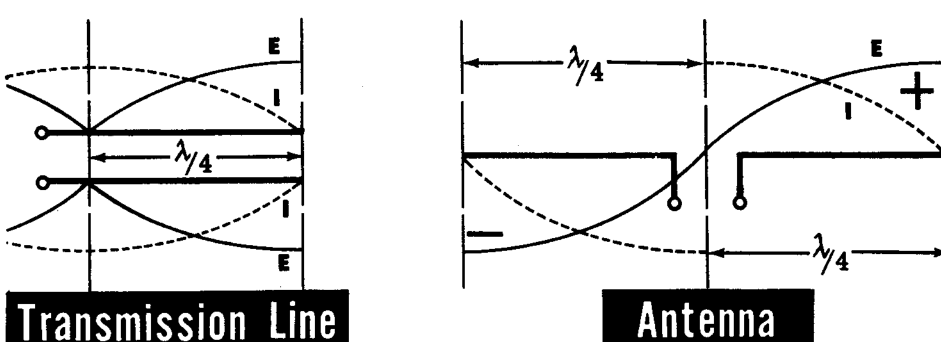
If the wires of an open-ended transmission line are bent back a quarter wavelength from the open end, at right angles to the line, a simple antenna is formed called a "half-wave dipole", a "doublet" or a "Hertz antenna".

The voltage and current distribution on the antenna are the same as on the original transmission line.



Although the voltages at any two points on the antenna wires (also on the transmission line), equidistant from the ends, are equal in amplitude, they are opposite in polarity just as the ends of a transformer winding are equal in amplitude but opposite in polarity. The same holds true for current. Therefore, to indicate polarity as well as amplitude on the wires that comprise the transmission line and antenna, the wave forms are redrawn as shown.

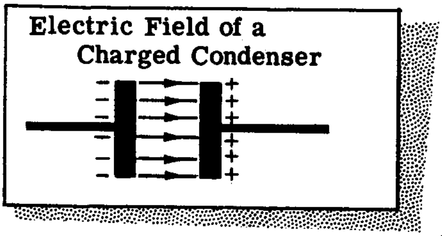
WAVE FORMS SHOWING POLARITY AND AMPLITUDE

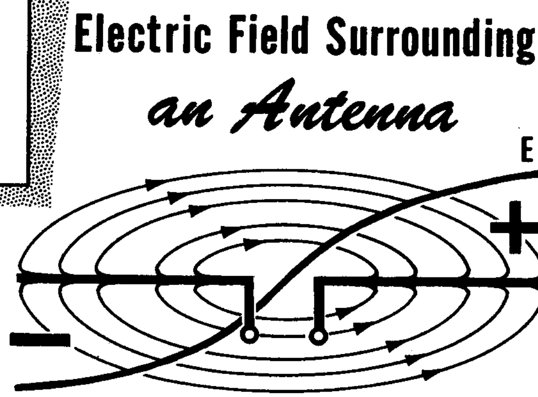


Observe that the standing waves of voltage and current indicate that the antenna ends are points of maximum voltage and minimum current, whereas the center of the antenna is a point of maximum current and minimum voltage.

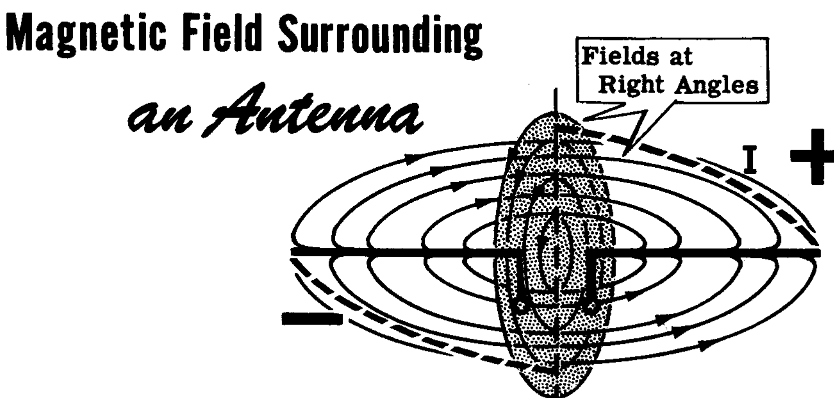
How an Antenna Works (continued)

Whenever there is a difference of voltage between two points, an electric field is set up between these points. You learned in Basic Electricity that when a capacitor is charged, one plate will be positive and the other negative. As a result, an electric field having a direction toward the positively charged plate is built up between the capacitor plates as shown. Similarly, the voltage difference between the two wires of an antenna also generates an electric field having a pattern and direction as shown below.





Besides this electric field, there is also a magnetic field which is generated by the antenna current. The plane of this magnetic field is at right angles to the direction of the current flow and therefore is at right angles to the antenna, as shown. The electric and magnetic fields must therefore be at right angles to each other.



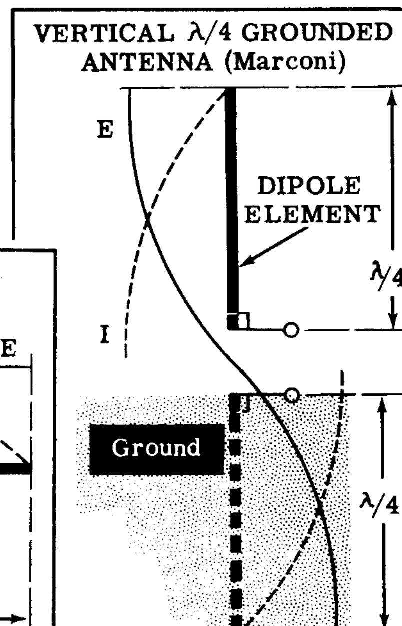
These electric and magnetic fields alternate about the antenna, building up, reaching a peak, collapsing, and building up again in the opposite direction, at the same frequency as the antenna current. In the process of building up and collapsing, a portion of these fields escape from the antenna and become the electromagnetic waves which radiate through space conveying the transmitted intelligence to distant receivers.

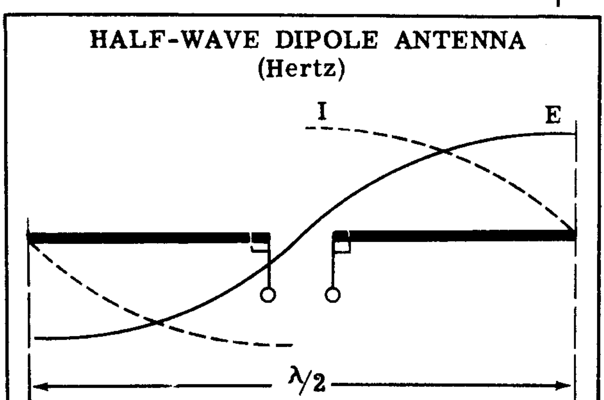
Basic Antennas

The half-wave dipole or Hertz antenna is one type of basic antenna which finds wide application in many types of transmitting and receiving equipment.

Another basic antenna is a vertical quarter-wave grounded antenna sometimes called a "Marconi antenna." If one of the elements of a Hertz antenna is removed and the wire that went to that element is grounded, the result is a Marconi antenna. The earth actually takes the place of one of the quarter-wave elements so that the earth and the remaining quarter-wave element form an effective half-wave dipole. The current maximum and voltage minimum points are at the base of the antenna as shown.

BASIC ANTENNAS





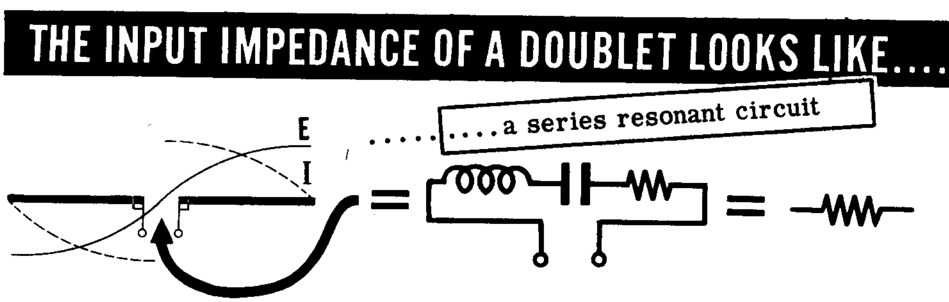
When a Marconi antenna is used, the earth directly beneath the antenna must be a good electrical conductor. Sometimes copper tubing is driven into the ground at the base of the antenna to improve the ground conductivity. On shipboard a vertical quarter-wave antenna may be some distance above the deck. A simulated ground is provided by using grounded metal rods at least a quarter wavelength long and placing them at the base of the antenna. This simulated ground is called a "counterpoise."

Since a quarter-wavelength dipole antenna is physically half as long as a half-wave grounded antenna, it is often preferred at low frequencies (large wavelength) especially when there are space restrictions on antenna mountings. At high frequencies the half-wavelength dipole is extensively used because even though it is longer than the quarter-wave antenna, its overall length will be small, and it can be made of metal tubing which is self-supporting.

Radiation Resistance

In a half-wave dipole antenna, the voltage at the center is minimum (practically zero) whereas the current is maximum. If you will recall the characteristics of a series-resonant circuit, you will remember that the voltage across it is also minimum and the current through it is maximum. At its center, a half-wave dipole is equivalent to a series-resonant circuit when operated at the proper frequency. A generator that supplies power to a series-resonant circuit works into a pure resistance since X_L and X_C cancel each other—the resistance being mainly the wire resistance of the coil.

Similarly, a transmission line works into a pure resistance when a half-wave dipole is connected to it. This resistance consists of both the resistance of the wire and a resistance called the "radiation resistance." The resistance of the wire is neglibible, so only the radiation resistance is considered.



The radiation resistance is not an actual resistance. It is an equivalent resistance which, if connected in place of the antenna, would dissipate the same amount of power as the antenna radiates into space.

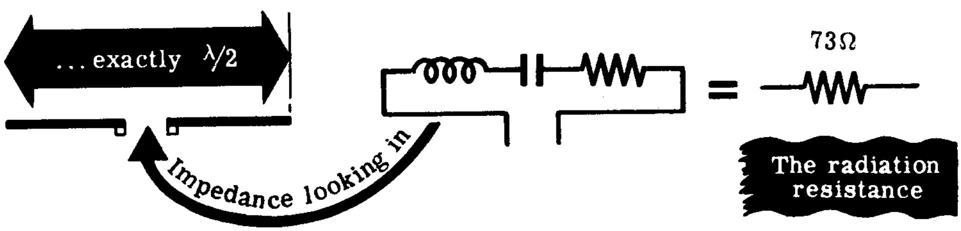
The value of the radiation resistance can be determined from the power formula, $R = \frac{P}{I^2}$, where P is the power radiated from the antenna and I is equal to the antenna current at the center of the antenna. For a half-wave dipole the radiation resistance is about 73 ohms, measured at the center of the antenna. This value is fairly constant for different frequency half-wave dipoles.

Antenna Impedance

Since a half-wave dipole acts like a series-resonant circuit, it will exhibit either inductive or capacitive properties as the RF frequency applied to the antenna is varied.

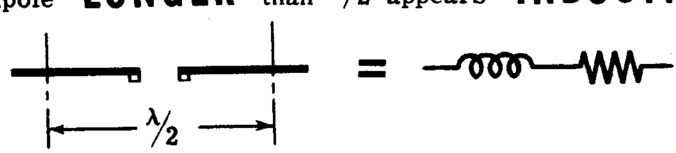
When the frequency of the RF is just right, the dipole is exactly a half wavelength long and is series-resonant, with its impedance resistive and equal to the radiation resistance. In transmitting it is always desirable that the antenna present a resistive load to the transmission line so that a maximum amount of power will be absorbed by the antenna and radiated.

Optimum condition for **Maximum Power Radiation**



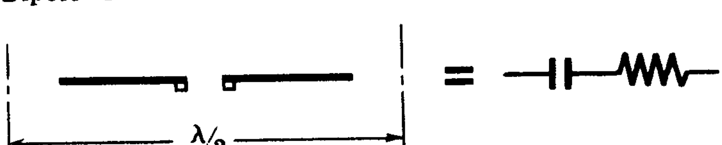
If the frequency of the transmitter goes up, the antenna will be longer than a half wavelength. The series circuit is then operating at a frequency which is above its resonant frequency. At this applied frequency, the inductive reactance is larger than the capacitive reactance and the antenna appears inductive to the transmitter.

Dipole **LONGER** than λ/2 appears **INDUCTIVE**



If the frequency of the transmitter goes down, the antenna will be slightly shorter than a half wavelength. The series circuit is then operating at a frequency which is below its resonant frequency. The capacitive reactance is larger than the inductive reactance and the antenna appears capacitive to the transmitter.

Dipole **SHORTER** than λ/2 appears **CAPACITIVE**

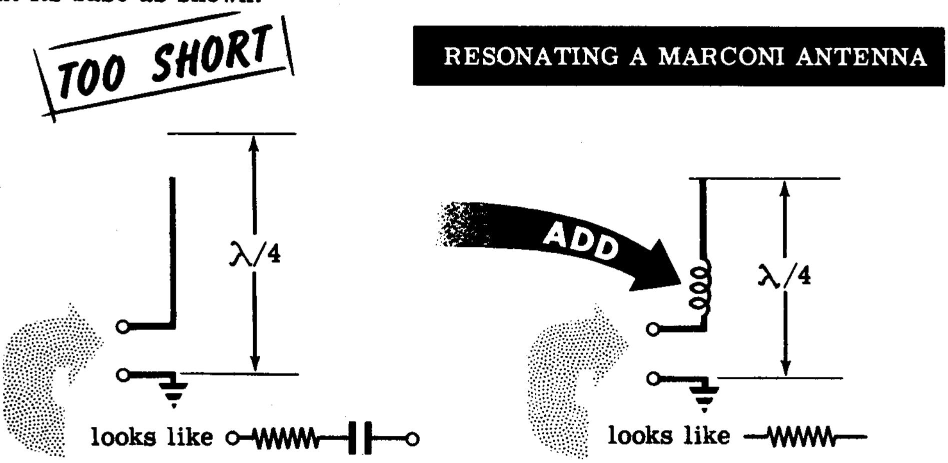


Tuning the Antenna

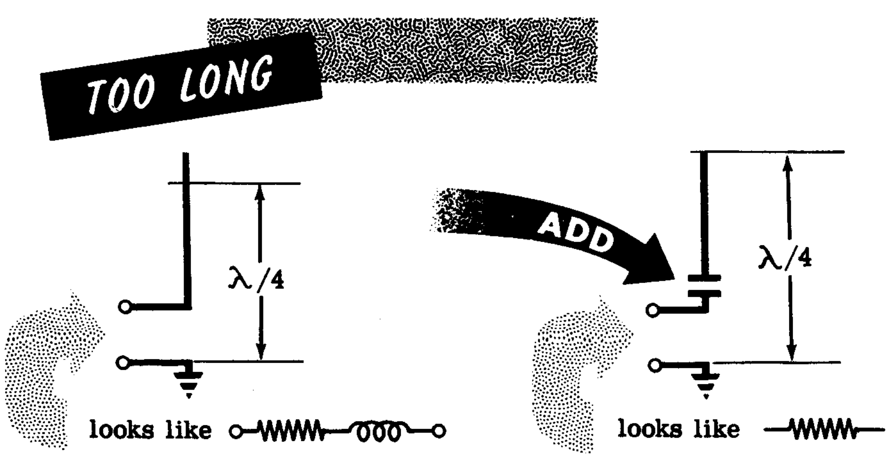
You have seen that as the frequency of the transmitter is varied, the electrical length of the antenna varies as does the impedance at its input. Since it is desirable to have the antenna impedance resistive for all transmitter frequencies (for maximum radiated power), the antenna can be resonated by adding inductors or capacitors to effectively increase or shorten its electrical length.

For example, if a vertical quarter-wave grounded antenna is less than a quarter wavelength long, its input impedance at its base will be resistive and capacitive. The antenna can be electrically lengthened (resonated) by adding the right size inductor to cancel the capacity, thus leaving the antenna resistive. The inductor must be placed in series with the antenna at its base as shown.

RESONATING A MARCONI ANTENNA



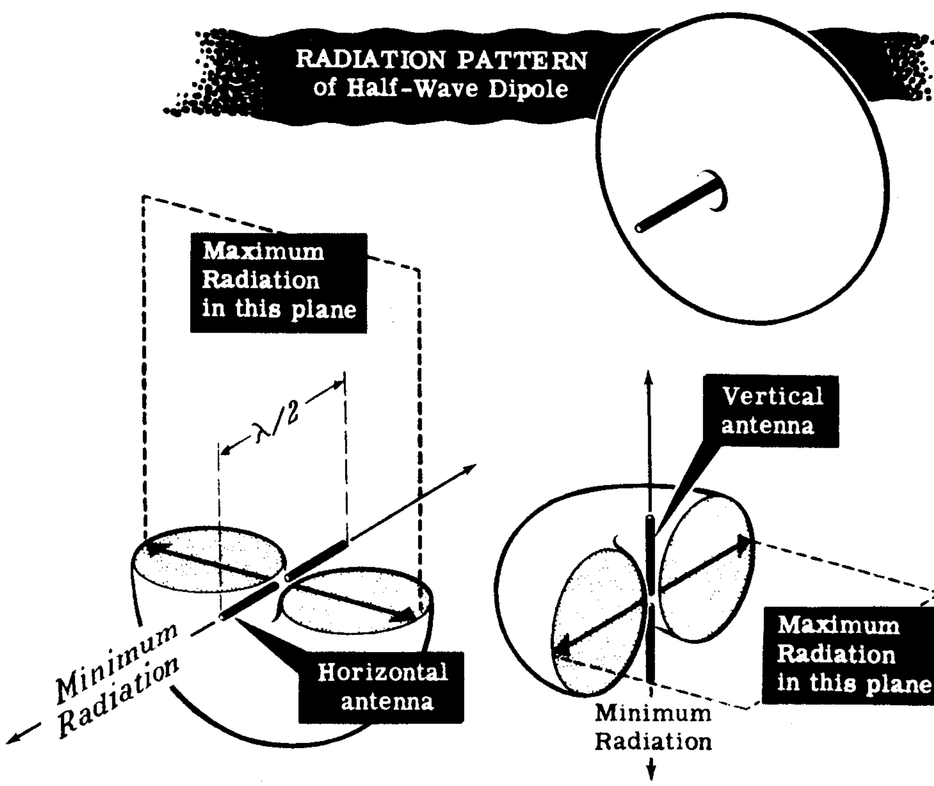
If a vertical quarter-wave grounded antenna is longer than a quarter wavelength, the input impedance at its base is resistive and inductive. The antenna can be electrically shortened by adding the right size capacitor to cancel the inductance, thus leaving the antenna resistive.



Radiation Pattern

When an antenna radiates electromagnetic waves, the radiation will be stronger in some directions than in others. The antenna is said to be directional along the line of strongest radiation which is at right angles to a point of maximum current on the antenna.

A radiation tester, called a "field strength meter," can be used to measure the radiation strength at all points around the antenna. If these field strength readings are plotted on a three dimensional graph, the three dimensional curve obtained will be the antenna radiation pattern. The radiation pattern for a horizontally positioned half-wave dipole is doughnut shaped as shown. Observe that the thickest part of the doughnut pattern is in a plane which is at right angles to the antenna at its center. Maximum radiation takes place in this plane. The thinnest part of the doughnut lies along its axis which corresponds to the line of minimum radiation. If the antenna is rotated 90 degrees in a vertical plane, maximum radiation occurs in a horizontal plane.



The above radiation patterns assume that the antenna is isolated in space away from all grounds. In actual practice, the antenna is located near ground surfaces so that the radiation pattern is altered appreciably from that shown above.

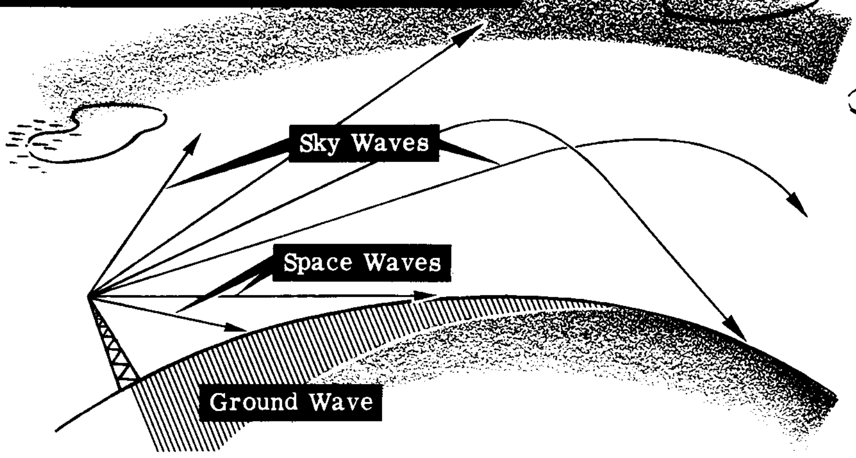
Wave Propagation

You know that the function of an antenna is to radiate electromagnetic energy into space. Once this energy is released from the antenna, it travels through space until it is picked up by a receiving antenna or is reflected off an object, as is the case with radar transmission.

It is important to know what happens to a radiated wave in space (namely, what its path is, if it is absorbed by the earth, if it is reflected by the sky, etc.) in order to tell how far the wave will travel before it can be picked up. The study of what happens to a radiated electromagnetic wave once it leaves the antenna is called "wave propagation."

When a radiated wave leaves the antenna, part of the energy travels through the earth following the curvature of the earth and is called the "ground wave." The rest of the energy is radiated in all directions into space. Those waves which strike the ground between the transmitter and the horizon are called "space waves." Waves which leave the antenna at an angle greater than that between the antenna and the horizon are "sky waves."

COMPONENTS OF A RADIATED WAVE

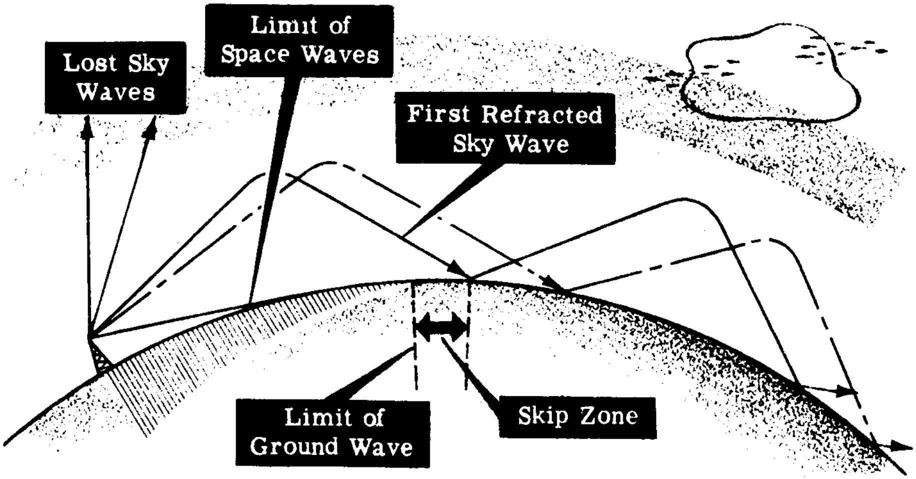


The ground wave, the space waves and the sky waves contain the transmitted intelligence. However, at certain frequencies one of the waves will be much more effective in transmitting the intelligence than the others. At comparatively low transmitted frequencies, most of the radiated energy is in the ground wave. Since the earth is a poor conductor, the ground wave is rapidly attenuated and therefore is not effective for transmission over great distances unless large amounts of transmitted power are used. The standard broadcast frequencies are examples of transmissions using ground waves. At these frequencies the effective radiating area is within 100 miles of the transmitter. As a result,neighboring cities more than 100 miles away from each other can transmit on the same frequencies and yet not interfere with each other.

Sky Wave and Ground Wave

At first one would be inclined to think that sky waves can serve no useful purposes since they will only travel straight out into space and get lost. For very high frequencies this actually happens and therefore the sky wave is useless. Below a certain critical frequency, however, the sky wave does not travel straight out but is bent back to earth in the upper layers of our atmosphere. This returning wave is not sharply reflected as is light from a mirror. It is bent back slowly as if it were going around a curve, and is therefore called a "refracted wave." This refracted wave, once it returns to earth, is reflected back to the sky again where it is once again refracted back to earth. This process of refraction from the sky and reflection from the earth continues until the wave is completely attenuated, since the energy of a radiated wave drops as its distance from the transmitting antenna increases.

A receiving antenna will be able to pick up a signal at every point where the refracted wave hits the earth. If the sky wave were radiated to the sky at only one angle, no signal would exist between points where the refracted wave hits the earth. The sky waves, however, are radiated at all angles to the sky and therefore the earth's surface (beyond a certain minimum distance from the antenna) is completely covered with radio signals. As the angle of radiation of the sky wave increases, an angle is reached where the wave is no longer refracted back to earth but continues traveling into space. As a result, there is a zone around the antenna in which no refracted sky wave hits the earth. The ground wave itself is only effective a short distance. Therefore, the zone between the maximum effective radiating distance of the ground wave, and the point where the first sky wave is refracted back to earth, is an area of radio silence (no signals) called the "skip zone."

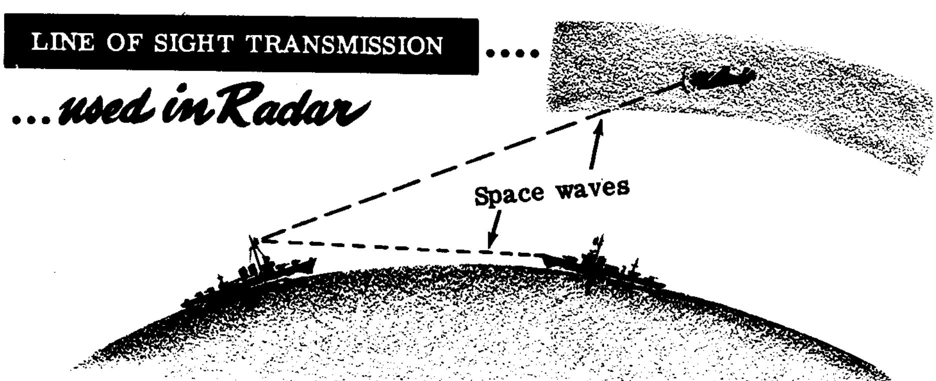


The critical frequency, which is the frequency above which no sky waves can return to earth, varies depending upon numerous factors such as the time of day, the time of year, the weather, etc. As a result, long distance communication can sometimes be achieved with frequencies which normally have no returning sky wave.

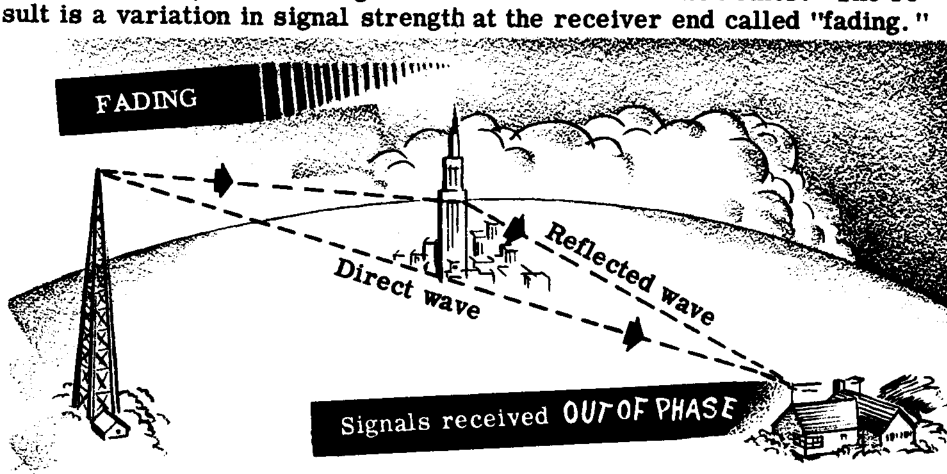
Space Wave and Fading

At frequencies above the critical frequency, neither the ground wave nor the sky wave can be used for transmission. At these high frequencies, the ground wave is rapidly attenuated and the sky wave is not refracted back to earth. As a result, the only radiated wave that can be used for transmission at these frequencies is one that travels in a direct line from the transmitting antenna to the receiving antenna. This type of transmission is called "line of sight transmission," and the radiated wave is called a "space wave."

Line of sight transmission is used in radar for detecting enemy craft and in ship-to-plane communication. The frequencies used are usually above 30 megacycles.



Sometimes a receiving antenna picks up two signals which have traveled along different paths from the same transmitting antenna. For example, one signal may travel direct from the antenna, and the other signal may have been reflected off an object. Since the signal paths are constantly changing, the two signals will sometimes be in phase and at other times be out of phase, thus tending to cancel or reinforce each other. The result is a variation in signal strength at the receiver end called "fading."



Frequency Spectrum

The following is an outline of the components of a radiated wave which are used for transmission at various frequencies:

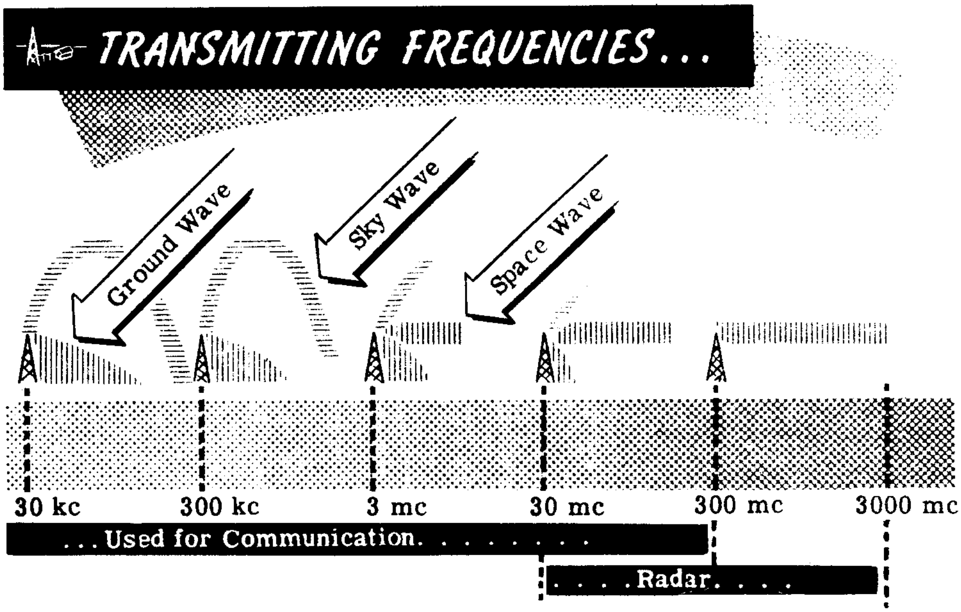
From 30 to 300 kilocycles (low frequency band) the ground wave is largely used for medium range communication since its stability is not affected by seasonal and weather changes. For very long distance communication, the sky wave is used.

From 300 to 3000 kilocycles (medium frequency band), the range of the ground wave varies from 15 to 400 miles. Sky wave transmission is excellent at night for ranges up to 8000 miles. In the daytime, however, sky wave transmission becomes erratic, especially at the high end of the band.

From 3 to 30 megacycles (high frequency band), the range of the ground wave decreases rapidly and sky wave transmission is highly erratic depending upon the seasonal factors previously mentioned. Space wave transmission begins to become important.

From 30 to 300 megacycles (very high frequency band VHF), neither the ground wave nor the sky wave are usable, and space wave transmission finds major application.

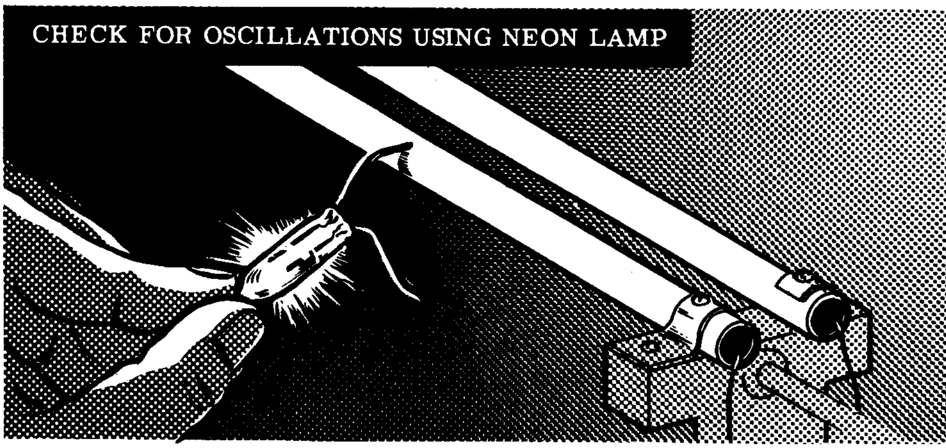
From 300 to 3000 megacycles (ultra-high frequency band UHF), space wave transmission is used exclusively.



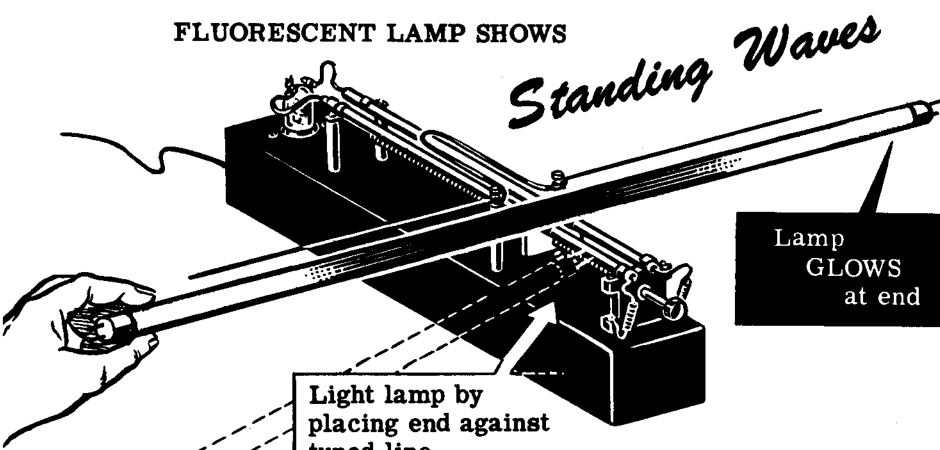
Demonstration—Current Distribution Along an Antenna

The very high frequency tuned-line transmitter is set to oscillate at about 160 megacycles. At 160 megacycles, a wavelength is about 6 feet long. Therefore, a quarter-wavelength is 1-1/2 feet (18 inches), which is the length of each pole of the doublet antenna.

The instructor connects a dipole antenna section to each transmitter output terminal. He then energizes the transmitter, and the oscillator tube filament starts to glow immediately. A quick check for oscillations is made by holding the glass end of a neon lamp and pressing one lead against one of the tuned lines. If the lamp glows it means that RF is present and therefore the tube is oscillating.

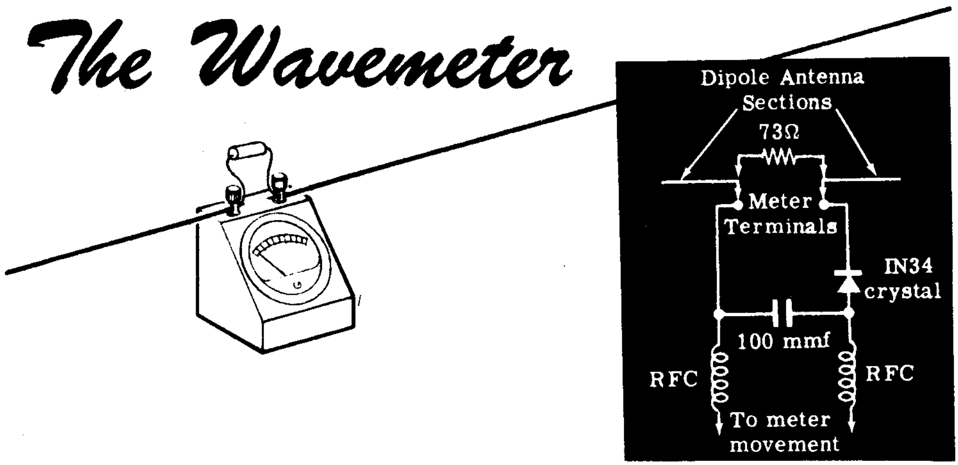


Once oscillations have been verified, the instructor demonstrates the presence of standing waves along the half-wave antenna by holding a fluorescent lamp close to and parallel with the antenna. The lamp is ignited by placing one end against the tuned line. The lamp glows at the ends and is out in the middle.

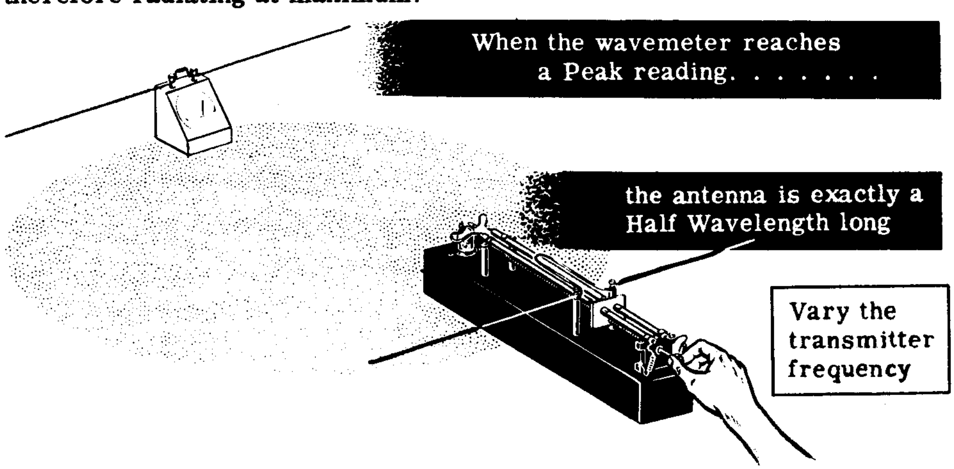


Demonstration—Radiation Pattern of an Antenna

To demonstrate the radiation pattern around the antenna, a wavemeter is used which is made up of a half-wave antenna connected to an RF current meter. A 73 ohm resistor is placed across the antenna input for proper termination and a germanium crystal diode and a capacitor are connected across the resistor. The crystal rectifies the RF and the capacitor filters out RF from the rectifier voltage. The DC milliammeter is connected across the capacitor through two RF chokes which block RF but pass DC through to the meter. When the antenna picks up RF radiation, the meter deflects an amount proportional to the intensity of the radiation.

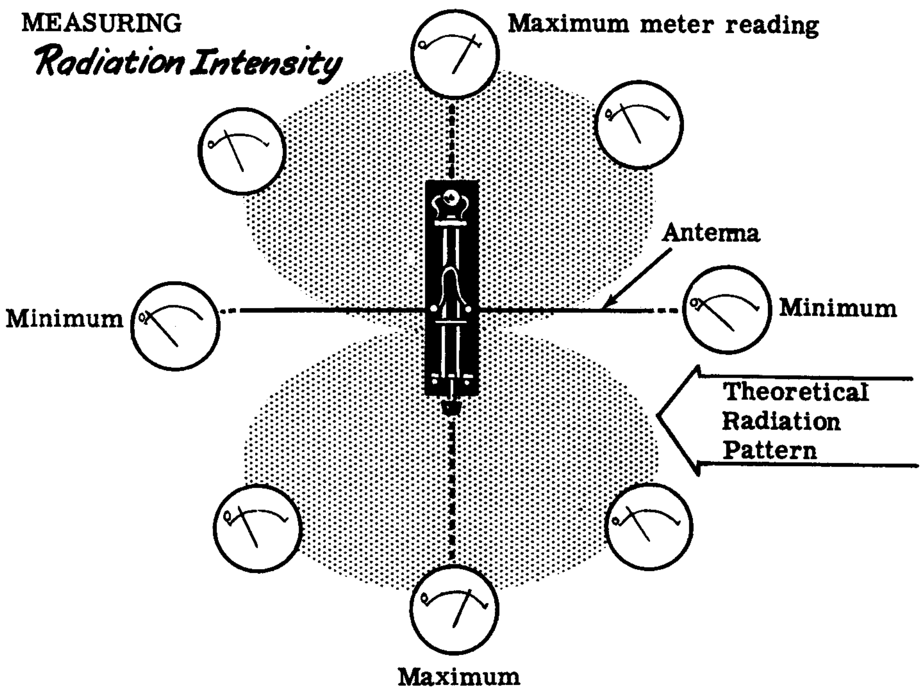


The instructor places the wavemeter far enough away from the transmitting antenna so that the meter needle does not deflect off scale. Then,the transmitter frequency is varied until the meter goes through a peak reading. At this point the transmitting antenna is exactly a half-wavelength long and is therefore radiating at maximum.

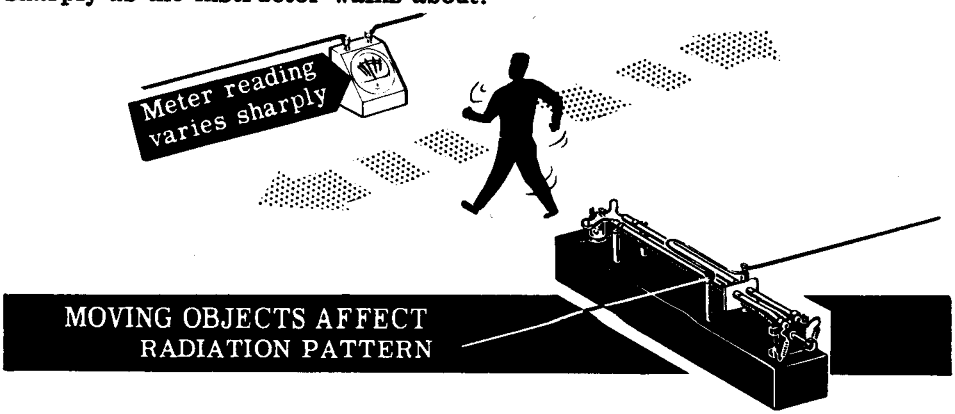


Demonstration—Radiation Pattern of an Antenna (continued)

Next, the instructor shows the intensity of the radiated field by placing the wavemeter at different positions around the antenna. Theoretically the radiation intensity is maximum in a plane at right angles to the antenna at its center and is minimum at the ends of the antenna. Actually this is not so since ground effects and multiple reflections around the room distort the radiation pattern.

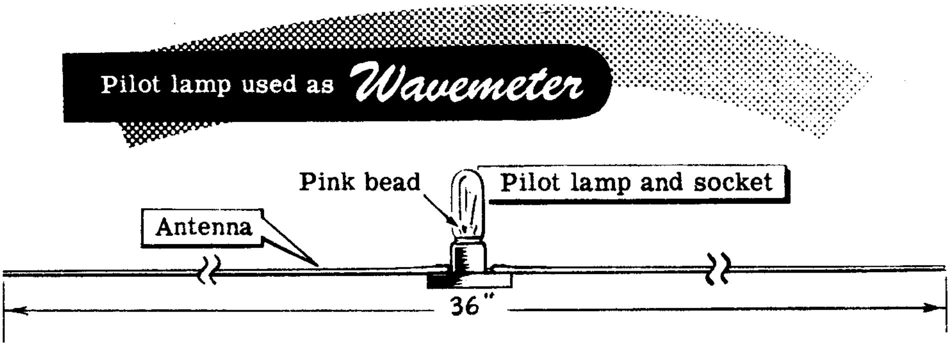


To show that movement of objects near the antenna affect the radiation pattern, the instructor sets the wavemeter down at a given point and walks between the meter and the antenna. Observe that the meter reading varies sharply as the instructor walks about.

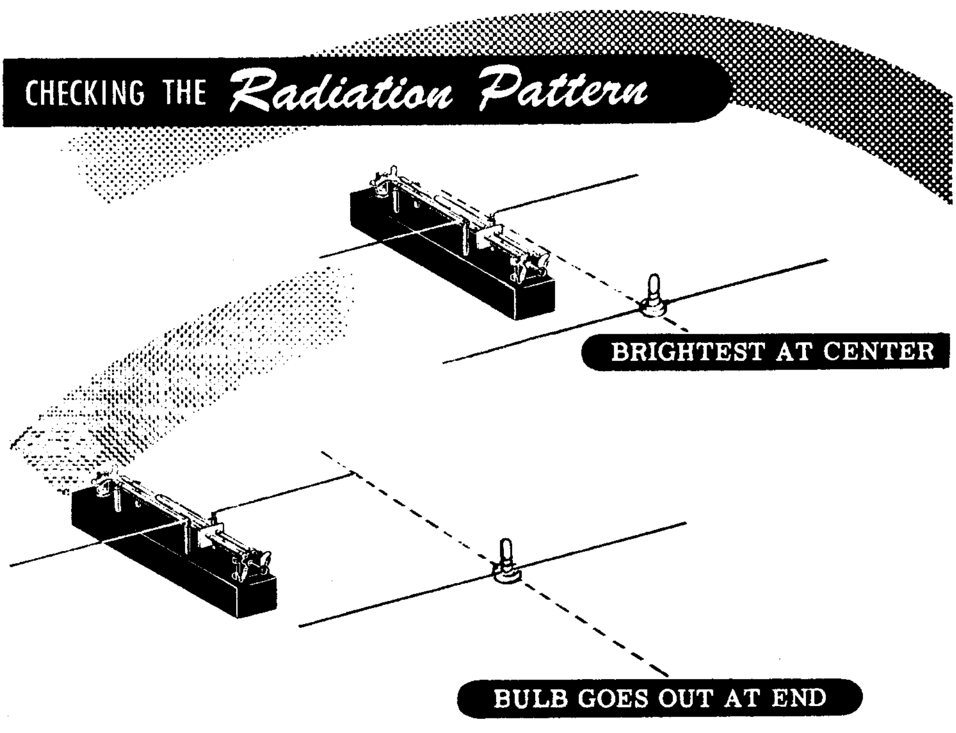


Demonstration—Radiation Pattern of an Antenna (continued)

The instructor demonstrates another type of wavemeter using a half-wave dipole connected to a pilot lamp. When the antenna picks up radiation, there will be a maximum of current at its center, which will flow through the lamp causing it to light.

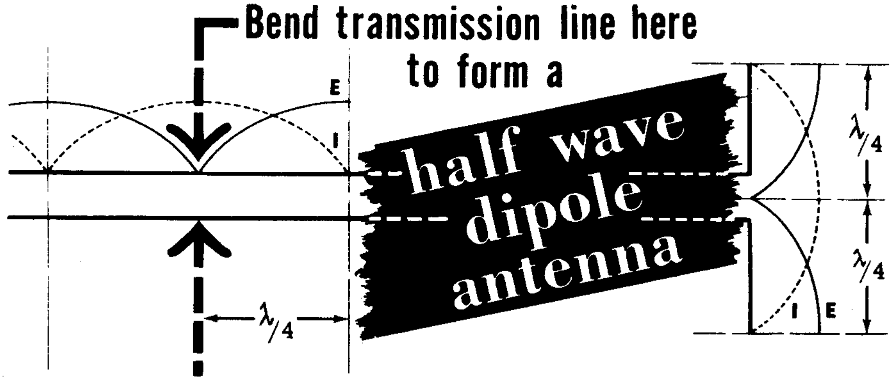


First, the transmitter is retuned until the bulb is brightest. Then, the intensity of the radiation around the antenna is demonstrated by moving the dipole, parallel to the antenna, from the center out to either end. Observe that the bulb is brightest when the center of the wavemeter dipole is lined up with the center of the antenna, and the bulb goes out when the center of the wavemeter dipole is in line with the end of the transmitting antenna.

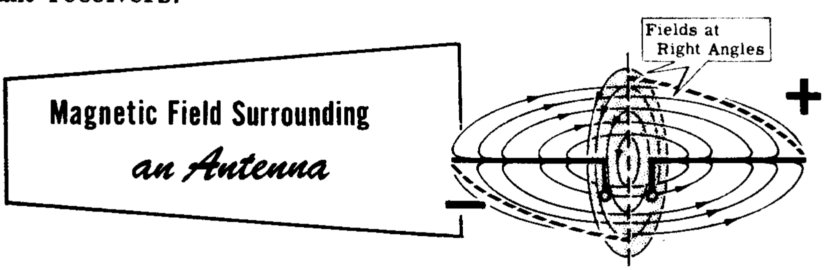


Review of Antennas

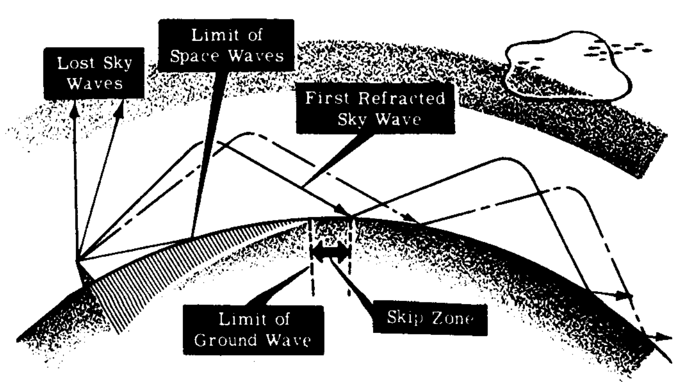
HALF-WAVE DIPOLE — A half-wave dipole antenna can be considered as a parallel wire transmission line whose wires are bent at 90 degrees to the line a quarter wavelength from the open end.



RADIATION — The voltage and current distributions along the antenna generate electric and magnetic fields at right angles to each other which are radiated into space as electromagnetic waves. These waves contain the intelligence of the modulating signal and can be detected by distant receivers.



WAVE PROPAGATION — The energy radiated from an antenna consists of sky waves, space waves and ground waves. Each of these is used for transmission at frequencies for which it is best suited.

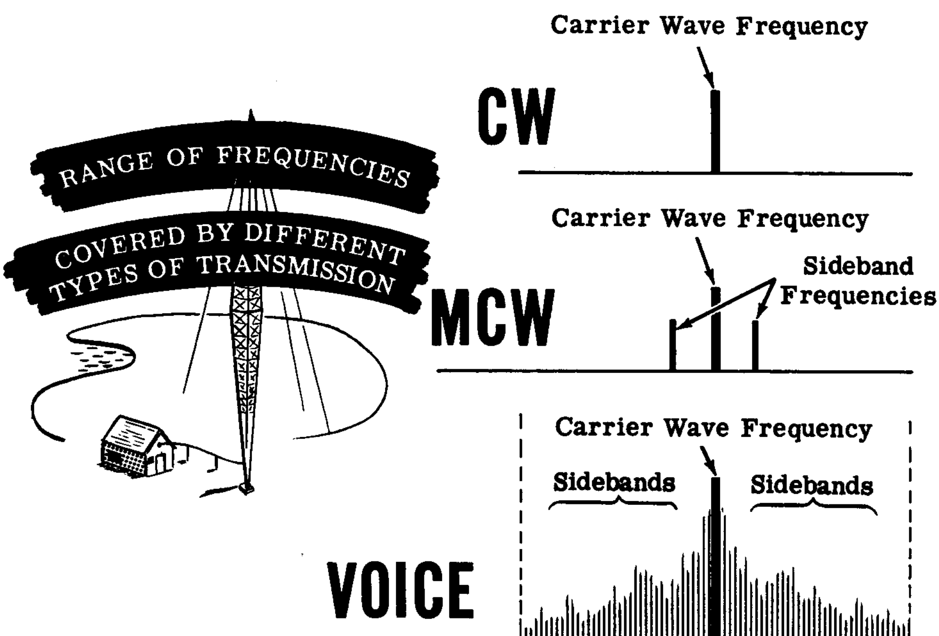


Advantages of CW Transmission

You may remember from the introductory topic on transmitters that a message can be transmitted by either code or voice. Code transmission is either CW (continuous wave) or MCW (modulated continuous wave). In both cases the RF radiated by the antenna is turned on and off by a hand key in dot and dash sequence.

CW transmission is used very widely. When a transmitter is modulated by voice or MCW, it sends out not only the carrier frequency, but also the sum and difference (beat) frequencies of the carrier and the modulation signal. These additional frequencies are called "sideband frequencies." A receiver, in order to pick up a voice or MCW signal, must be broadly tuned so that it will pick up both the carrier and the sidebands. As a result the receiver may pick up a nearby signal in addition to the desired one. This interference may make it impossible to understand the desired signal.

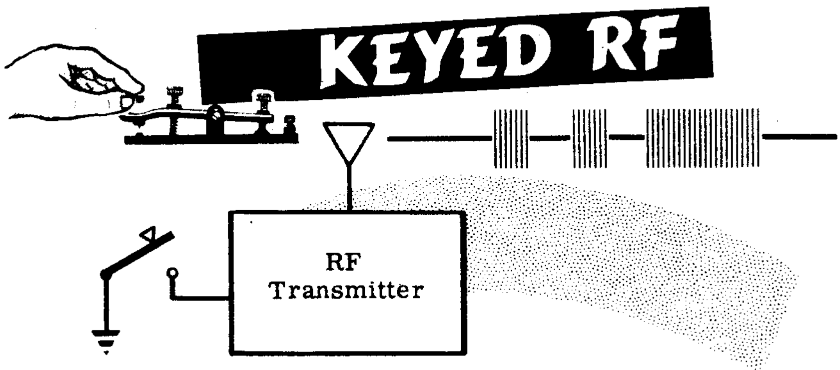
CW transmission, on the other hand, does not contain sidebands. Notice that the receiver would not need to cover as wide a range of frequencies for a CW signal as it would for a voice signal. Therefore, there is not likely to be interference when receiving a CW signal. This is the main advantage of CW over either MCW or voice.



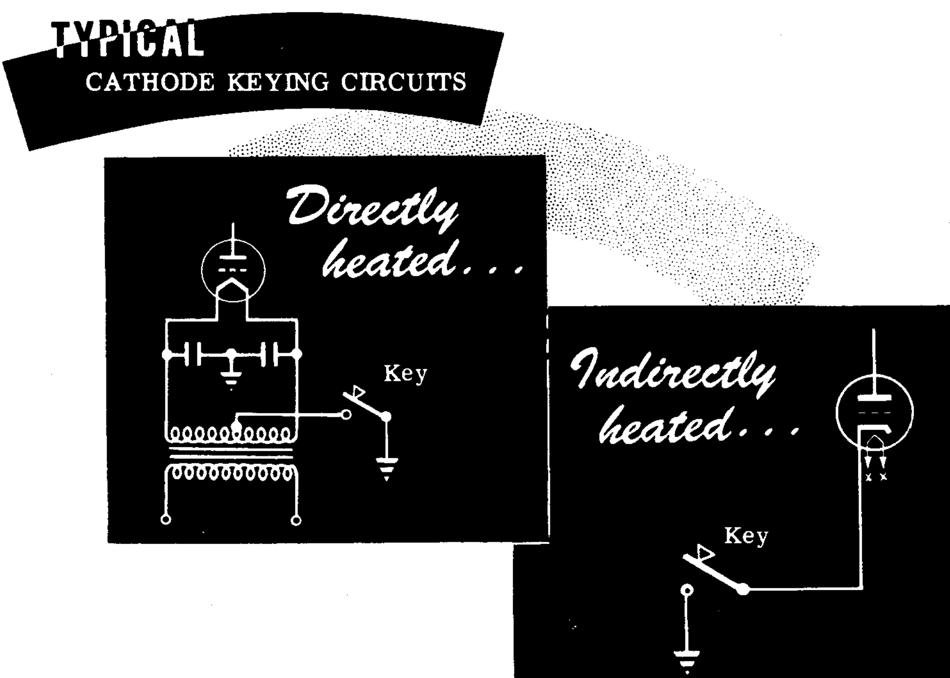
There are many different circuits which are used to obtain CW transmission. They look different and operate differently, but each has the same purpose—to turn the RF of the transmitter on and off. You will learn about some of these circuits on the next few sheets. In the next topic, you will find out more about MCW and voice transmission.

Cathode Keying

Regardless of the circuit used, the CW output of a transmitter looks like a series of pulses of RF separated by gaps of no RF. The gaps between the RF pulses occur when the key is up, while the length of each RF pulse is determined by the length of time the operator holds the key down.

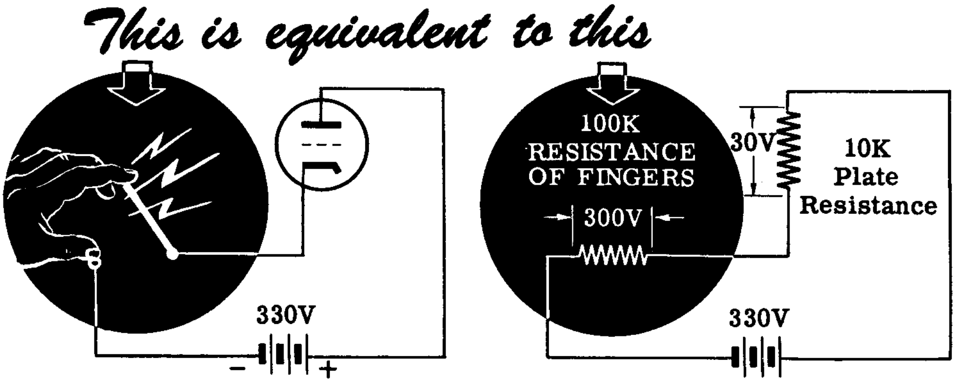


The simplest and most commonly used method of obtaining CW transmission is by "cathode keying." In this type of circuit, the key is connected in the cathode's DC return to ground. Thus, when the key is opened, no current can flow and no RF can be radiated from the antenna. When the key is closed, the circuit operates normally. The stage that is usually keyed in this manner is the master oscillator itself or the master oscillator plus one or more of the following amplifier stages.



Cathode Keying (continued)

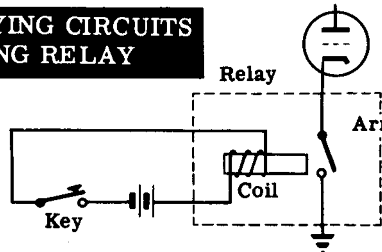
The disadvantage in using direct cathode keying is that the operator will get a shock if he gets his fingers across the key contacts, while the key is open. When the key is up, the series circuit of the key, tube and B+ is open at the key and no current can flow. With the operator's fingers across the contacts, the circuit is completed and current flows. The plate resistance of the tube and the resistance of that part of the operator's hand across the key contacts form a voltage divider circuit across B+. The resistance of the operator's hand will usually be large compared to the plate resistance, with the result that most of the B+ voltage will be across the key and therefore the operator's hand.



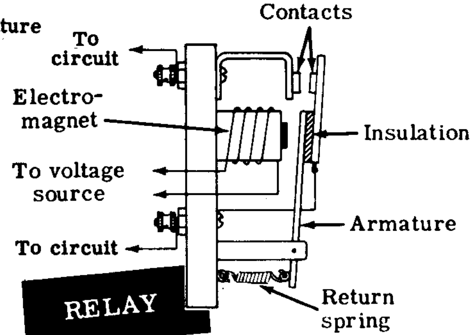
HOW A VOLTAGE DEVELOPS ACROSS THE OPEN KEY CONTACTS

To safeguard the operator, a slight variation is made on this basic circuit. The variation involves the use of a relay. The key is connected to a low voltage circuit containing the coil of the relay. When the coil of the relay is energized, the contacts of the relay, which are in series with the cathode circuit close, permitting the stage to operate normally.

KEYING CIRCUITS USING RELAY



The relay consists of soft iron core, a coil and an armature which will be attracted to the core when the coil is energized, thereby closing the contacts. A spring opens the contacts when the coil is de-energized.



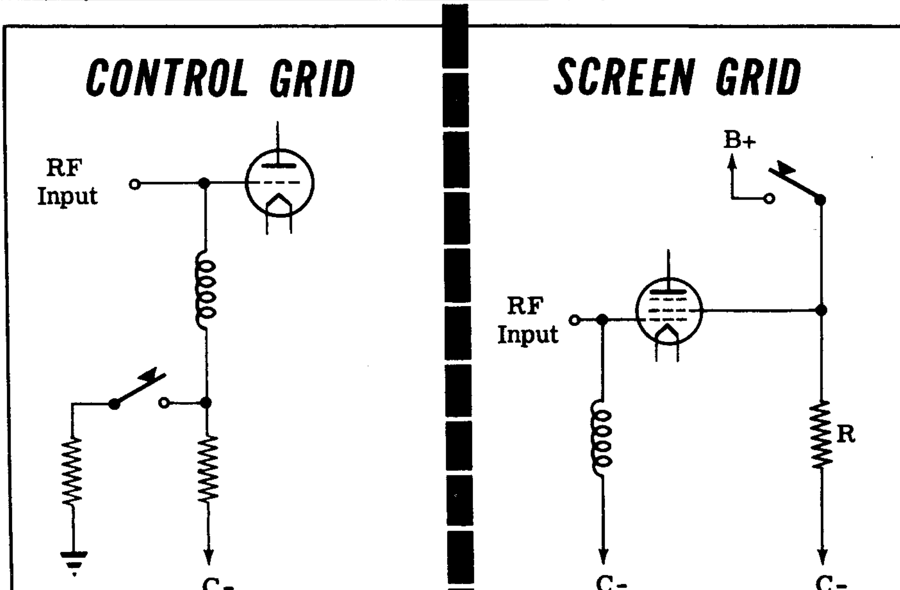
Blocked-Grid Keying

Keying can also be accomplished by changing the grid voltage of the stage being keyed. When the key is open, the grid bias is many times cut-off, so that the RF grid signal can never bring the tube into conduction. As a result, no RF signal appears at the plate. When the key is closed, the bias is the normal value for Class C operation and the stage operates normally. This type of keying is known as "blocked-grid keying."

In the circuit shown below, the key (or relay) controls the DC bias on the grid of an intermediate power amplifier. With the key open, the voltage on the grid is equal to C- which is many times cut-off. With the key closed, the grid is connected to a voltage divider which provides normal operating bias to the tube. Therefore with the key down, the transmitter is sending out an RF signal. This signal is interrupted each time the key is opened.

The same idea can be applied to the screen grid. The circuit on the right is for screen grid keying. In this circuit, the voltage varies from a positive operating voltage, with the key closed, to a negative blocking voltage with the key open. When the key is opened, the screen is connected through resistor, R, to C- which is sufficient to cut off the stage completely. When the key is closed, the screen is connected directly to B+. The purpose of R is to limit the current flowing from C- to B+ when the key is closed. In this circuit, as in the last, a relay (not shown) is used in place of the key to protect the radio operator from high DC voltages.

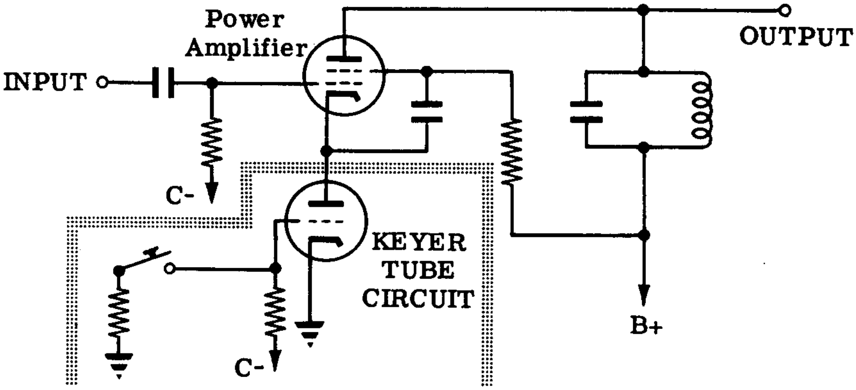
BLOCKED GRID KEYING CIRCUITS



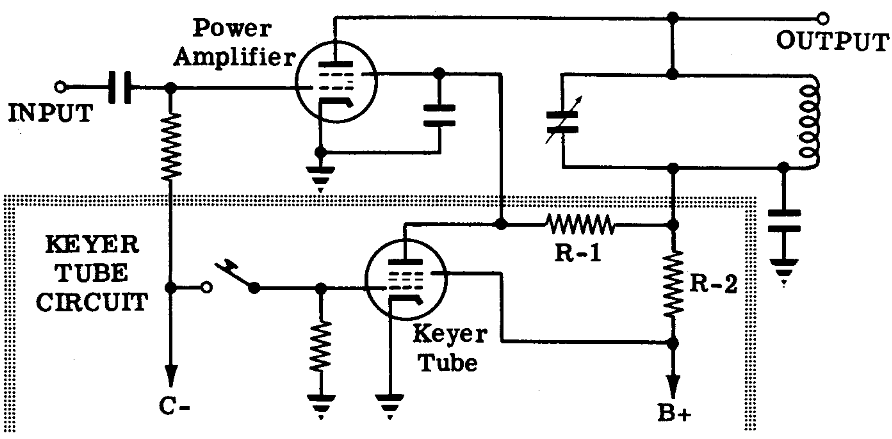
Keyer Tube Circuits

Relay or key contacts cannot close or open circuits as quickly as a vacuum tube can start or stop conducting. Therefore some applications use one or more vacuum tubes to key the RF circuits. These tubes are called "keyer tubes." There are several variations of keyer tube circuits, but they all turn the transmitter on when the hand key is closed and off when the key is opened.

In the circuit shown below, the keyer tube is connected in series with the cathode of the power amplifier tube. The transmitter will be on when the keyer tube conducts and will be off when the keyer tube is cut off. The keyer tube can be keyed by any of the blocked-grid keying methods described previously.



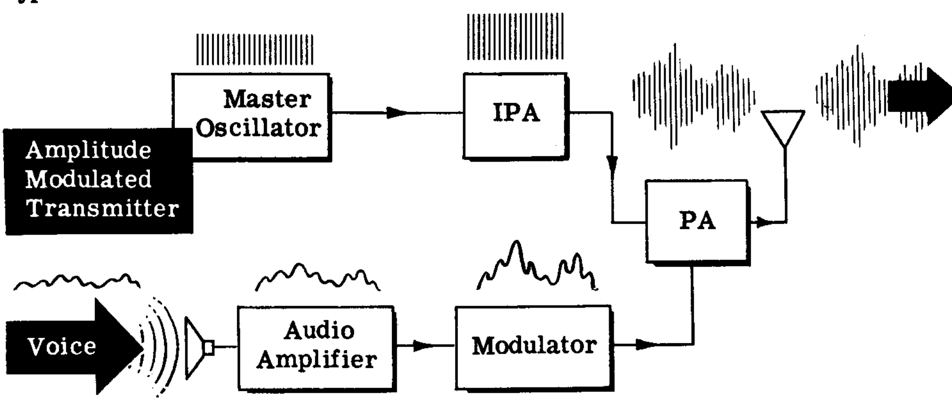
A simplified schematic of another type of keyer tube circuit is shown below. With the key open, current flows through R-1 and R-2 producing a large voltage drop across these resistors. Resistor R-1 is the PA screen dropping resistor and resistor R-2 is the PA plate dropping resistor. The keyer tube current flows through R-1 and R-2 causing the power amplifier's screen and plate voltages to drop, thereby cutting off the power amplifier. When the key is closed, C- is applied to the grid of the keyer tube so that it will be cut off. As a result, the screen and plate voltages of the power amplifier increase to their normal values, the power amplifier conducts, and the transmitted pulse is radiated from the antenna.



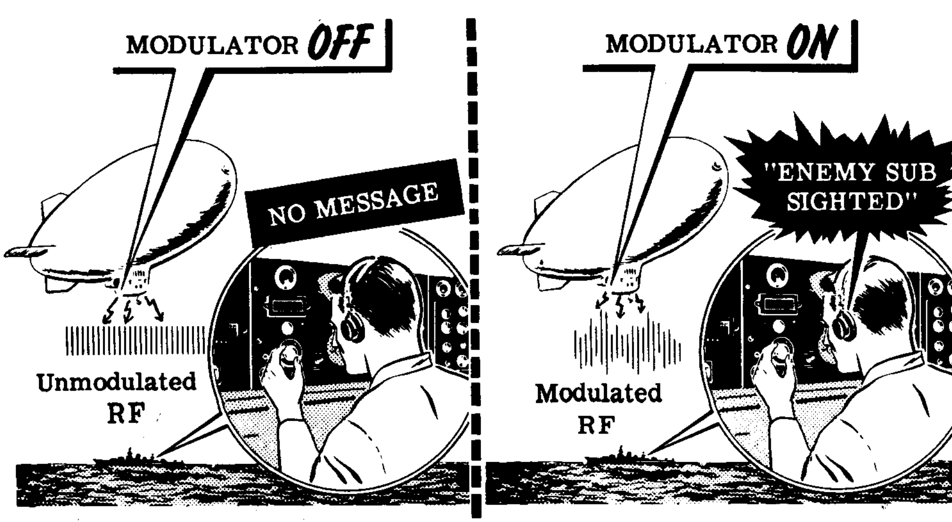
What Amplitude Modulation Is

The type of voice transmission most commonly used is one in which the amplitude of the carrier is varied in accordance with the amplitude of the voice signal. This method of modulating the carrier is called "amplitude modulation." MCW transmission is amplitude modulation in which a steady audio frequency is used, instead of voice, to vary the amplitude of the RF carrier.

In addition to the oscillator and power amplifiers, an AM transmitter contains a modulator, which applies the audio frequency signal to the PA where it is combined with the RF carrier wave. A block diagram of a typical voice AM transmitter is shown below.

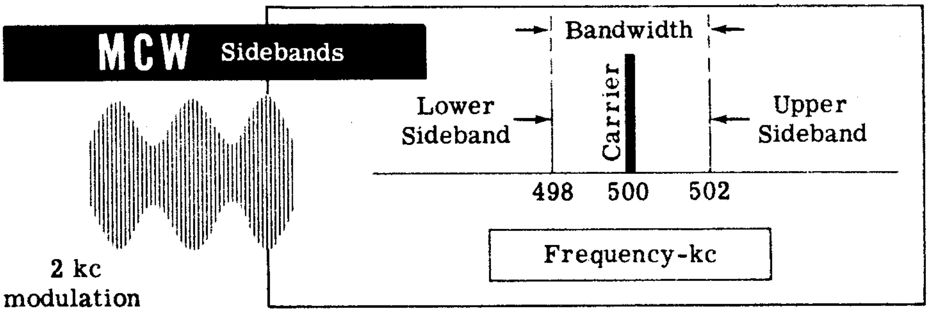


In the operation of an AM transmitter, it is essential that the modulator unit be on during transmission because the intelligence that is to be transmitted must come through the modulator. If the modulator is either off or defective, only unmodulated RF will be transmitted and a receiver at some distant point will not receive any message.

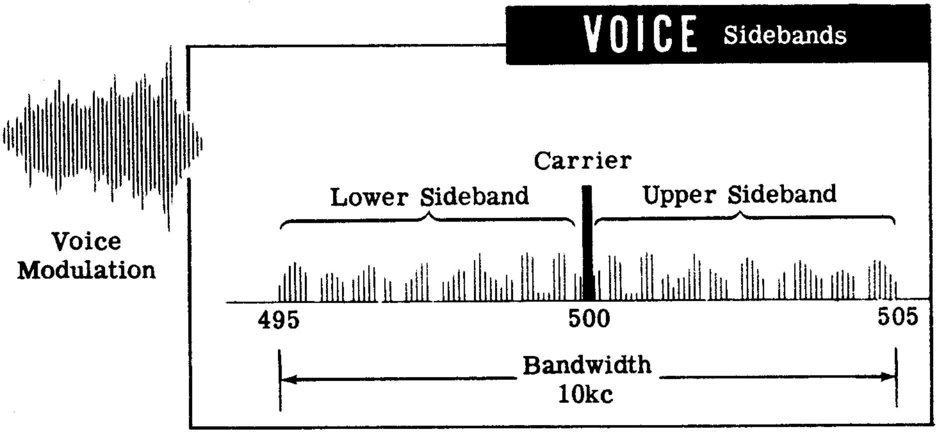


Sidebands

When an RF carrier is amplitude modulated, the effect is to add new frequencies to the transmitted signal in addition to the original carrier frequency. For example, if in MCW transmission a 500 kc carrier is modulated with a 2000 cycle audio note, the frequencies radiated by the antenna will contain, in addition to the carrier frequency, the sum (502 kc) and difference (498 kc) frequencies between the carrier and the modulating audio frequency. These new frequencies are called "sidebands"—the higher frequency being known as the "upper sideband" and the lower frequency the "lower sideband." The range of frequencies transmitted from the lower sideband to the upper sideband is known as the "bandwidth" of the transmission. In the above example the bandwidth is 4 kc—from 498 kc to 502 kc. If the modulating audio signal is reduced in frequency from 2000 to 1000 cycles, the sidebands will be closer to the carrier frequency and the bandwidth will be only 2 kc. It is the sideband frequencies, and not the carrier frequency, that contain the intelligence of the transmission. If, for example, an MCW receiver were to pick up only the carrier and exclude the sidebands, no intelligence would be heard.

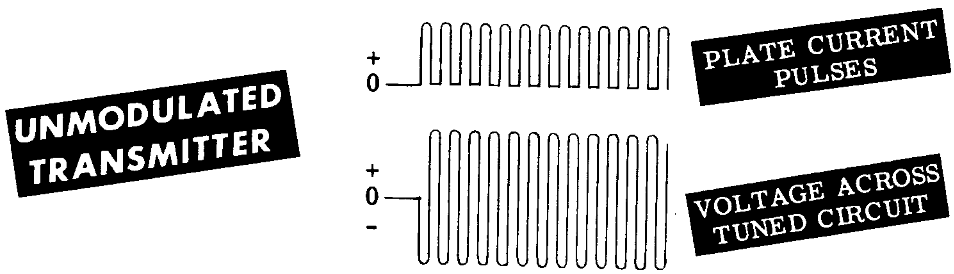


In a voice transmission, the modulating signal contains many frequencies —some as high as 5000 cycles per second. As a result, voice transmissions contain many sidebands (one sideband for each frequency) which may be as much as 5 kc above and 5 kc below the carrier frequency. This type of transmission, therefore, may cover a range of frequencies 10 kc wide.

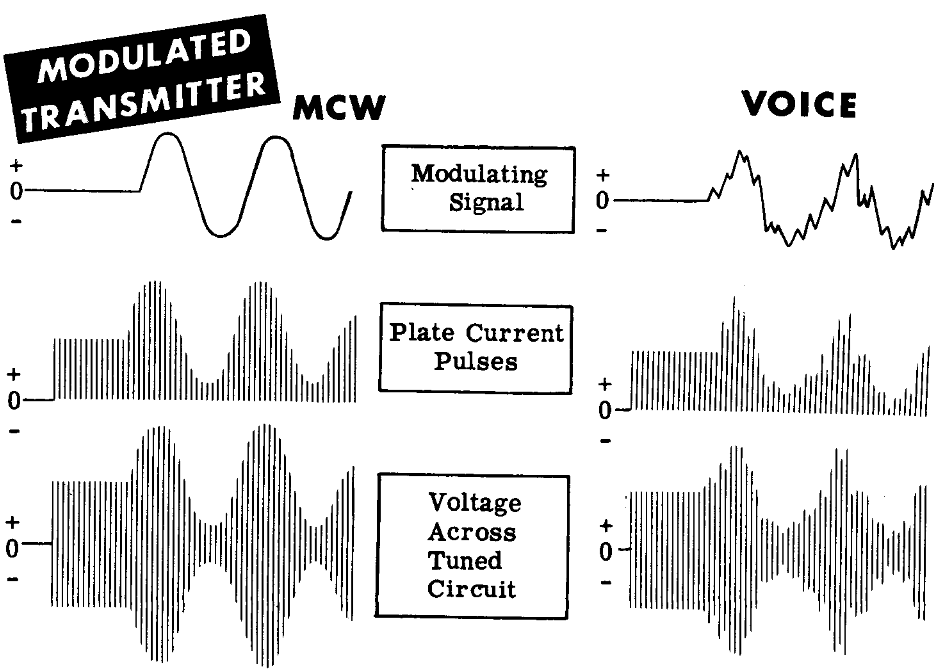


How Modulation Is Accomplished

In an unmodulated transmitter, the amplitudes of the plate current pulses in the Class C amplifiers are the same, cycle after cycle. These plate current pulses flow to an LC circuit which is tuned to the RF frequency or a multiple of it. The pulses of current deliver a certain amount of power to the tuned circuit and this power remains the same for each cycle. Therefore,the amplitude of RF voltage across the tuned circuit remains the same for every cycle.



When the transmitter is modulated, the amplitude of the plate current pulses is made to vary according to the amplitude of the modulating signal. Thus the amplitude of the RF current varies from one cycle to the next and the power delivered to the tuned circuit also varies. This varying power causes the RF voltage across the tuned circuit to vary. These variations will follow the modulating signal in amplitude and frequency. This is how modulation is accomplished.



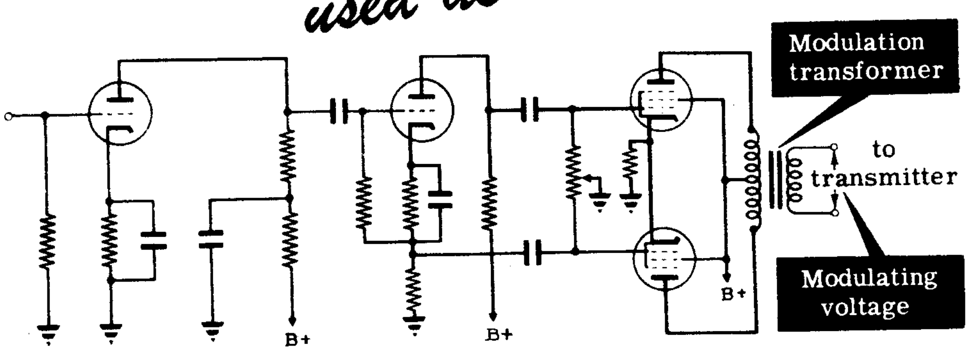
The Modulator

In MCW and voice amplitude modulation, a modulator is used to impress the audio on the RF. For voice, the modulator is nothing more than an ordinary audio amplifier which provides the voltage or power needed to vary the amplitude of the transmitter's RF. For MCW, the modulator contains an audio oscillator which drives the audio amplifier. The output is a pure sine wave which varies the amplitude of the RF pulses in the same manner as the amplitude of the audio varies.

Since the modulator is connected to the stage of the transmitter that is to be modulated, its output must be of sufficient power to produce the necessary variations of current in the modulated stage of the transmitter. For this reason, Class B push-pull amplifiers are often used as the final stage in the modulator unit.

The following schematic illustrates a push-pull amplifier which can be used as a modulator. It is almost exactly the same as the push-pull amplifier shown in Volume 2 of Basic Electronics. The only difference lies in the modulation transformer which has a different turns ratio and higher current capacity than the previously used output transformer.

PUSH-PULL AMPLIFIER *used as a modulator*



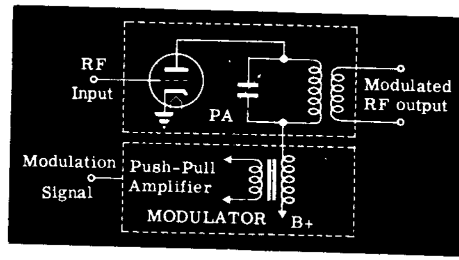
The modulating voltage may be applied in series with any of the tube's elements. The name of the type of modulation used depends on the tube element to which the secondary winding of the modulation transformer is connected. For example, plate modulation is achieved by connecting the output of the modulator in series with the plate circuit. Other types of modulation used with triode tubes are grid modulation and cathode modulation. In pentode tubes, screen grid modulation or suppressor grid modulation may be used in place of the other methods.

Plate Modulation

In the simplified circuit of the power amplifier shown below, the modulating audio voltage is applied to the plate of the tube. The audio voltage, since it is in series with the DC plate supply voltage, will cause the total applied plate voltage to vary above and below B+ by an amount equal to the peak audio voltage and at a rate equal to the frequency of the audio.

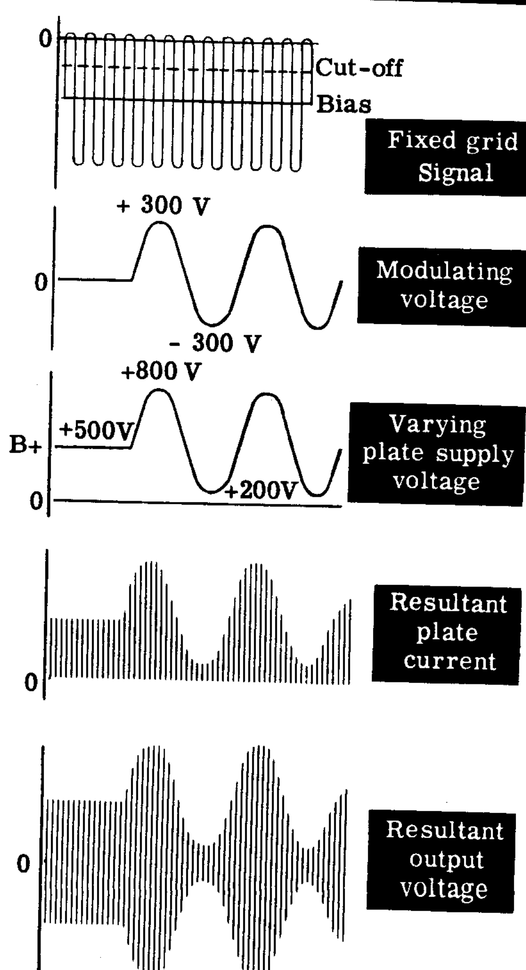
Simplified circuit for

Plate Modulation



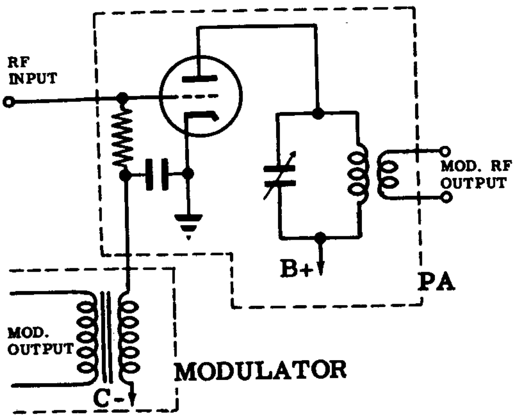
While the applied plate voltage is varying, a constant amplitude of RF is being fed to the grid of the tube from the output of the previous stage, the IPA.

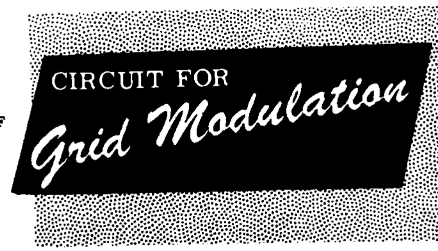
During the positive cycles of the audio, the plate voltage of the PA is higher than B+ and as a result more plate current flows. Therefore, on the positive half-cycles of the AF modulating voltage, a greater RF voltage is developed across the tuned circuit. During the negative cycles of the audio, the plate voltage is lower than B+, resulting in less current flow and less voltage developed. As a result, the amplitude of the output voltage varies in the manner shown. The wave illustrated is an amplitude modulated wave.

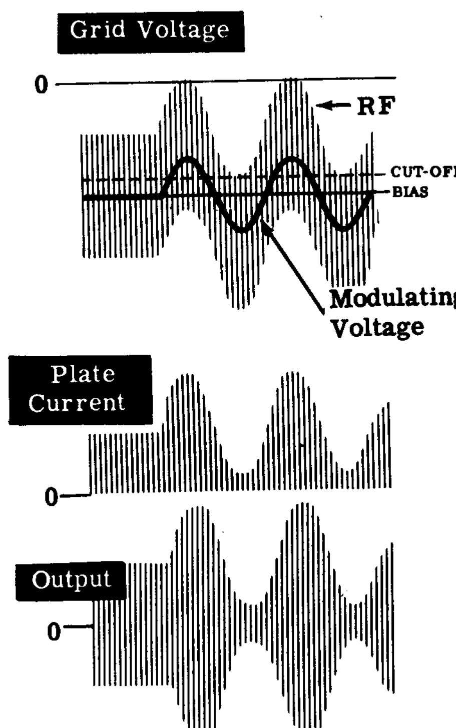


Grid Modulation

If the audio voltage is applied in the grid circuit instead of the plate circuit, you have grid modulation. The effect of the modulating voltage is to vary the grid bias at an audio rate. As a result of this, the plate current that flows during each RF cycle will vary as the grid bias increases and decreases.







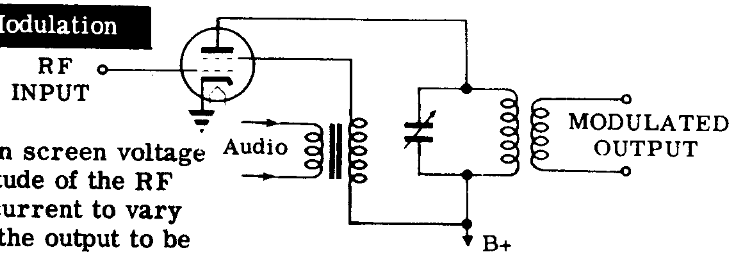
In the accompanying wave forms you can see that the total grid voltage is the sum of three voltages—the RF input voltage, the AF modulating voltage and the DC bias voltage. During the positive half-cycles of the modulating voltage the bias decreases and during the negative half-cycles, the bias increases. Since the RF will always vary about the bias level, the positive cycles of RF are raised during positive modulation peaks and depressed during the negative modulation peak. As a result, the plate current pulses are larger in amplitude during the positive half-cycles of the audio voltage than during the negative half-cycles. Since the voltage developed across the plate tank varies with the plate current amplitude, the RF output voltage also varies according to the modulating signal.

Grid modulation is used in compact or mobile transmitters because this type of modulation does not require a modulator with a large power output. When the modulator's weight is only a minor consideration, plate modulation with the larger modulator it requires is used because it produces much better results than grid modulation.

Other Methods of Modulation

Plate voltage has almost no effect on the plate current in a pentode or a tetrode and in these tubes plate modulation is never used. Instead the audio voltage is applied to the screen grid and the results are almost identical to those of plate modulation with a triode.

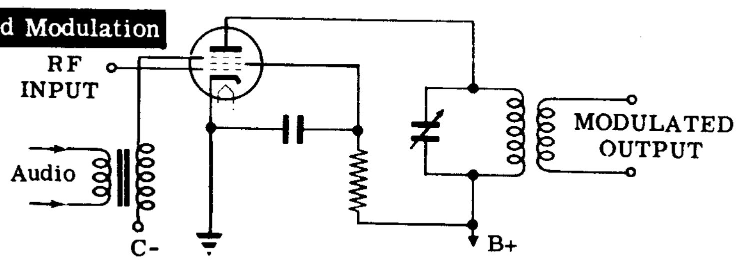
Screen Grid Modulation



The variations in screen voltage cause the amplitude of the RF pulses of plate current to vary and this causes the output to be modulated by the audio signal.

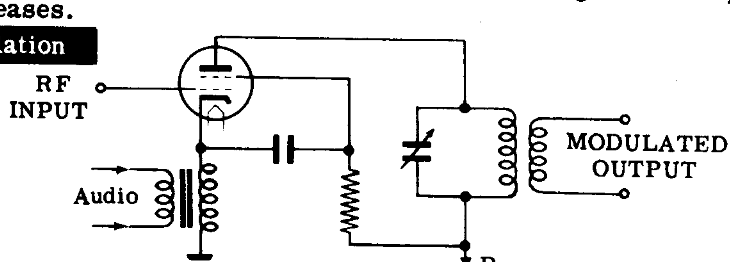
Modulation can also take place when the audio output of the modulator is connected in the circuit of the suppressor grid. With a negative voltage on it, the suppressor can control plate current the same way a control grid can, except that the tube is less sensitive to voltage changes on the suppressor. Of course, only pentode tubes which have external connections to the suppressor can use this type of modulation. The operation is very similar to control grid modulation and the modulator does not need a large power output.

Suppressor Grid Modulation



If the audio voltage were applied to the cathode (or filament) of the tube, the cathode's voltage would vary with respect to ground. This would have the same effect as applying the audio voltage to every other element in the tube simultaneously; applying the voltage to the cathode causes the voltage on every other tube element to vary with respect to the cathode. Therefore cathode modulation is, in effect, a combination of the other types of modulation. The only difference is that as the cathode's voltage is raised, the current decreases.

Cathode Modulation

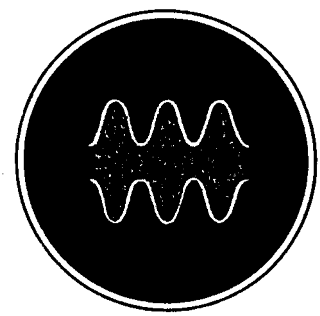


Time Base Modulation Pattern

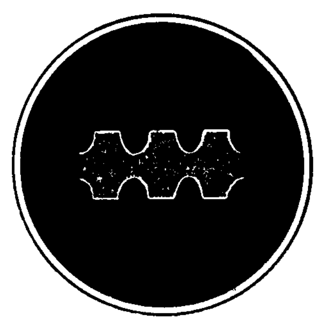
The oscilloscope can be used to good advantage to indicate the extent to which the output of a transmitter is modulated. It can also point out distortion existing in the modulation. If a pickup loop, which is connected to the 'scope input terminals, is brought close to the plate tank coil in the output circuit of a modulated transmitter, the 'scope will show the modulation pattern.

TIME-BASE *Modulation Pattern*

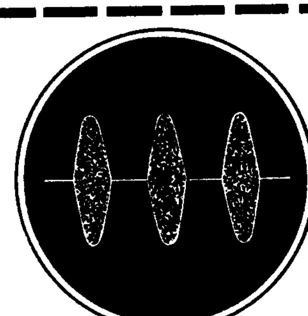
If the modulating voltage is a sine wave (as in MCW) and the sweep (called the time-base) is produced inside the oscilloscope, the pattern on the right is obtained. This pattern is useful in determining the presence of distortion.



A pattern such as this would indicate that the positive peaks of the modulating voltage are not causing corresponding peaks in plate current. This may be due to improper grid bias, saturation due to low emission, or insufficient excitation of the power amplifier stage.



If the transmitter output shows breaks in the modulation pattern, the transmitter is said to be "over-modulated." This is usually due to excessive modulating voltage but may also be due to insufficient signal voltage on the grid or excessive grid bias voltage.



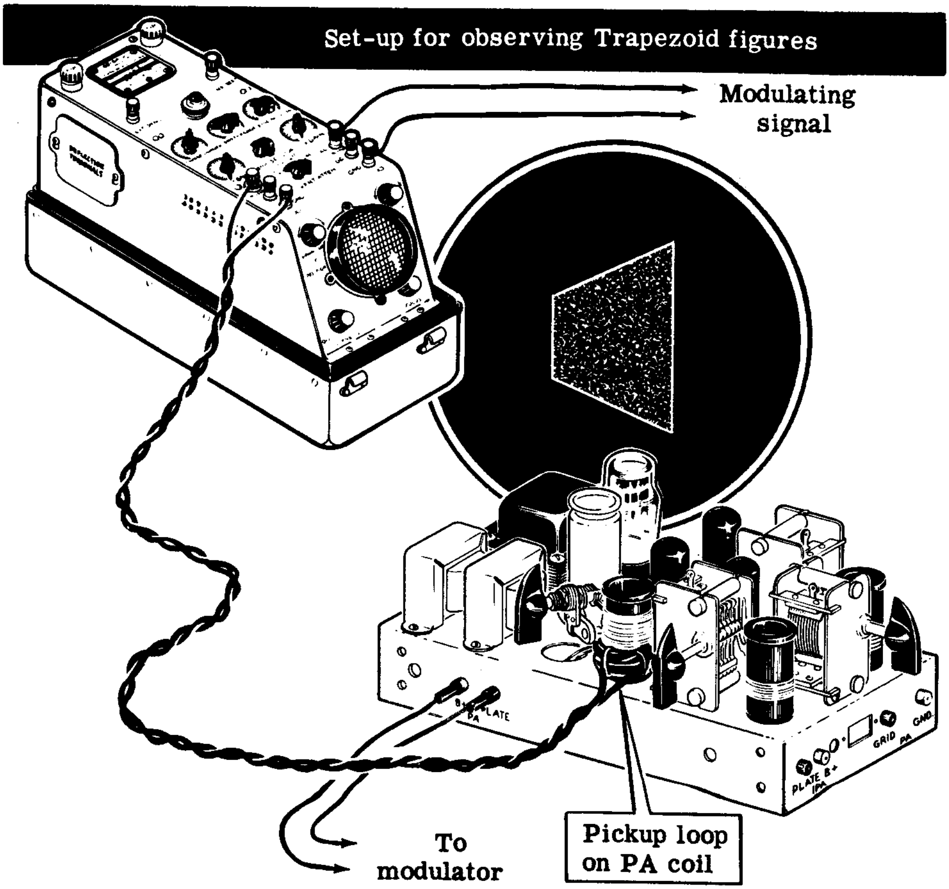
Trapezoid Figure

The trapezoid figure is another type of oscilloscope pattern that is often used to determine the presence of distortion in the modulated signal and also how much the signal is being modulated. The trapezoid figure has the advantage of making possible the detection of certain types of distortion which cannot be detected by means of the time-base pattern. To produce the trapezoid figure, the modulating signal is used as an external horizontal sweep signal instead of the internal sweep of the 'scope. The vertical deflection is still the modulated RF output of the transmitter. The advantage of using trapezoid figures over time-base modulation patterns to analyze the operation of a transmitter is that they are easier to interpret.

A typical set-up for showing trapezoid figures is illustrated below. The vertical input of the 'scope is coupled to the plate coil of the power amplifier and the horizontal input is coupled to the audio output of the modulator.

In order to understand how trapezoid figures are formed, you have to know something about the action of the vertical and horizontal plates inside the cathode ray tube.

Set-up for observing Trapezoid figures

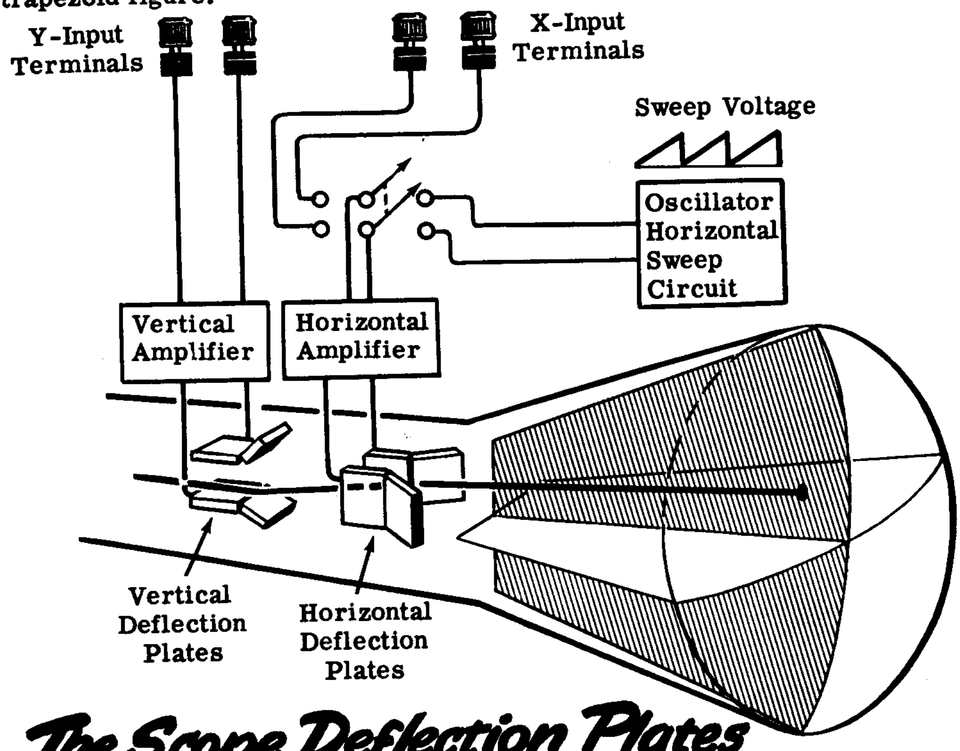


Trapezoid Figure (continued)

The picture you see on an oscilloscope screen is the path followed by a beam of electrons striking the inner surface of the cathode ray tube. In the cathode ray tube there are two pairs of metal plates which deflect the electron beam from its path. The top and bottom plates are called "vertical plates" because they move the electron beam vertically. The left and right plates are called "horizontal plates" and they move the electron beam horizontally from left to right.

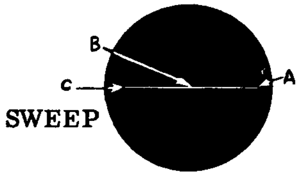
The vertical plates are connected to the signal under observation. This signal displaces the electron beam in a vertical direction. Under normal operating conditions, the horizontal plates are connected to the output of an oscillator built into the oscilloscope. This oscillator, called a "sweep" oscillator, generates a saw tooth voltage which sweeps the electron beam across the face of the 'scope screen, from left to right, at a constant speed. If the input signal to the vertical plates is the familiar sine wave of voltage, the combined action of this signal and the horizontal sweep acting on the electron beam produce the sine wave picture.

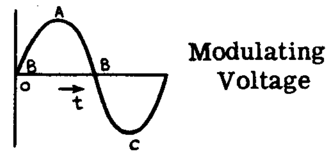
Sometimes the internal horizontal sweep is disconnected and an external signal is used as the sweep voltage. This is what is done to produce the trapezoid figure.



The Scope Deflection Plates

Trapezoid Figure (continued)

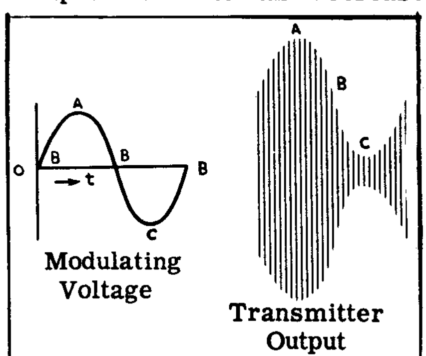


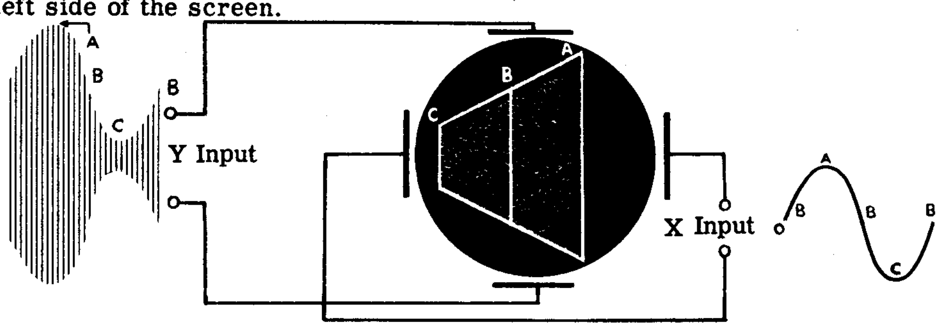


The trapezoid figure is produced in the following manner. When the modulating voltage is at its most negative value, the 'scope sweep (which is produced by the modulating voltage) will be at the left of the 'scope screen. As the modulating voltage increases to its most positive value, the electron beam will swing over to the right side of the screen (Point A). When the modulating voltage is at its most negative value, the spot will be on the left (Point C). If the modulating voltage were a perfect sine wave, the electron beam would be midway between the sides of the trapezoid figure (Point B) when the modulating voltage is zero. At any instant the position of the electron beam in the horizontal direction is a measure of how negative or positive the modulating voltage is.

At the same time that the electron beam is moved from one side of the screen to the other under the influence of the modulating voltage, the modulating voltage is causing the transmitter output to increase and decrease.

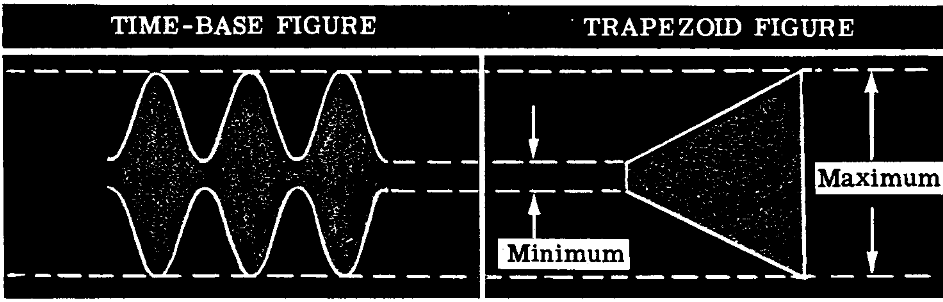
The transmitter output is applied to the 'scope to produce vertical deflections. When the modulating voltage is at its positive peak, the transmitter output and the height of the 'scope picture are greatest. Thus, the right side of the trapezoid figure shows the largest amplitude. When the modulating voltage is at its negative peak, the transmitter output and the height of the 'scope picture are at their minimum. This occurs when the electron beam is at the left side of the screen.





Because of the way in which trapezoid figures are obtained, they represent a graph of the output voltage as compared to the modulating voltage. If the output voltage is always proportional to the modulating voltage—as it will be when the modulation is linear—there will be a straight line along the top and on the bottom of the trapezoid.

Trapezoid Figure (continued)

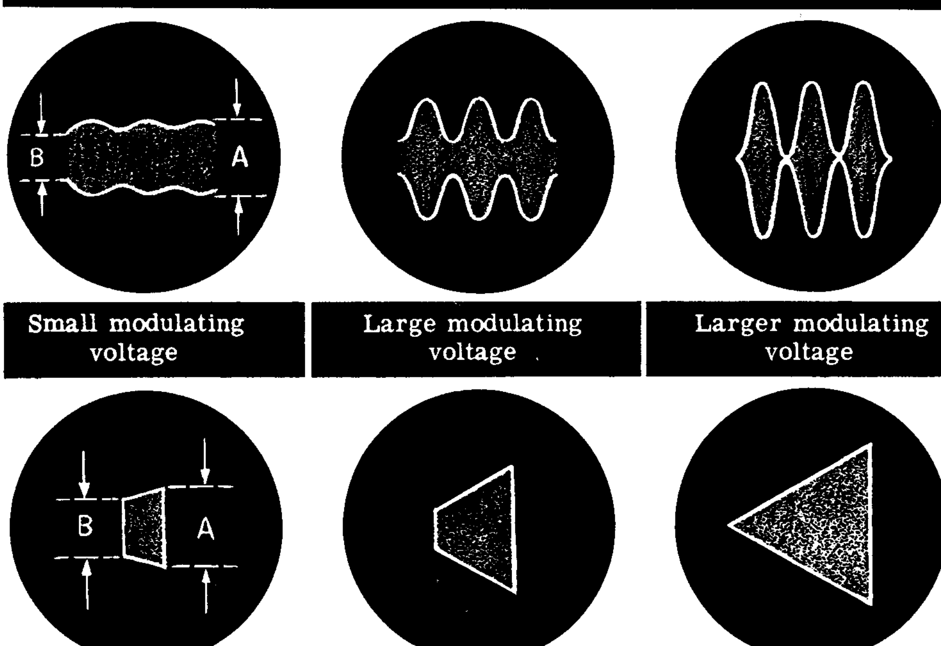


The two 'scope presentations shown above are for the same condition of modulation. You could determine the maximum height (peak) and the minimum height (trough or valley) of the RF from either figure. You could also determine the linearity of the modulation from either presentation, but it is easier to do so from the trapezoid.

If the modulating voltage is varied in amplitude, the peak and trough points on the time-base wave pattern come closer together. The same effect is seen in the trapezoid pattern as a decrease in the horizontal and vertical dimensions.

The following illustrations show both types of wave form presentation for three different modulating voltage amplitudes.

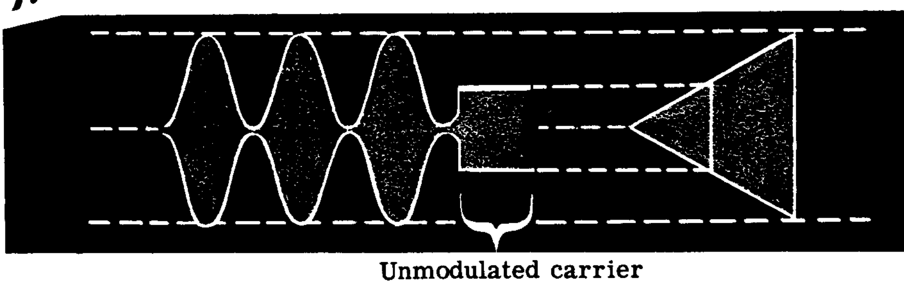
EFFECT OF VARYING AMPLITUDE OF MODULATING VOLTAGE



Percentage Modulation

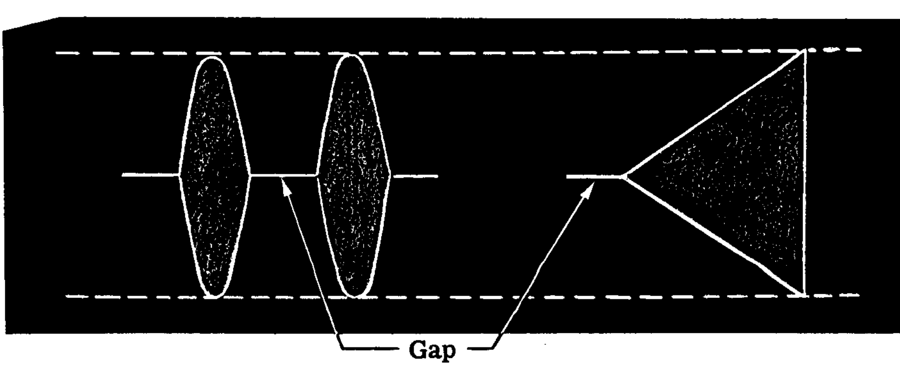
The percentage modulation is a measure of the extent to which the carrier is modulated. If the carrier is modulated 100 percent, the maximum height of the modulated wave is twice that of the unmodulated wave and the minimum height is zero. The trapezoid figure is a triangle for this modulating condition. In voice communication the goal is always 100 percent modulation because the RF signal is then transmitted at maximum power.

100% Modulation — For maximum power in transmission. modulate 100%



If the maximum height of the modulated wave is more than twice that of the unmodulated wave and the minimum height is zero for more than an instant during the cycle, the carrier is overmodulated. The percentage modulation is more than 100 percent. This condition is characterized by gaps in the time-base figure and a line extending from the left side of the triangle in the trapezoid figure. The more the wave is overmodulated, the longer are the gaps of the time-base figure and the longer the line in the trapezoid figure. Overmodulation is undesirable because it distorts the signal and generates unwanted sidebands which may interfere with adjacent carrier frequencies.

Overmodulation — distorts the signal and interferes with other carrier frequencies



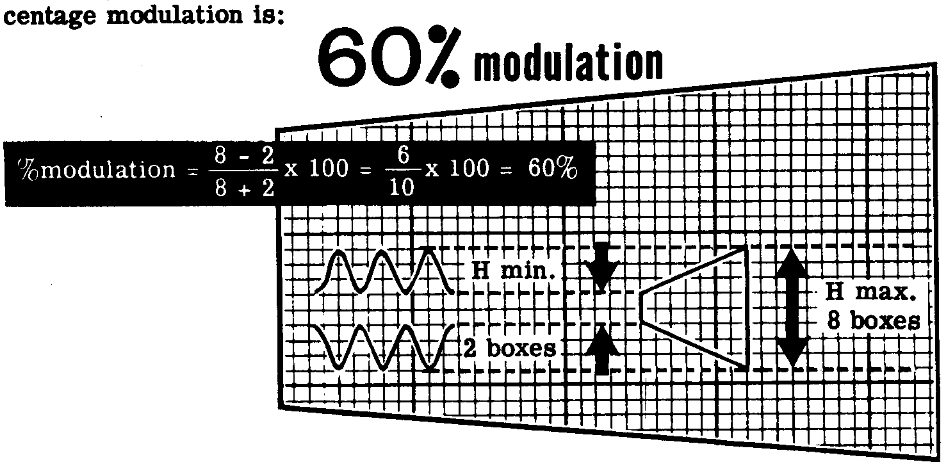
Percentage Modulation (continued)

Sometimes it is desirable to know the exact percentage of modulation. If the maximum height of the modulated wave is less than twice that of the unmodulated wave and the minimum height is more than zero, the percentage modulation is less than 100 percent. This is the most common condition. The exact percentage modulation can be calculated using the formula below.

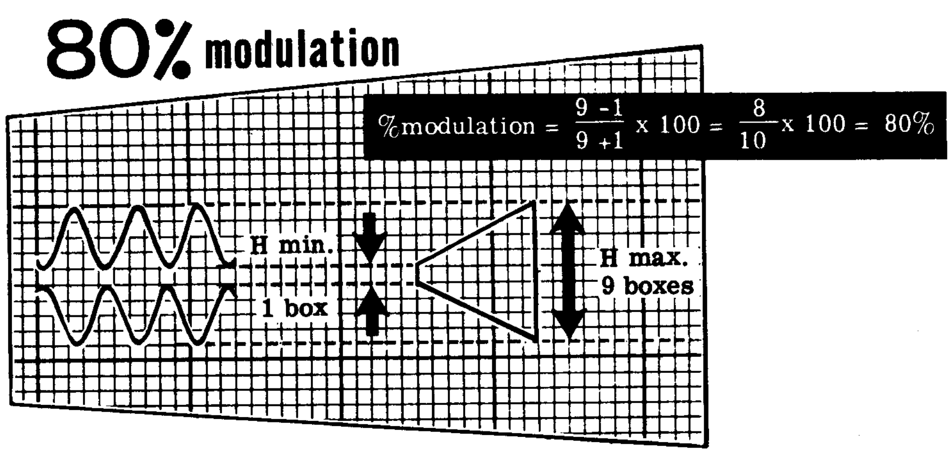
$$\%\ \text{modulation} = \frac{\text{H max.} - \text{H min.}}{\text{H max.} + \text{H min.}} \times 100$$

"H max." is the maximum height of the modulated wave and "H min." is the minimum height. These values can be measured from the 'scope pictures—the trapezoid figure is more convenient for this purpose but the time-base figure gives sufficiently accurate results.

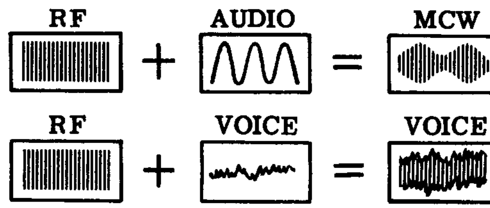
In the figures below, H max. is 8 boxes and H min. is 2 boxes. The percentage modulation is:



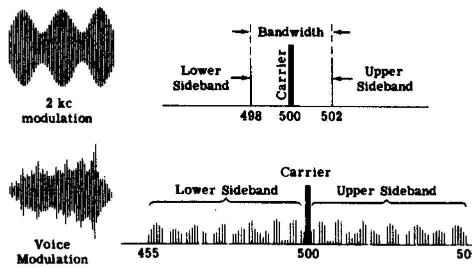
If H max. is 9 boxes and H min. is 1 box, the percentage modulation is:



Review of Amplitude Modulation



AMPLITUDE MODULATION—The method which uses voice or an audio signal to vary the amplitude of an RF carrier wave. The modulator is the component of the AM transmitter which combines the audio and RF signals.



SIDEBANDS—Frequencies contained in the transmitted signal in addition to the RF carrier frequency. Sidebands are equal to the sum and difference of carrier and modulating signals. MCW has two sidebands; voice has many.

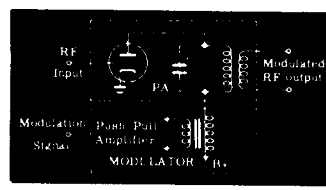
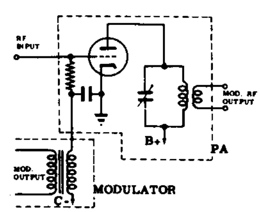
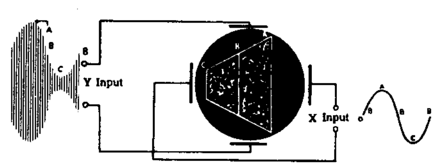


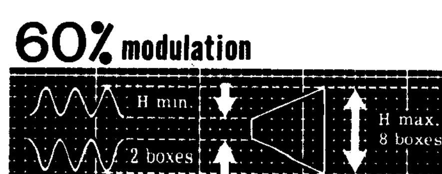
PLATE MODULATION—The method whereby the modulating signal varies the PA tube voltage, thus modulating its output in response to the audio signal.



GRID MODULATION—The modulating signal is applied to the grid of the PA tube. Varying grid voltage in this manner controls PA tube plate current and hence modulates output voltage.



TRAPEZOID FIGURE—The oscilloscope pattern obtained by using the transmitter output voltage as 'scope's Y input, and the modulating signal as X input.

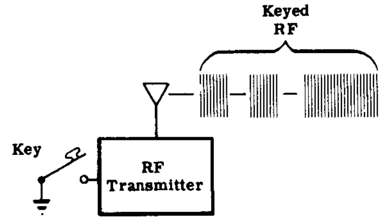


PERCENTAGE MODULATION—The measure of the extent to which the RF carrier is modulated. 100 percent modulation is desireable for voice transmission so that maximum power is transmitted. Overmodulation produces a distorted signal and introduces unwanted sidebands.

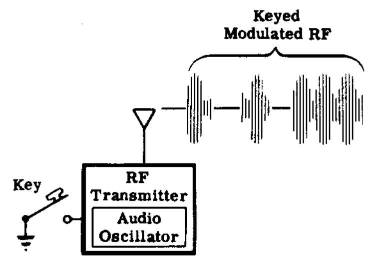
Review of Transmitters

Let's pause and review briefly what you have learned about transmitters.

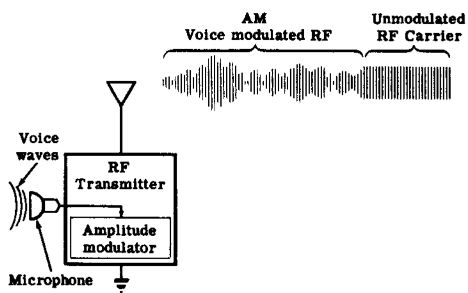
<u>CW TRANSMISSION</u>—An RF signal is generated in the transmitter by an RF oscillator, and radiated into space. Intelligence is imparted by turning transmitter on and off with a key. CW is used most often for long distance communications.



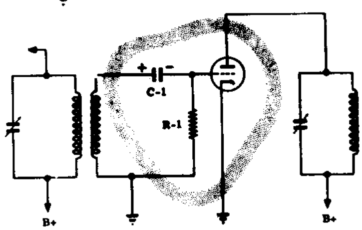
<u>MCW TRANSMISSION</u>—A constant amplitude audio frequency signal is superimposed on the RF carrier wave. Transmitter is turned on and off by means of a key as in CW transmission. MCW is used for emergency applications.



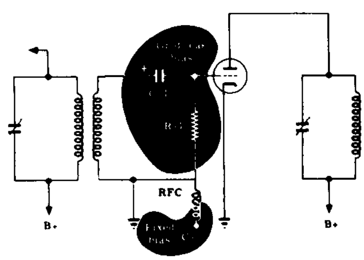
<u>VOICE TRANSMISSION</u>—In amplitude modulation a voice signal varies the amplitude of the RF carrier. Transmission is continuous, and is the type used for standard radio broadcasting.



<u>GRID-LEAK BIAS</u>—A resistor and capacitor in the grid circuit of an amplifier tube to make the amplifier operate Class C. The amount of bias depends on the grid current, and varies as the strength of the input signal changes.

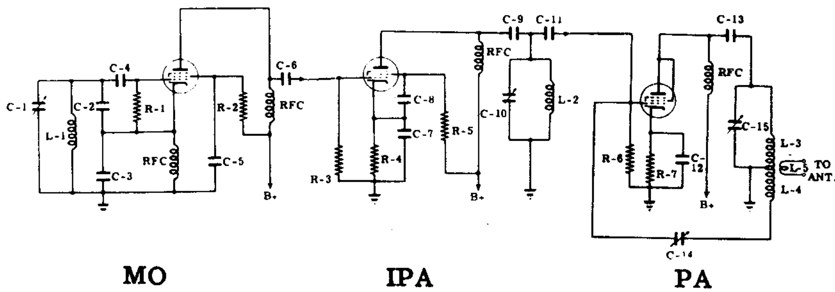


<u>COMBINATION BIAS</u>—A combination of fixed and grid-leak bias most commonly used in transmitters.

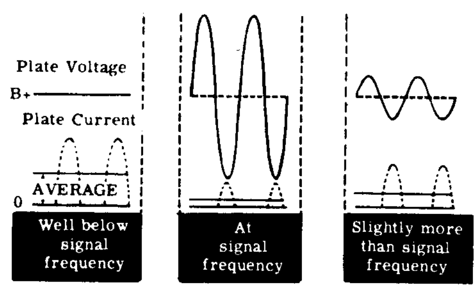


Review of Transmitters (continued)

THREE-STAGE TRANSMITTER—The master oscillator (MO), intermediate power amplifier (IPA) and final power amplifier (PA) make up the basic three-stage transmitter.



TUNING—For efficient operation, the plate tank circuit of the amplifiers must resonate at oscillator frequency. Adjusting the variable capacitor to reach this condition is called "tuning." Plate voltage is maximum and current minimum at signal frequency.



NEUTRALIZATION—Plate or grid neutralization circuits may be used to counteract the feedback effect at the grid-to-plate capacity of triodes used in transmitter amplifiers.

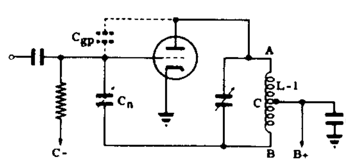
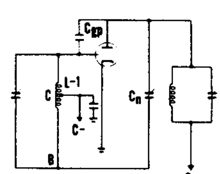
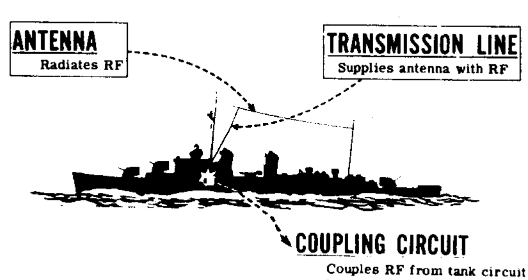


Plate Neutralization



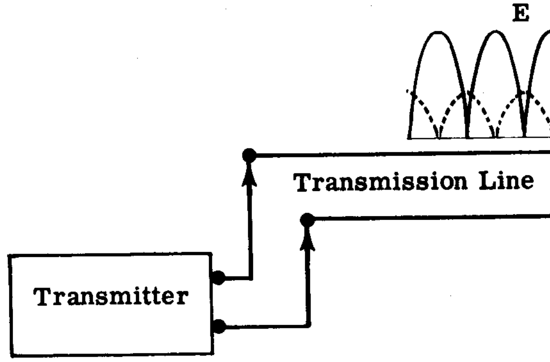
Grid Neutralization

TRANSMISSION LINE—Used to convey the RF signal from the transmitter to the antenna. For maximum power output the characteristic impedance of the line should equal the input impedance of the antenna. Coupling circuits are used to couple the transmission line to the transmitter.

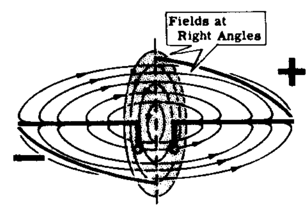


Review of Transmitters (continued)

STANDING WAVES—Voltage and current distribution along a transmission line or antenna can be represented by wave forms called "standing waves."



ANTENNA—Radiates energy, received from transmission line, into space. Electric and magnetic fields generated by current and voltage waves on antenna expand and collapse as transmitter signal varies.



SIDEBANDS—Frequencies contained in the transmitted signal in addition to the RF carrier frequency. MCW has two sidebands; voice has many sidebands.

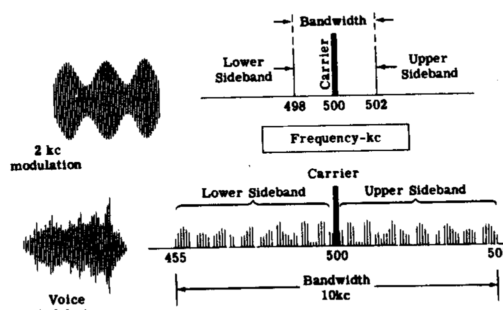
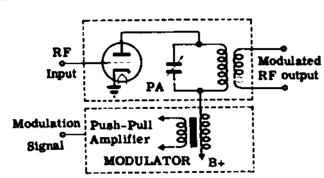
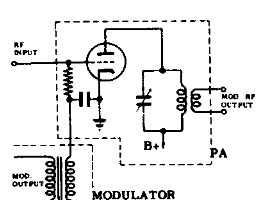


PLATE MODULATION—A method whereby the modulating signal varies the PA tube plate voltage, thus modulating its output in response to the audio signal.



GRID MODULATION—The modulating signal is applied to the grid of the PA tube. Varying grid voltage in this manner controls PA tube plate current and hence modulates output voltage.



INDEX TO VOL. 4

(Note: A cumulative index covering all five volumes in this series will be found at the end of Volume 5.)

HOW THIS OUTSTANDING COURSE WAS DEVELOPED:

In the Spring of 1951, the Chief of Naval Personnel, seeking a streamlined, more efficient method of presenting Basic Electricity and Basic Electronics to the thousands of students in Navy speciality schools, called on the graphiological engineering firm of Van Valkenburgh, Nooger & Neville, Inc., to prepare such a course. This organization, specialists in the production of complete "packaged training programs," had broad experience serving industrial organizations requiring mass-training techniques.

These were the aims of the proposed project, which came to be known as the Common-Core program: to make Basic Electricity and Basic Electronics completely understandable to every Navy student, regardless of previous education; to enable the Navy to turn out trained technicians at a faster rate (cutting the *cost* of training as well as the time required) without sacrificing subject matter.

The firm met with electronics experts, educators, officers-in-charge of various Navy schools and, with the Chief of Naval Personnel, created a dynamic new training course . . . completely up-to-date . . . with heavy emphasis on the visual approach.

First established in selected Navy schools in April, 1953, the training course comprising Basic Electricity and Basic Electronics was such a tremendous success that it is now the *backbone* of the Navy's *current* electricity and electronics training program!*

The course presents one fundamental topic at a time, taken up in the order of need, rendered absolutely understandable, and hammered home by the use of clear, cartoon-type illustrations. These illustrations are the most effective ever presented. *Every page has at least one such illustration—every page covers one complete idea!* An imaginary instructor stands figuratively at the reader's elbow, doing demonstrations that make it easier to understand each subject presented in the course.

Now, for the first time, Basic Electricity and Basic Electronics have been released by the Navy for civilian use. While the course was *originally* designed for the Navy, the concepts are so broad, the presentation so clear—*without* reference to specific Navy equipment—that it is ideal for use by schools, industrial training programs, or home study. *There is no finer training material!*

"Basic Electronics" consists of *five* volumes, as follows: *Vol. 1*—Introduction to Electronics, Diode Vacuum Tubes, Dry Metal Rectifiers, What a Power Supply Is, Filters, Voltage Regulators. *Vol. 2*—Introduction to Amplifiers, The Triode Tube, Tetrodes & Pentodes, Audio Voltage & Power Amplifiers. *Vol. 3*—Video Amplifiers, RF Amplifiers, Oscillators. *Vol. 4*—Transmitters, Transmission Lines & Antennas, CW Transmission & Amplitude Modulation. *Vol. 5*—Receiver Antennas, Detectors & Mixers, TRF Receivers, Superheterodyne Receivers.

**"Basic Electricity,"* the first portion of this course, is available as a separate series of volumes.

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basic electronics

by VAN VALKENBURGH,
NOOGER & NEVILLE, INC.

VOL. 5

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PREFACE

The texts of the entire Basic Electricity and Basic Electronics courses, as currently taught at Navy specialty schools, have now been released by the Navy for civilian use. This educational program has been an unqualified success. Since April, 1953, when it was first installed, over 25,000 Navy trainees have benefited by this instruction and the results have been outstanding.

The unique simplification of an ordinarily complex subject, the exceptional clarity of illustrations and text, and the plan of presenting one basic concept at a time, without involving complicated mathematics, all combine in making this course a better and quicker way to teach and learn basic electricity and electronics.

In releasing this material to the general public, the Navy hopes to provide the means for creating a nation-wide pool of pre-trained technicians, upon whom the Armed Forces could call in time of national emergency, without the need for precious weeks and months of schooling.

Perhaps of greater importance is the Navy's hope that through the release of this course, a direct contribution will be made toward increasing the technical knowledge of men and women throughout the country, as a step in making and keeping America strong.

Van Valkenburgh, Nooger and Neville, Inc.

New York, N. Y.

February, 1955

TABLE OF CONTENTS

Vol. 5 — Basic Electronics

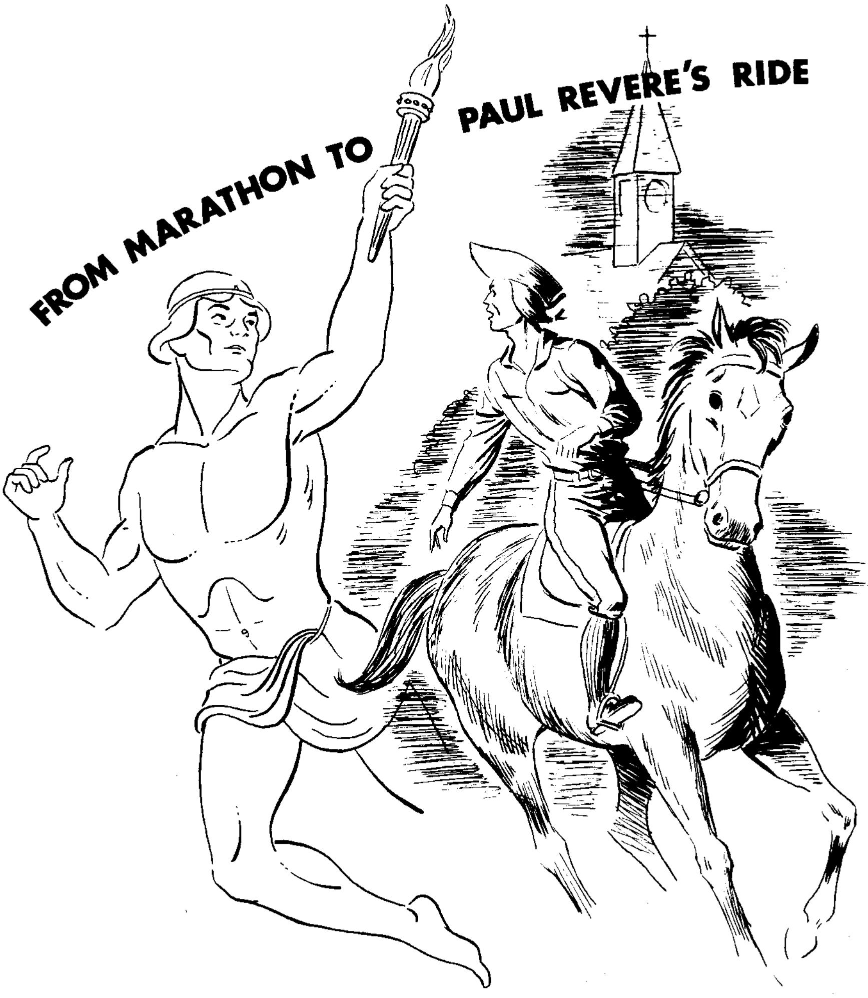
History of Communication

Did it ever occur to you to ask, "Why is there such a thing as a radio receiver?" To answer this question, you have to know something about the history of man's attempt to improve his methods of communication.

Since the earliest days, man has always tried to increase the distance over which he could send messages.

History of Communication (continued)

Since the dawn of history, good communications have played an important part in the art of warfare. The victory message of the Battle of Marathon carried by a Greek runner was one of the earliest recorded instances of battle communications. Our own history offers another famous example in Paul Revere's ride.



GOOD COMMUNICATIONS HAVE WON BATTLES

A result of poor communications was effectively demonstrated in the Battle of New Orleans during the War of 1812. Because news of the cessation of hostilities did not reach those in command until it was too late, this battle was fought several days after the war had ended.

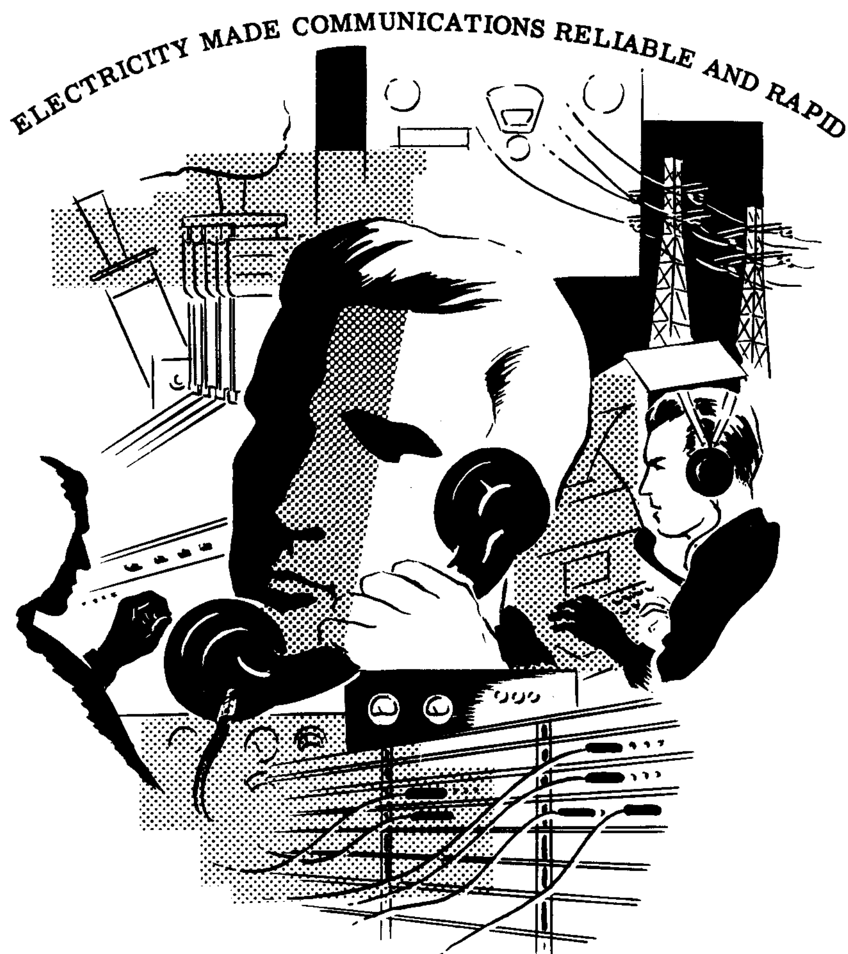
History of Communication (continued)

Some of the more primitive methods of communication—human messengers and homing pigeons—have limited application. Today we still use semaphore signals and interrupted flashes of light to convey messages. Colored lights, rockets and flares perform functions similar to those of the warning hilltop fires of old, while whistles and sirens are still being used.

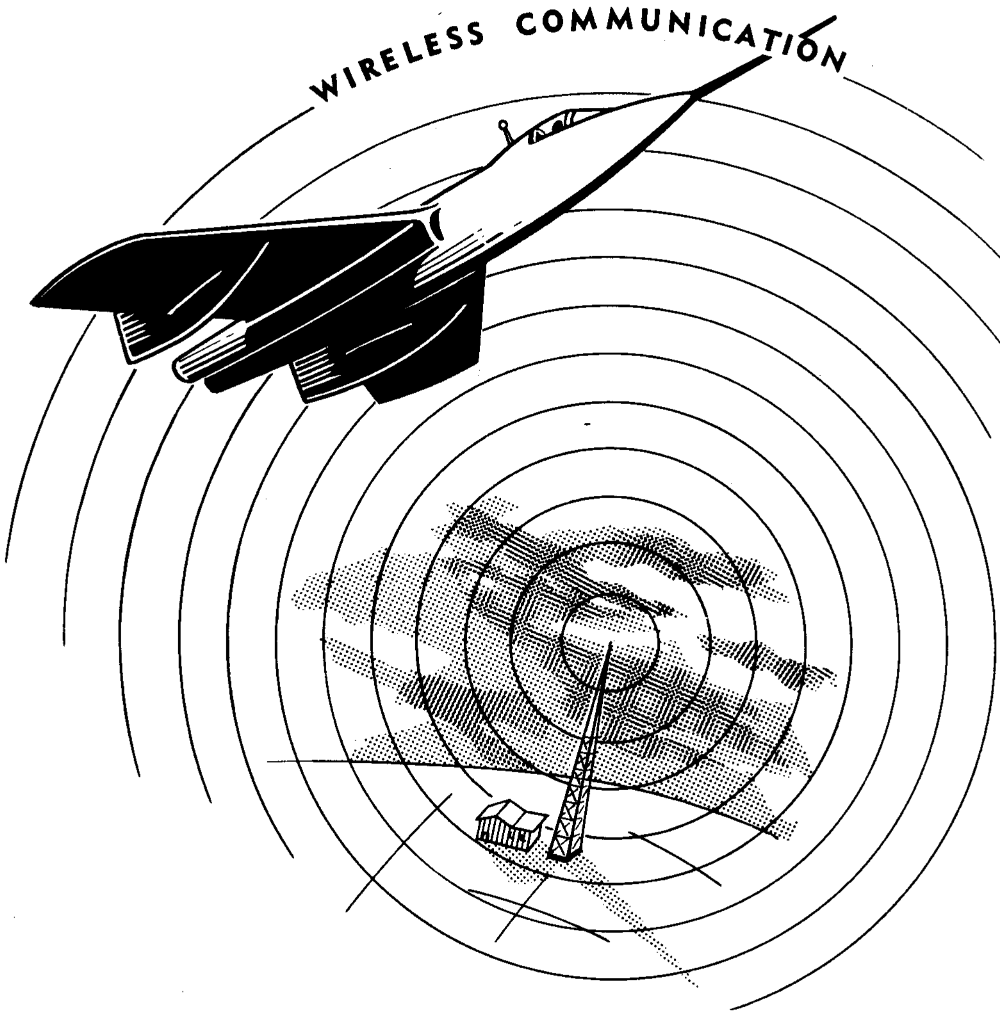
History of Communication (continued)

These simple signaling systems are at best slow and unreliable. If the wind is blowing from the wrong direction, sound signals will not be received. In thick fog or heavy rain, visual signals fail to deliver the message. Runners and pigeons are slightly more reliable, but their rate of travel is relatively slow.

The problem of rapid and reliable communication was solved by harnessing electricity to the task. Improvements on the inventions of Morse, Bell and Marconi have led to the development of modern telegraph, telephone and wireless communication systems capable of transmitting messages almost instantaneously over thousands of miles of space.



Modern Wireless Communication



Today, with the advent of wireless communication, or as it is more commonly known—radio communication, the use of electricity for transmitting messages has reached its highest point. No longer is transmission limited to those places which a wire can reach, as is the case with telephone.

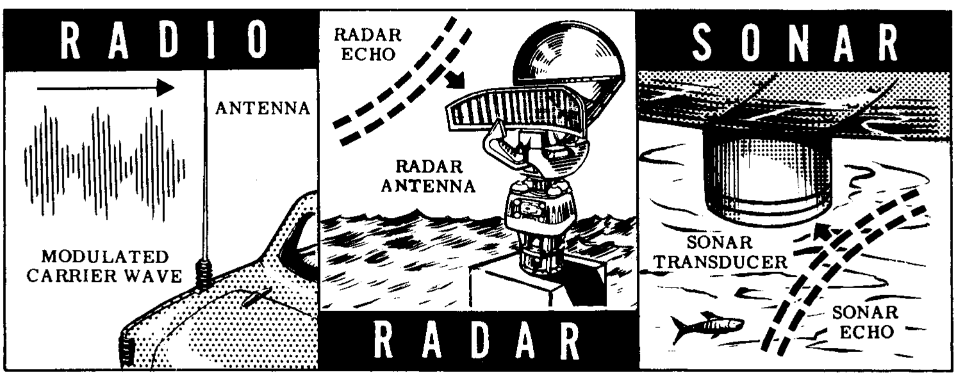
This remarkable electronic device, the radio, consists of two parts—the transmitter and the receiver. The transmitter sends out the message, in the form of radio waves, into the atmosphere. The radio receiver picks up the radio waves sent out by the transmitter, and converts them into the message which was originally put into the transmitter. This section will deal with the receiving end of radio communication—the receiver.

The Jobs a Receiver Performs

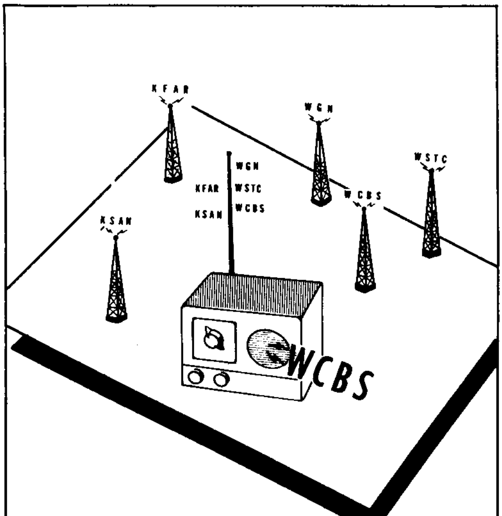
The jobs that a receiver must perform are very much the same in radio, radar and sonar equipment. Both the type of signal going into the receiver and the type of signal coming out of the receiver are different for each type of equipment; but the steps the incoming signal must go through before it emerges as a useful output are almost identical, whether the receiver is used for radio, radar or sonar. The function of any receiver can be broken down into five separate steps.

1. Picking up incoming signals: In radio and radar, the incoming signals are electromagnetic carrier waves sent out by a transmitter. When these waves cut across the receiving antenna, a very weak current is caused to flow. The current varies in frequency and amplitude to duplicate the signal radiated from the transmitter antenna.

   In sonar, the "antenna" is an underwater microphone called a "transducer" which converts the incoming signal to a weak current flow and serves the same purpose as the radio and radar antennas.



2. Selecting the desired signal: Many transmitters are sending out signals that reach the receiver antenna, and of these many signals, the receiver must be able to select the desired one. Each transmitter uses a different frequency, while the receiver contains circuits tuned to only the frequency that the operator desires to receive. The more tuned circuits used, the sharper the tuning. By tuning these circuits to the frequency of the signal of one of the transmitters, you can select that desired signal and reject all other signals.



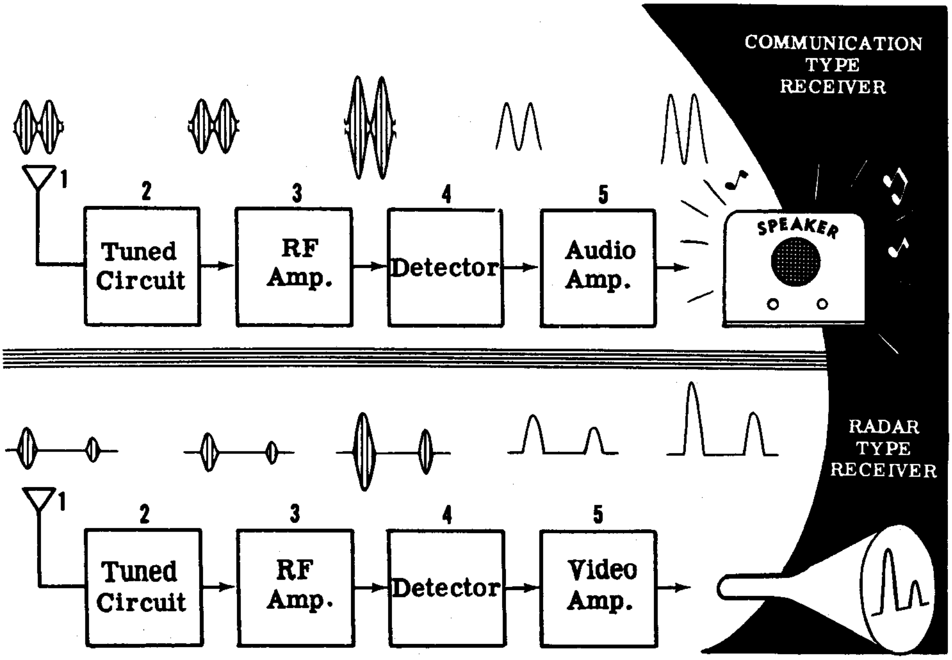
The Jobs a Receiver Performs (continued)

3. Amplifying the desired RF signal: The currents generated by the incoming signals in the antenna or transducer are extremely weak. RF amplifiers similar to those you have already studied are used to amplify these weak signals before they reach the detector.

4. Detecting or demodulating the amplified signal: A detector stage follows the last RF amplifier in a receiver. The detector does the important job of separating the "envelope" of the signal from the RF carrier. Because the envelope is the modulation of the signal, a detector is sometimes called a "demodulator." The signal, after demodulation, may be a voice or code signal as in communications radio receivers, or a sharp voltage rise and fall as in radar or sonar receivers.

5. Amplifying the audio or video signals: In radio receivers, the audio signal which comes from the detector undergoes further amplification. Audio voltage amplifiers and power amplifiers, similar to those you have already studied, build up the audio signal enough to operate a pair of earphones or a loudspeaker so that the signal may be heard.

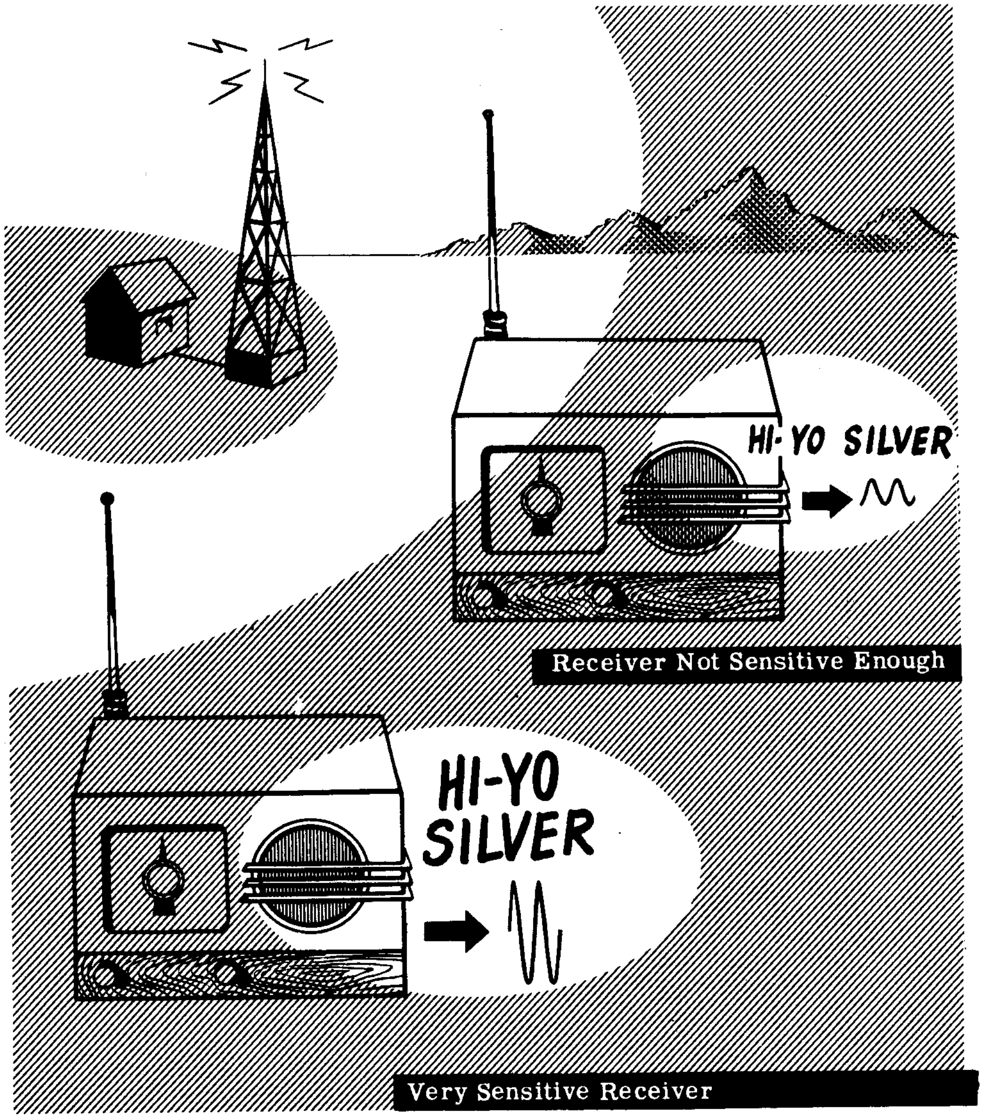
   In some sonar sets, the signal is heard in a loudspeaker, and the receiver is similar in design and operation to a radio receiver. In radar and certain other types of sonar receivers, the signal will show up as a "pip" on a 'scope. In these receivers, a video amplifier similar to those you have already learned about, would be used to amplify the voltage "pips." The video amplifiers take the signal from the detector and build it up so that it can be seen on the radar or sonar 'scope.



Receiver Sensitivity

There are several characteristics of a receiver which you can determine by simply comparing the input signal and the receiver output. These characteristics will tell you how well your receiver is working. The first of the characteristics—there are three in all—is sensitivity.

Sensitivity can be defined as the ability of the receiver to pick up weak signals, amplify them and deliver a useful output. No matter what type of equipment the receiver is in, sensitivity is important because many input signals which the receiver must amplify are extremely weak. Only a sensitive receiver can develop a sizable output with a weak input.



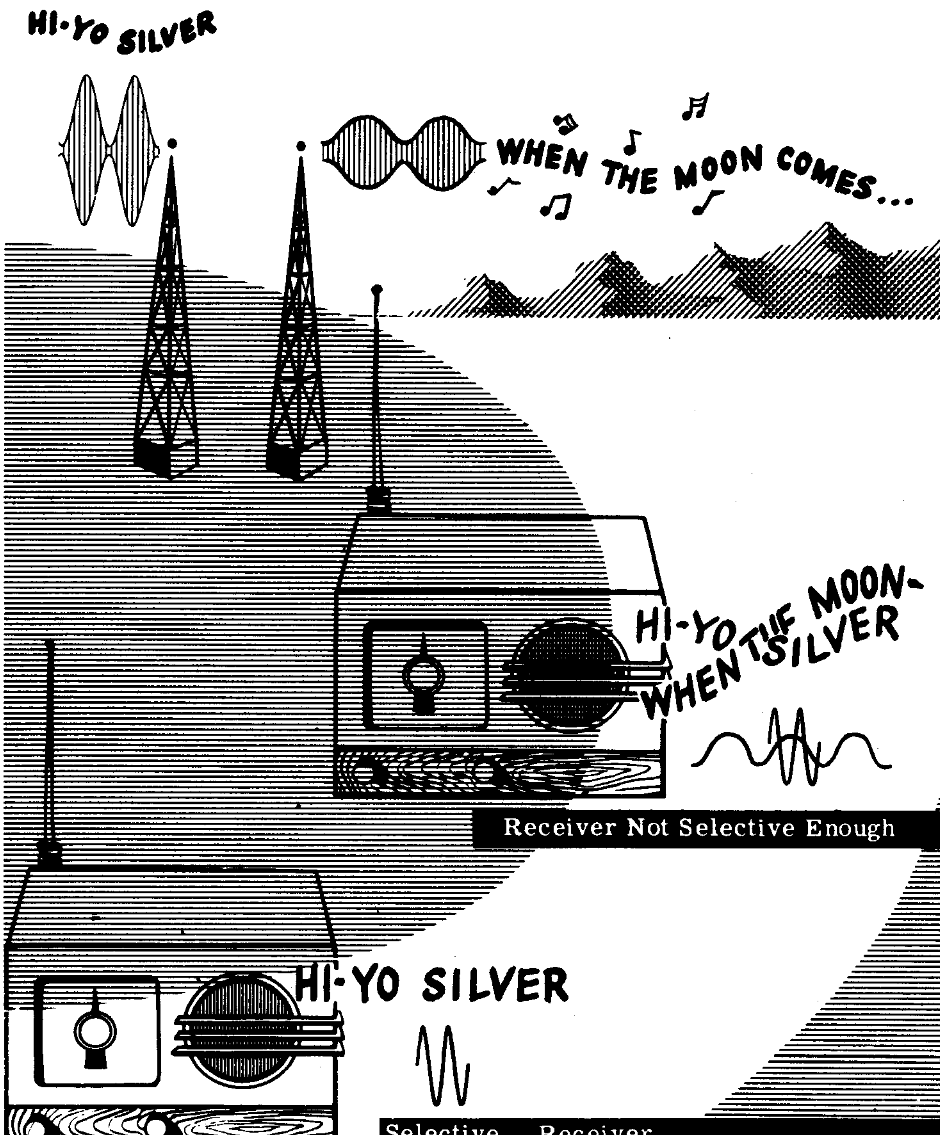
Receiver Not Sensitive Enough

Very Sensitive Receiver

Receiver Selectivity

Sensitivity, by itself, does not make a receiver good enough for use. It must also be selective.

Selectivity is the ability of a receiver to select a desired signal and discriminate against all undesired signals. If every signal which struck the antenna were amplified, the output, although strong enough, would be worthless because of all the interference caused by the presence of the undesired signals.



Receiver Not Selective Enough

Selective Receiver

Fidelity

For some applications, if the receiver can pick out one signal from the many which strike the antenna (selectivity) and can amplify it so as to produce a useful output even though the signal may be weak (sensitivity), the receiver is good enough to be used. For other applications, one more thing is important—the receiver must be able to reproduce the incoming signal without distortion. A receiver which can do this is said to have "good fidelity"; a receiver which cannot, has "poor fidelity."

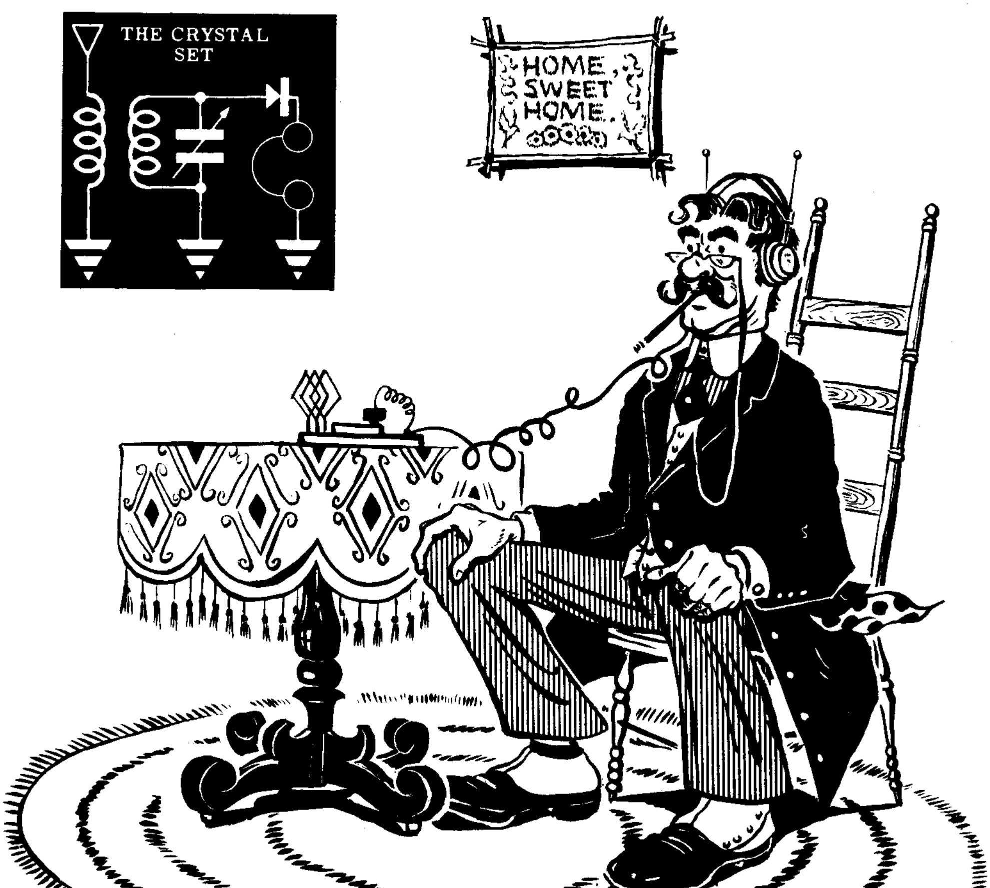
Home radio receivers usually have good fidelity since they are made for enjoyment. Communications receivers are made to duplicate voice, but only so that it is intelligible, and are therefore not usually designed with good fidelity in mind. Sonar and radar receivers, on the other hand, have good fidelity because the operator gets a great deal of information from the sound or 'scope appearance of the receiver output.

The Crystal Receiver

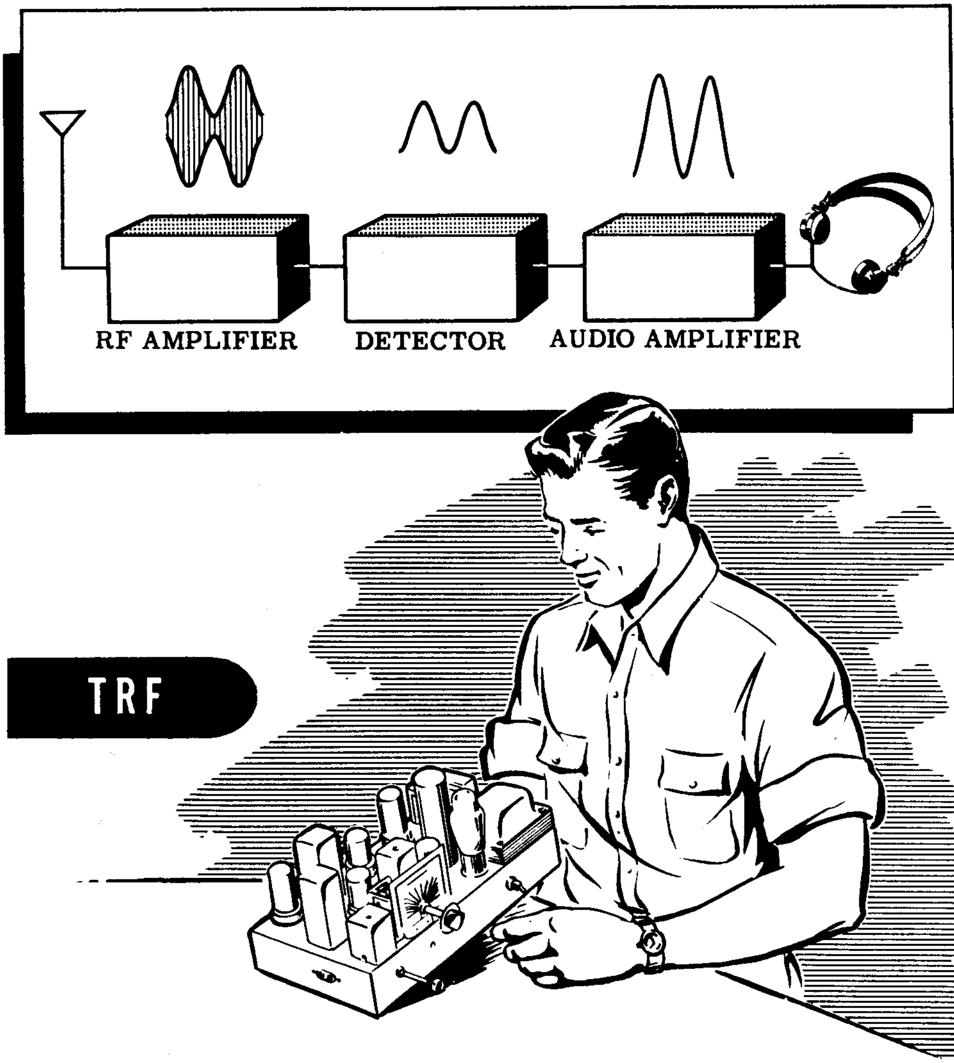
The first receivers were used in the early 1900's and were called "crystal sets." In their simplest form, they consisted of an antenna, a crystal detector, a "cat's whisker" and a pair of earphones.

The antenna picked up any signals in the air—in those days there were very few—and the crystal (which operated as a rectifier) allowed the antenna currents to flow directly to ground on every positive half cycle of RF, but blocked the negative half cycles. These positive half cycles of current flowed through the "cat's whisker," a delicate wire contact on the crystal, to the earphones where weak sounds sometimes were heard. Crystal sets at best had one tuned circuit before the crystal, but even so, the selectivity was very poor. Because no vacuum tubes were used, the sensitivity was so bad that crystal sets could not be used very far from a transmitting station. Today these sets are curiosities, and have no practical applications.

IN THE BEGINNING...



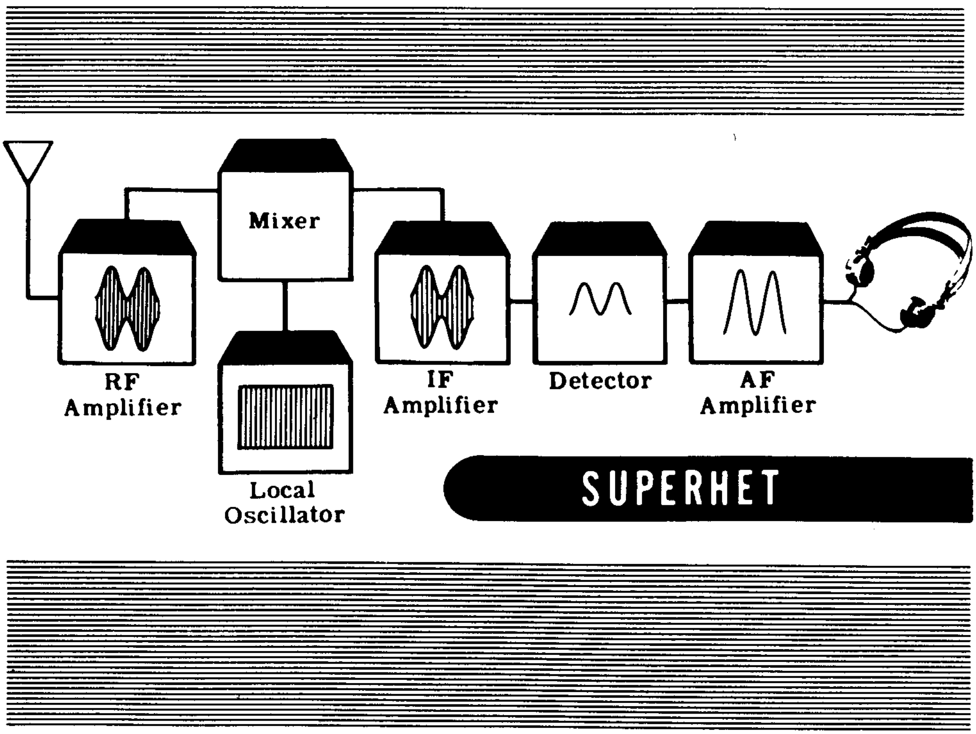
The TRF Receiver



By 1920, crystal sets were on their way out and were being replaced by tuned radio frequency (TRF) receivers, which made use of vacuum tubes. The first few vacuum tubes, and their tuned circuits, make up the RF amplifier which gives the TRF receiver better selectivity and sensitivity than the old crystal sets. The detector does the same thing as the crystal detector and sometimes amplifies the signal as well. After the detector, the audio signal is amplified in the audio amplifier. The output of the audio amplifier is a fairly powerful signal which can be used to drive a loudspeaker or a pair of earphones. TRF receivers are not used very often today, but some receivers are still of this type.

The Superheterodyne Receiver

The most common type of receiver used in home radios and in other equipment is the superheterodyne receiver. In this type of receiver, all the RF amplification does not take place at the incoming signal frequency. Most of the RF amplification occurs after the incoming signal has been converted to an intermediate frequency (IF), which is always the same no matter what the frequency of the desired signal is. You will see how this is accomplished later.



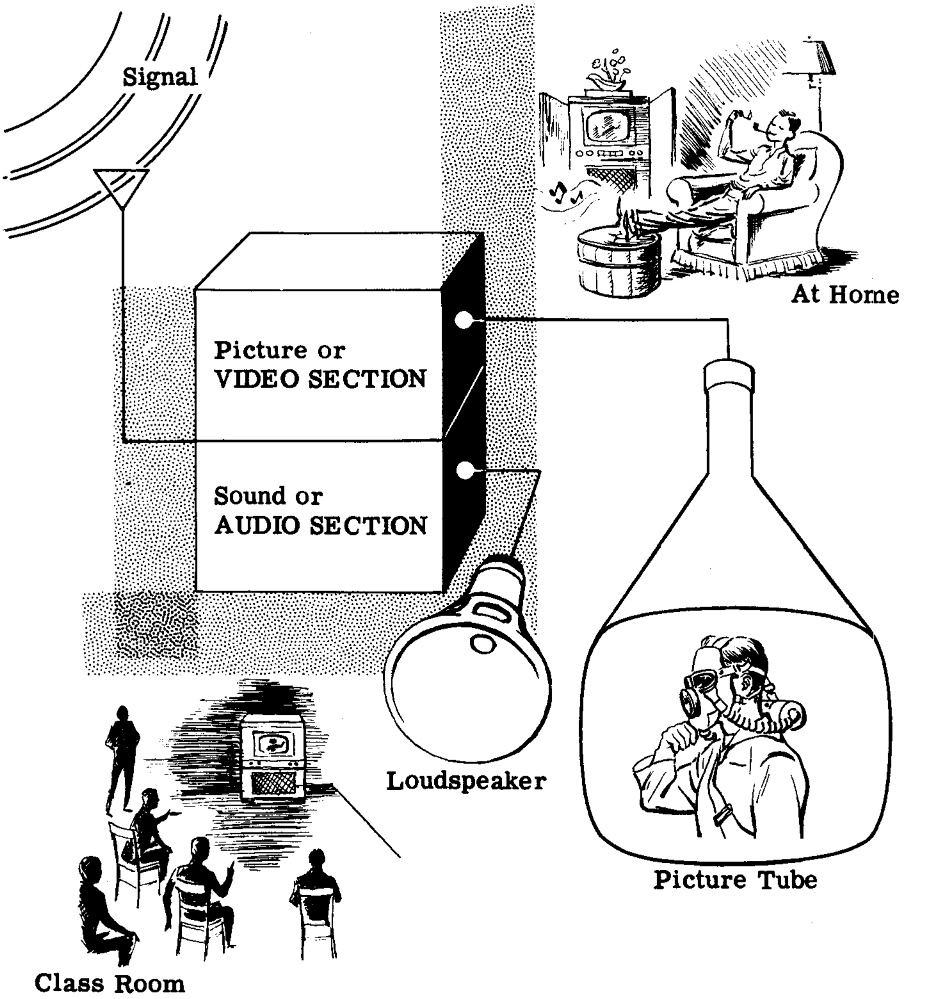
The only parts in a superhet which differ from those in a TRF are the variable frequency local oscillator, the mixer and the IF amplifier. The variable frequency local oscillator is similar to the oscillators with which you have already worked. The oscillator produces a pure RF signal which is "mixed" in the mixer stage with the signal from the RF amplifier. The resulting IF frequency is the difference between the input signal frequency and the local oscillator frequency. The IF is a fixed frequency and the IF amplifiers are therefore fixed-tuned. This allows them to be very accurately tuned so that high gain and selectivity can be obtained at the chosen frequency.

You will find out exactly how a superhet receiver works a little later in this section. For the time being, it is enough for you to know that the advantage of the superhet over the TRF receiver is that the superhet has higher gain and greater selectivity.

Recently Developed Uses of Receivers

Receivers play a very important role in the relatively new field of television, which finds wide application both in the civilian and military field.

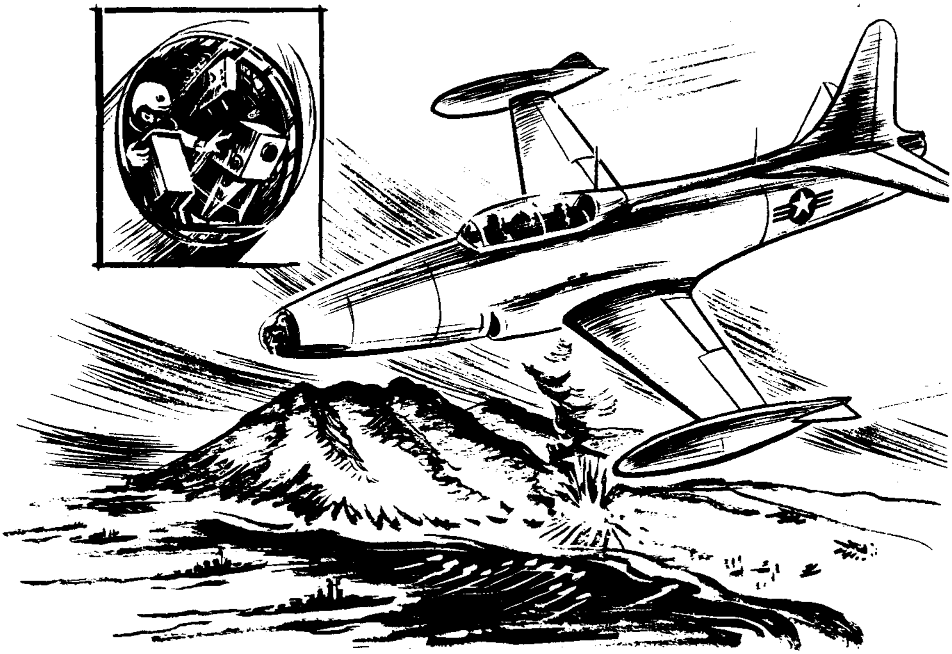
Every home television set has at least two receivers. One receiver is designed to change part of the incoming signal into sound, while the other converts the remainder of the signal into a picture or image which appears on a screen.



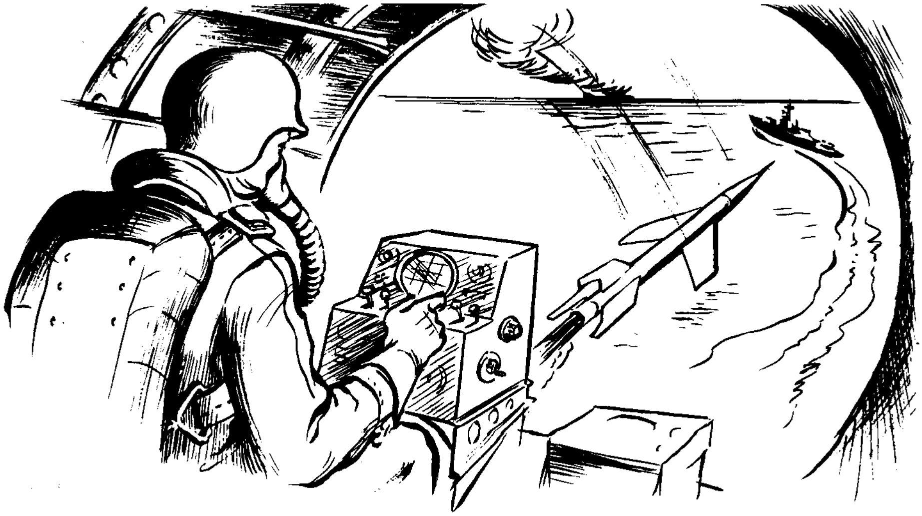
We are all aware of television as a source of entertainment. Another application, designed for improving and enriching training programs, involves the use of televised demonstrations. These demonstrations may be observed simultaneously in dozens of classrooms.

Recently Developed Uses of Receivers (continued)

Airborne television equipment can be used to transmit an overall survey of localized operations back to a flagship or to headquarters.

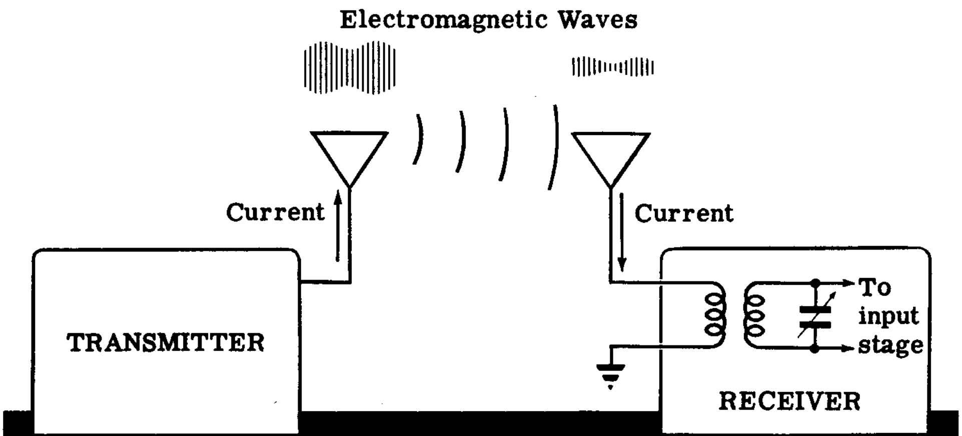


One of the most interesting and significant applications of radio reception to modern warfare is in connection with the development of guided missiles. The path followed by these missiles can be controlled by radio signals transmitted by a distant operator.



The Function of Receiver Antennas

The purpose of the receiver antenna is to intercept the electromagnetic waves radiated from the transmitter. When these waves cut across the antenna, they generate a small voltage in it. This voltage causes a weak current to flow in the antenna-ground system. This feeble current has the same frequency as the current in the transmitter. If the original current in the transmitter is amplitude modulated, the antenna current will vary in exactly the same manner. This weak antenna current, flowing through the antenna coil, induces a corresponding signal in the grid circuit of the first RF amplifier stage of the receiver.



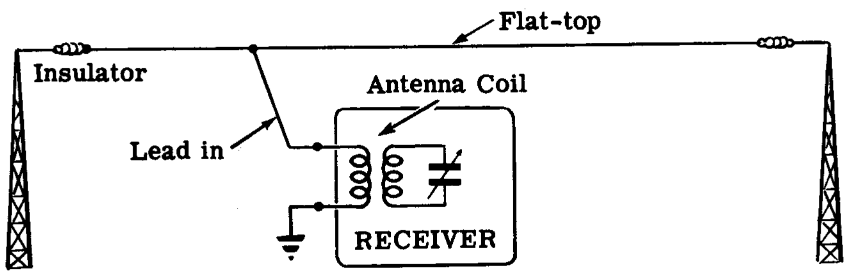
RECEIVER ANTENNAS INTERCEPT THE RADIO WAVES SENT OUT BY THE TRANSMITTER

A receiving antenna should feed as much signal and as small an amount of undesired interference to the receiver as possible. It should be constructed so that the signal is not lost or dissipated before reaching the receiver. It should give maximum response for the frequency or band of frequencies to which the receiver is tuned. An antenna can also be directional, which means that it will give best response in the direction from which the operator wishes to receive.

The receiver antenna problem is easily solved when the receiver is operated in conjunction with a transmitter. Since the transmitting antenna is usually designed to incorporate the desirable features which have just been listed, the same antenna is used for both transmitter and receiver. A switch or relay is used to connect the antenna to the piece of equipment that is operating at that particular moment. However, when no transmitter antenna is available it may be necessary to erect a separate receiving antenna, paying attention to the four considerations of noise, signal loss, frequency response and directivity. Before discussing these considerations of antenna design, it might be a good idea to become familiar with a few of the more common types of receiving antennas.

Types of Receiver Antennas

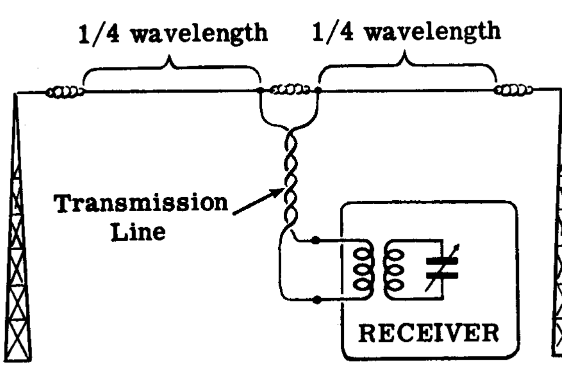
One of the simplest and most commonly used antennas is the inverted L. It consists of a wire, known as a "flat-top," which is suspended horizontally between two insulators. The length of the wire should be from 50 to 75 feet for broadcast-band reception and from 20 to 40 feet for high-frequency reception. The flat-top should be suspended from 30 to 50 feet above the ground. A wire known as the "lead-in" is used as a transmission line from the antenna to the receiver. It is connected near one end of the flat-top and brought down to the primary winding of the receiver antenna coil.



INVERTED L ANTENNA

Another common type of antenna is the doublet or dipole antenna. It consists of a horizontal wire divided into two equal sections by an insulator. Each half of the antenna should be a quarter wave long for the frequency band most commonly used. The transmission line from the antenna is connected to the two ends of the primary of the antenna coil.

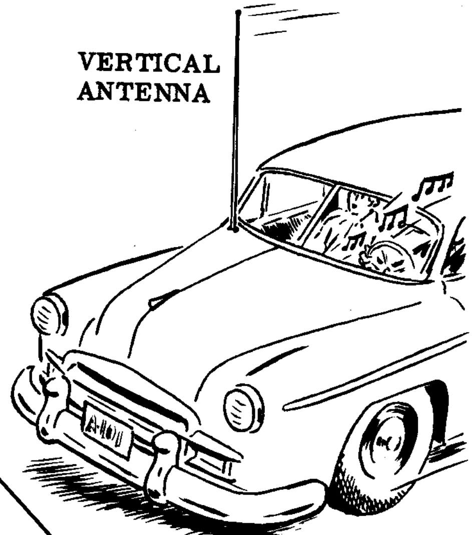
This type of antenna will give excellent high-frequency response and will also give comparatively noise-free reception on the broadcast band. It may be of interest to note that most television receiver antennas are modifications of the dipole antenna, with metal bars replacing the less rigid wires.



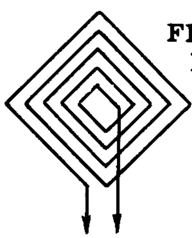
DIPOLE ANTENNA

Types of Receiver Antennas (continued)

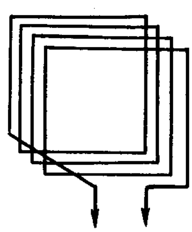
Where lack of space makes horizontal antennas impractical, a vertical antenna is used. Vertical antennas, consisting of telescoping metal masts from 3 to 14 feet in length, are commonly used for automobile and portable receivers, and sometimes for home broadcast receivers. An ordinary lead-in wire is run from the bottom of the antenna to the primary of the antenna coil of the receiver. The other end of the primary should be grounded.



VERTICAL ANTENNA

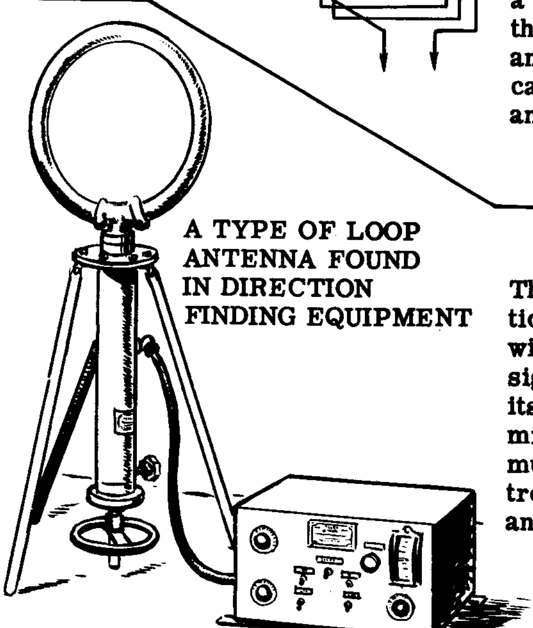


FLAT OR PANCAKE LOOP ANTENNA



BOX LOOP ANTENNA

Another type of antenna used for portable and home receivers is the loop antenna. The loop consists of a coil of wire which is connected to the two ends of the primary of the antenna coil. Most home broadcast-band receivers contain a loop antenna within the cabinet.

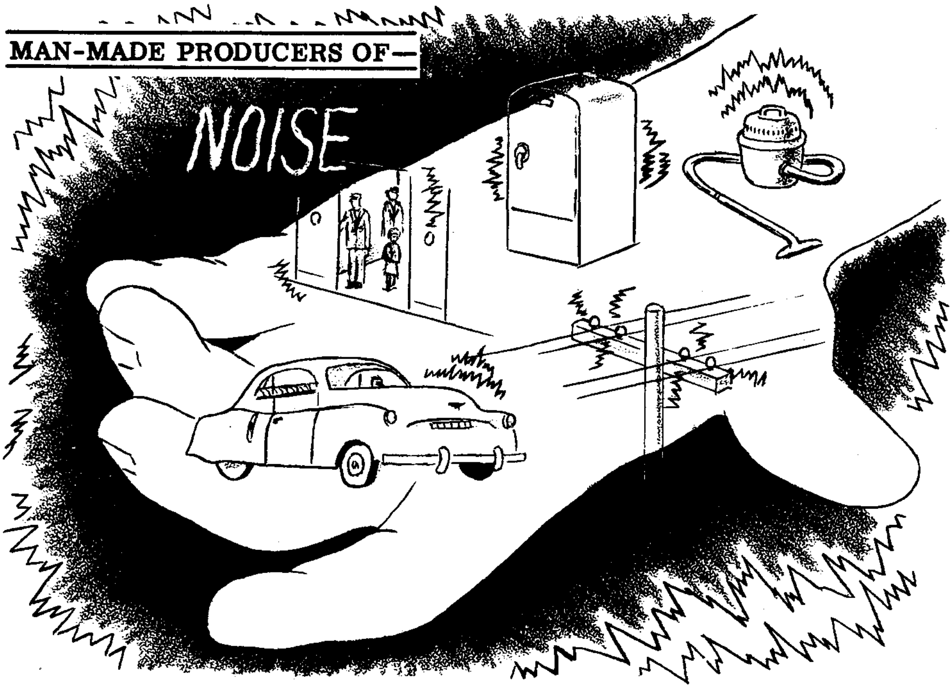


A TYPE OF LOOP ANTENNA FOUND IN DIRECTION FINDING EQUIPMENT

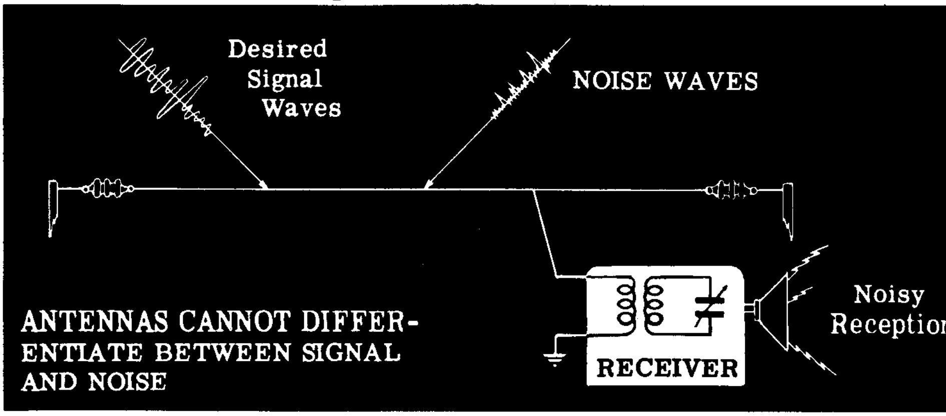
The loop antenna is highly directional. When it is pointed edgewise toward a transmitter, the signal pickup is maximum; when its flat side is toward the transmitter, the signal pickup is minimum. This property makes it extremely useful for radio-beacon and direction-finding equipment.

Considerations in Selecting and Installing an Antenna—Noise

An important consideration in antenna installation is that of noise. Noise consists of radio waves of many frequencies and is produced by both man-made and natural electrical disturbances. Among the more important man-made noise producers are elevators, fans, refrigerators, automobile ignition systems, vacuum cleaners, X-ray and diathermy equipment, and power lines.



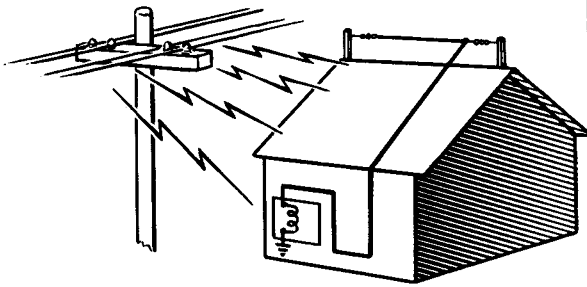
The antenna cannot differentiate between desired signals and undesired radio noise. It is customary to compare the signal pickup of the antenna with the noise pickup. This relationship is known as the "signal-to-noise ratio." A high signal-to-noise ratio is necessary if one desires to obtain relatively noise-free reception.



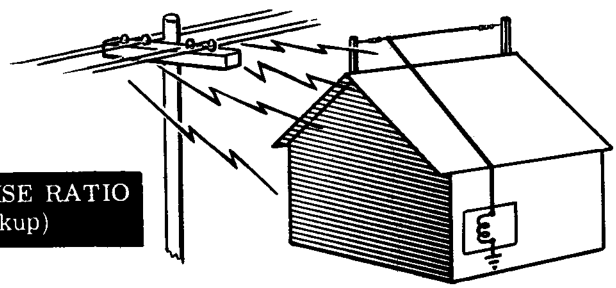
Considerations in Selecting and Installing an Antenna—Noise (continued)

There are various ways by which a high signal-to-noise ratio may be obtained. The first method is by locating the antenna as far as possible from elevator shafts, street car and power lines and other devices likely to produce noise. Placing the antenna at right angles to the power line will also reduce the amount of noise.

HIGH SIGNAL-TO-NOISE RATIO (Low Noise Pickup)



LOW SIGNAL-TO-NOISE RATIO (High Noise Pickup)



The second method is by increasing the height of the antenna as much as practical considerations will allow. This tends to increase the signal strength and reduce the amount of noise.

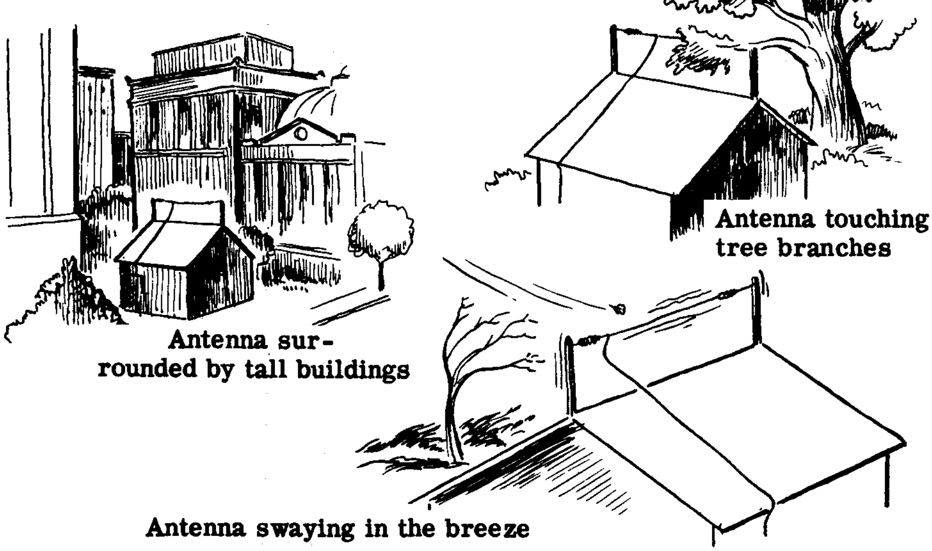
The third method involves using a good ground connection to the receiver when provision is made for one. A poor ground lead may pick up noise; therefore, it should be as short as possible and away from noise-producing devices. A good ground lead should use rubber-insulated wire, size No. 14 or larger. It should make good contact through a ground clamp to a grounded object, such as a radiator or water pipe. Gas pipes should never be used for grounding purposes.

A good deal of noise may be picked up by the lead-in. If the lead-in uses two wires, as in the case of the transmission line used with a doublet antenna, noise can be reduced by using twisted wires or by reversing the positions of the wires every few feet. Noise can also be reduced by using shielded lead-in wires.

Considerations in Selecting and Installing an Antenna—Signal Losses

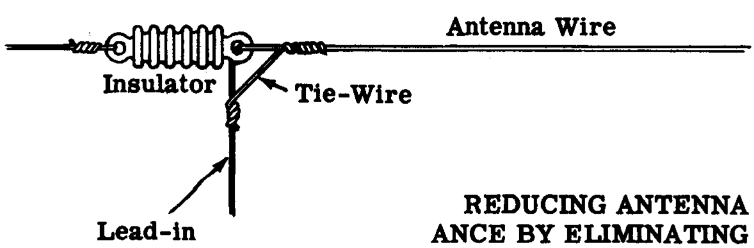
The second factor to be considered in selecting and installing an antenna is that of signal losses. The antenna should be placed as far as possible from metal objects, chimneys, walls, and tree branches which absorb radio waves and thus reduce the strength of the signal reaching the antenna. A loose or swinging antenna may cause the signal to fade.

FACTORS THAT CAUSE ANTENNA SIGNAL LOSSES...



Signal losses will also be increased if a high resistance is present in the antenna circuit. To reduce resistance, all joints and connections should be carefully soldered and, wherever possible, the antenna and lead-in should consist of a single piece of wire with no joints.

Signal losses may be further increased by leakage of current through poor supporting insulators. These insulators should be made of materials such as glazed porcelain or pyrex glass, which do not readily absorb moisture and thus provide a leakage path for current.



REDUCING ANTENNA RESISTANCE BY ELIMINATING JOINTS

Considerations in Selecting and Installing an Antenna— Frequency Response and Directivity

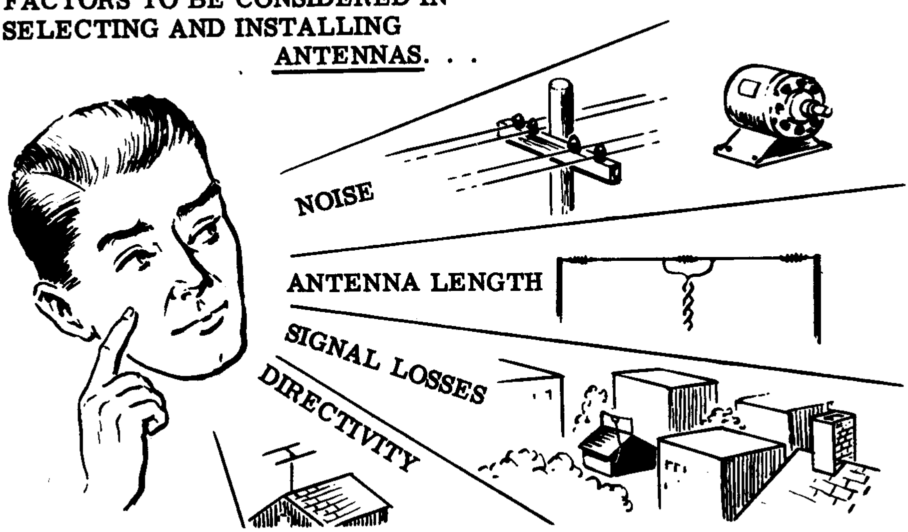
The third consideration is that of frequency response which is related to the antenna length. A maximum signal, at a given frequency, will be induced in the antenna if it is one-quarter or one-half the wavelength of the signal to be received. If desired, it is possible to change the effective length of an antenna by placing a coil or capacitor in series with it. Adding inductance increases the electrical length of the antenna, while adding capacity shortens it. The front panel of certain receivers contains a control marked ANT. COMP. (antenna compensation). This control varies the size of a small capacitor and is used to compensate for variations in antenna length. In general, adjustment of the antenna to the correct length is not nearly as important or critical for receiving equipment as for transmitters.

The final consideration if that of directivity. All antennas, except the vertical type consisting of a single perpendicular wire, have a directional effect and receive signals from certain directions better than from others.

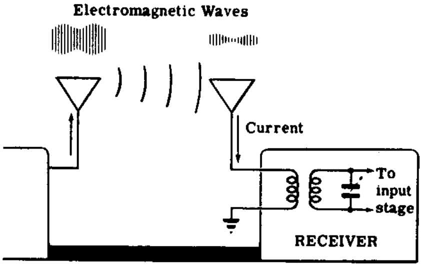
A horizontal or inverted L antenna will receive best when the signal cuts the antenna wire at right angles. For any one station the antenna may be turned so that it produces the maximum signal pickup. However, since it is extremely unlikely that all transmitters will be broadcasting from the same direction, the placement of the antenna will probably be a compromise for all stations.

The directional effects of the loop antenna have already been discussed and need not be repeated. Dipole antennas may be made highly directional by arranging them into systems called "arrays," similar to those employed with television systems.

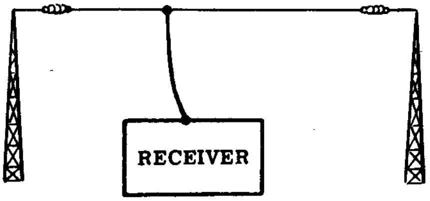
FACTORS TO BE CONSIDERED IN SELECTING AND INSTALLING ANTENNAS. . .



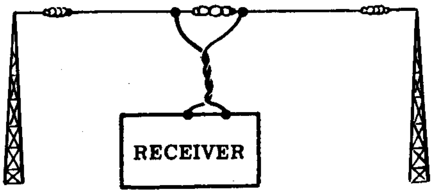
Review of Receiver Antennas



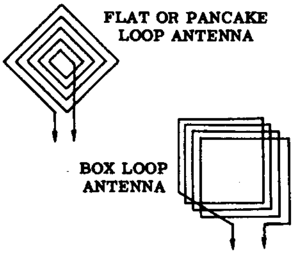
ANTENNA FUNCTION—The receiver antenna picks up signals radiated by a transmitter, and transmits these signals—via the lead-in or transmission line—to the primary of the receiver antenna coil. The electromagnetic waves cutting the antenna induce voltages, thus causing currents to flow which are amplified by the receiver.



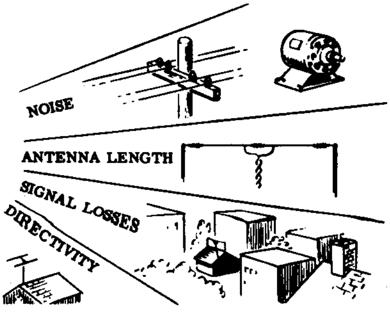
INVERTED L ANTENNA—This is one of the simplest and most commonly used types of antennas, consisting of a horizontally supported wire, with the lead-in attached near one end.



DIPOLE ANTENNA—This type of antenna is the same as is used in transmitters, and consists of two quarter wavelength sections supported horizontally. It gives excellent high-frequency response.



LOOP ANTENNA—The loop antenna is used with many portable and home broadcast-band receivers. Because it is highly directional, it is also used in direction-finding equipment.



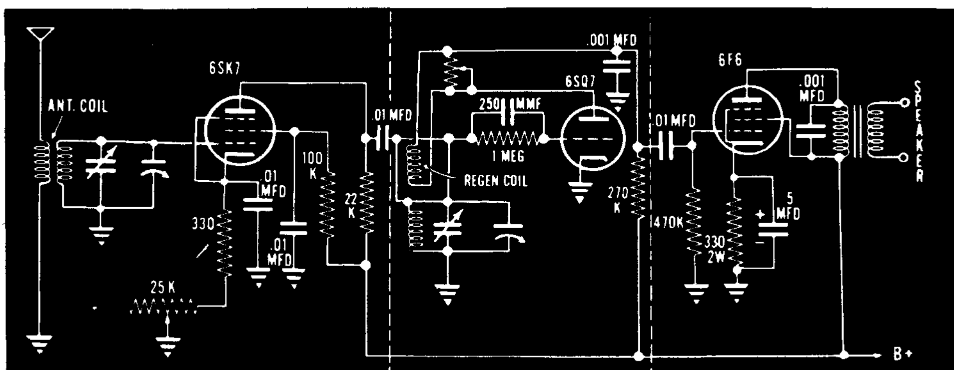
SELECTION AND INSTALLATION—Noise, signal loss, frequency response and directivity are the four factors which must be considered when selecting and installing an antenna.

The TRF Receiver

The TRF receiver is the type of receiver you will study first. You will recall from "Introduction to Receivers" that the TRF consists of an RF amplifier, a detector and an audio amplifier.

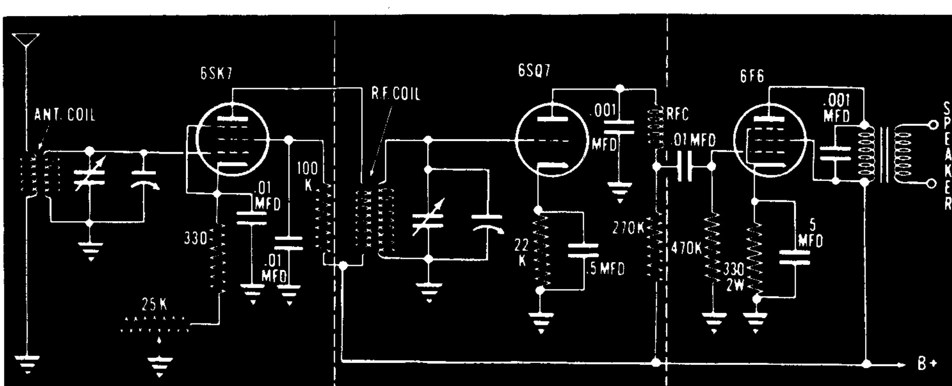
So that you may have in mind the goal toward which you are working, shown below are the circuit diagrams of the two TRF receivers you will learn about.

TRF RECEIVER WITH A REGENERATIVE DETECTOR



RF AMPLIFIER | REGENERATIVE DETECTOR | AUDIO AMPLIFIER

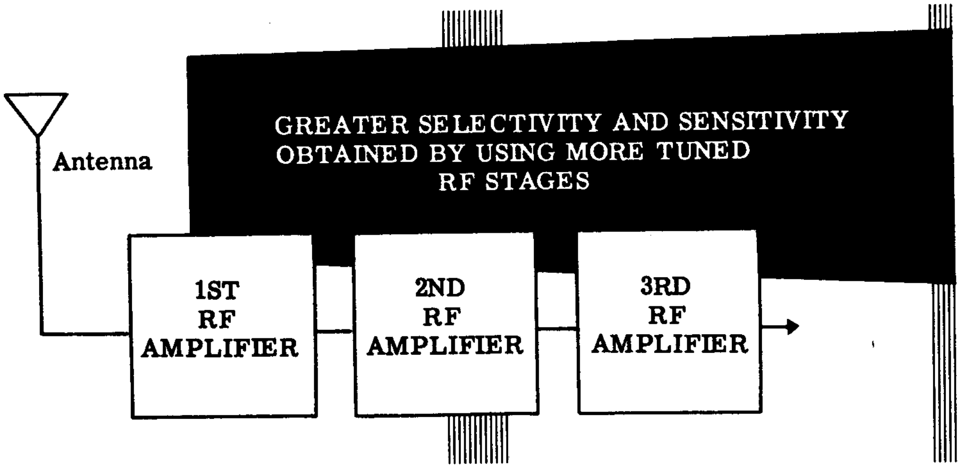
TRF RECEIVER WITH A PLATE DETECTOR



RF AMPLIFIER | PLATE DETECTOR | AUDIO AMPLIFIER

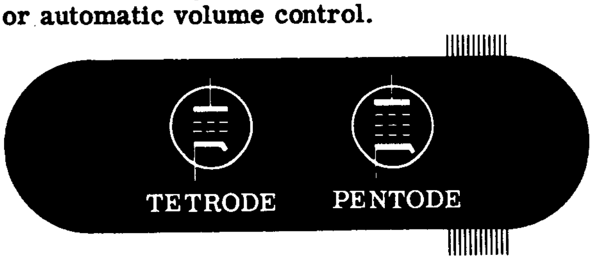
The RF Amplifier Stage

Every TRF receiver contains one or more stages of RF amplification preceding the detector. The main purpose of these amplifiers is to provide additional selectivity and sensitivity. You will recall that selectivity indicates how well a receiver receives a desired signal and rejects unwanted signals, and that sensitivity is a measure of the receiver's ability to pick up a weak signal. In general, the more RF amplifier stages used, the greater will be the selectivity and sensitivity. On this and the following few sheets you will review some of the outstanding points about RF amplifiers.



Since the RF amplifier stage is designed primarily for voltage amplification, any tube suitable for voltage amplification may be used. However, triodes are not considered satisfactory because they have a strong tendency to produce undesirable oscillations when employed in RF amplifier stages. Unless the triodes are carefully neutralized to prevent feedback, the oscillations produced are likely to cause considerable trouble.

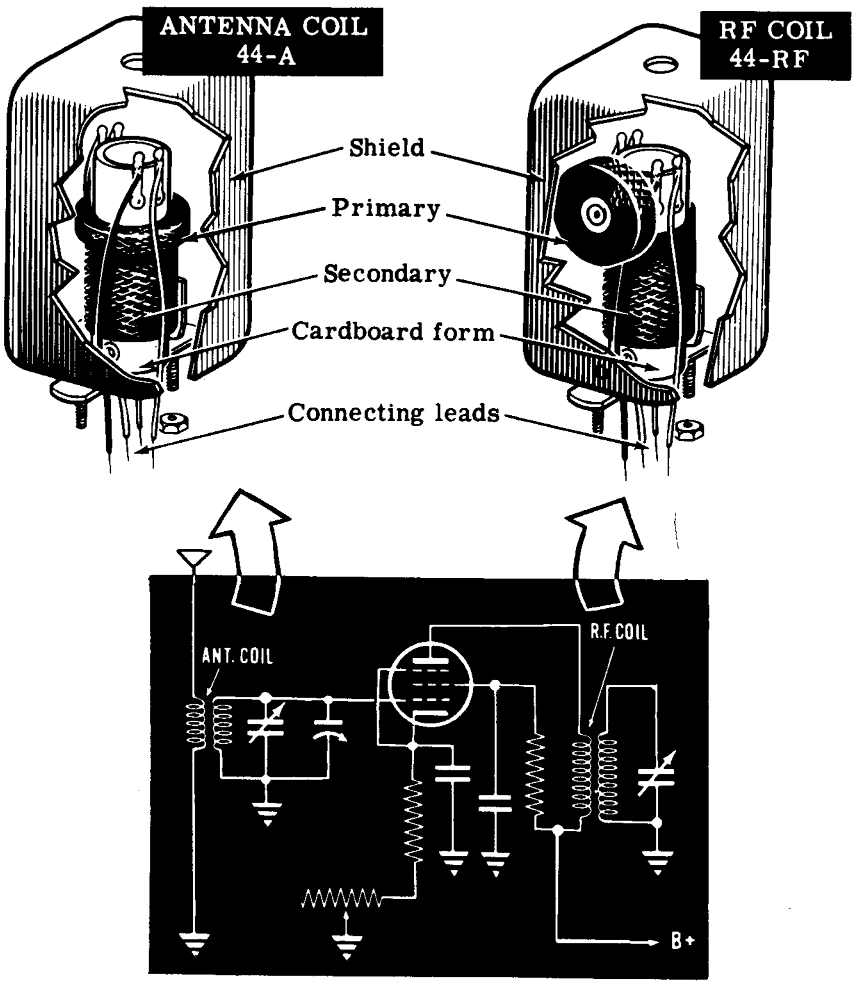
Tubes containing a screen grid do not suffer from this disadvantage and as a result, most RF amplifiers found in receivers employ either tetrodes or pentodes. The tube which is generally preferred as an RF amplifier is a variable-mu pentode. The use of this type of tube not only provides for considerable voltage gain, but also minimizes certain types of interference from powerful undesired signals. Since varying the grid bias of a variable-mu pentode changes the amount of amplification, this type of tube lends itself admirably to applications in circuits involving manual volume control or automatic volume control.



Only screen grid tubes are used in receiver RF amplifiers

RF Transformers

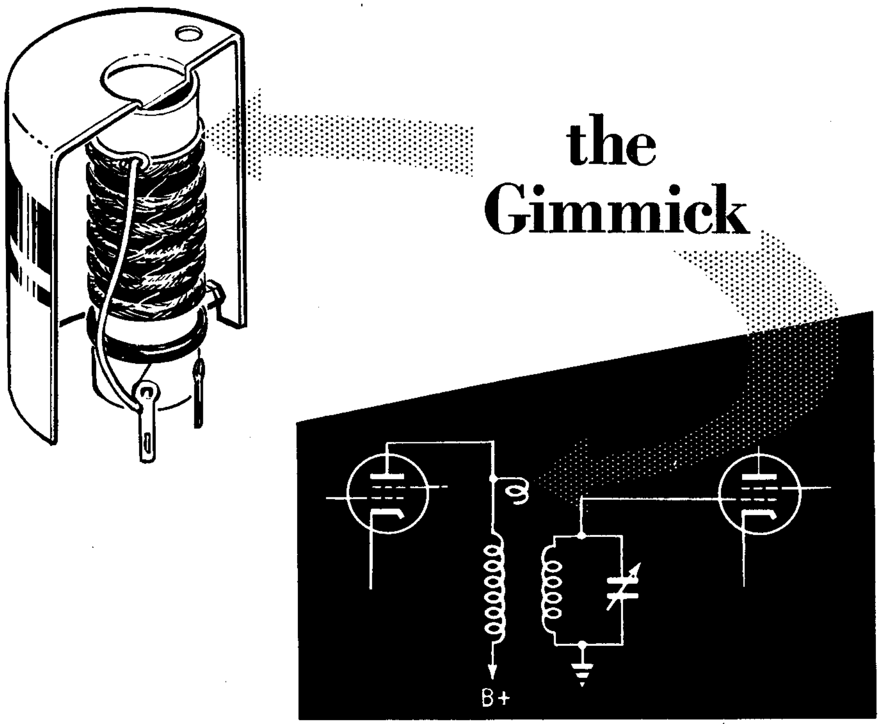
In the schematic of an RF amplifier stage shown below, you will note that the RF amplifier has two RF transformers. The first, the antenna coil, is designed to couple the antenna circuit to the grid circuit of the amplifier. The second, often referred to as the RF coil, couples the plate circuit of the RF amplifier with the grid circuit of the next stage.



The coils are usually wound on a form made of cardboard or bakelite. They are generally of the air core type, although occasionally, when the frequency of operation is not too high, powdered iron cores may be employed.

RF Transformers (continued)

RF transformers used for broadcast band reception have relatively large primary windings which tend to resonate at low frequencies and produce greater gain at the low end of the dial. To compensate for this, capacitive coupling between primary and secondary is used to increase the gain at the high frequency end of the dial. This is accomplished during the manufacture of the coil, by connecting a small capacitor of from 3 to 10 mmfd capacity between the primary and secondary windings, or by using a loop of wire, known as a "gimmick" or "capacity turn." This wire is connected to the primary and is wrapped around, but insulated from, the secondary.



Perhaps you will recall some references, made in "RF Amplifiers," to the "Q" of a resonant circuit. This Q, which is equal numerically to the reactance of the coil divided by its resistance, determines both the selectivity and voltage gain that can be obtained from a resonant circuit. In order to keep the selectivity high, it is therefore necessary to use RF transformers whose resistance is fairly low.

Another important consideration is that of shielding. Unless RF transformers are shielded by means of copper or aluminum shields grounded to the chassis of the receiver, there probably will be undesirable coupling and the production of unwanted oscillations. It should also be noted that shielding changes the inductance and Q of a coil. Consequently any receiver adjustments, such as the alignment process which will be described shortly, should be performed with the shields in place.

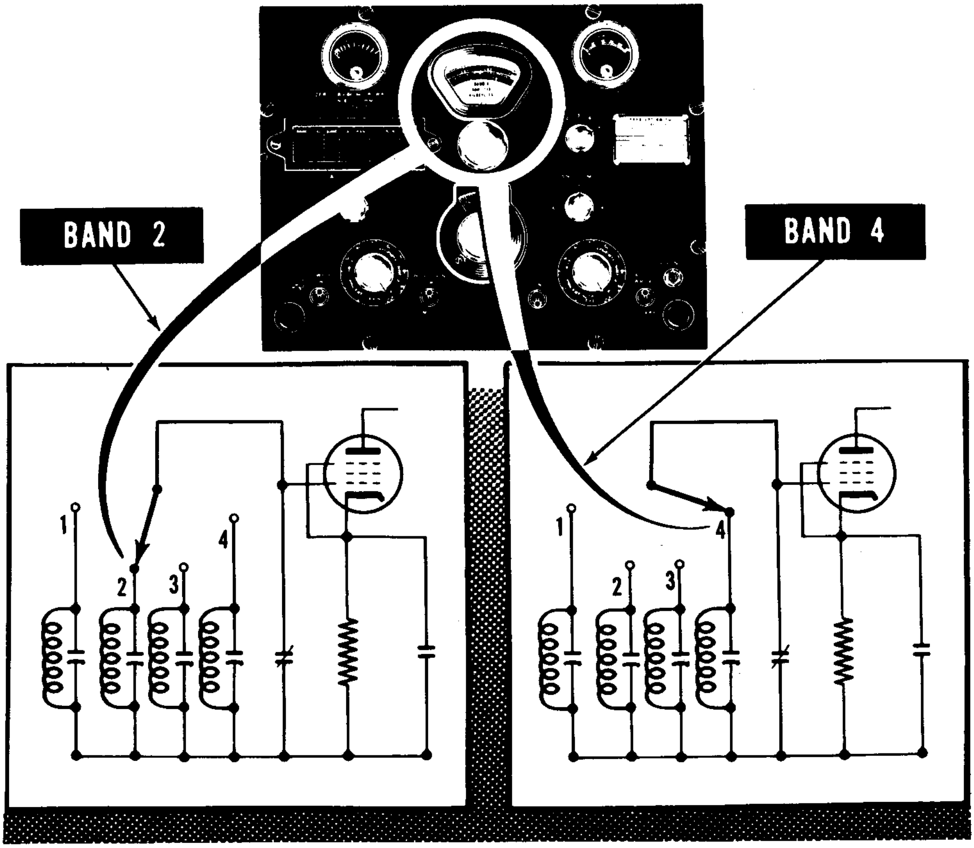
Band Switching

You will note that while the primaries of these transformers are untuned, variable capacitors are connected across the secondary coils, thus forming resonant or tuned circuits. These resonant circuits are responsible for the high selectivity and sensitivity of the TRF receiver.

If a receiver is to cover a frequency range greater than one coil and one tuning capacitor will allow, it will be necessary to change the tuning circuits. This is usually accomplished by substituting a different coil. One system uses removable plug-in coils, while another system uses several mounted coils whose leads run to a multicontact rotary switch, known as a "selector" or "band switch." By turning the switch, any coil may be connected to the tuning capacitor and thus provide a satisfactory response for any desired band of frequencies.

A good example of a receiver employing band switching is shown below. In this receiver the selection of the frequency band is accomplished by rotating a four-position switch. Each switch section can connect any one of four RF coils to a variable capacitor.

BAND SWITCHING



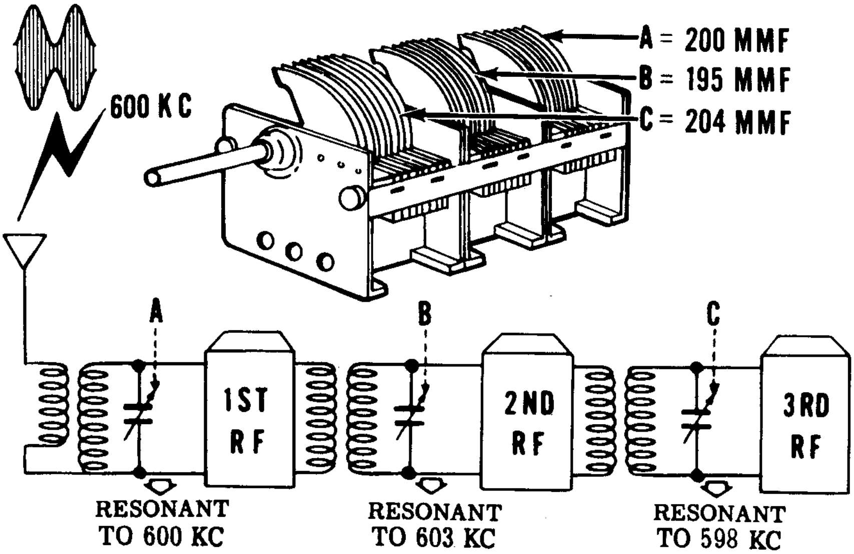
Ganged Capacitors and Alignment

Every TRF receiver has a minimum of two tuned circuits, one associated with the RF amplifier and one with the detector. In the early days of the TRF, each variable capacitor in the tuned circuit was connected to its own individual tuning knob. In order to tune your radio to a station, you had to turn each knob individually until each tuned circuit was resonant to the frequency of the desired station.

The modern TRF receiver eliminates the need for individual tuning knobs by having the variable capacitors of all the tuned circuits mounted on one shaft. This allows the receiver to be tuned with a single control which varies all the tuned circuits together and at the same time. This is called "ganged" tuning. In a receiver having two RF amplifier stages plus a detector, a three-gang capacitor would be used.

Since all of the tuned circuits are varied together, all of the variable capacitors should have exactly the same capacity, at the same time, for various settings. All of the tuned circuits would then be resonant to the same frequency at the same time—resulting in maximum sensitivity and selectivity.

Unfortunately, no two capacitors can be manufactured exactly alike, and therefore the individual capacitor sections on a ganged unit will have slightly different capacities at every setting. If nothing were done to compensate for these differences in capacity, the tuned circuits in a receiver would be resonant to slightly different frequencies for every setting of the tuning knob—causing poor receiver selectivity and sensitivity. Such a receiver is said to be "out of alignment."



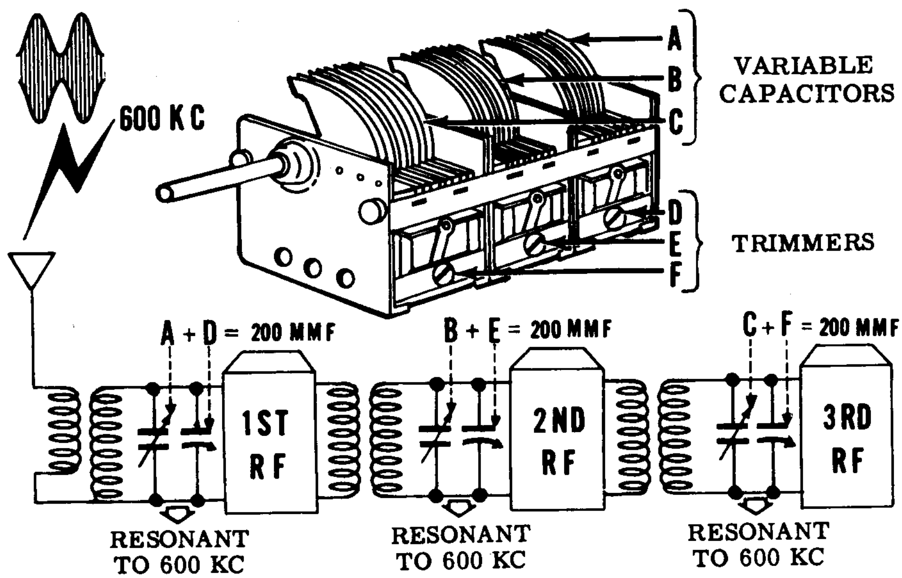
RECEIVER OUT OF ALIGNMENT

Trimmer Capacitors and Coils

The problem of misalignment can be solved by adding small variable capacitors, called "trimmer capacitors," in parallel with the main variable tuning capacitors.

Sometimes the adjustment is made in the coil of a tuned circuit rather than on the capacitors. In this case, an iron-cored slug is moved in and out of the coil, causing the inductance to vary. This is called "slug tuning."

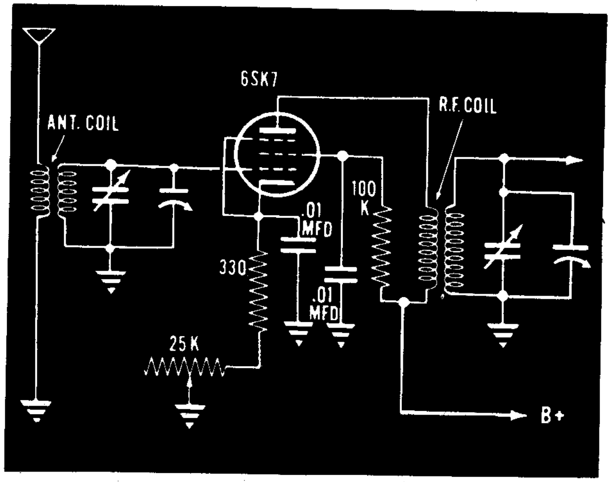
In receivers covering only one band, the trimmers are usually located on the ganged capacitors, one for each section. In receivers using band switching, the trimmers for each range are usually mounted on, and in parallel with, the individual coils. These trimmer capacitors are adjusted after the main capacitors have been set at minimum capacity at the high end of the dial. They are adjusted to make the total capacity of the individual tuned circuits the same at every setting of the tuning control. The tuned circuits will, therefore, be tuned to the same frequency, simultaneously, all over the band—resulting in high receiver sensitivity and selectivity.



RECEIVER IN ALIGNMENT

It sometimes happens that although the circuits are properly adjusted at the high end of the dial, they may not tune to identical frequencies at the other end of the dial. A correction may be made for this, in some sets, if the end rotor plates are of the slotted type. Adjustments can be made by bending a portion of the slotted plates toward, or away from, the stator plates. When all of the stages tune to identical frequencies at all dial settings, they are said to be "tracking" and the receiver is in alignment.

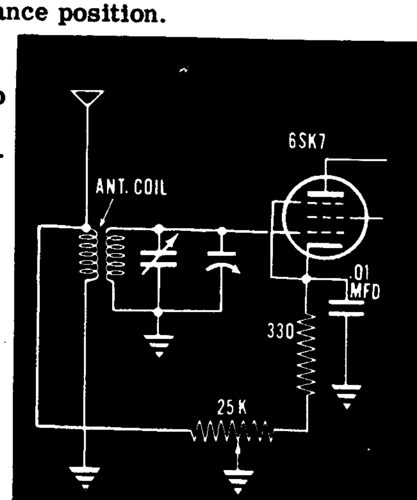
Grid Bias Manual Volume Control



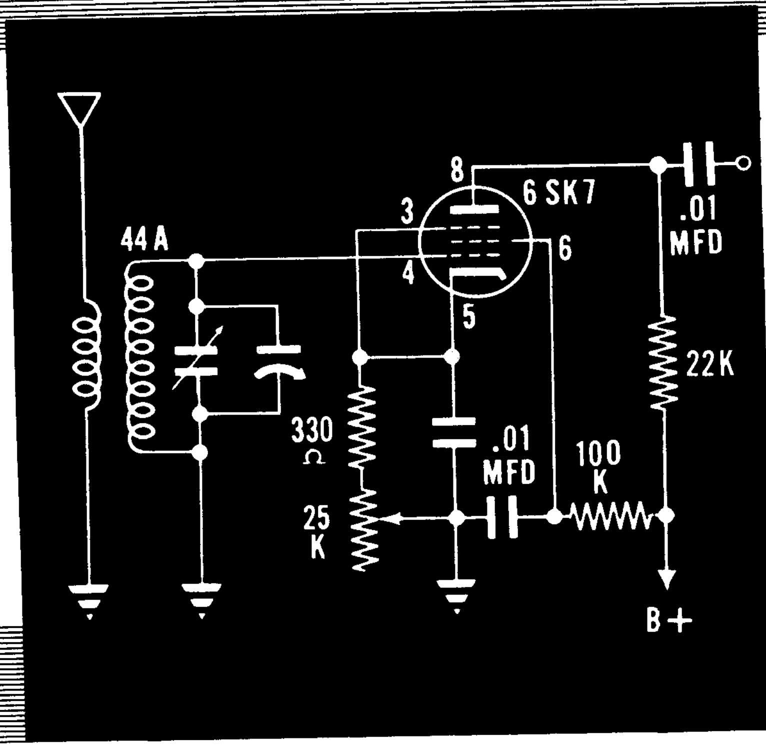
Since signals arriving from different transmitters will vary in intensity, it is necessary to provide a volume control so that the gain of the RF amplifier and the loudness of the signal can be varied. One of the most common methods of controlling the gain of a TRF is to change the bias voltage of the RF amplifier stage by placing a variable resistor in the cathode circuit.

You will recall, from previous discussion, that the RF amplifier stage usually employs a variable-mu pentode tube. Varying the bias of this variable-mu tube causes the amplification factor of the tube to vary, and therefore the gain of the stage to vary. If there are several RF amplifiers, the variable resistor may be connected in such a manner as to vary the bias of all of the RF amplifiers. The fixed resistor in the cathode circuit is placed there to provide the proper bias when the variable resistor is set for maximum gain at the zero resistance position.

A variation of the grid bias volume control employs a potentiometer, which also acts as a variable shunt across the primary of the antenna coil. When the moving arm of the potentiometer is moved to the left, the resistance across the primary coil is reduced while the cathode resistance is increased. This results in a weaker signal on the grid and reduced voltage amplification. When the sliding arm is moved to the extreme right, the resistance across the primary is increased, while the cathode resistance is reduced. This produces a stronger signal on the grid and increased voltage amplification.



Analysis of the RF Amplifier



The RF Amplifier

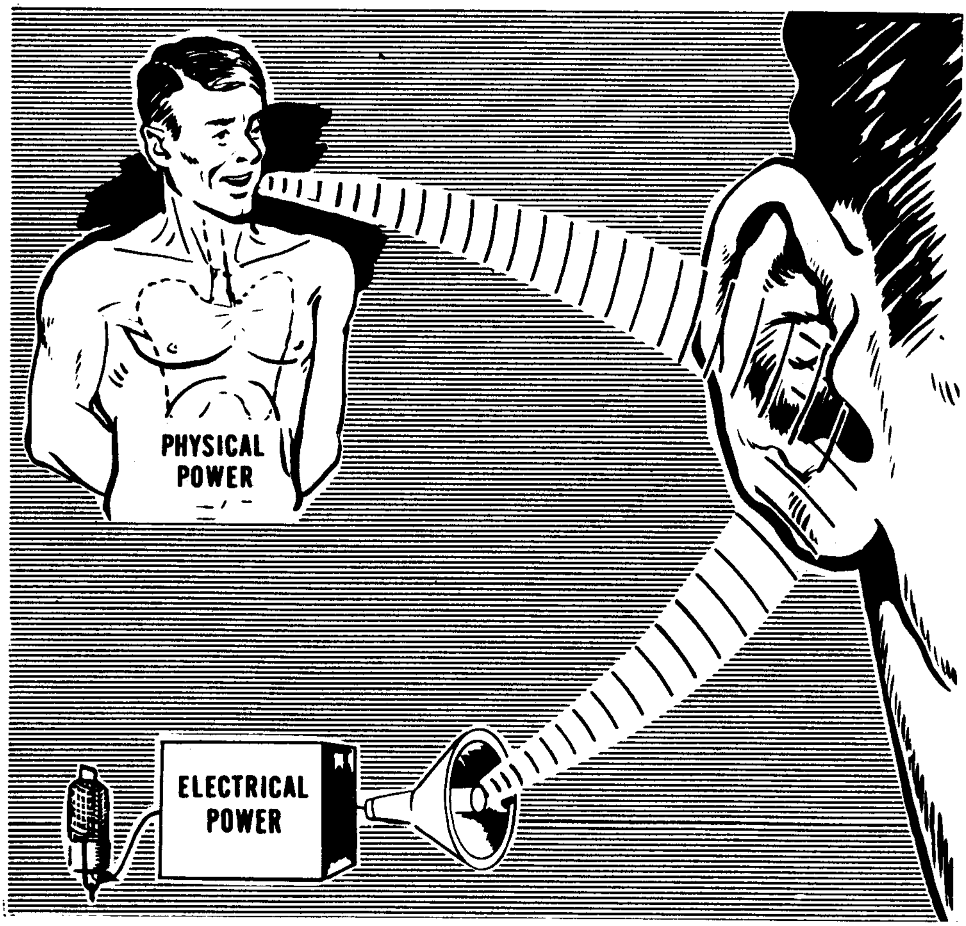
Suppose you pause for a moment to examine the RF amplifier shown above and to review the purpose of each component. The antenna coil couples the antenna to the control grid of the RF amplifier. The variable capacitor enables the operator to tune the amplifier to the frequency of the desired signal, and thus provides selectivity. The 25K variable resistor acts as a volume control, while the 330-ohm resistor provides limiting cathode bias. The .01 mfd capacitor between the cathode and ground is the cathode bypass capacitor. The 100K resistor in the screen grid circuit is the screen grid voltage dropping resistor, which serves to keep the screen grid at a lower positive potential than the plate. The .01 mfd capacitor in the screen grid circuit is the screen grid bypass capacitor, which acts as a bypass for RF signals, and enables the screen to act as a shield between the plate and the control grid. The 22K resistor in the plate circuit is the plate load, while the .01 mfd capacitor in the plate circuit is used for the purpose of coupling the plate circuit to the grid of the next stage, and at the same time effectively blocking the passage of direct current.

What the Audio Power Amplifier Does

Your next job with radio receivers will be to review an audio power amplifier. You need an audio power amplifier in your receiver because you will want to pick up stations and hear them in a loudspeaker. Loudspeakers have to push the air and make it move in order to produce sounds.

A loudspeaker converts electrical power into sound power. To supply the loudspeaker with sufficient power, an audio power amplifier is put in as the last stage of a receiver.

Like the RF amplifier, you will find an audio power amplifier in just about every receiver you will repair or operate. Here is a chance to add another building block to your know-how on receivers.

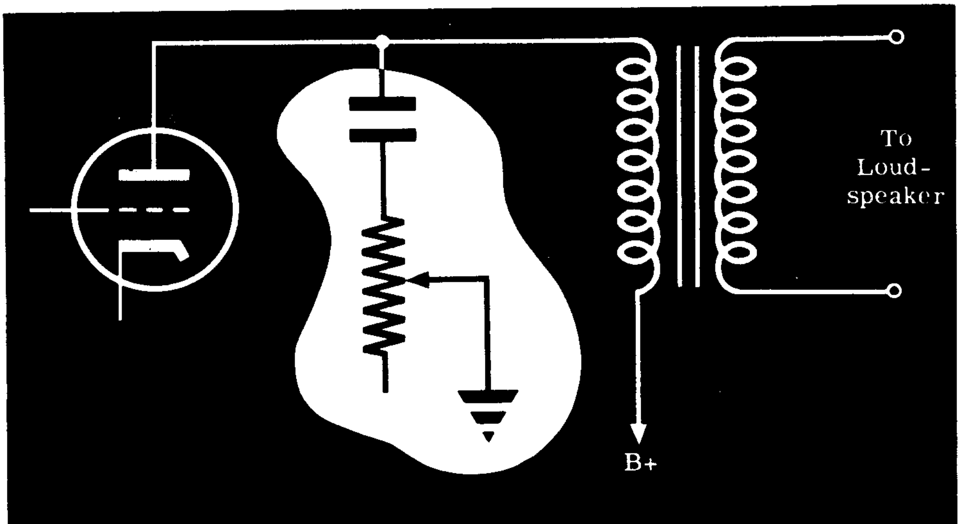


AF Amplifier Tone Control Circuits

The tone or pitch of a complex sound depends upon whether there is a greater proportion of high frequency or low frequency waves in the sound. In other words, a high-pitched sound has more high frequency sound waves, while a low-pitched sound consists mainly of low frequency sound waves.

The sound emitted by a radio receiver may differ considerably from the original sound applied to the transmitter. The main reason for this is that audio amplifiers do not amplify all the frequencies by the same amount, and loudspeakers do not respond equally well to all frequencies.

Other causes of distortion are static and tube noises which generally are high audio frequencies of a random nature. To prevent the annoying interference from static and noise, and to provide a deeper bass effect which most radio listeners seem to prefer, many radio receivers employ some means of tone control. This is accomplished by eliminating some of the higher frequencies—shunting them to ground or bypassing them around the output transformer.

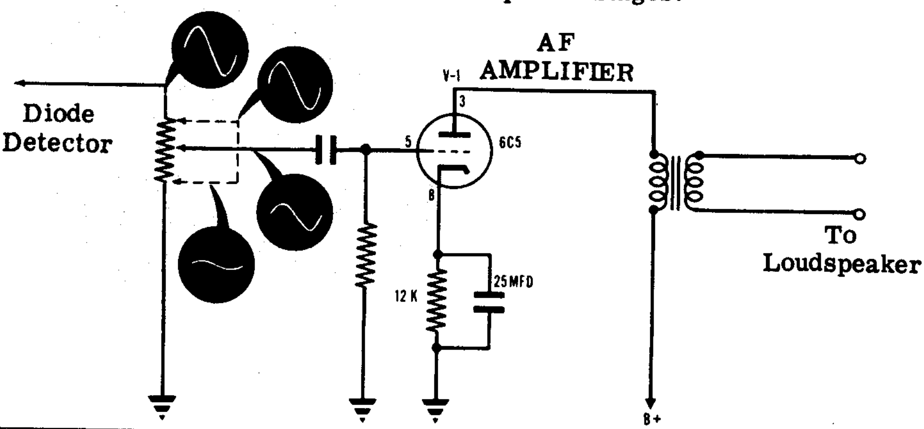


A METHOD OF TONE CONTROL IN AUDIO AMPLIFIERS

You will note that the capacitor in the plate circuit offers a relatively easy path for the higher audio frequencies, while the lower audio frequencies encounter a path of less opposition by traveling through the primary coil of the transformer. In this way, the amount of high frequency sound reaching the loudspeaker is considerably reduced. The variable resistor acts as a means of tone control. If the resistance is made very high, the path through the capacitor to ground becomes one which offers high opposition to the passage of high frequency as well as low frequency signals. As a result less high frequency current flows through the bypass capacitor and there is a rise in the pitch of the sound coming out of the loudspeaker.

AF Amplifier Volume Control

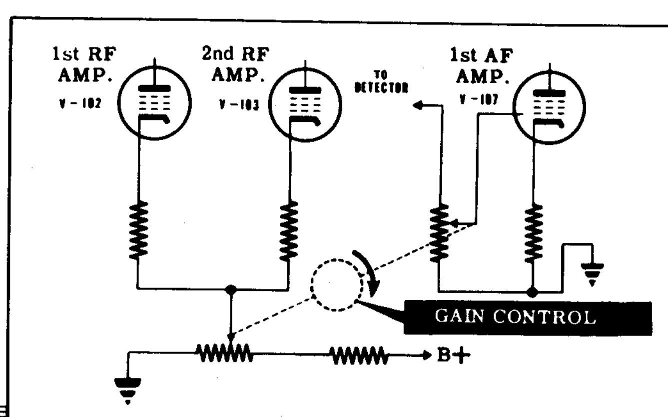
You have previously been given a description of one method of controlling the volume of a receiver. This method involved varying the bias of the RF amplifier stage. There is another commonly used method of volume control involving the detector and AF amplifier stages.



DETECTOR-OUTPUT VOLUME CONTROL

Notice that the detector is coupled to the AF amplifier by means of resistance-capacity coupling circuit. The volume control is basically a voltage divider, the moving arm tapping off the desired amount of signal voltage which is then applied, through the coupling capacitor, to the grid of the AF amplifier. This type of volume control is frequently employed in superhet receivers.

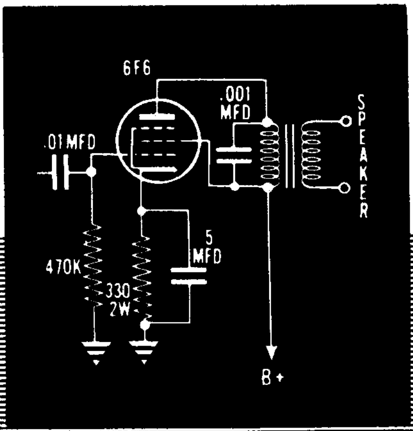
Some receivers employ a dual type of volume control. This control regulates the gain in the first and second RF amplifier stages by varying the cathode bias, and also controls the gain by varying the amplitude of the input signal applied to the first AF amplifier.



GRID CONTROL OF RECEIVER

Analysis of the AF Amplifier Circuit

Now stop for a few minutes and analyze the functions of the various component parts of the AF power amplifier circuit shown here. Notice that no provision is made in this AF amplifier stage for volume or tone control.



The 0.01-mfd coupling capacitor and 470K grid resistor found in the control grid circuit couple the control grid of the amplifier to the preceding detector stage. The capacitor also reduces the possibility that any DC voltages from the detector stage might be impressed upon the control grid of the amplifier.

The 330-ohm resistor acts as a cathode bias resistor, while the 5-mfd capacitor bypasses the varying component of the plate current around the cathode resistor, thus preventing the production of a varying bias and the accompanying reduction in amplification.

The primary of the output transformer acts as the plate load and couples the amplifier to the loudspeaker. The .001-mfd capacitor across the primary bypasses high frequency audio signals around the primary and this reduces the amount of high frequency sounds and noises emitted by the loudspeaker.

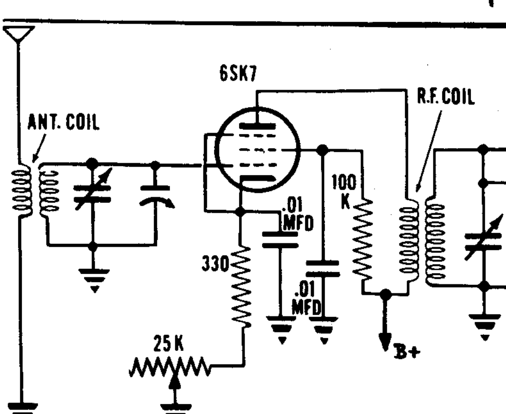
Components	Functions
0.01-mfd capacitor and 470K resistor	Couples AF amplifier to preceding detector stage
330-ohm resistor	Provides cathode bias
5-mfd capacitor	Bypasses signal around cathode bias resistor
0.001-mfd capacitor	Prevents high frequency audio signals from entering loudspeaker
Output transformer	Acts as plate load and couples amplifier to loudspeaker

Comparison of RF and AF Amplifiers

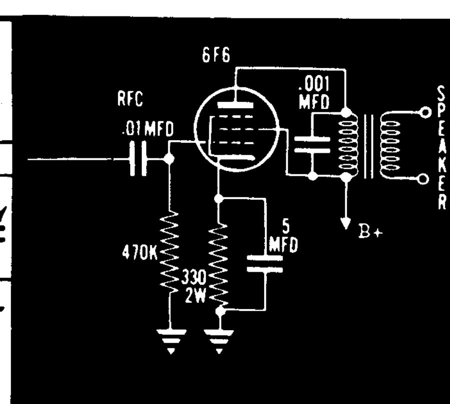
Since most radio receivers you will encounter contain both RF and AF amplifiers, you must possess a clear understanding of the differences between them and the advantages and disadvantages of each. The following comparisons should serve to clarify your conceptions of RF and AF amplifiers.

RF Amplifiers	AF Amplifiers
1. Designed to amplify frequencies above 20,000 cycles.	1. Designed to amplify frequencies between 15 cycles and 20,000 cycles.
2. Usually have tuned circuits, thereby adding selectivity.	2. Untuned and do not add to selectivity of set.
3. Usually coupled to other stages by RF air-core transformers.	3. Coupled to other stages by AF iron-core transformers, or by resistance-capacity coupling.
4. Precede the detector stage.	4. Follow the detector stage.
5. Designed for voltage amplification.	5. Designed for power amplification.
6. If triodes are used they lack stability and must be neutralized.	6. Very stable and not likely to oscillate—if triodes are used, no neutralization is required.
7. Generally employ variable-mu pentodes.	7. Generally employ triodes, beam-power tetrodes, and power pentodes.

TYPICAL RF AMPLIFIER STAGE



TYPICAL AF AMPLIFIER STAGE

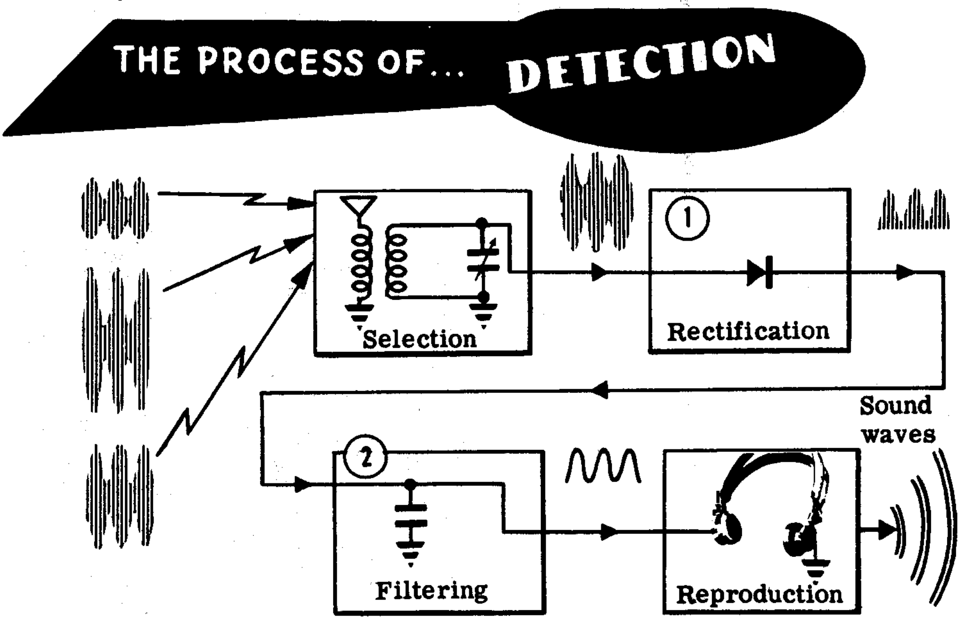


What the Detector Does

The detector is the key circuit of the radio receiver. The primary purpose of this circuit is to change the RF signal into a signal which can be reproduced as sound by the headphones or loudspeaker. Without the detector, radio reception is not possible. The simplest radio receiver contains a detector, an antenna and a pair of headphones. All of the other stages which are found in more complex receivers, such as the TRF and superhet, have been placed there for the primary purpose of enabling the detector to do a better job. In order to understand the purpose of the detector, it is necessary to review briefly the theory of radio-telephone transmission.

In the section on radio transmitters, it was made clear that radiotelephone transmission requires the generation of a radio-frequency carrier wave. Intelligence is impressed upon this wave by varying the amplitude of the carrier wave in direct proportion to the amplitude of the sound impulses. This combination of audio-frequency waves superimposed upon a carrier wave is known as an amplitude-modulated signal. It is this combination of waves that is picked up by the antenna of the radio receiver.

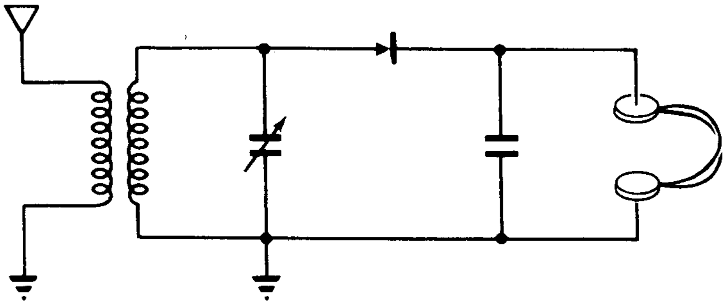
When transmitted signals reach a receiver, the desired signal is selected by the tuned circuit of the detector, or of the RF amplifier stage if the receiver employs such a stage. The selected signal is then rectified by a crystal or vacuum tube rectifier in the detector. The RF component is filtered out of the rectified signal, and the audio component is changed into sound waves by earphones or a loudspeaker. The process of detection includes the rectification and filtering steps, and these two steps are performed by the detector.



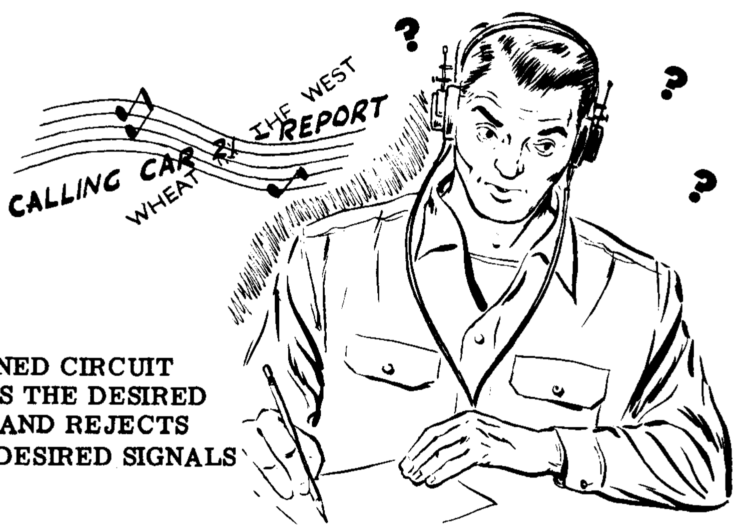
The Crystal Detector

The simplest of all detectors is the crystal type. If you understand how it works, you should have very little trouble understanding the operation of the somewhat more complicated vacuum-tube detectors.

A CRYSTAL DETECTOR



The modulated radio waves which are radiated from the transmitter's antenna induce corresponding signal voltages and currents in the antenna-ground system of the radio receiver. These signals are then transferred to the detector circuit by means of a radio-frequency transformer. If there are several transmitters in operation nearby, there will be several signals found at this point. Unless these signals are separated from each other, they will all be detected and the listener will hear a confused mixture of sounds. In other words, the selectivity will be extremely poor. It is the function of the coil and variable capacitor to separate these signals and thus provide selectivity. The coil and capacitor are called the "tuned circuits."



THE TUNED CIRCUIT SELECTS THE DESIRED SIGNAL AND REJECTS THE UNDESIRED SIGNALS

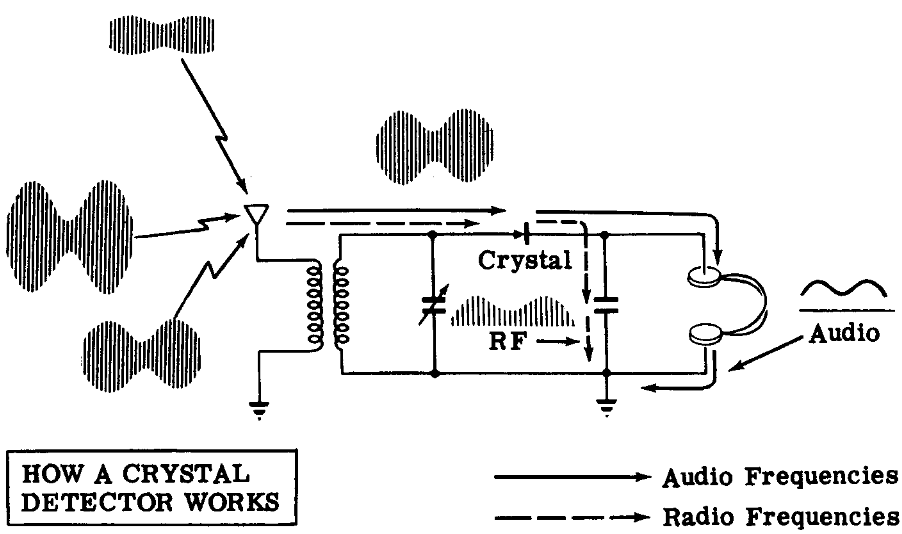
How the Crystal Detector Works

You will probably recall from a previous discussion dealing with the selectivity of RF amplifiers that signals of differing frequencies can be separated from each other by taking advantage of the selective properties of a resonant or tuned circuit. A circuit of this type generally contains a fixed coil and a variable capacitor. It is capable of selecting or accepting radio signals of one particular frequency and rejecting those of all other frequencies. In addition, the tuned circuit produces a step-up or gain in signal voltage at resonance.

The tuned circuit can be adjusted to resonate or respond to a higher or lower frequency signal by varying the size of the capacitor. You will also encounter tuned circuits in which the capacity is kept constant and the tuning is accomplished by varying the inductance of the coil. Nevertheless, most resonant circuits are tuned by varying the capacitor.

Returning to our crystal detector, it is apparent that the variable capacitor and the secondary of the RF transformer form a tuned circuit. It is this circuit that gives the detector some degree of selectivity or ability to discriminate between desired and undesired signals.

The selected signal is rectified by the detector and the result is a pulsating DC signal containing two components, one of which is radio frequency and the other, audio frequency. The AF component passes through the headphones and produces sound waves similar to those originally used to modulate the radio wave. The RF component is bypassed around the headphones by the filtering action of a small capacitor placed across the headphones.



HOW A CRYSTAL DETECTOR WORKS

Characteristics of the Crystal Detector

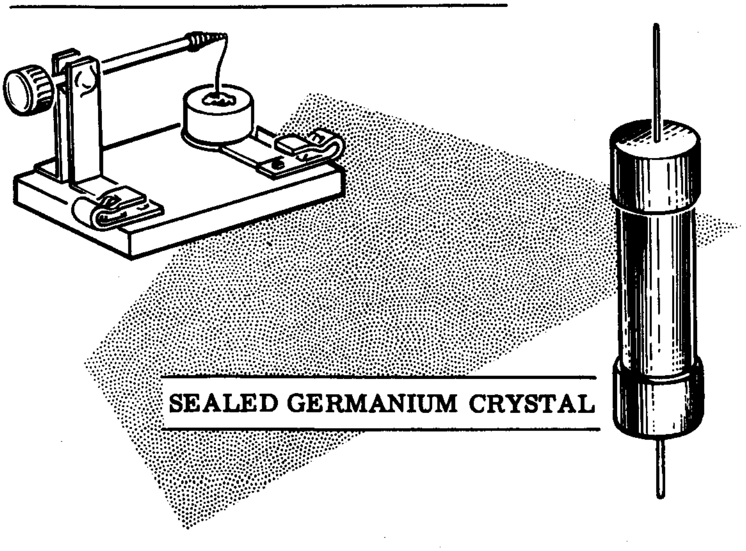
The crystal detector possesses the advantages of simplicity and economy. In addition, it requires no batteries or other local sources of power. There are no filaments to burn out or produce hum and noise. In applications requiring the detection of ultra-high frequency signals, the crystal possesses certain decided advantages over the vacuum-tube detector.

Although transistors, which are crystals capable of amplifying signals, have been developed recently, the ordinary crystal detector provides no amplification. The crystal detector is therefore characterized by low sensitivity.

The galena crystal has still another disadvantage. Certain portions of the face of the crystal have better rectifying properties than the remaining portions. This makes it necessary to explore the face of the crystal with a wire probe called a "cat's whisker" until a sensitive rectifying point is found. The wire can easily be dislodged from this sensitive point and consequently, reception is likely to be erratic. In addition, dirt, grease or air-borne dust may spoil the sensitive spot and make it necessary to search for another spot.

These difficulties have been overcome in the more modern germanium and silicon crystal rectifiers. These consist of small sealed cartridges containing contact wires that cannot be dislodged. They have an extremely long life and resist shock and vibration better than most conventional vacuum tubes.

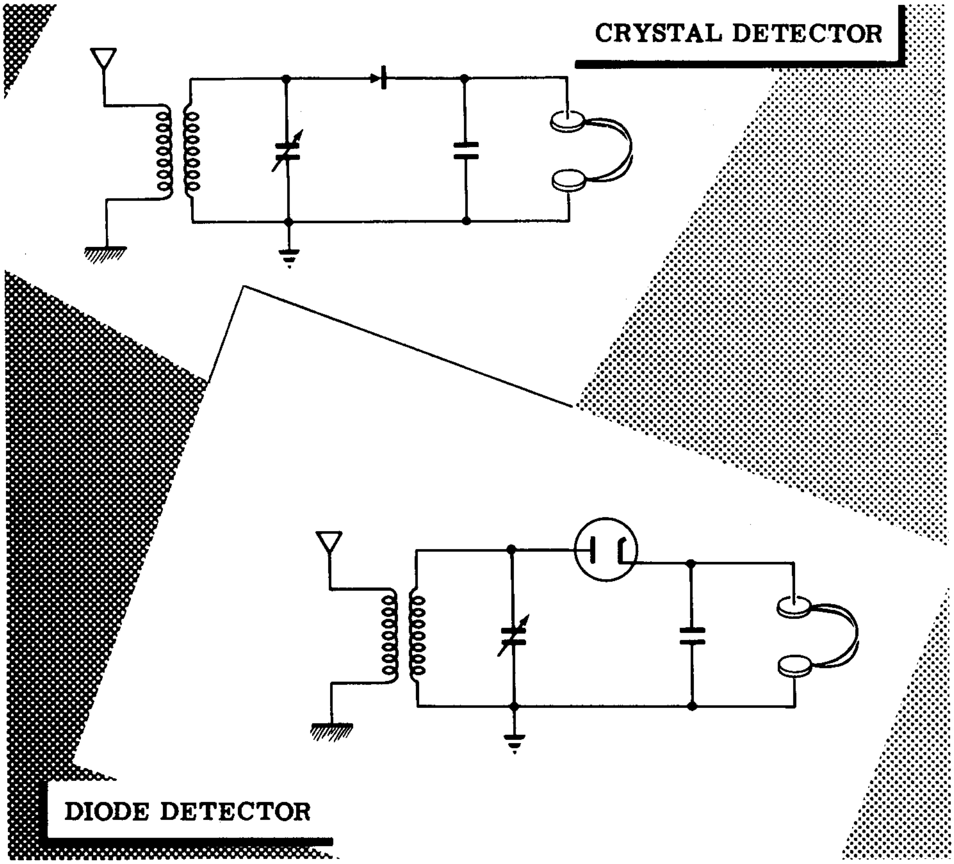
OPEN TYPE CRYSTAL DETECTOR



SEALED GERMANIUM CRYSTAL

The Diode Detector

The fundamental circuit of the diode detector closely resembles that of the crystal detector. Consequently, the operating principles and characteristics of these two detectors resemble each other closely.



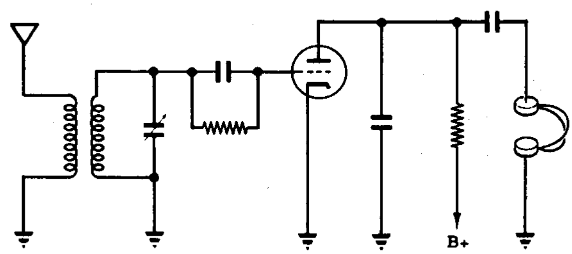
You will observe that the only difference between the diode and crystal detectors is the replacement of the galena crystal by a diode tube. The processes of selection, rectification and filtering are carried on in the manner previously described under crystal detectors. Diode detectors are characterized by faithful reproduction and low sensitivity. When the detector is operating, plate current flows through the tuned circuit during the positive half of each signal cycle. This plate current flow produces what is known as a "loading effect." This in turn has the effect of reducing both the voltage gain and selectivity of the tuned circuit.

Because of these factors and because it is capable of handling large signal voltages without distortion, the diode detector is generally preceded by one or more tuned RF amplifiers which provide increased sensitivity and selectivity. The detector is usually followed by one or more stages of AF amplification to provide sufficient power to operate a loudspeaker.

The Grid-Leak Detector

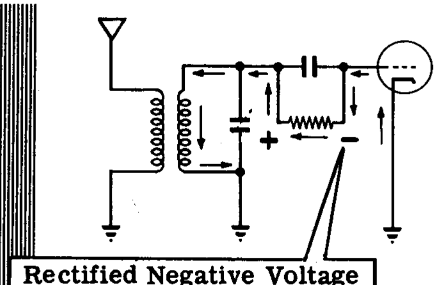
You have seen that since the diode detector cannot amplify, it is generally used in a receiver containing several stages of amplification. If you desire a receiver which uses fewer tubes, it is necessary to use a more sensitive detector—one which amplifies as well as detects. In order to amplify, the detector must of necessity use a tube containing a control grid, such as a triode, tetrode or pentode.

The triode detector which is easiest to understand is the grid-leak detector. This is because the grid-leak detector is basically a diode detector followed by a stage of audio-frequency amplification.



GRID-LEAK DETECTOR

Suppose you examine the grid and cathode circuits of this detector and temporarily forget about the plate circuit. The result will be the circuit shown in the following diagram:



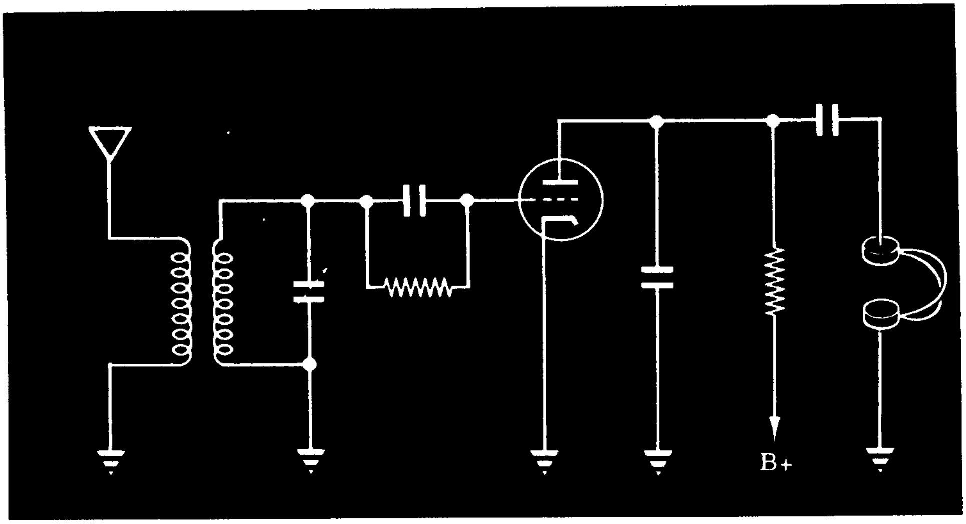
Note that this is basically the circuit of the diode detector. The control grid of the triode is taking the place of the diode plate, the grid-leak resistor has replaced the diode load or earphones, and the grid capacitor is acting as an RF filter capacitor across the load.

When a modulated signal voltage is applied to this circuit, the grid will attract electrons from the cathode during the positive half-cycles. The flow of current through the grid-leak resistor to ground produces a voltage drop across the grid-leak resistor. Because of the fact that current can flow in only one direction in the grid circuit, this voltage remains constant in polarity. The grid is thus biased, or kept at a negative voltage with respect to the cathode. The amount of bias will vary in accordance with the amplitude or modulation of the signal. In other words, the bias will vary at an audio-frequency rate.

The Grid-Leak Detector (continued)

Suppose you consider the complete grid-leak detector circuit.

Schematic of a grid-leak detector



You will recall that the plate current of a triode is dependent upon the grid voltage. Consequently the audio frequency variations in bias should produce a corresponding pulsating plate current. Any radio frequency component of the plate current is filtered out by capacitors and RF chokes placed in the plate circuit. As a result, the voltage developed across the plate load is an amplified reproduction of the audio frequency voltage developed across the grid-leak resistor.

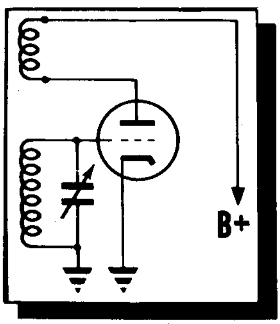
When there is no incoming signal, no bias is produced. Consequently, the plate current is high when no signal is being detected. When a signal is received, the grid becomes biased negatively and the average amount of plate current decreases.

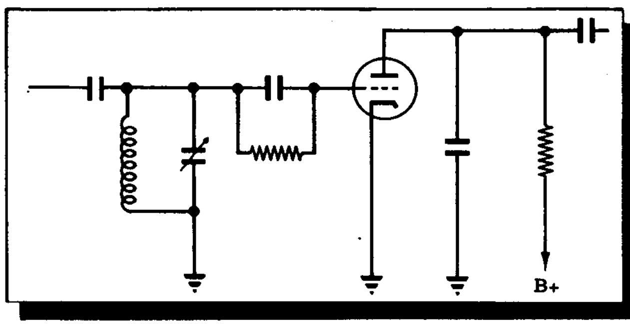
The amount of grid bias developed is equal numerically to the amount of grid current multiplied by the amount of resistance of the grid-leak. Therefore the larger the grid-leak resistor, the greater will be the amplitude of the signal developed. For that reason, extremely sensitive grid-leak detectors usually use grid-leak resistors whose values are between one and five megohms.

However, if a strong signal comes in, it is quite possible that enough bias may be created to cut off the flow of plate current during part of the cycle, thus producing distortion. In order to reduce this distortion, grid-leak power detectors are used. They are designed for use with more powerful signals and generally employ smaller resistors in the grid circuit.

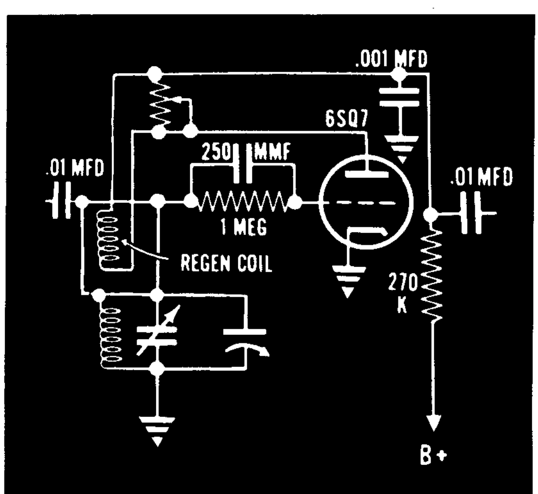
The Regenerative Detector

The regenerative detector, which is extremely sensitive, is a modification of the grid-leak detector. It utilizes the principle of regeneration, or strengthening the signal by feeding the amplified signal produced in the plate circuit back to the grid. From your work with oscillators you should have acquired an understanding of the nature and importance of regeneration. A regenerative detector is nothing more than a combination of an oscillator and a grid-leak detector. If you understand the operating principles of each of those circuits, the regenerative detector should give you very little trouble.





An Oscillator + A Grid-Leak Detector



= A Regenerative Detector

How the Regenerative Detector Works

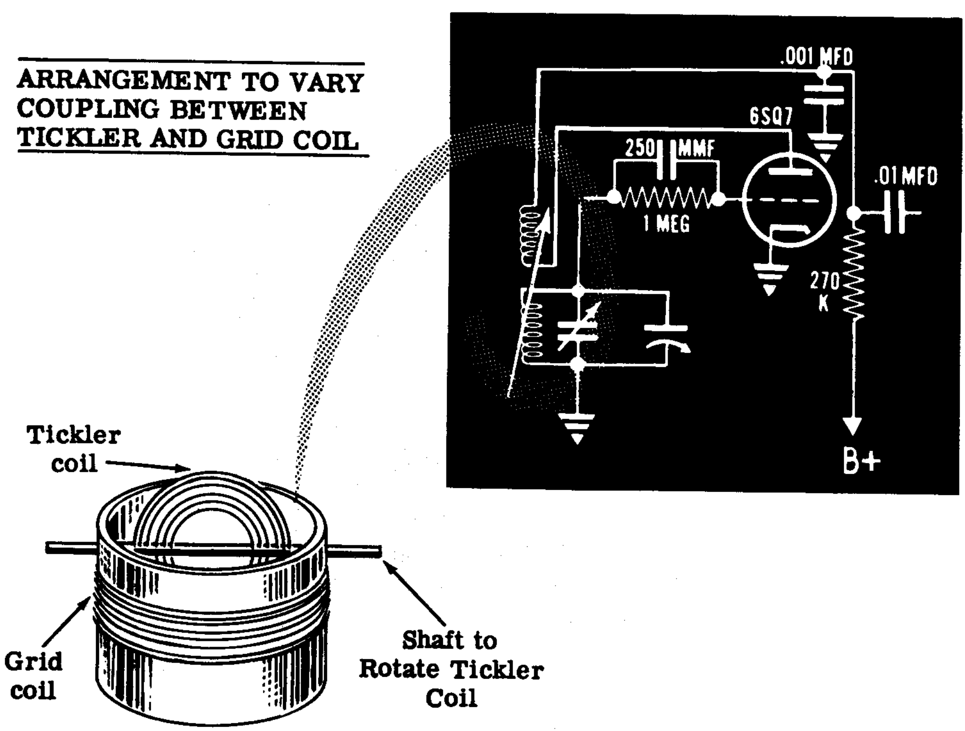
The regenerative detector circuit is similar to that of the grid-leak detector except for the coil in the plate circuit and the variable resistor across the coil. This circuit is shown on the previous sheet.

The plate coil, sometimes called the "tickler coil," feeds back voltage to the grid circuit in phase with the incoming signal voltage, thus increasing the voltage gain and sensitivity of the detector. The variable resistor is placed across the coil to control the amount of feedback or regeneration.

Why control the amount of feedback? The answer becomes obvious if you consider that when feedback becomes excessive, a circuit will begin to oscillate and produce squeals and howls. On the other hand, if there isn't enough feedback, this detector is hardly any more sensitive than the grid-leak detector. Control of feedback enables us to avoid the two extremes and strike a happy medium.

There are many ways of controlling the amount of feedback. One method which has been used involves varying the physical position of the tickler coil with respect to the grid coil. If the coupling between the two coils is reduced by moving the tickler coil away from the grid coil, or rotating it so that its axis is at an angle to the axis of the grid coil, the amount of feedback will be reduced. When this method is used to control feedback, a potentiometer is not connected across the tickler coil.

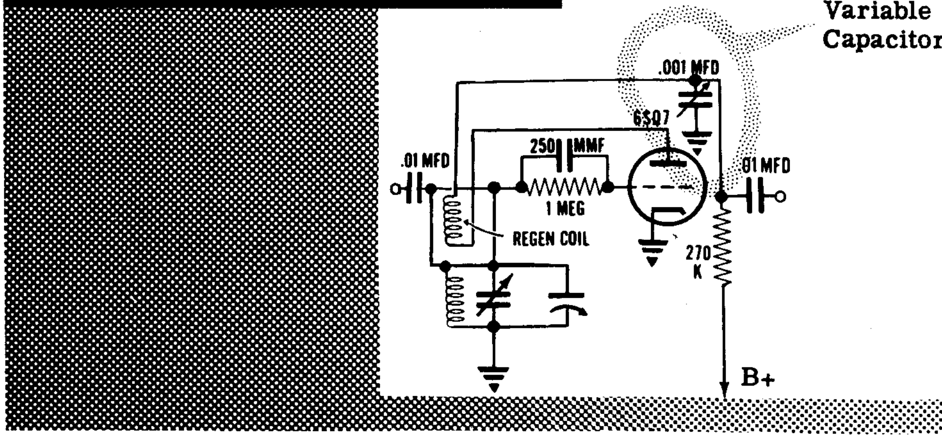
ARRANGEMENT TO VARY COUPLING BETWEEN TICKLER AND GRID COIL



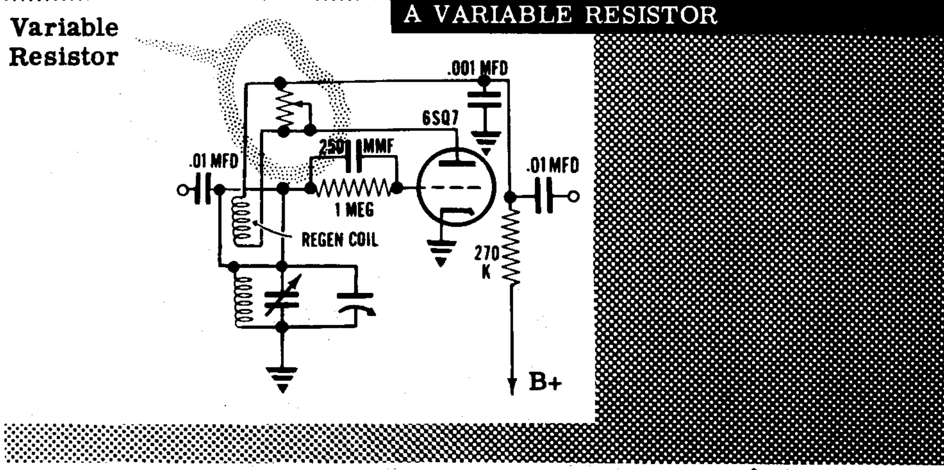
How the Regenerative Detector Works (continued)

Another method of regeneration control makes use of a variable capacitor which is placed between one side of the tickler coil and ground. Decreasing the size of the capacitor, reduces the amount of RF energy available in the plate circuit for regeneration.

REGENERATION CONTROL EMPLOYING A VARIABLE CAPACITOR



REGENERATION CONTROL EMPLOYING A VARIABLE RESISTOR



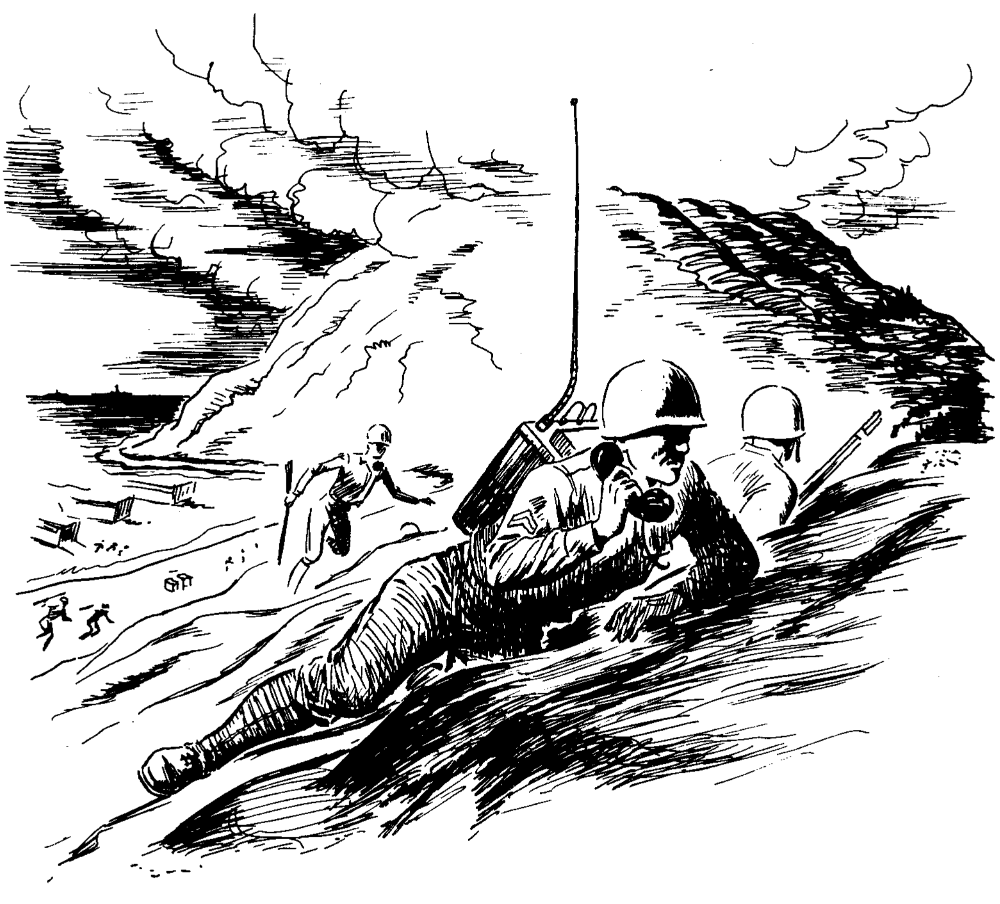
In the detector shown above, regeneration is controlled by a variable resistor placed across the tickler coil.

When the movable arm of the potentiometer is in the upper position, the tickler coil is effectively shorted out and there is no regeneration. The detector is now, for all practical purposes, a grid-leak detector. When the potentiometer arm is moved to the other extreme position, most of the RF current will flow through the tickler coil rather than through the potentiometer. As a result, the circuit will probably begin to oscillate.

How the Regenerative Detector Works (continued)

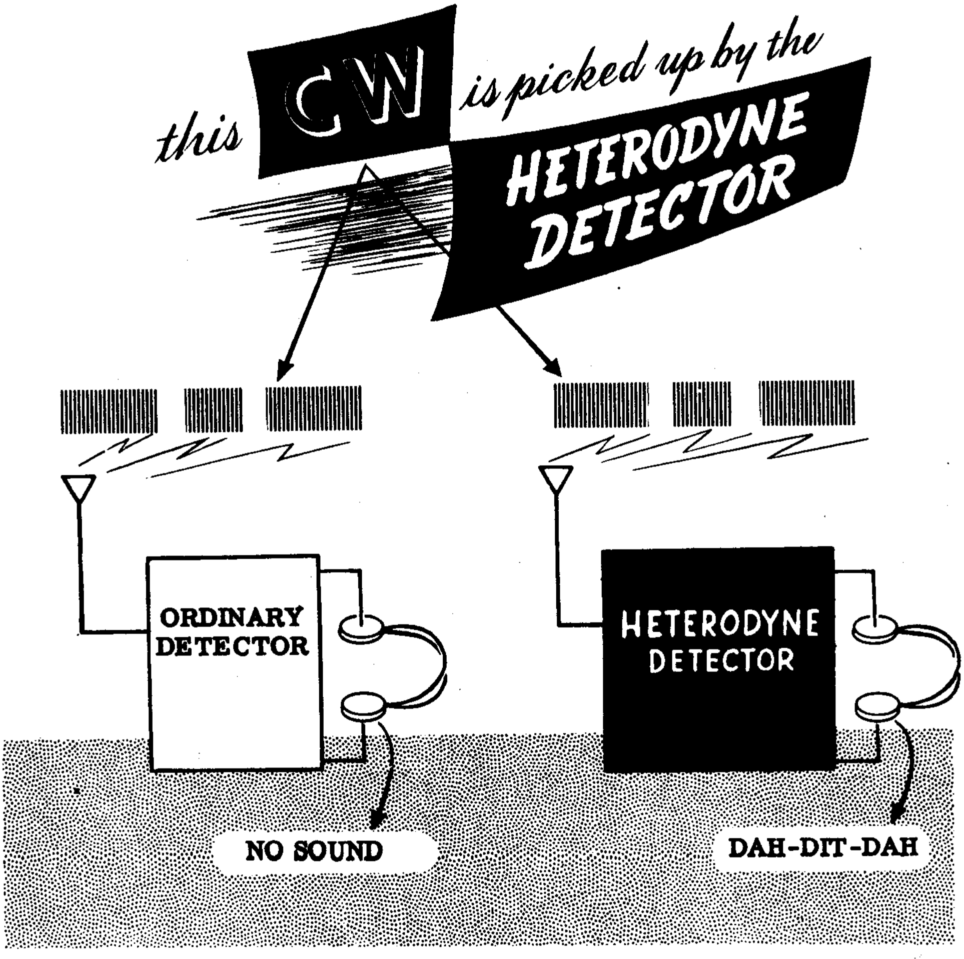
No matter what method is used to control regeneration, the control is usually advanced as far as possible without producing oscillations. In actual practice this is accomplished by tuning in a station, just as with any other type of detector. Then the regeneration control is turned up to the point at which whistles, howls and clicks are heard. This indicates that the detector is oscillating. The regeneration control is then turned back to the point where these interfering sounds just disappear. The regenerative detector is properly adjusted for maximum selectivity and sensitivity. This process of adjusting the regeneration control must be repeated each time a new signal is tuned in.

The regenerative detector is the most sensitive detector capable of receiving amplitude-modulated signals. The familiar walkie-talkie, used so successfully during the last war, employed a modified regenerative detector circuit.



The Regenerative Detector as a CW Receiver

You may recall from your study of transmitters that there are several methods of impressing intelligence upon a carrier wave. One of these methods is known as "amplitude modulation." The crystal, diode and grid-leak detectors we have considered up to this point are designed for use with amplitude-modulated (AM) signals. Another method of conveying intelligence involves the interruption of a carrier wave in accordance with a code such as the Morse Code. These signals are called "interrupted continuous wave" or "CW signals." Since there is no modulation in this type of signal, it cannot be detected by crystal, diode or grid-leak detector circuits. In order to hear the signal, it is necessary to use a detector which employs the heterodyne principle. The heterodyne principle involves mixing the CW signal with a signal obtained from an oscillator. The result of this mixing is an AM signal which is interrupted in the same manner as the original CW signal. This AM signal can then be detected and the familiar "dit-dah" sound of code will be heard in the earphones.



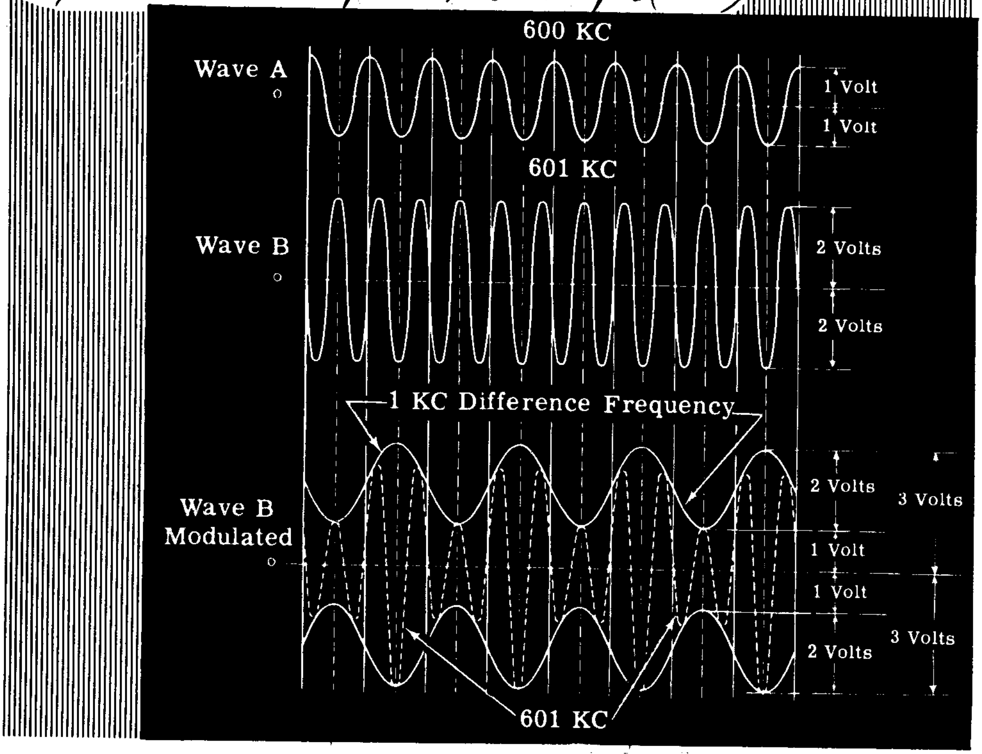
The Regenerative Detector as a CW Receiver (continued)

You may have observed that when two adjacent piano keys are struck at the same time, a distinct throbbing sound can be heard. This throbbing sound, known as a beat, has a frequency equal to the difference of the frequencies of the two notes struck. If the two notes struck have frequencies of 264 and 297 cycles respectively, the beat frequency will be equal to the difference between them, or 33 cycles.

Similarly, when two alternating voltages of slightly different frequencies are combined in a detector, the resultant wave circuit produced in the output will have a frequency which is equal to the difference between the frequencies of the two original voltages. This is the basis of the heterodyne principle.

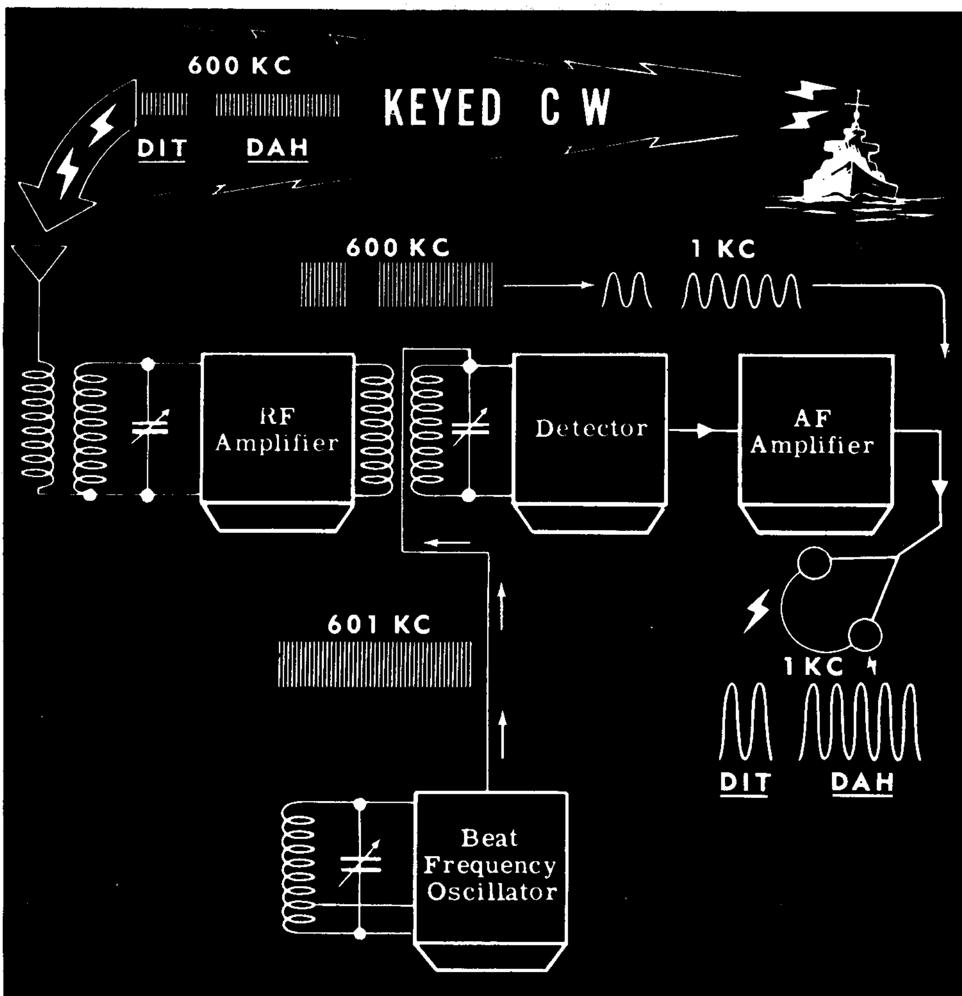
For example, if two inaudible RF waves whose frequencies are 600 kc and 601 kc, respectively, are applied to a detector tube, the smaller wave (A) will add and subtract from the larger wave (B) to make the amplitude of the larger wave (B) vary in the manner shown. The rate of variation of the amplitude of wave B is the difference between the frequencies of the two waves—in this case 1 kc. Observe that wave B, because of the introduction of wave A, has been transformed into an amplitude-modulated wave. The audio modulation can be heard by detection of this AM signal.

The Heterodyne Principle



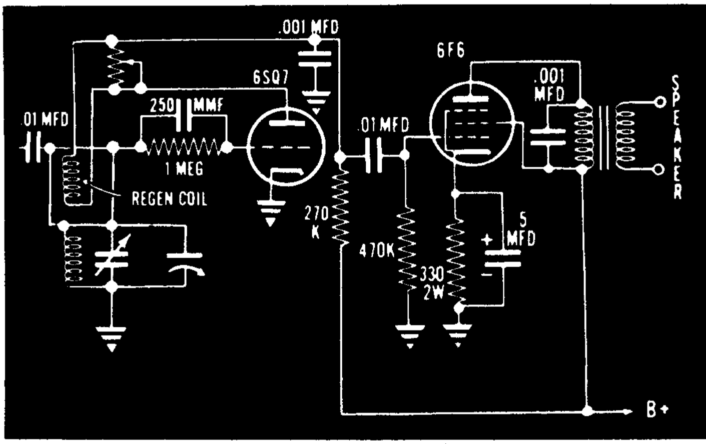
The Oscillating Detector

Some receivers designed for reception of CW signals employ a separate local oscillator known as a "beat-frequency oscillator" or "BFO." If the output of this oscillator is heterodyned against a continuous radio wave which is interrupted in accordance with the Morse Code, the audio beat note that is produced will be interrupted in a similar manner. In this way, the heterodyne principle makes possible the detection of CW signals. The heterodyne principle will also be applied in a later lesson dealing with the superheterodyne receiver.



USE OF A BFO TO DETECT CW SIGNALS

Analysis of the Regenerative Detector Circuit



You know how the RF and AF amplifiers work. Suppose you review the functions of the various component parts used in the regenerative detector.

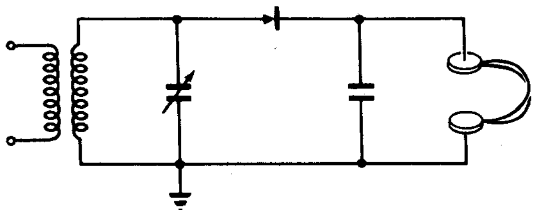
The .01-mfd capacitor found in the grid circuit is used to couple the preceding RF amplifier stage to the detector. The grid coil and variable capacitor provide tuning and selectivity. The 1-megohm resistor provides grid-leak bias while the 250-mmf capacitor acts as an RF bypass capacitor around the grid-leak resistor. The plate or tickler coil is inductively coupled with the grid coil and thus provides feedback, while the potentiometer across the tickler coil controls the amount of feedback. The .001-mfd capacitor is an RF filter or bypass capacitor around the 270K plate load resistor, and the .01-mfd capacitor in the plate circuit is used to couple the detector to the following AF amplifier stage.

COMPONENTS	FUNCTIONS
.01-mfd capacitors	Couple detector to preceding and following stages
Coil and variable capacitor	Provide selectivity
1 megohm resistor	Provides grid-leak bias
250-mmf capacitor	Bypasses RF around grid-leak resistor
Regeneration coil	Provides feedback
500K potentiometer	Controls feedback
.001-mfd capacitor	Filters RF component of signal
270K resistor	Acts as plate load of detector

Review of Detectors

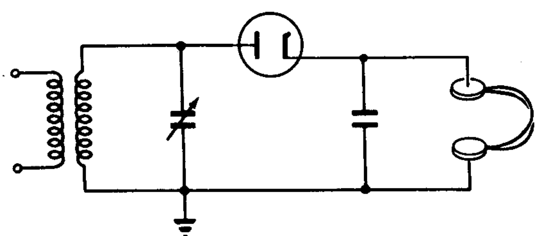
You have become acquainted with the basic principles of operation of four important types of detectors. We will now review the basic circuits and operating characteristics of each type.

CIRCUITS	CHARACTERISTICS



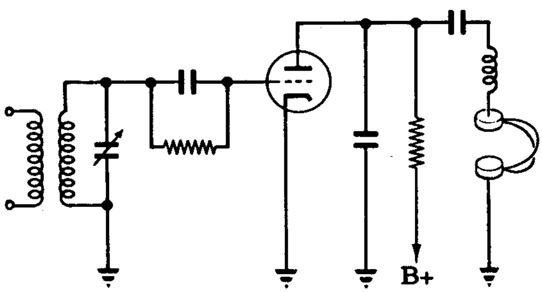
CRYSTAL DETECTOR

Low sensitivity
Poor selectivity
Good fidelity
Low reliability
Capable of handling strong signals
Simple and economical to operate



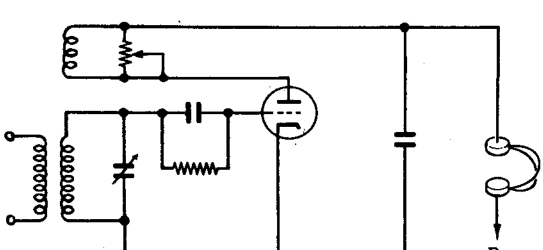
DIODE DETECTOR

Low sensitivity
Poor selectivity
Excellent fidelity
High reliability
Capable of handling strong signals
Capable of supplying AVC voltages



GRID-LEAK DETECTOR

High sensitivity
Poor selectivity
Low fidelity
Moderate reliability
Easily overloaded by strong signals
Plate current decreases when a signal is received

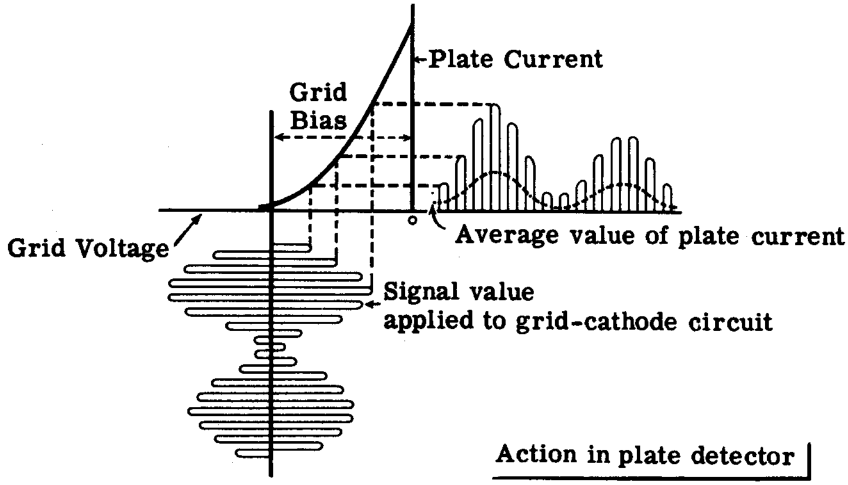


REGENERATIVE DETECTOR

Extremely high sensitivity
Excellent selectivity
Very poor fidelity
Low reliability
Easily overloaded by strong signals

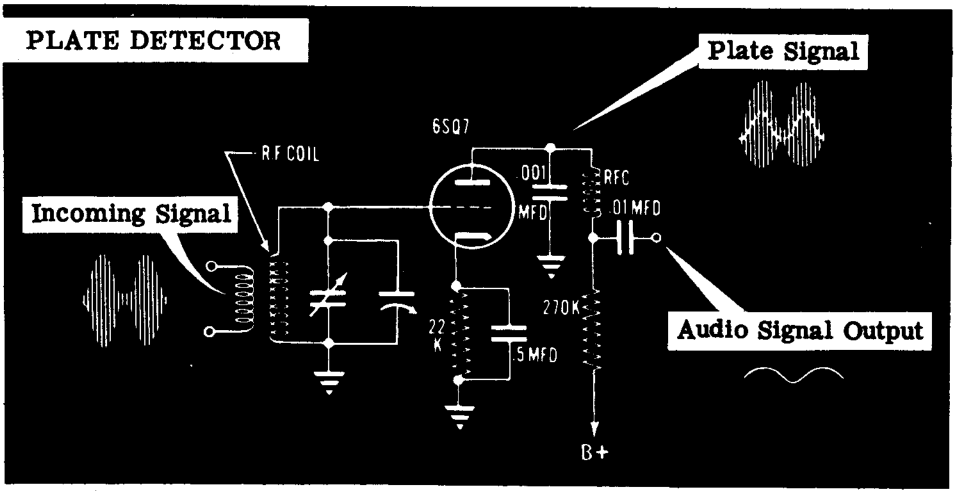
How the Plate Detector Works

The plate detector employs a triode or pentode biased at, or near, cut-off. The bias is usually provided by means of a cathode bias resistor, or less frequently, by means of a bias battery placed between grid and cathode. The plate current will be at, or near, zero when no signal is being received.



Action in plate detector

When a modulated RF signal is impressed on the grid, there will be a pulse of plate current during the positive half cycle and little or no plate current during the negative half cycle. The plate current will contain an amplified and rectified version of the input signal. The filtering of the RF component is accomplished by connecting a small capacitor between the plate and ground and an RF choke in series with the plate load. It is important that a small capacitor be used, since a capacitor that is too large will tend to filter out the higher audio frequencies as well as the radio frequencies.



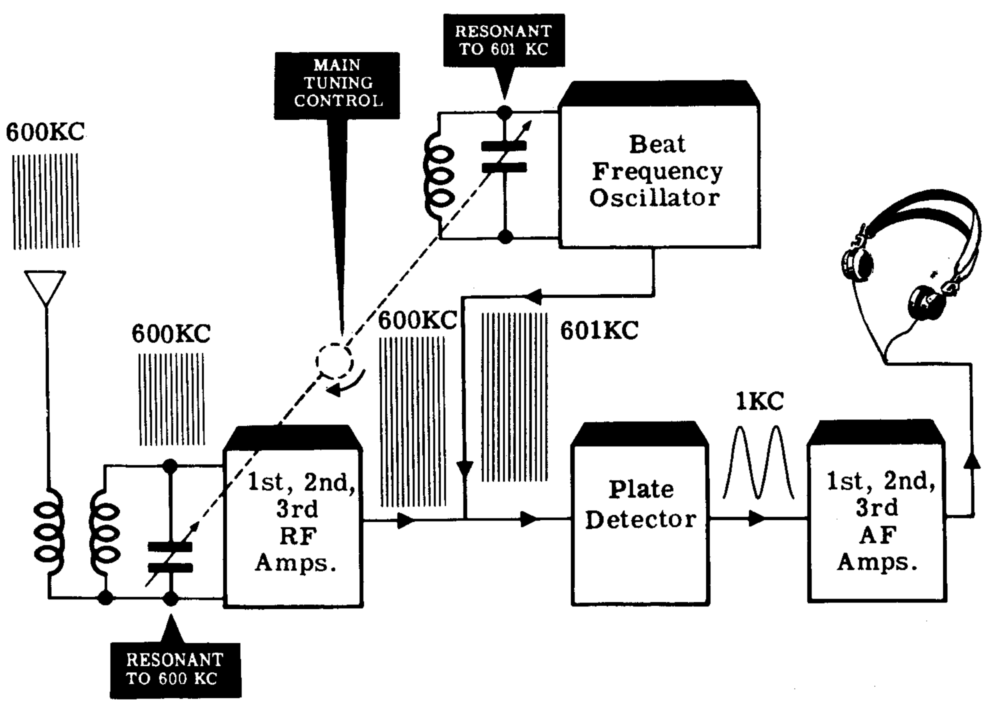
How the Plate Detector Works (continued)

In contrast with the action of the grid-leak detector, plate current in the plate detector is at a minimum with no incoming signal. Up to a certain point, the average plate current increases in direct proportion to the amplitude or strength of the signal impressed on the grid. Another important characteristic is that if care is taken not to drive the grid positive, the plate detector will consume no input power and there will be no loading effect upon the tuned circuit. Consequently the selectivity and fidelity of the plate detector surpasses that of the grid-leak detector.

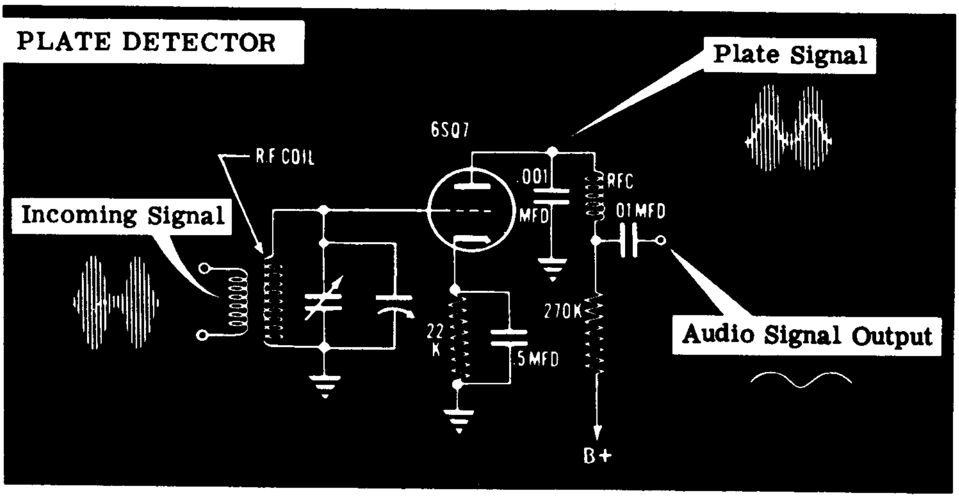
On the other hand, among the disadvantages of the plate detector may be listed the fact that its sensitivity to weak signals is much less than that of the grid-leak detector. It also produces more distortion than the diode detector and it cannot directly provide a voltage to be used for automatic volume control.

The receiver shown below is a TRF receiver containing a plate detector. It also contains a beat-frequency oscillator to provide for reception of CW signals. The tuning capacitor of this oscillator is ganged with the RF amplifier stages in such a manner that a beat note of 1000 cycles will be heard when the receiver is tuned to a CW signal.

RECEIVER EMPLOYING A PLATE DETECTOR



Analysis of the Plate Detector Circuit



A brief analysis of the functions of the components used in the plate detector should help you to understand how this detector operates.

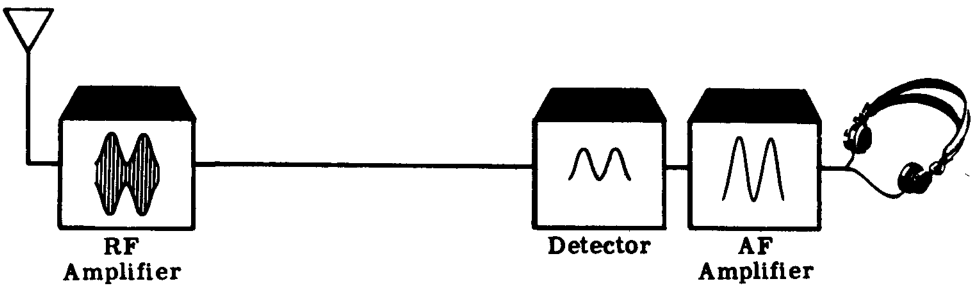
The coil and variable capacitor in the grid circuit form a tuned circuit and are obviously intended to provide selectivity. In addition, the grid coil of the detector is inductively linked with the plate coil of the preceding RF amplifier and thus couples these two stages. The 22K resistor in series with the cathode acts as the cathode bias resistor, biasing the tube almost to the point of cut-off, while the 0. 5-mfd capacitor acts as a by-pass capacitor around the cathode bias resistor. The RF choke and .001-mfd capacitor in the plate circuit serve to filter out the RF component of the signal while the 270K plate load resistor and the .01-mfd capacitor couple the detector to the following AF amplifier stage.

COMPONENTS	FUNCTIONS
RF coil and variable capacitor	Provide selectivity and couple detector to preceding RF amplifier stage
22K resistor	Provides cathode bias
0. 5-mfd capacitor	Bypasses signal around cathode bias resistor
.001-mfd capacitor and RF choke	Filter RF component of signal
270K resistor	Acts as plate load of detector
.01-mfd capacitor	Couples detector to following AF amplifier stage

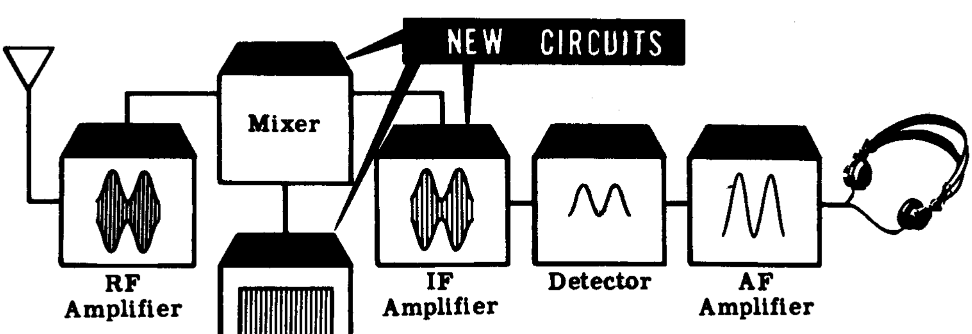
Introduction

The superheterodyne receiver is the most popular type of receiver in use today. Practically all commercial home radios are of this type. You will find either a superheterodyne circuit or a TRF circuit in practically every piece of electronic equipment that contains a receiver. This includes radar, sonar, communications gear—any device that picks up and receives a signal.

Knowing the TRF receiver gives you a good start toward learning the superheterodyne, because it uses all the basic components of a TRF—with three additional units. See the block diagram of a superheterodyne, showing the three additional units—mixer, local oscillator and intermediate frequency (IF) amplifier—which are in addition to the basic TRF circuit.



THE TRF RECEIVER

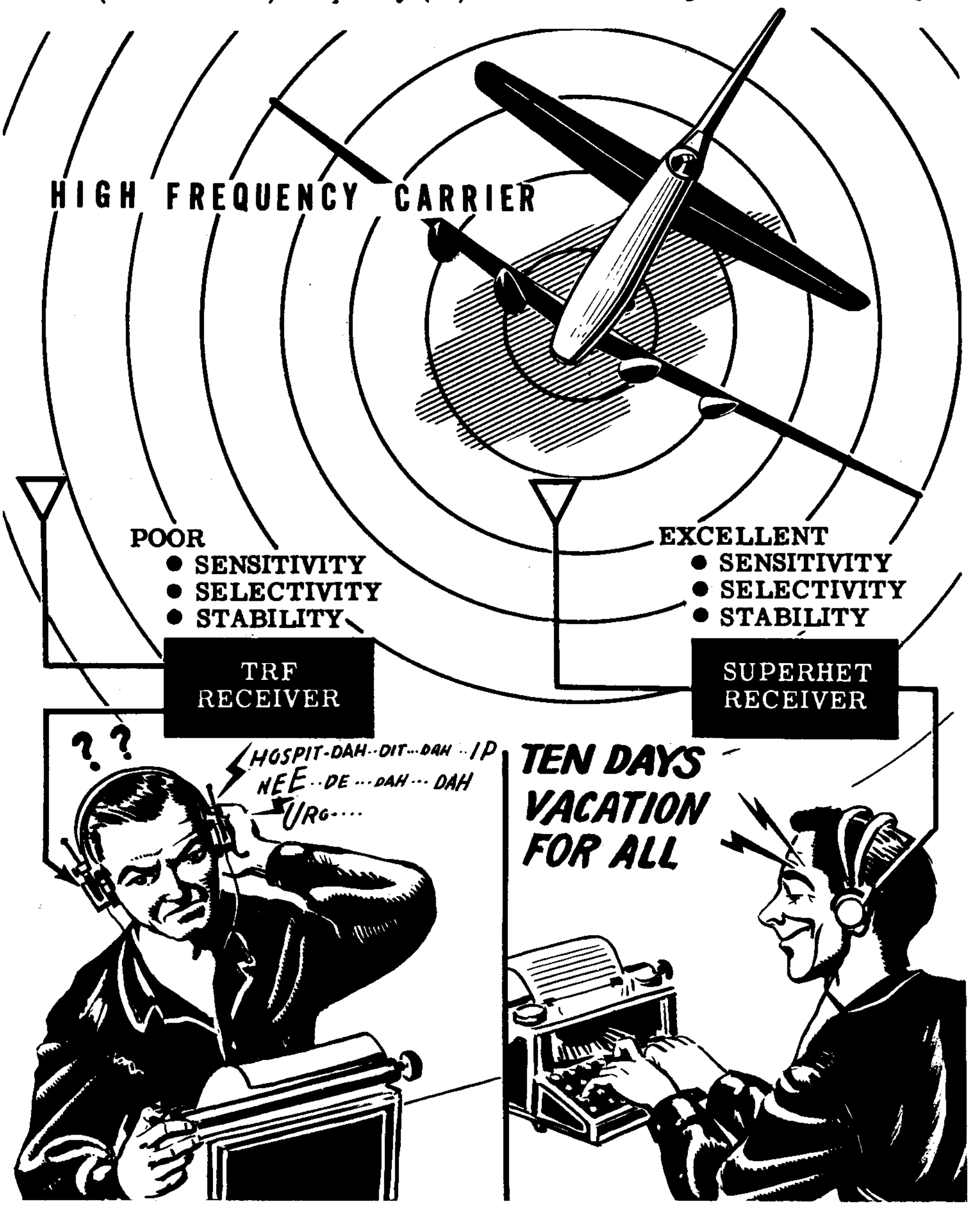


THE SUPERHET RECEIVER

The Superhet at High Frequencies

At high frequencies, the TRF receiver does not work as well as it does at lower radio frequencies. Above 20 mc,a conventional RF amplifier does not have the necessary sensitivity and selectivity.

The superheterodyne receiver avoids the difficulties encountered with the TRF at high frequencies by converting the selected signal frequency to a lower (intermediate) frequency (IF) which can be amplified more easily.

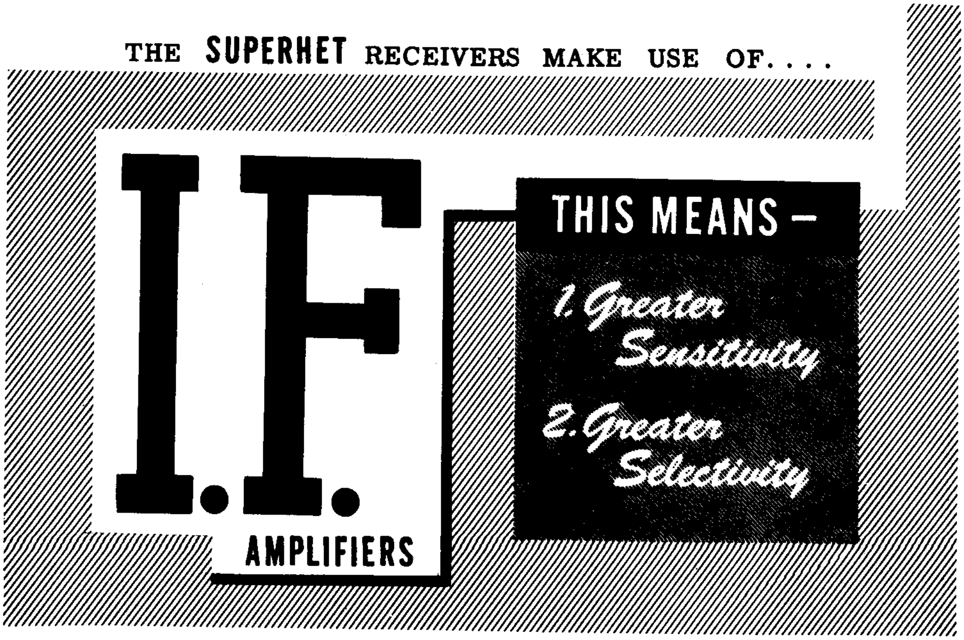


How the Superhet Works

If you know why the superheterodyne was developed, you will easily learn how it works. TRF receivers use RF amplifiers with variable tuned circuits to select and amplify the received signal. If the receiver has three RF stages before the detector, it will contain four tuned circuits. For the best selectivity and sensitivity, each of these four tuned circuits must be tuned to the same frequency. However, it is extremely difficult to make a multi-ganged tuning capacitor so that each section will tune its circuit to exactly the same frequency as the other sections. Therefore, the gain and selectivity of the TRF receiver is limited since more RF stages cannot be added conveniently.

The superheterodyne receiver overcomes this problem. It takes the incoming signal and converts the carrier frequency to another frequency. This new frequency is called the "intermediate frequency" (IF) and it does not vary regardless of the frequency to which the receiver is tuned. The IF signal is amplified in a series of high-gain amplifiers which are pretuned to this fixed IF frequency. Because it eliminates the many-ganged tuning capacitor, the superhet with its fixed frequency IF amplifiers can be used to give very large gains and very fine selectivity.

This is how the signal frequency is changed in the superhet. The incoming signal and the CW output of the local oscillator are fed into the mixer tube. The plate current is varied according to both of these signals which are of different frequencies. A beat (or difference) frequency appears in the resulting signal. This signal is then passed through the IF amplifiers which are tuned to this difference frequency. The IF signal has exactly the same modulation as the RF carrier. The only change has been the substitution of the IF frequency for the RF.

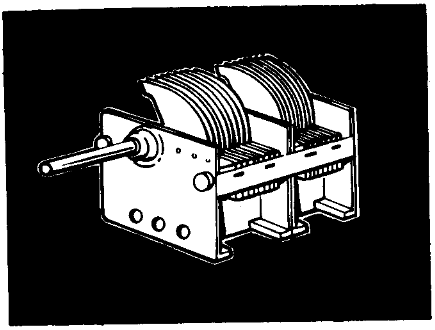


Selectivity of the Superhet

This is what happens in a home superheterodyne radio set. When you tune it to a station of 880 kc, you are setting the tuned RF circuit to 880 kc and at the same time you are automatically tuning the local oscillator to 1336 kc. Two signals—one of 880 kc, the other of 1336 kc—are fed into the mixer stage. The output of the mixer stage contains a frequency of 456 kc which is the difference of its two inputs.

If at the same time the antenna picks up another station at a frequency of 1100 kc, the signal, if strong enough, can get by the first tuned circuit and would be mixed with the local oscillator output in the mixer stage. This undesired signal of 1100 kc would produce a beat-frequency of 1336-1100 or 236 kc.

The IF amplifier tuning, however, does not vary. It is always tuned to 456 kc. So you can see that only the beat signal produced by the desired station (880 kc) will be amplified by the IF amplifier. Since the undesired signal of 1100 kc produced a beat-frequency which is different from the IF frequency, its beat signal is not amplified. Thus, the superhet has selected the proper input signal on the basis of the frequency of the beat signal produced in the mixer stage.



THE *ganged tuning capacitor*

KEEPS THE LOCAL OSCILLATOR

"TRACKING" THE TUNED RF

In order to hear the 1100-kc station, the receiver would have to be retuned. Turning the knob changes the frequency to which the RF amplifier is tuned and, at the same time, changes the local oscillator frequency. A two-section ganged tuning capacitor does the trick. Tuning the receiver does not affect the IF stages. When the RF tuned circuit is set at 1100 kc, the oscillator will be putting out a signal of 1556 kc; the IF remains at 456 kc.

Now it is the 1100-kc signal which produces the 456-kc beat-frequency. The beat produced by the 880-kc signal would be the difference between its frequency and the 1556-kc local oscillator frequency—676 kc—and this frequency will not be amplified by the IF stages.

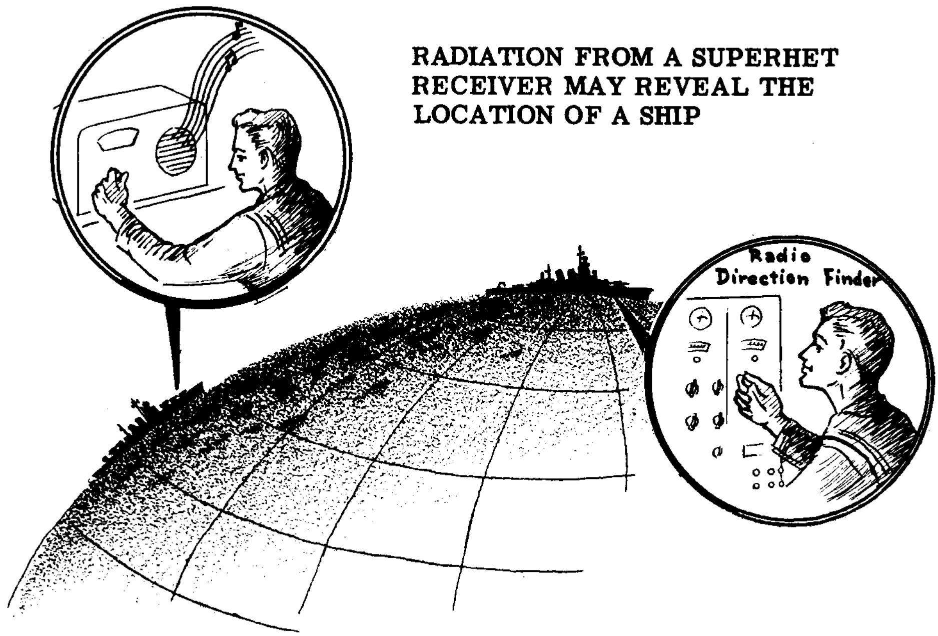
In order for the superhet to work properly, the local oscillator must be adjusted so that it will always tune to a frequency which is a fixed number of kilocycles different from the desired RF frequency. Thus, as the receiver —that is, the RF tuned circuit—is tuned from 550 to 1600 kc, the local oscillator should tune from 1006 to 2056 kc. Then, any signal picked up at the frequency to which the receiver is tuned will produce an IF frequency of 456 kc (which is the standard IF frequency for commercial receivers).

RF Amplifier Stage

Many superhet receivers do not contain an RF amplifier stage. In such receivers the signal from the antenna is fed to the signal grid of the mixer or converter stage. However, you will encounter other receivers which contain stages of RF amplification preceding the mixer. You will therefore have a better understanding of the operation of superhet receivers if you know the reasons for including an RF amplifier stage.

The first function of the RF amplifier is to improve the signal-to-noise ratio. The mixer stage usually produces more tube noise than an RF stage of amplification. The signal, plus the tube noise, is amplified by the following IF amplifier stage. However, if the signal strength is increased by placing an RF amplifier stage before the mixer, less amplification is required in the IF amplifier stage. Since tube noises produced by the mixer are not amplified as much as they were when no RF stage was present, a greater signal-to-noise ratio is obtained.

The second function of the RF amplifier stage is related to radiation from the oscillator stage. It should not be forgotten that this oscillator is a low-powered transmitter. If there is no RF amplifier stage, the oscillator is connected through the mixer stage to the antenna. This antenna will radiate some energy from the oscillator. This radiated signal may cause interference with reception in nearby receivers and may also divulge the location of the receiver. This radiation may be reduced or prevented by using one or more stages of RF amplification, and by carefully shielding the oscillator stage.



RADIATION FROM A SUPERHET RECEIVER MAY REVEAL THE LOCATION OF A SHIP

RF Amplifier Stage (continued)

The third function of the RF amplifier stage is concerned with selectivity. You will recall that in the TRF receiver the RF amplifier stages enabled the operator to select the desired signal from a group of signals whose frequencies were very close to each other. The RF amplifier in a superhet serves to prevent interference from a signal whose frequency may be several hundred kilocycles above that of the desired signal. This type of interference is called "image-frequency interference."

Let us assume that you have a superhet receiver without an RF amplifier stage and that the receiver is tuned to a station operating at a frequency of 600 kc. The oscillator in the receiver will be tuned to 1056 kc and the resulting IF signal will have a frequency of 1056 kc minus 600 kc or 456 kc. However, if there is a powerful station nearby, broadcasting at a frequency of 1512 kc, some of the signal from this station will enter the mixer stage where it will beat against the signal from the oscillator. The resulting signal will be 1512 kc minus 1056 kc or 456 kc—the same intermediate frequency as that produced by the desired station. The IF amplifier stage will amplify both signals equally well, since they are both at the correct frequency of 456 kc. This interference produces whistles and a confusing mixture of sounds coming out of the loudspeaker.

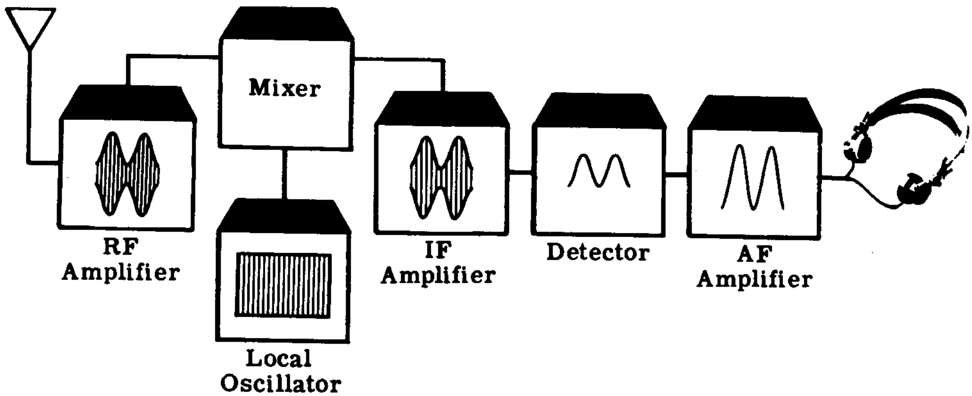
It should be noted that when the intermediate frequency is 456 kc, image interference is produced when there is a second station broadcasting at a frequency that is twice the intermediate frequency or 912 kc above that of the desired signal. Thus the image frequency of a station broadcasting on 600 kc is 912 kc higher, or 1512 kc. Image-frequency interference can be reduced by the use of an RF amplifier stage before the mixer. For this reason the RF amplifier is sometimes called a "preselector stage."

In any receiver in which images might present a problem, one tuned circuit is not enough to guarantee the elimination of this interference. There will be as many as two or three stages of RF amplification at the signal frequency before the signal is fed into the mixer. These stages are not as selective as those in a TRF, but are selective enough to discriminate between the desired signal and the image frequency. These stages, called "preselector" stages, do not present the alignment problems of the TRF since none of these stages need to be sharply tuned to the resonant frequency.

The preselector serves another purpose besides suppressing the image. It also isolates the antenna from the local oscillator so that there will be no possibility of the receiver radiating energy.

The Local Oscillator

In a superhet receiver circuit, the local oscillator is tuned by a variable capacitor ganged with the tuned RF circuit in the antenna input. The local oscillator is tuned to oscillate and put out a signal at a frequency that is above or below the RF frequency by a fixed difference for every position of the tuning dial—every received frequency. The local oscillator output is mixed with the RF carrier. The fixed frequency difference is the IF output of the mixer.



The process of mixing or beating two frequencies together to get a difference frequency is called "heterodyning." That is why the receiver was named superheterodyne.

The superhet you will discuss will have a tuned-grid type oscillator that operates at 456 kc above or below the RF frequency. The IF is 456 kc. The variable capacitor in the oscillator tank is ganged with the tuning capacitor in the antenna tuned circuit, as shown in the illustration of that section.

As the receiver is tuned to an incoming signal, the local oscillator is also varied to keep it at a frequency of 456 kc higher or lower than the signal to which the antenna circuit is tuned. The table below gives examples of typical operating frequencies.

TYPICAL OPERATING FREQUENCIES FOR THE SUPERHET

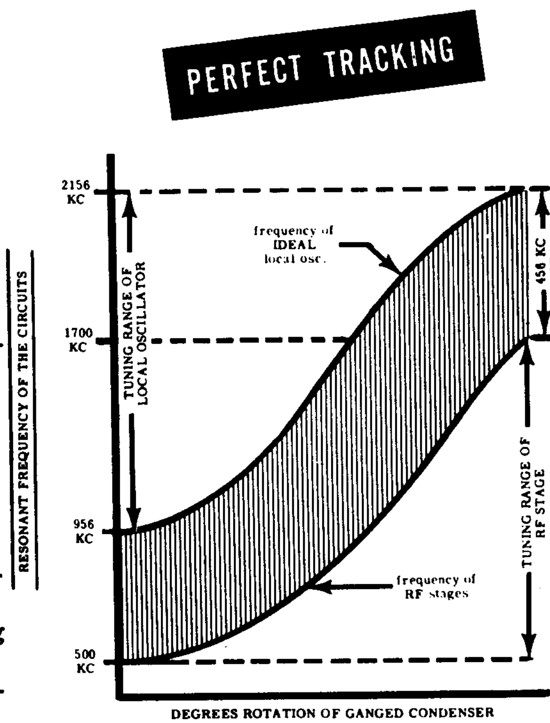
FREQUENCY OF RF CARRIER	FREQUENCY OF LOCAL OSCILLATOR	IF DIFFERENCE FREQUENCY
550 kc	1006 or 94 kc	456 kc
710	1166 or 254	456
880	1336 or 424	456
1440	1896 or 984	456

The Local Oscillator (continued)

There are several types of oscillators that may be employed as local oscillators. However, the types most frequently used are modifications of the Armstrong tickler-coil and the Hartley oscillators. An ideal local oscillator should possess the following characteristics:

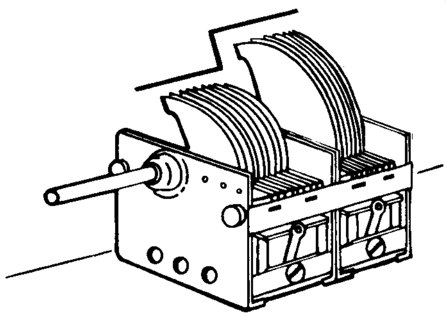
1. The frequency of its output should be stable and free from drift at all settings.
2. It should be capable of delivering considerable voltage to the mixer. This voltage should be approximately ten times greater than that of the RF signal.
3. The strength of the output should be constant over the entire frequency range.
4. The oscillator should have minimum interaction with other tuned circuits. If the oscillator interacts with other tuned circuits, there will be a change in oscillator frequency each time the other circuits are tuned.
5. The oscillator should radiate a minimum of energy into space.

The oscillators found in receivers used for broadcast band reception are usually designed to produce a signal whose frequency is 456 kc higher than the frequency of the incoming radio wave. The tuning capacitor of the oscillator is ganged with the capacitor of the RF tuned circuit so as to maintain a constant difference in frequency as the receiver is tuned across the band. This is known as "tracking." Perfect tracking is the condition when the oscillator tuned circuit is resonant exactly 456 kc higher than the RF tuned circuits for all settings of the tuning dial. The process of adjusting the tuned circuits, to maintain this constant difference at both the high and low ends of the tuning bands, is known as "aligning." The process of adjusting a receiver to obtain good tracking will be discussed more completely in the section dealing with the alignment and adjustment of superhet receivers.

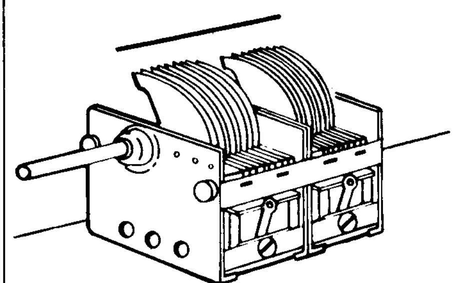


The Local Oscillator (continued)

There are two ways of designing the oscillator tank circuit so that it will produce a signal 456 kc higher than that of the RF circuit. One method employs a special kind of ganged capacitor. The plates of the oscillator section of this capacitor are made smaller than the plates of the RF section. Since the capacity of the oscillator section is less than that of the RF section, the oscillator section will resonate at a higher frequency. In addition, the plates of the oscillator section are shaped so as to produce correct tracking as the plates are meshed or unmeshed.



(1) Ganged capacitors with sections of differing sizes



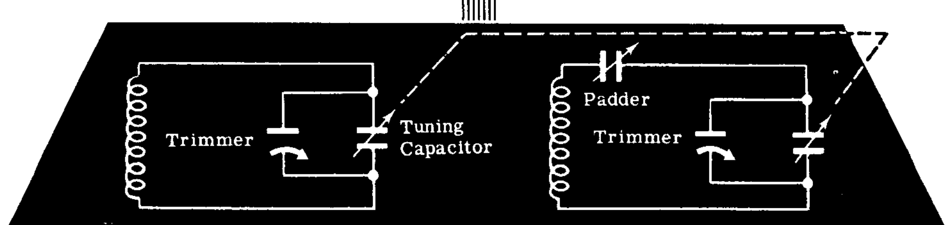
(2) Ganged capacitors with identical sections

When both sections of the capacitor are identical, the total capacity of the oscillator tank circuit is reduced by placing an adjustable mica capacitor, called a "padder" capacitor, in series with the oscillator tuning capacitor. As a result of this reduction in capacity, the oscillator circuit resonates at a higher frequency. The capacity of the padder is usually between 500 and 1000 mmf. In the process of alignment, the padder capacitor is adjusted for perfect tracking at the low frequency end of the band.

In order to align the superhet receiver at the high frequency end of the band, trimmers are placed in parallel with each section of the tuning capacitor, just as they are in TRF receivers. These trimmers are adjustable mica capacitors whose capacity varies between 2 and 20 mmf.

TYPICAL RF TANK CIRCUIT

TYPICAL OSCILLATOR TANK CIRCUIT



How the Mixer Stage Works

The mixer works on the following principle: If two different frequencies are mixed or combined in a tube, the output will contain four different frequencies which are:

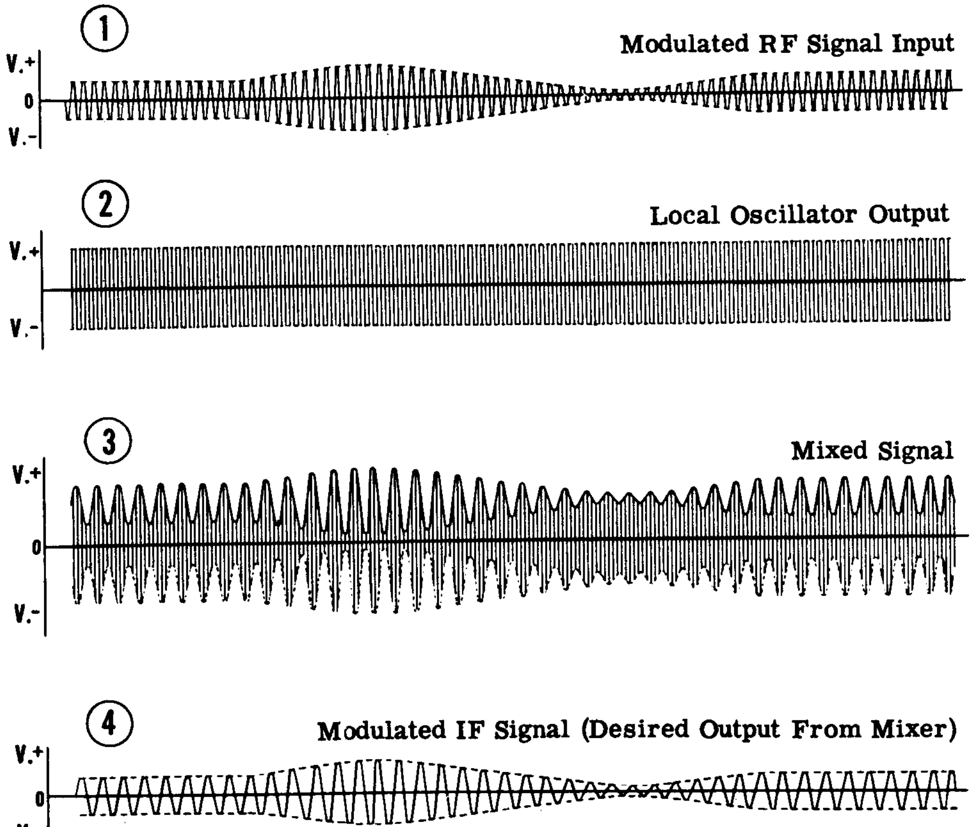
1. The modulated RF signal from RF amplifier or antenna

2. The unmodulated local oscillator RF output

3. The sum of 1 and 2

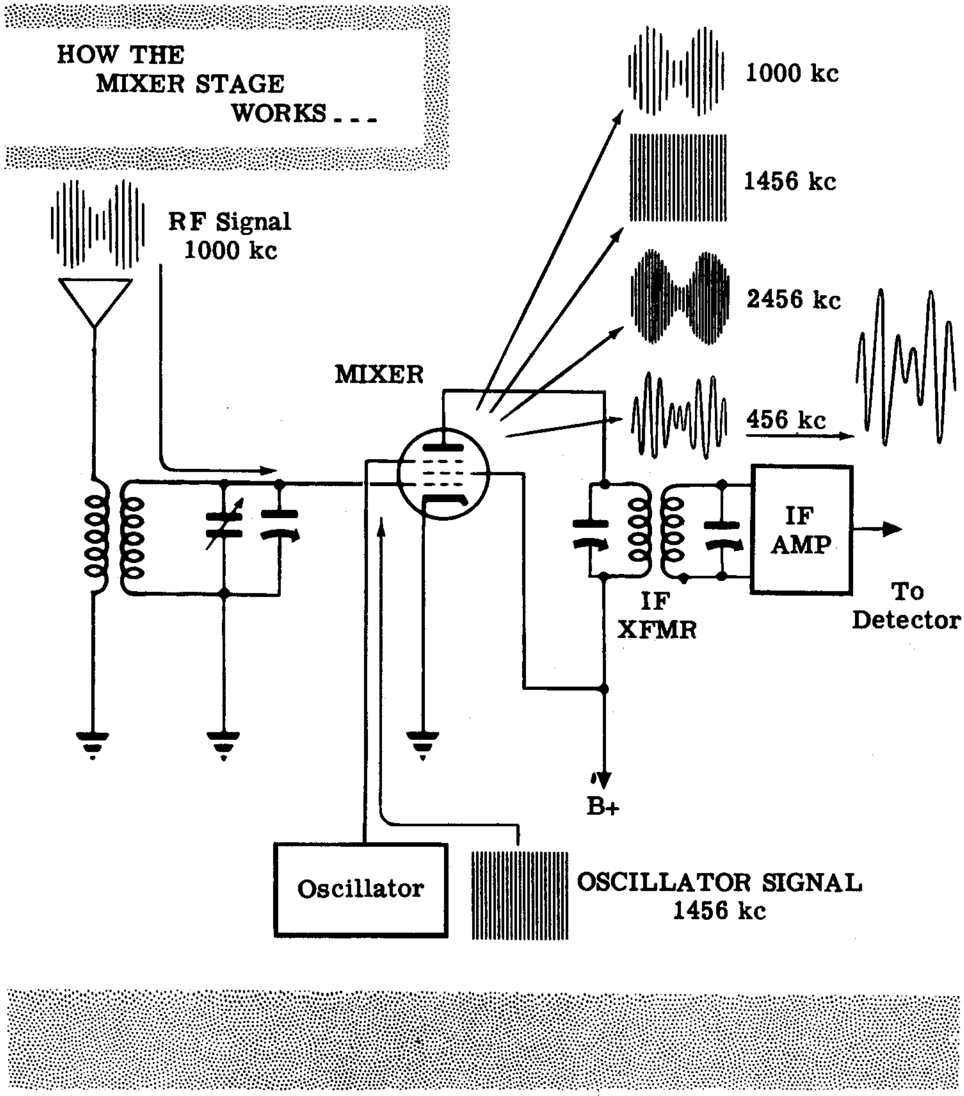
4. The difference of 1 and 2

The difference frequency is the desired signal. This signal resulting from the mixing of a modulated carrier with the unmodulated output from the oscillator will have exactly the same modulation shape as the original carrier wave. Tuned circuits are used to amplify the desired signal and discriminate against the others.



How the Mixer Stage Works (continued)

From among the several frequencies present in the plate circuit of the mixer tube—the original RF signal, the oscillator signal, a signal whose frequency is the sum of the first two signals, and another signal whose frequency is equal to their difference—only the latter or IF signal must be passed on to the next stage. This is accomplished by using the primary of a tuned IF transformer as the plate load. The primary and secondary coils are tuned to the intermediate frequency which generally is 456 kc. In this manner, maximum response is obtained for the IF signal. This IF signal is passed on to the following IF amplifier stage, while the other signals are rejected by the selective action of the tuned IF transformer.

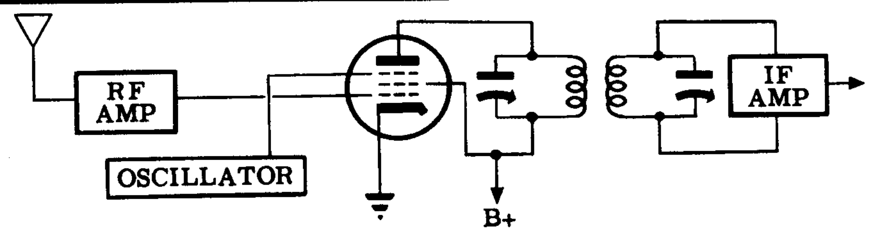


How the Mixer Stage Works (continued)

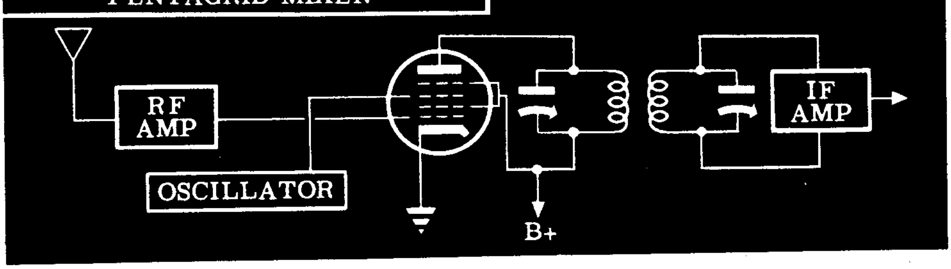
From the preceding discussion it may be seen that the principal function of the mixer or first detector stage is to act as a frequency converter. The input to this stage is a modulated RF signal whose frequency is relatively high. This signal is converted to a lower frequency modulated IF signal by means of the heterodyning action taking place in the mixer. The IF signal now possesses all the intelligence originally contained in the RF signal.

There are a large number of combinations of tubes and circuit components capable of serving as frequency converters. Among the tubes which may be employed are triodes, pentodes and pentagrid (five-grid) tubes. The oscillator may be coupled inductively or capacitively to either the cathode, control grid, screen grid, or suppressor grid of the mixer. It may even be coupled to a special grid, called the "injector" grid, which is found in certain types of mixer tubes. Some pentagrid tubes are designed to combine the functions of oscillator and mixer in one tube. They are then known as "pentagrid converters."

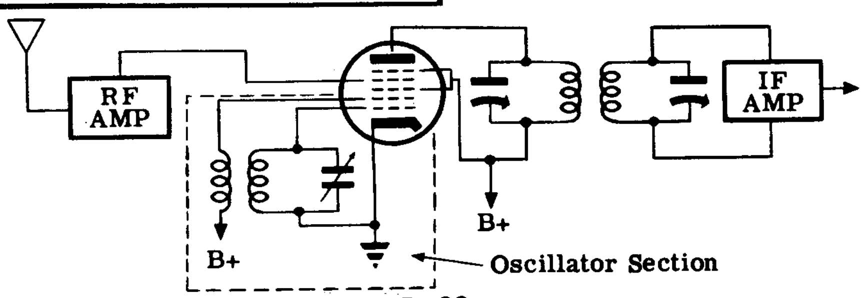
PENTODE MIXER



PENTAGRID MIXER

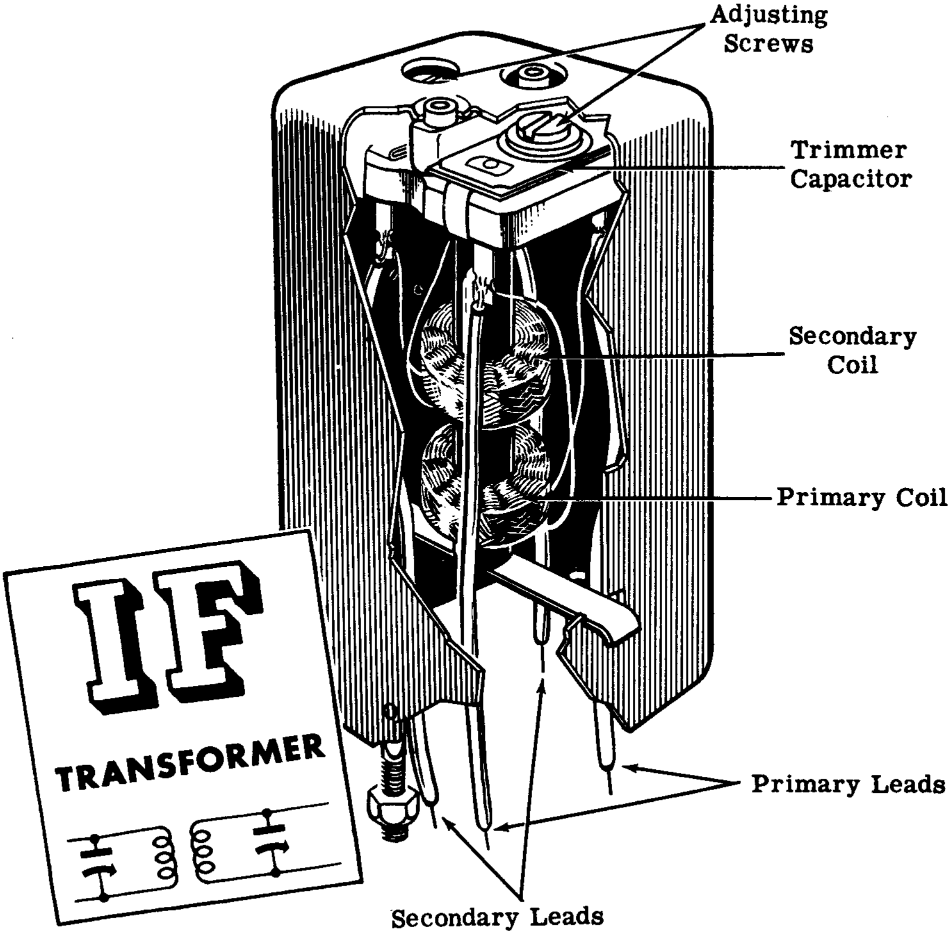


PENTAGRID CONVERTER



How the Mixer Stage Works (continued)

Most IF transformers are tuned by adjusting small mica trimmer capacitors to the correct frequency. This process of adjustment will be discussed later. The coils and capacitors are mounted in small metal cans which act as shields Small holes in the tops of the cans make it possible to vary the value of the capacitors by turning adjusting screws without removing the shield.



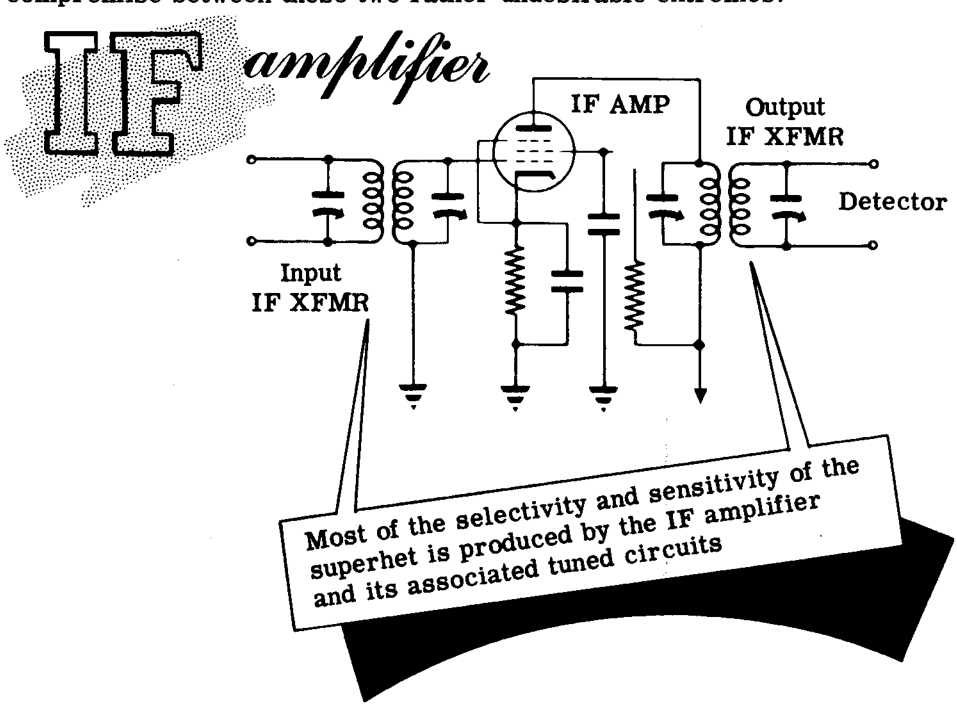
There are also some IF transformers that have powdered iron cores and fixed mica capacitors. Tuning is accomplished by turning a set screw which moves the iron core in or out of the coil. This type of transformer is known as a "permeability-tuned" transformer. No matter what method is used to tune the transformer, you will find that nearly all IF transformers are double tuned. This means that both primary and secondary are tuned to the intermediate frequency. This produces a very high degree of selectivity.

How the IF Amplifier Works

The intermediate-frequency amplifier is permanently tuned to the constant difference in frequency between the incoming RF signal and the local oscillator. The tuning of the IF amplifier stage is accomplished by means of two tuned IF transformers. The one associated with the grid circuit of the amplifier is called the "input" IF transformer, while the one associated with the plate circuit is called the "output" IF transformer. The tubes employed in IF amplifiers are generally variable-mu pentodes.

Since this amplifier is designed to operate at only one fixed frequency, the IF circuits may be adjusted for high selectivity and maximum amplification. It is in the IF stage that practically all of the selectivity and voltage amplification of the superhet is developed. Simple superhet receivers may contain only one IF amplifier, while more complex receivers contain as many as three IF amplifier stages.

The intermediate frequency used most often in superhet receivers is 456 kc, although intermediate frequencies as low as 85 kc and as high as 12,000 kc or higher have been used in special types of superhet receivers. Using a low intermediate frequency, such as 175 kc, results in high selectivity and voltage gain, but also increases the possibility of image-frequency interference. A high intermediate frequency reduces the possibility of image interference, but also reduces the selectivity and voltage gain. The choice of 456 kc as the intermediate frequency for most receivers represents a compromise between these two rather undesirable extremes.

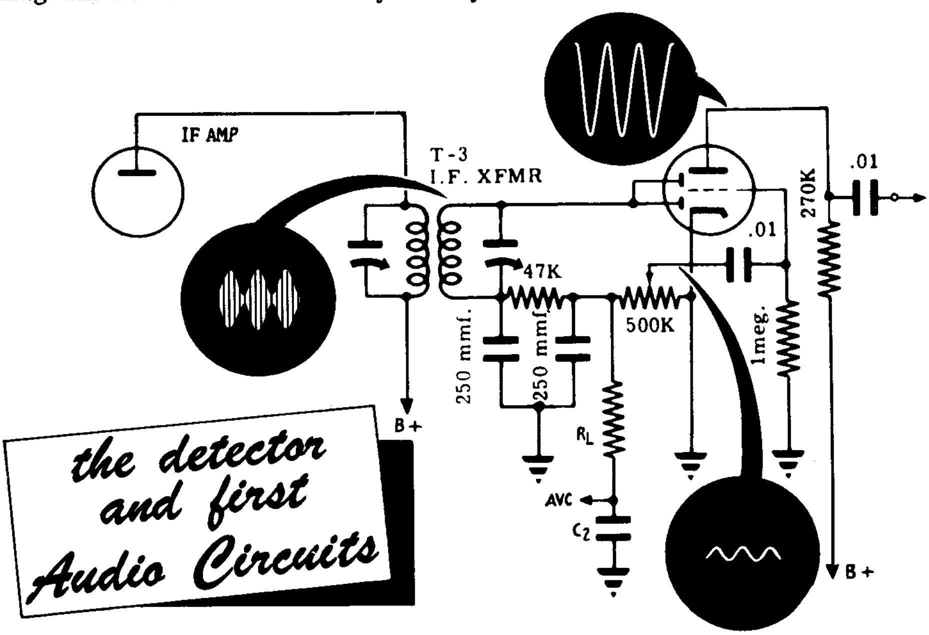


How the Detector Works

The conversion of the IF signal into an audio signal is accomplished by means of a diode detector. Since the mixer is sometimes called the "first detector", this diode detector is frequently referred to as the "second detector".

The second detector circuit in the superhet receiver will sometimes be combined in one tube with the first stage of audio amplification. The receiver's manual volume control and automatic volume control are also often included as part of the same tube circuit. The tube employed for this purpose may be a 6SQ7 which is a twin-diode high-mu triode. The diode section acts as the detector, and the triode section as the audio amplifier.

Since a detailed explanation of the operation of diode detectors has already been given under the topic TRF Receivers—Regenerative Detector, the operation of the diode detector which is shown in the accompanying circuit diagram will be described only briefly.



The diode acts as a rectifier and conducts current during that half of the signal cycle in which the plate is made positive with respect to the cathode. During the other half-cycle, when the plate is negative, no current flows. This produces a pulsating direct current which contains two components, one of which is audio frequency and the other intermediate frequency. The filter circuit, consisting of the 47K resistor and the two 250 mmf capacitors, filters out the IF component. The audio component of the pulsating direct current produces an AF voltage across the 47K fixed resistor and the 500K potentiometer. The AF voltage is applied to the grid of first audio amplifier and amplified at the plate as shown. Automatic volume control (AVC) which you will study later is developed across capacitor C_2.

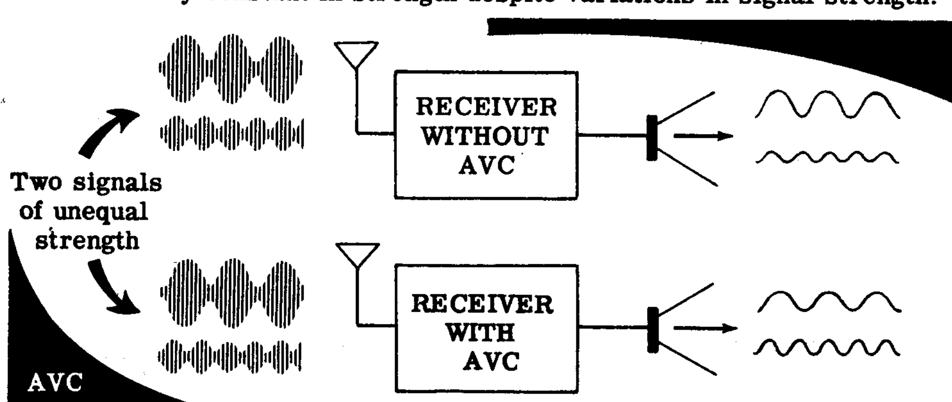
How the Audio Amplifiers Work

The audio signal developed across the 500K potentiometer is taken off the sliding arm and applied to the grid of the first audio amplifier. The potentiometer is connected as a voltage divider and functions as a detector-output type of volume control. The triode acts as an audio amplifier which increases the voltage of the AF signal and passes it on to the last stage, which is known as the "second audio" or "final power amplifier" stage. The purpose of this stage is to amplify the signal output of the first AF stage until it is strong enough to operate a loudspeaker. Power output is the main consideration in this stage. The operation of the audio power amplifier has been discussed previously under TRF Receivers—Audio Amplifier Stage. It would be an excellent idea at this time to review the previous material dealing with audio power amplifiers before proceeding further.

How Automatic Volume Control Works

Atmospheric conditions may sometimes cause fading of signals coming from certain stations. The resulting output of the receiver may at one moment be loud enough to blast the listener from his seat, while it may fade during the next moment to the point of becoming inaudible. Also, as you tune from one station to another, the signal strength may vary in the same way. One method of preventing this is to have the operator continually adjust the manual volume control in such a manner as to keep the output constant despite variations in signal strength. A better way of solving this problem is by the addition of a circuit which will accomplish this task automatically—an automatic volume control or AVC circuit.

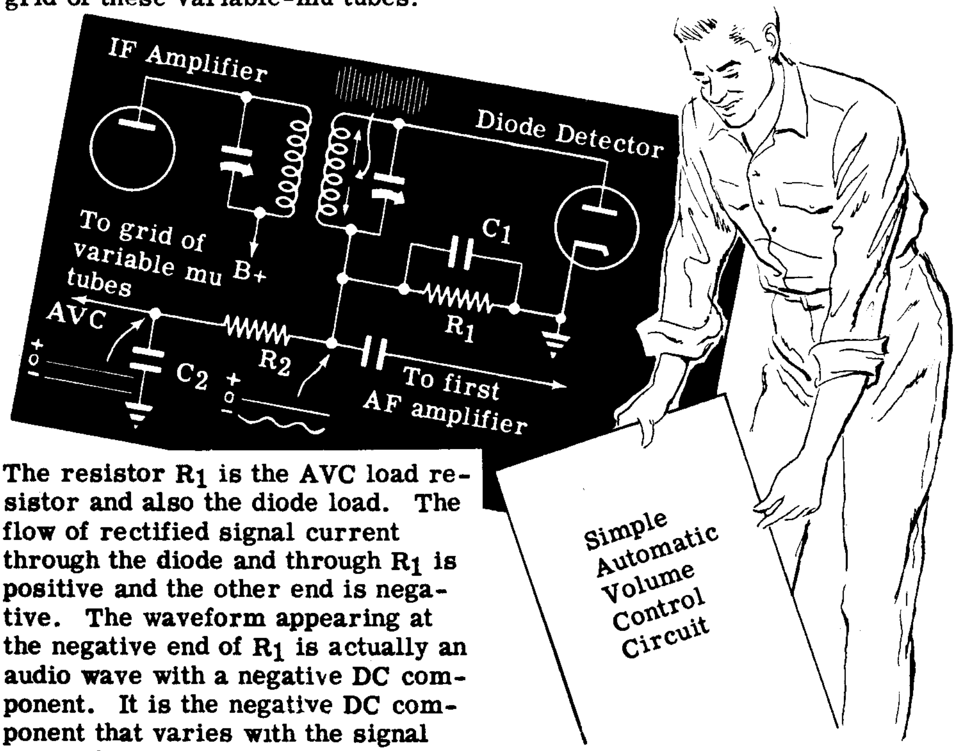
The function of the AVC circuit is to vary the sensitivity or gain of the receiver in accordance with the strength of the signal. It reduces the sensitivity when a strong signal comes in and increases the sensitivity when the signal becomes weaker. The result is that the output of the receiver remains fairly constant in strength despite variations in signal strength.



COMPENSATES FOR VARIATIONS IN SIGNAL STRENGTH

How Automatic Volume Control Works (continued)

The conventional AVC circuit most frequently encountered is incorporated in the diode detector stage. It requires that at least one, and preferably all, of the preceding IF amplifier, mixer or RF amplifier stages employ the variable-mu type of tube. It also requires some means of transferring the negative voltage that is developed by the AVC circuit to the control grid of these variable-mu tubes.



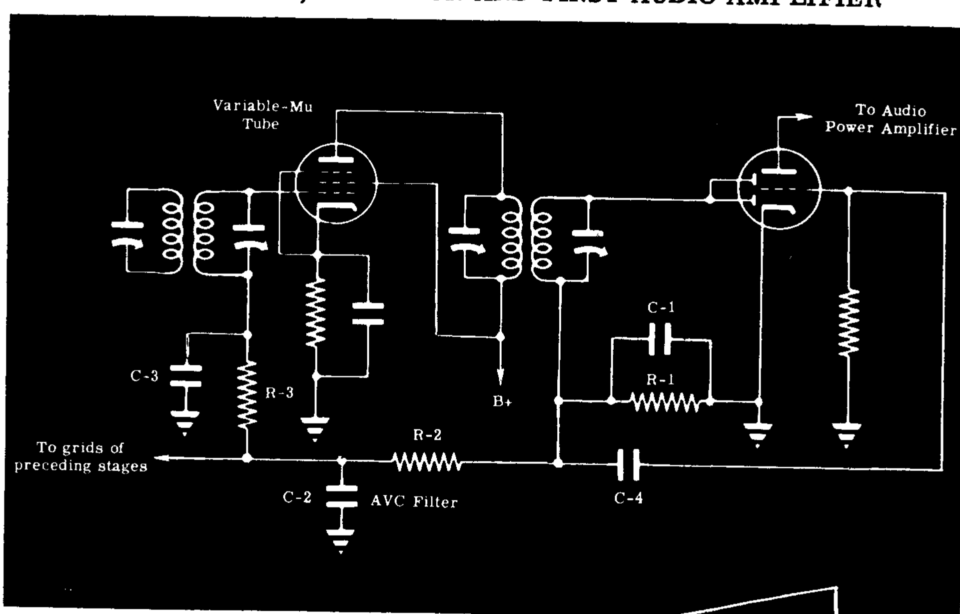
The resistor R_1 is the AVC load resistor and also the diode load. The flow of rectified signal current through the diode and through R_1 is positive and the other end is negative. The waveform appearing at the negative end of R_1 is actually an audio wave with a negative DC component. It is the negative DC component that varies with the signal strength. The AVC filter circuit, consisting of R_2-C_2, filters out the audio and C_2 charges up to the negative DC component. It is this negative voltage that is applied through the AVC line to the grids of the variable-mu tubes in the preceding stages.

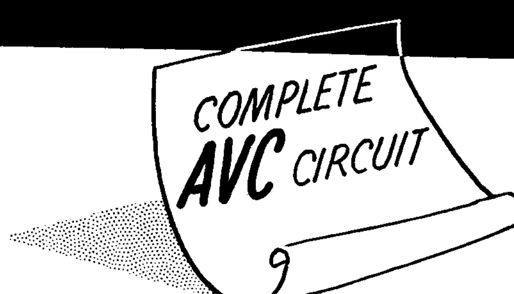
The amount of negative voltage developed will vary in accordance with two factors. One is the relatively rapid variation in strength and amplitude produced by the audio signal at the transmitter during the process of modulating the carrier wave. The second factor is the slower variation in negative AVC voltage produced by variations in signal strength due to atmospheric conditions. If the rapid variations produced by the audio modulating signals were allowed to travel down the AVC line to the preceding IF or RF stages, undesirable effects would be produced. The AVC filter circuit, consisting of R_2 and C_2, is added to remove these audio frequency variations of the negative AVC voltage. The slower variations in signal strength which show up as a slowly varying negative DC voltage are not bypassed and pass down the AVC line to the grids of the preceding amplifier stages.

How Automatic Volume Control Works (continued)

Since these preceding IF and RF stages employ variable-mu tubes, the amount of gain produced in each stage is dependent upon the amount of bias present on the control grid. When the signal increases in strength, a high negative AVC voltage is developed between one end of R_1 and ground. This negative voltage is applied through the AVC filter circuit and the AVC line to the control grids of the preceding stages, thus increasing the negative bias on these tubes. Because of this increased bias, there is a considerable decrease in the amount of amplification or voltage gain. In other words, the sensitivity of the receiver has been reduced. On the other hand, when a weak signal enters the receiver, a much smaller negative AVC voltage is developed. The bias on the amplifier tubes is reduced, resulting in considerably greater receiver sensitivity and voltage amplification for the weak signal. As far as the human ear is concerned, these variations in receiver sensitivity, as the signal strength varies, occur almost instantaneously, thus producing an output whose volume is reasonably constant.

IF AMPLIFIER, DETECTOR AND FIRST AUDIO AMPLIFIER

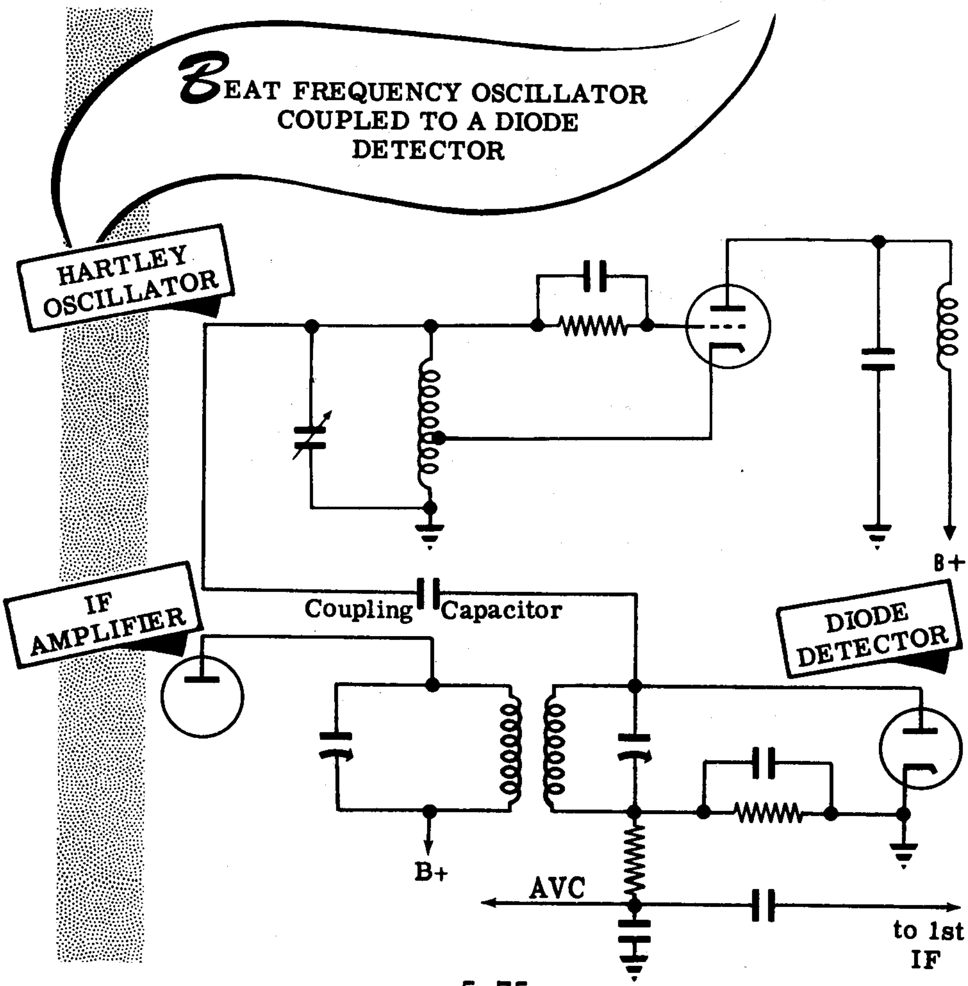




How the Beat Frequency Oscillator Works

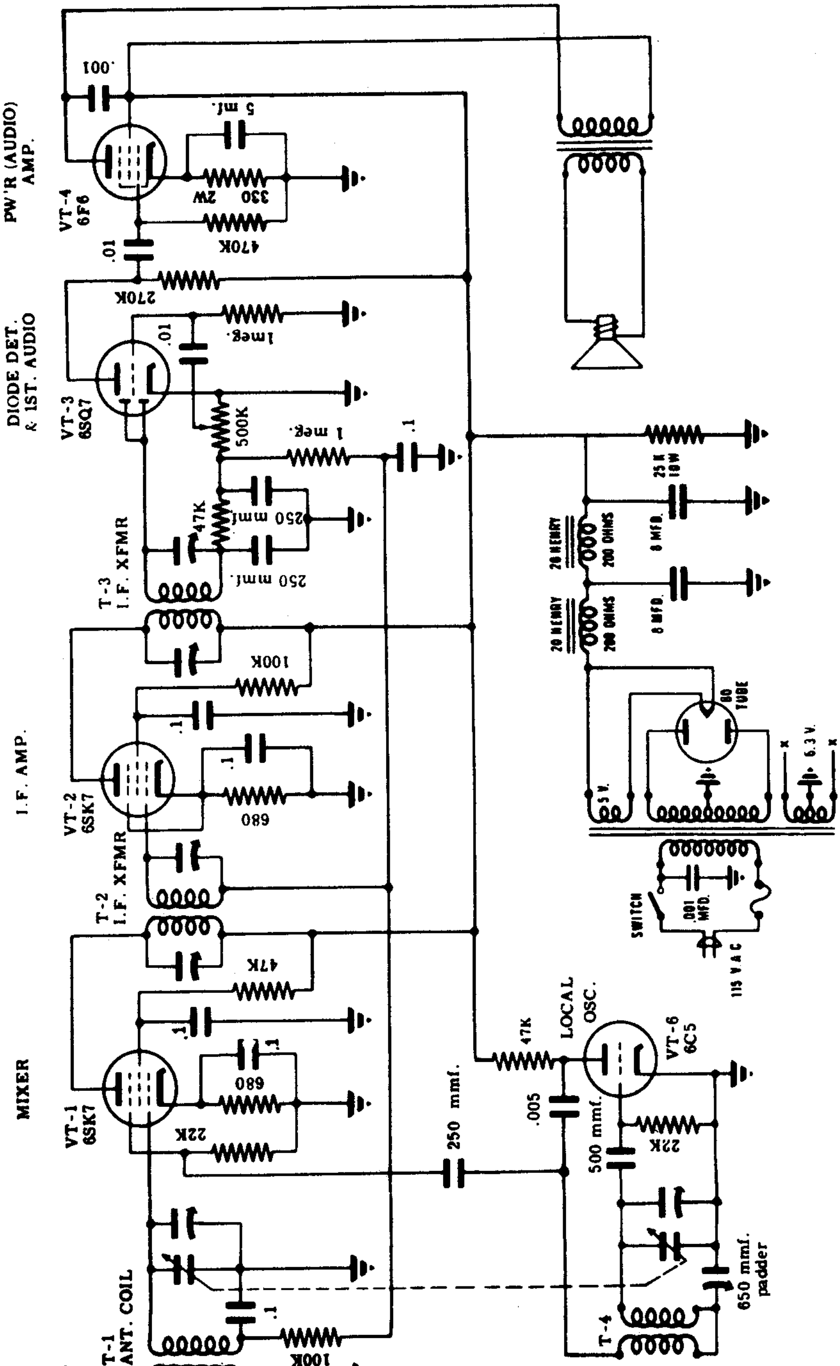
It will be recalled from the topic entitled TRF Receivers—Regenerative Detector that in order to receive CW signals on a regenerative detector, it was necessary to make the detector oscillate. The frequency of these oscillations differed slightly from that of the incoming signal, in order to produce an AF signal by the process of heterodyning.

In superhet receivers this is often accomplished by means of a separate BFO, or beat frequency oscillator, capacitively coupled to the diode detector. The BFO may be a Hartley oscillator tuned to a frequency 1 kc above that of the intermediate frequency. Thus, if the IF is 456 kc, the frequency of the BFO is 457 kc and a 1-kc audio signal will be produced in the diode detector. The frequency of the BFO is variable over a small range, making it possible to vary the pitch of the resulting beat note until a satisfactory tone is produced.



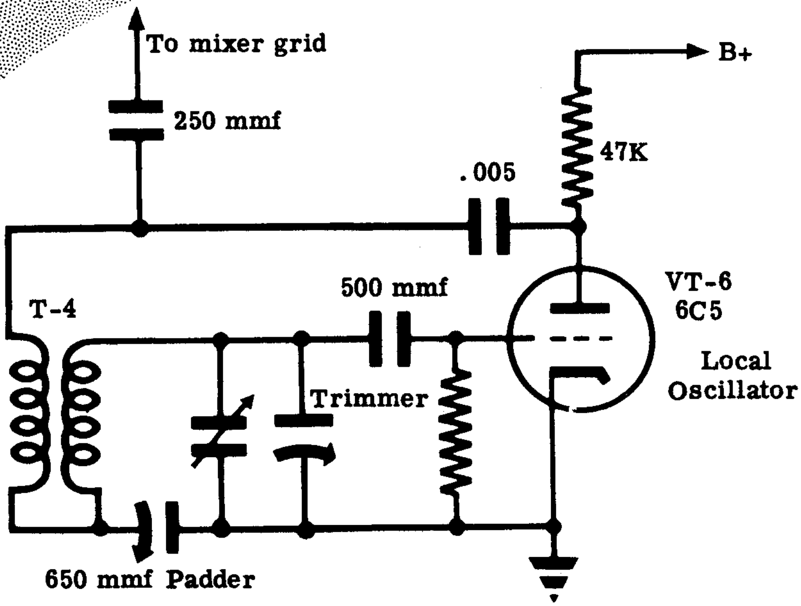
Complete Schematic of a Superheterodyne Receiver

The stages shown below include: a mixer, a local oscillator, one IF amplifier, a diode detector, an audio voltage amplifier, an audio power amplifier and a rectifier.



Analysis of the Local Oscillator Stage

THE *Local Oscillator*

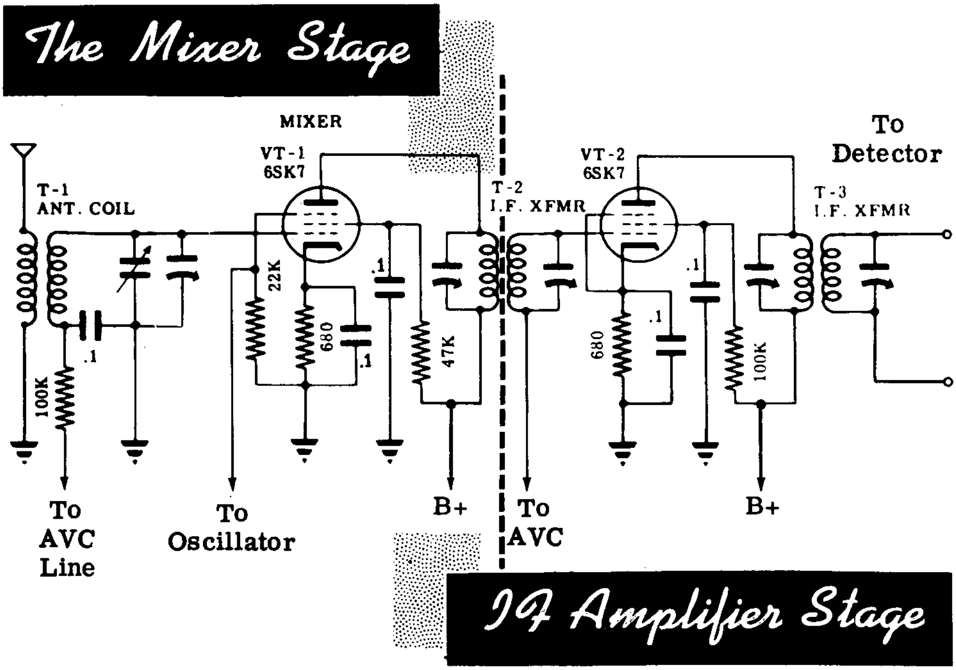


Now that you have seen the complete schematic of a superhet, it will be worth your while to spend a little time analyzing the function of the circuit components used in the oscillator, the mixer, and the detector stages.

The local oscillator circuit is basically that of an Armstrong (tickler coil) oscillator. Feedback is accomplished inductively using coil T-4. The variable tuning capacitor is ganged to the variable tuning capacitor of the mixer stage. The 650-mmf capacitor is a padder capacitor. It is used to make adjustments in the process of aligning the oscillator tuned circuit. It also serves to reduce the total capacity of the oscillator tank circuit so that the oscillator resonates at a frequency higher than that of the incoming signal.

The 500-mmf capacitor is a grid capacitor used to couple the tank circuit to the grid, while the 22K resistor is the grid-leak resistor. The 47K resistor is a plate load resistor which also blocks RF from going toward the power supply, and the .005-mfd capacitor couples the RF output of the plate circuit back to the tickler coil while effectively blocking the flow of direct current. Finally, the 250-mmf capacitor is used to couple the output of the oscillator with the suppressor grid of the mixer.

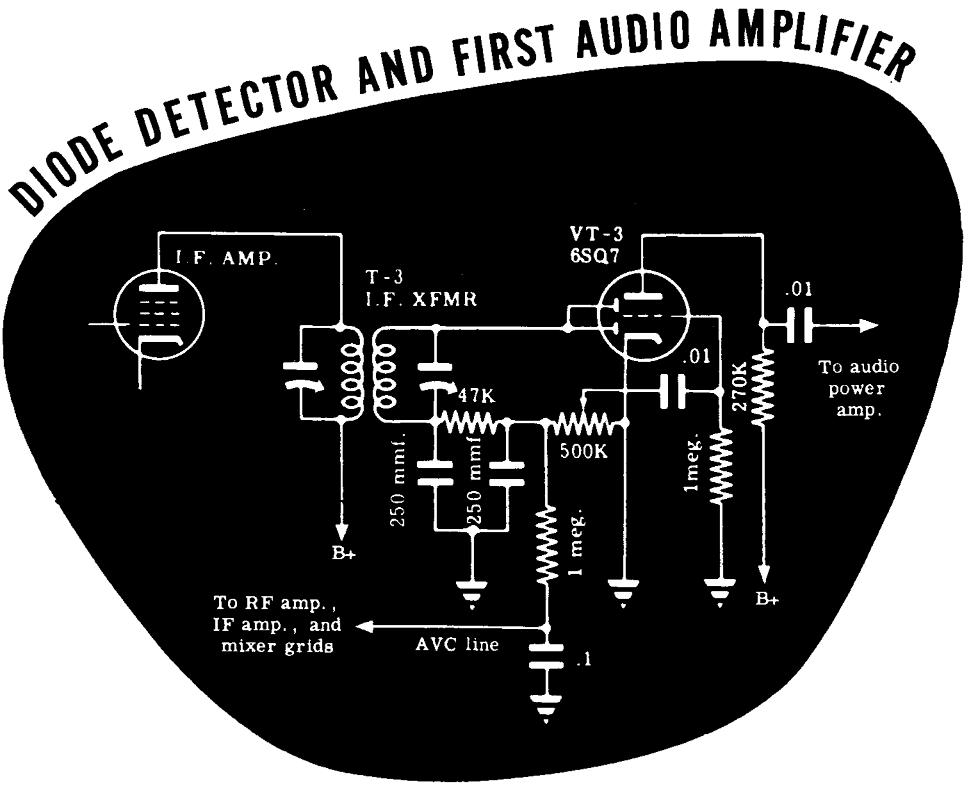
Analysis of the Mixer and IF Stages



T-1 is the antenna coil used to couple the antenna with the control grid of the mixer. The variable tuning capacitor is used to tune the receiver to the desired station. It is ganged to the variable capacitor of the oscillator tank circuit. The signal from the oscillator is impressed upon the suppressor grid, and the 22K resistor is used to provide a path to ground for electrons that may collect on the suppressor grid. The 680-ohm resistor is a cathode bias resistor, while the 0.1-mfd capacitor in parallel with it is used to bypass the RF signal around the cathode bias resistor. The 100K resistor and 0.1-mfd capacitor connected to the bottom portion of the secondary winding of the antenna coil act as a decoupling network whose function is to keep the RF signal out of the AVC line. The 47K resistor and 0.1-mfd capacitor connected to the screen grid function as the screen grid voltage-dropping resistor and bypass capacitor respectively. T-2 is the input IF transformer which couples the 456 kc IF signal found in the plate circuit of the mixer with the grid circuit of the following IF amplifier.

The 680-ohm resistor and 0.1-mfd capacitor found in the cathode circuit of the IF amplifier serve as the cathode bias resistor and bypass capacitor respectively. The 100K resistor in the screen grid circuit is the screen grid voltage dropping resistor, while the 0.1-mfd capacitor in the screen circuit is the screen grid bypass capacitor. T-3 is the output IF transformer used in couple the IF amplifier with the diode detector. Both IF transformers are permanently tuned to the intermediate frequency—456 kc.

Analysis of the Diode Detector and First Audio Stages



The two 250-mmf capacitors function as the detector filter capacitors. Their purpose is to bypass the IF component of the signal to ground around the 47K and 500K diode load resistors. The 47K resistor is part of the filter network, while the 500K potentiometer also acts as a bleeder resistor across the filter. It controls the amount of detector output delivered through the .01-mfd coupling capacitor to the grid of the first audio amplifier and thus serves as a volume control.

The 1-meg. resistor and 0.1-mfd capacitor in the AVC line filter out the relatively rapid variations in AVC voltage produced by the audio component of the signal. They allow the slower variations in AVC voltage produced by variations in signal strength to pass unimpeded down the AVC line.

The 1-meg. resistor connected to the control grid serves as a path to ground for any electrons that may accumulate on the grid. The 270K resistor acts as the plate load of the first audio stage, while the .01-mfd capacitor in the plate circuit couples the output of the first audio amplifier to the grid of the audio power amplifier.

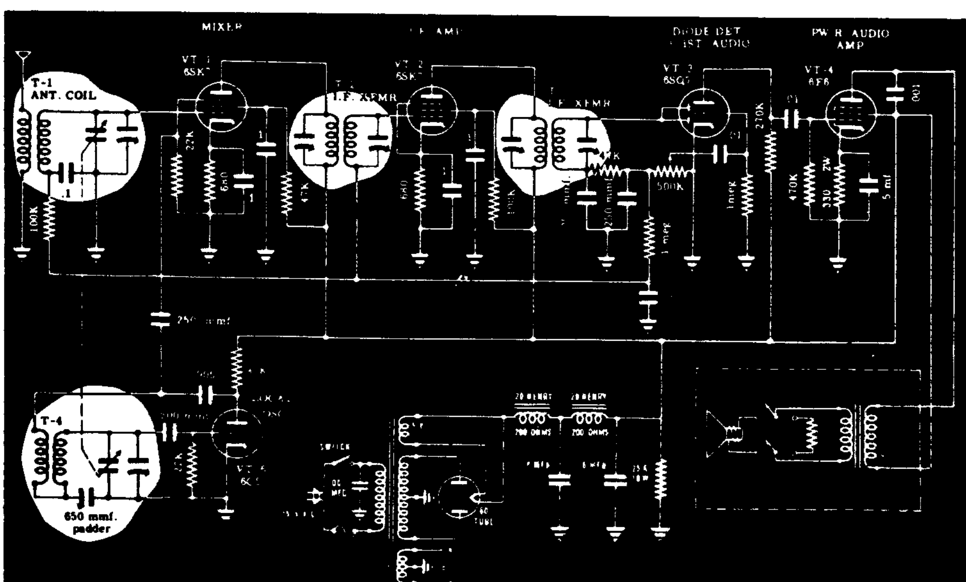
The circuit of the audio power amplifier does not require further analysis, since the circuit is the same as that of the power amplifier previously discussed under the topic entitled TRF Receivers—Audio Amplifier Stage.

What Alignment Is

The superheterodyne receiver must be adjusted almost as carefully as a jeweler adjusts a watch. This process, called "alignment," is the same for all superheterodyne receivers. You align your superhet to make it operate at its best output. The purpose of alignment is to get the maximum gain in the superhet receiver for any setting of the main tuning dial. When the dial is set to receive a station transmitting at 980 kc, you want the receiver to give the greatest gain at 980 kc. The same thing must be true for every setting on the dial. The tuned circuits—RF, local oscillator, and IF—must be adjusted to give always the maximum output. How does the superhet circuit have to be tuned to give the greatest gain for each dial setting?

1. The IF transformers must be tuned to the fixed IF frequency.
2. The RF tuned circuit must be tuned to the frequency on the dial.
3. The local oscillator must be tuned to give an output at each setting of the main dial that is above or below the dial setting or RF frequency by a difference equal to the IF frequency.

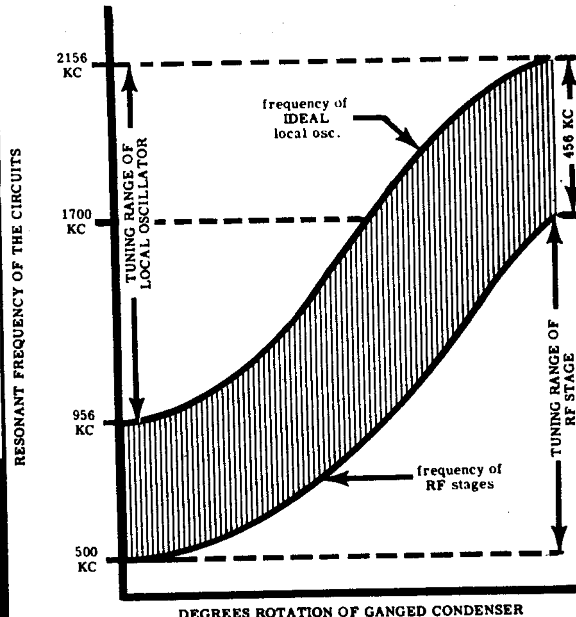
A review of the superheterodyne circuit will show you how the tuning is done in the circuit itself. The diagram below includes all the tuned circuits in the receiver. The tuned circuits in the IF transformers are fixed to give maximum gain at the IF frequency. The RF circuit in the mixer grid is gang-tuned with the local oscillator. The trimmers on the two-gang variable capacitor and the padder capacitor in the local oscillator tank circuit are adjusted to keep the frequency difference between the RF circuit and the local oscillator constant at the IF frequency. For any setting of the dial, the local oscillator output must be above (or, in some sets, below) the received RF signal by the fixed difference of the IF frequency.



The Alignment Procedure

There are only three steps to follow to get the RF and the local oscillator tuned circuits adjusted in such a way that at any dial setting, there will be the best "tracking" possible. Perfect tracking would mean that as the RF tuning is varied, the local oscillator tuning will vary so as to maintain a fixed frequency difference.

PERFECT TRACKING



The first step is to adjust the trimmers on the two-ganged variable capacitor. Since these trimmers are in parallel with the tuning capacitors, they affect the total capacitance more at the high frequency end of the band (when the variable capacitor has minimum capacitance) than at the low frequency end. For this reason, the trimmers will be adjusted at 1500 kc, which is close to the high end of the broadcast band.

The local oscillator padder is in series with the tuning capacitor and will have more effect on the total capacitance when the tuning capacitor has maximum capacitance. This occurs at the low end of the tuning range where the plates of the variable capacitor are fully meshed. The padder will be adjusted at 600 kc, the low end of the band.

There is a problem here. When the 600-kc signal is fed into the input, even if the RF circuit is not set exactly to 600 kc, it is possible to adjust the local oscillator's padder for a maximum output; but this is not the best setting of the padder although the local oscillator frequency is 1056 kc. The real maximum will occur when the local oscillator is adjusted to 456 kc above 600 kc at the same setting that the RF circuit is tuned to 600 kc. The correct adjustment is achieved by a process called "rocking in." In rocking in, you make adjustments of the padder at several settings of the tuning dial in the vicinity of 600 kc. The setting at which the maximum output is greatest is the correct one. The local oscillator padder has been adjusted so that the local oscillator frequency differs from the resonant frequency of the RF circuit by 456 kc.

After the padder has been properly adjusted, you will tune back to 1500 kc, inject a signal of 1500 kc, and readjust the trimmer capacitors at the high end of band.

What Sensitivity Measurements Are

Sensitivity measurements are used to determine how sensitive a receiver is. A receiver may be operating normally, as far as your ear or even an oscilloscope can detect, but, if the overall gain of the set is low, you may not be able to receive weak signals. This would only show up by measuring the overall gain of your receiver and comparing the results with the overall gain of a standard receiver.

If a receiver was tested and found to have low sensitivity, the cause would then have to be determined. This would be done by checking the gain of each stage and comparing the results with some standard, thereby determining which stage has the low sensitivity. This trouble is almost always due to a weak tube in the stage which has low sensitivity.

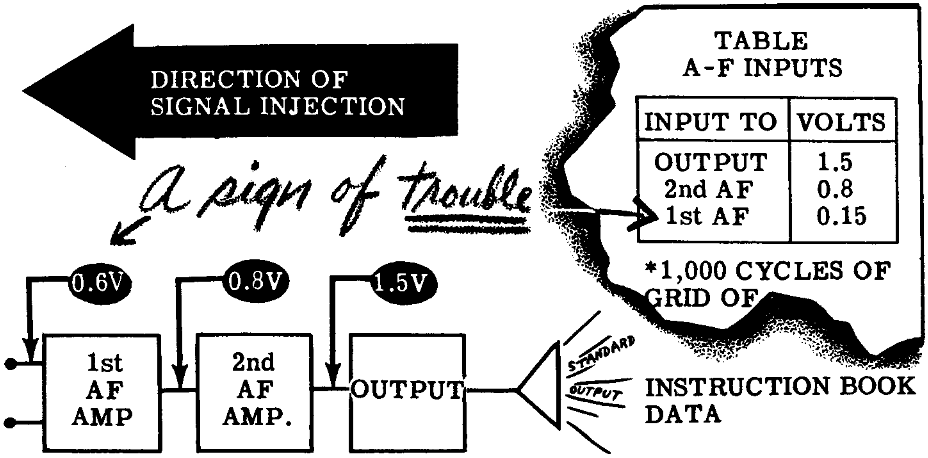
Consider a typical broadcast-band receiver. Broadcast receivers are not designed to be very sensitive since very powerful stations are relatively close to the receivers. In these receivers, a loss of sensitivity would mean you would turn up the volume control and nothing more. Therefore, sensitivity measurements are not necessary. Only when reception becomes so poor that it is uncomfortable or impossible to hear a station, would you attempt to repair the receiver.

The Importance of Sensitivity Measurements

In some receivers, sensitivity measurements are very important. In a radar or sonar receiver, lack of sensitivity would mean that distant targets which should be detected would not be noticed at all. Decreased gain in a communication receiver would mean that weak signals could not be heard. If any of these devices have low sensitivity, you could not discover this fact by operating them, since you usually have no way of obtaining all the necessary data. You can't tell that a distant target is present unless you pick it up; you can't tell that a weak, distant transmitter is calling you unless you hear the message. Your only check on the performance of the receiver is through sensitivity checks.

Here is the typical way sensitivity measurements would be made with receiving equipment. An output meter is used to measure the output of the last stage of the receiver. The instruction book for the piece of equipment will tell how many microvolts are required as the input to this receiver for a standard output as measured on the output meter. Using a signal generator which has a calibrated output, you inject a signal of the proper frequency into the receiver input. You adjust the signal generator output until you read the standard amount of output on the output meter. By comparing the input you needed with the instruction book's data, you can tell if the receiver is working up to par. If the input you used is larger than that stated in the instruction book, your receiver has too low a sensitivity. You would then take stage-by-stage sensitivity measurements to determine the weak stage.

Starting with the last stage of the receiver, you inject a signal of proper frequency and adjust the signal generator output until the standard receiver output is obtained. If the input you used compares well with the instruction book data, the last stage of the receiver is working properly. You repeat this procedure for each stage, working backwards from the last stage. The stage that requires a larger input than that specified in the instruction book is the stage with low gain.



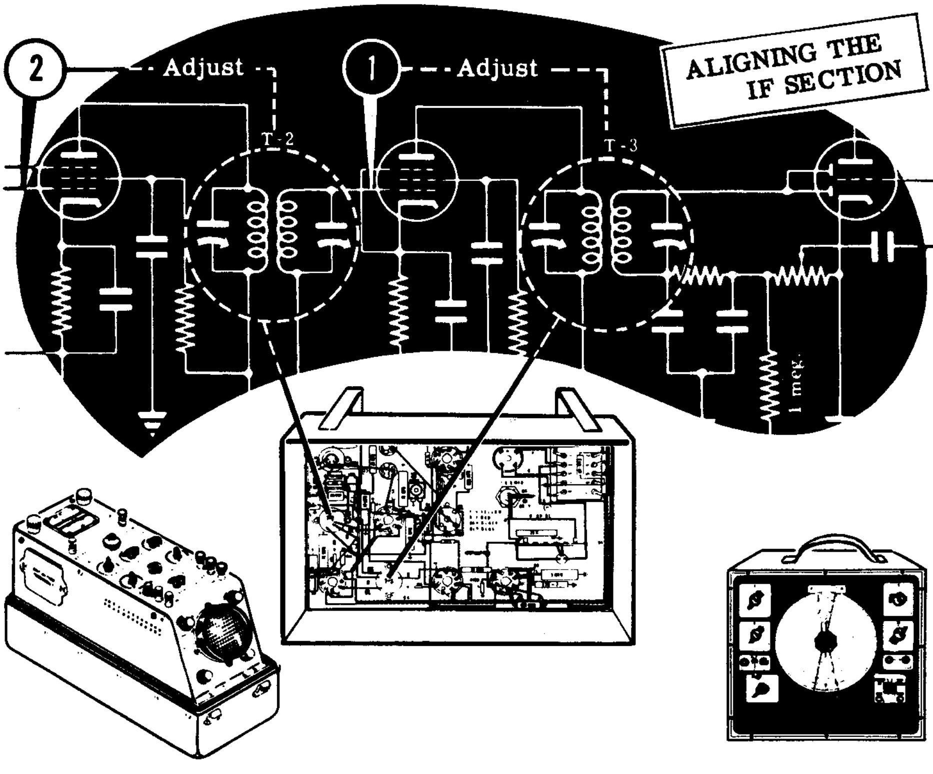
Demonstration—Aligning the IF Section

The first part of the receiver to be aligned is the IF section. The instructor removes the oscillator tube to prevent any signal other than that of the signal generator from entering the IF strip. He also shorts the AVC signal to ground since the AVC circuit, if operative, would tend to broaden the receiver response and thus make it more difficult to align the receiver sharply. The 'scope or output meter leads are connected across the speaker and the signal generator test leads are ready to be applied to the various test points in the IF section.

With the receiver gain at maximum, a modulated 456 kc signal is injected into point 1, the grid of the IF amplifier. Using an alignment tool, the instructor adjusts the trimmers on the IF output transformer for a maximum output on the 'scope screen. As the 'scope signal increases with the adjustment, the RF control knobs are lowered.

Next the RF signal is injected into point 2, the grid of the mixer stage, and the trimmers of the IF input transformer are adjusted for a maximum indication on the 'scope.

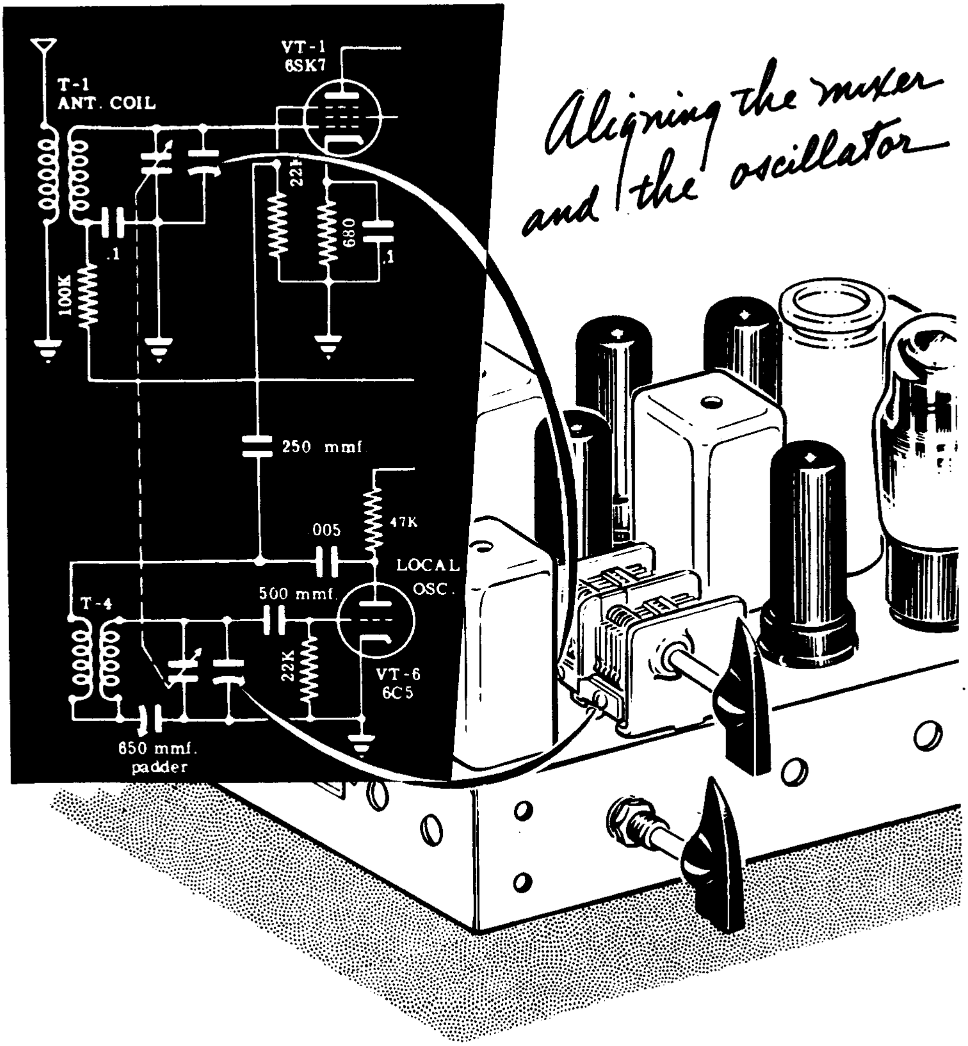
The trimmers on both the IF transformers are again touched up slightly to obtain optimum alignment of the IF section.



Demonstration—Aligning the Mixer and Oscillator

With the IF strip aligned, the RF tuned circuits in the grid of the mixer and the local oscillator are aligned next.

The instructor replaces the oscillator tube but leaves the AVC circuit shorted to ground. The signal generator test probe is moved to the antenna terminal and the signal generator is set to give a modulated RF output of 1500 kc. The receiver dial is set approximately to 1500 kc, and a signal is observed on the 'scope. With the alignment tool the instructor adjusts the oscillator and RF trimmers to give a maximum output on the 'scope screen. Now the RF circuit is tuned to resonate 1500 kc, and the oscillator is tuned to oscillate at 1956 kc.



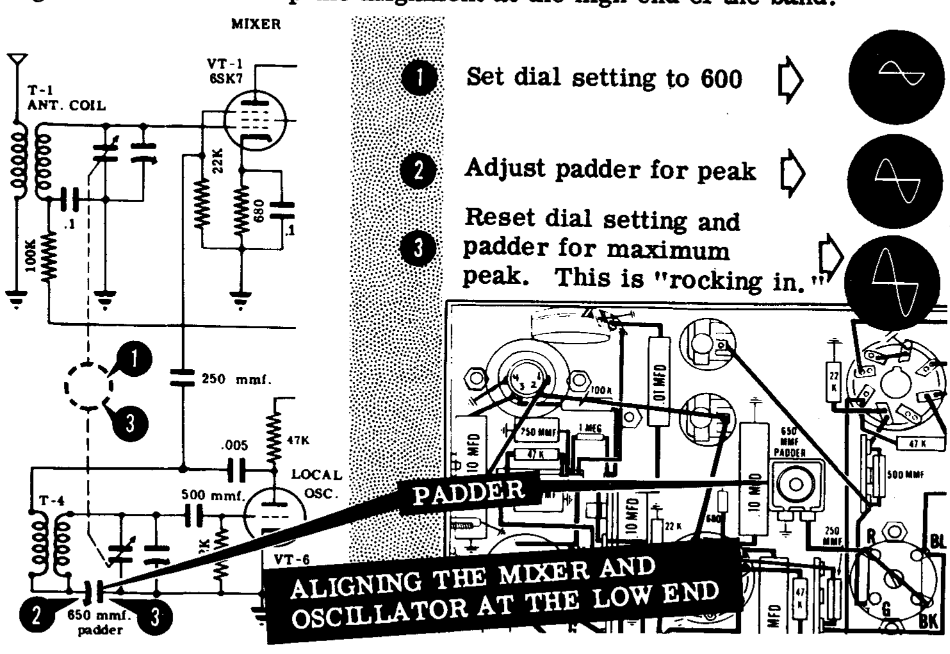
Demonstration—Aligning the Mixer and Oscillator (continued)

The mixer and oscillator tuned circuits must now be aligned at the low end of the band.

The instructor sets the signal generator at 600 kc and the receiver dial at 600 kc. He then adjusts the oscillator padder capacitor to give a maximum output on the 'scope. Now the oscillator is adjusted to oscillate 456 kc above the incoming signal of 600 kc.

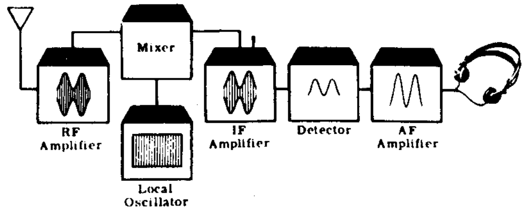
Although the dial is set at 600 kc, there is no assurance that the RF tuned circuit is resonant to 600 kc. The ideal alignment for maximum output is to have the RF tuned circuit exactly resonant to 600 kc with the oscillator tuned to 456 kc above 600 kc. The ideal alignment is obtained by a procedure called "rocking in."

First the instructor notes the size of the 'scope image, and then he tunes the receiver in one direction slightly away from receiver dial reading of 600 kc. He readjusts the padder for a maximum output on the 'scope. If the 'scope image is greater than it was before, he has changed the setting of the tuning dial in the right direction. If the output is less, he must tune the receiver in the opposite direction from the 600 kc dial reading. Having found the right direction, he keeps on varying the setting of the tuning dial and adjusting the padder until an absolute maximum 'scope image is reached. At this point the RF circuit is tuned exactly to 600 kc with the local oscillator tuned to 1056 kc. Making sure not to change the setting of the tuning capacitor, the instructor loosens the knob set screw and repositions the knob so that the pointer now reads 600 kc. The final step in alignment is to touch up the alignment at the high end of the band.

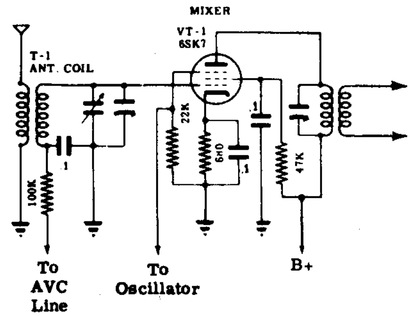


Review of the Superhet Receiver

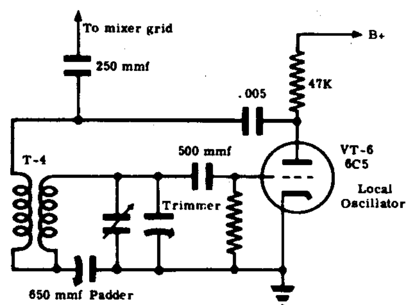
SUPERHETERODYNE—A type of receiver in which the RF signal is converted to a lower frequency RF and then amplified before detection. It has much higher sensitivity, selectivity and stability than the TRF.



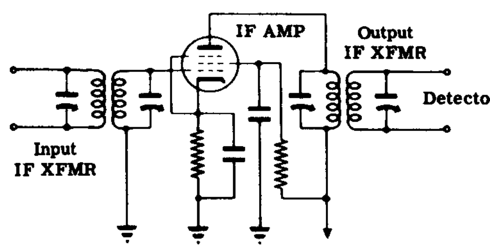
MIXER—This is the key circuit in a superhet. It takes the RF signal and beats it against the signal generated by a local oscillator. The resultant constant frequency signal is lower in frequency than the RF and thus is easier to amplify.



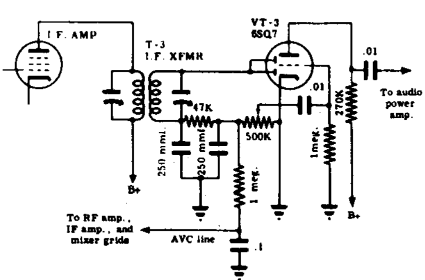
LOCAL OSCILLATOR—This circuit is tuned simultaneously with the RF tuned circuits in such a way that its output frequency is always 456 kc greater or less than the frequency of the signal being received. Its output is combined with the RF signal in the mixer, which thus always feeds a constant frequency signal to the IF amplifier.



IF AMPLIFIER—The section of the superhet which amplifies the fixed frequency signal coming from the mixer. Its input and output are usually coupled by transformers in which the primary and secondary are tuned. This results in high selectivity.

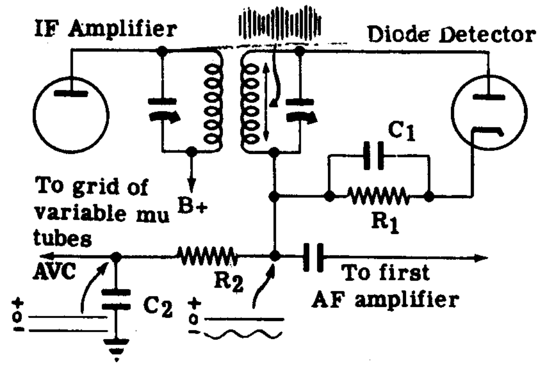


DETECTOR AND AF AMPLIFIER—These circuits perform the same functions as in the TRF receivers. In the superhet the diode detector is often combined with the first AF amplifier stage.

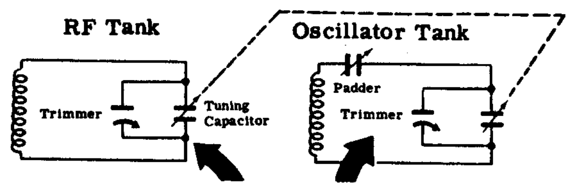


Review of the Superhet Receiver (continued)

AUTOMATIC VOLUME CONTROL (AVC)—This circuit compensates for variations in signal strength. A diode rectifies the negative half of the signal and feeds the DC output to the RF and IF amplifier grids. When the signal increases the diode output increases, thus putting more negative bias on the RF and IF amplifiers and lowering their gain.



TRACKING—When the difference between the local oscillator frequency and the RF signal frequency is constant over the entire tuning range of the superhet, it is said to have perfect tracking. This is never achieved in practice.



TRACKING: 456 kc difference over entire tuning range

BEAT FREQUENCY OSCILLATOR (BFO)—This is an oscillator used when it is desired to receive CW signals with the superhet. Its output is tuned close to the frequency of the IF and is fed into the detector. It beats with the incoming signal, producing a beat note in the audio range. With a BFO, a CW signal is heard as a pure tone. Without a BFO, CW signals are heard as a soft hiss or not at all.

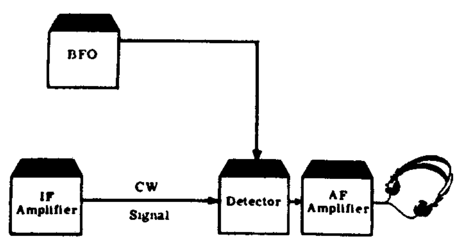
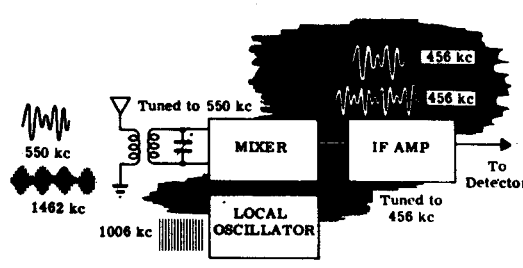


IMAGE FREQUENCIES—If the IF is 456 kc, then two signals (one 456 kc above and the other 456 kc below the oscillator frequency) will both send a signal through the IF amplifier and to the loudspeaker. One of them is the desired signal; the other is an image. The purpose of a tuned antenna coil and tuned RF amplifiers is to eliminate the image frequency.



Review of the Troubleshooting Method

If you have to fix a defective piece of equipment, here is one way that you might go about finding the trouble source. If there is a complaint tag attached to a piece of equipment, get as much information as you can from it, so that you don't waste time looking for troubles that aren't there. In the event that there is no complaint tag, follow the procedure described in the following paragraphs.

Inspect the Equipment

This is a very important step—many defects can be found by using your five senses. Once you have heard a transformer sizzle and smelled the smoke, you will be able to spot a burned-out power transformer without even turning the chassis over. Visual inspection does not take long—in about two minutes you should be able to see the trouble if it is the kind that can be seen.

You should fully realize the significance of visible defects and you should know just how they can be recognized. Remember that even though you do find and repair a defect, you must prove to yourself that the equipment is operating properly and that there are no other defects. Usually, there will be only one trouble in a piece of equipment unless the faulty component has been caused to burn out by some other fault. When you find a trouble by visual inspection, try to imagine another trouble which could have caused the one you've located. If you merely proceed to replace the faulty component and then turn the equipment on, the replacement part may burn out again. The most obvious example is a fuse which burns out, gets replaced, and then the second one burns out. You must locate the cause of the trouble before you replace the faulty parts.

Troubleshooting by Signal Tracing and Signal Injection

Devices such as radar, sonar and radio receivers are very complex. If you attempted to do troubleshooting on a radar receiver by means of voltage and resistance checks alone, you would have a long tiresome task ahead of you. There would be hundreds of voltage, current and resistance checks for you to perform, not to mention tubes and tuned circuits to be tested. And then there would always be the possibility that none of your checks would show you what was wrong, since static testing will not show up faults like misaligned tuned circuits, certain tube defects or defective automatic control circuits.

Fortunately, the signal injection method is an ideal way to locate quickly any receiver trouble.

Suppose you review the advantages of troubleshooting by signal tracing.

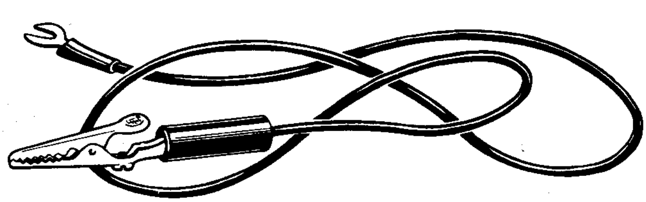
1. You can test each section of the receiver by putting in a signal and listening to the signal at the output or by examining the output with an oscilloscope.

2. You can determine immediately the defective section, since the signal at its output is either missing or distorted.

3. Knowing the section with the trouble, you can isolate the trouble to a particular stage by injecting a signal of the proper frequency and amplitude into the grid points, starting at the output and working back towards the input. The point at which the signal disappears or becomes distorted is the place to look for trouble.

4. Once the defective stage has been found the defective component can be isolated by using voltage and resistance checks.

Signal tracing and signal injection, therefore, enable you to find the trouble quickly and easily by greatly reducing the number of points to be tested. By the use of signal tracing, you can locate the stage which contains the trouble and sometimes, depending on the nature of the trouble, the faulty part. You also can narrow the trouble down to the particular stage or component with a minimum number of checks of those stages which are functioning properly.

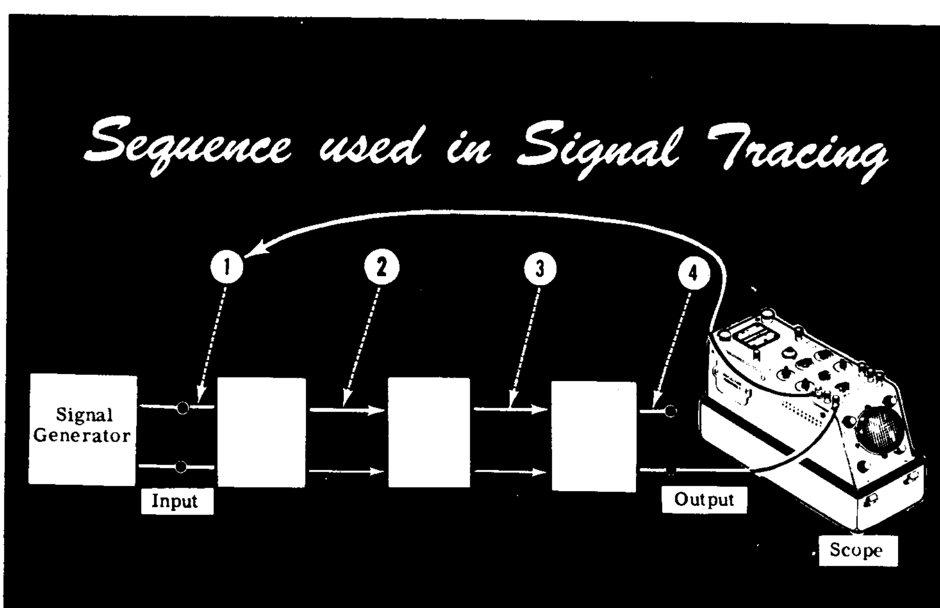


Troubleshooting by Signal Tracing

The best way to locate the trouble is to trace a signal through the equipment, using either signal tracing or signal injection. Signal tracing and signal injection are basically the same thing. Each has some advantages over the other for the testing of different types of basic circuits. The basic purpose of these signal tracing methods is to locate the exact area of a trouble. Any break or short in the signal path can be located immediately because the signal will disappear at that point. If the trouble is due to an improper voltage on a tube or is due to a faulty tube, the signal will not pass (or will be distorted) between the grid and plate circuit of the tube. If the trouble is of this nature, it can be localized immediately to the specific tube, and then the exact trouble can be located by voltage and resistance checks and by trying a tube known to be good. Let's review the procedure for signal tracing and signal injection.

In the procedure for signal tracing, the normal signal input for a piece of equipment is connected to the input terminals. The 'scope is then used to trace the signal from the input towards the output. The point at which the signal disappears or becomes distorted is the point to look for the trouble.

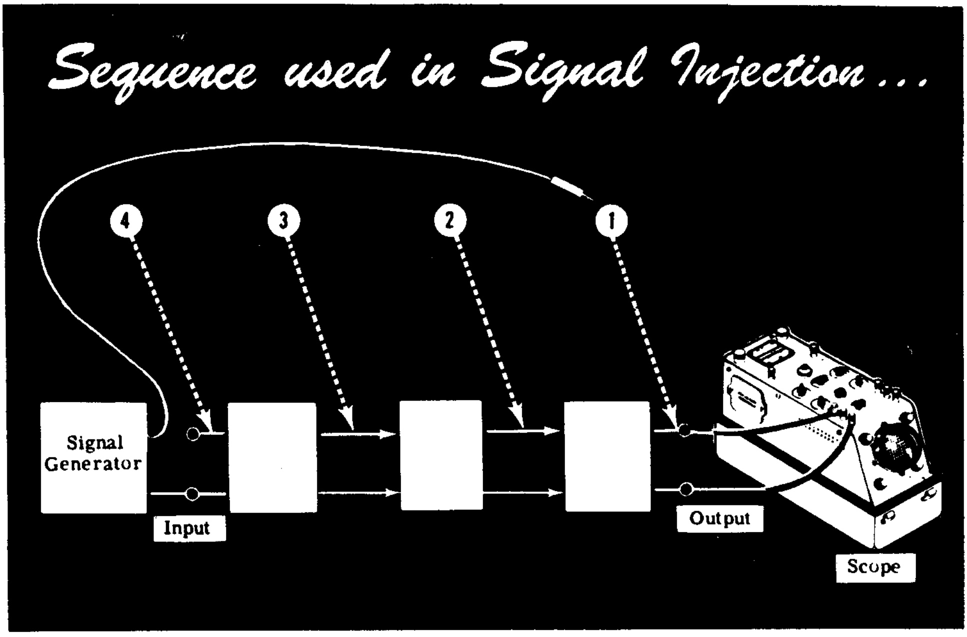
Signal tracing can be used with practically every type of circuit that you will come across. In general,it is most useful in equipment where there is an audio signal. It may be used also in equipment where there is an RF signal of voltage amplitude high enough to be seen on the 'scope. Signals cannot be traced easily in receivers because of the low voltage RF signals present in a major part of the circuit.



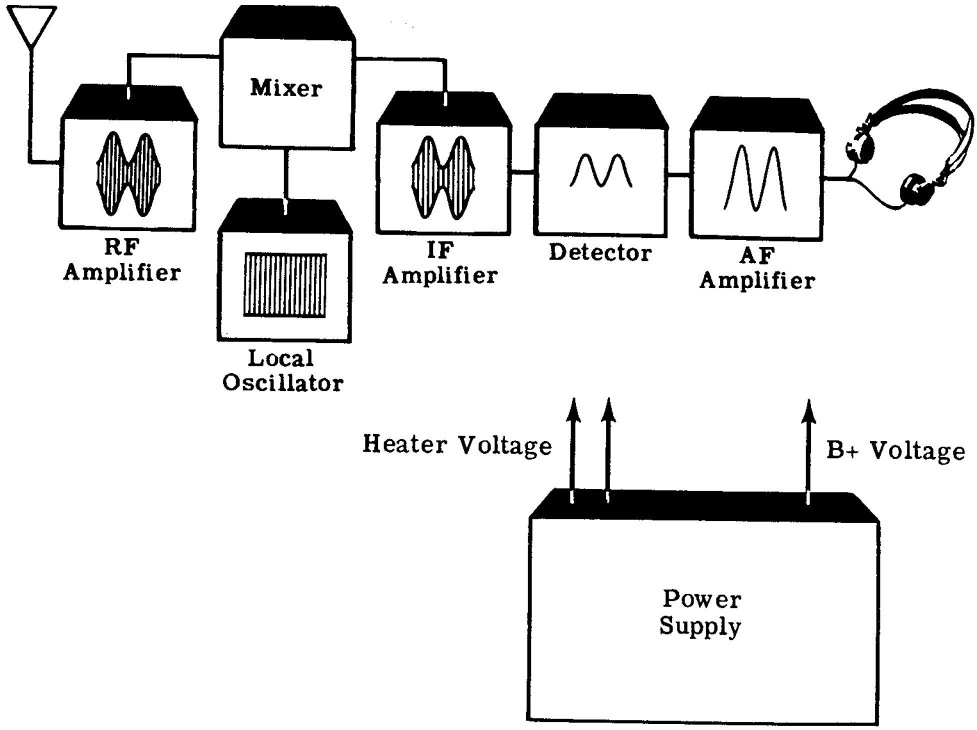
Troubleshooting by Signal Injection

In the procedure for signal injection, the 'scope is permanently connected to the output of a piece of equipment. The signal generator is used to inject a signal of the proper amplitude and frequency into the various test points, starting at the output and working towards the input. Signal injection has the disadvantage of seeming to be a "backwards" procedure; actually it is basically the same as signal tracing.

Signal injection is used mainly with receivers and other similar equipment where there are high frequency amplifiers with a very low input voltage. The 'scope amplifier cannot amplify signals of radio frequency and the signal amplitude is much too low to be seen if it were connected directly to the 'scope vertical deflection plates. Signal injection solves this problem by using a signal generator to inject signals into various parts of the equipment. The amplifiers in the equipment under test will give a large enough gain so that the signal can be seen on the 'scope screen. The first stage to check is the last stage of the piece of equipment. If this last stage is operating normally, the next to the last stage is checked by feeding a signal into that stage and checking the output at the same point as before. It is because the 'scope is always observing the output of the equipment in signal injection that the last stage in the equipment is the first one to be checked. Just as in signal tracing, the point where the signal becomes distorted or disappears is the point to look for the trouble. For example, if the last stage is checked O.K. but when the signal is placed on the input to the next to the last stage, the output is not normal, the trouble is in the next to the last stage.



Troubleshooting the Superheterodyne Circuits



Here is an outline of how to troubleshoot the various sections of a superhet receiver.

1. The Power Supply

The power supply furnishes B+ and heater voltage to the various components of the receiver. In troubleshooting a power supply, the AC signal from the line cord is traced through the transformer, the rectifier tube, the filter circuit and up to the power supply bleeder resistor. The final B+ voltage should be quite free of hum, even with the 'scope Y GAIN control turned all the way up.

2. The Audio Amplifier

In troubleshooting the audio amplifier in a receiver, use the signal injection method because you will have to use that method for the rest of the receiver. The 'scope should be connected across the loudspeaker at the output transformer secondary. An audio signal should be injected into the various test points from the 'speaker towards the detector. The point at which the signal disappears or becomes distorted is the point to look for the trouble with your voltmeter and ohmmeter.

Use the 400-cycle audio output of the signal generator. Remember to use a .01-mfd blocking capacitor at the end of the probe to keep B+ out of the signal generator.

Troubleshooting the Superheterodyne Circuits (continued)

3. The Detector

The operation of the diode detector has been described in this section and the operation of two other basic types of detectors will be found in the TRF section. The detector takes a modulated RF (or IF) signal and separates the audio from the RF component. The high frequency component is bypassed to ground and the audio signal is connected to the audio amplifier. In troubleshooting a detector, a modulated RF (or IF) signal is injected into the detector input. If an audio signal corresponding to the modulation does not appear on the 'scope screen, there is trouble in the detector. Don't forget to use a 200-mmf isolating capacitor at the end of the test probe.

4. The IF Amplifier

The IF amplifier is an RF amplifier operating at a fixed frequency of 456 kc. The operation of the IF amplifier is similar to that of the RF amplifier described in the amplifier section—the only difference being that the IF amplifier operates at a fixed frequency and, because of this, may be designed for a much higher gain. By injecting a modulated 456-kc signal, you can first test the output transformer, then the tube and finally the input transformer. In all cases an audio signal should appear on the 'scope. This method will localize the trouble in any one of these three circuits—the rest is a job for the voltmeter and ohmmeter.

5. The Mixer and the Oscillator

The mixer stage selects the desired modulated RF signal from the antenna and mixes it with the unmodulated signal from the local oscillator. The local oscillator and the mixer tuning circuit have mechanically-ganged tuning capacitors which keep the frequencies of the selected signal and the oscillator 456 kc apart. As a result of the mixer tube action, a modulated 456-kc signal is fed into the IF amplifier no matter what the frequency of the incoming RF signal. Information on the operation of oscillator circuits will be found in the oscillator section.

The mixer is tested by first injecting a modulated 456-kc signal into the grid. If this signal passes through the mixer and appears as an audio signal at the final output, the mixer stage is operating. Then an RF signal is injected into the antenna input and tuned in by means of the antenna tuning circuit—an audio signal should appear on the 'scope. If no signal appears, there is trouble in the antenna tuning circuit or the oscillator circuit.

Vacuum Tube Testing

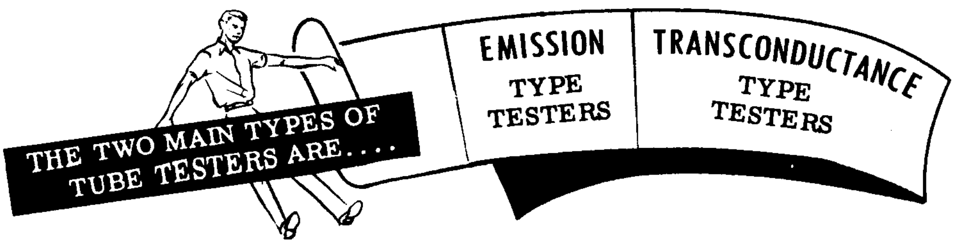
Contrary to the belief commonly held by the general public, the first step in troubleshooting is not the testing of tubes. It is necessary to isolate the defective stage and to check that stage to reveal the defective component. However, since many receiver defects are due to faulty tubes, it is important that you become familiar with the operation of tube testing equipment.

Since burned-out filaments cause the majority of tube failures, it is usually possible to discover such defective tubes by removing them from the receiver and testing with an ohmmeter. A noisy tube, called a "microphonic tube," may be discovered by turning the receiver power on and then tapping each tube gently. If a blast of noise or a squeal is produced, the tube in question should be replaced.

In general, however, the most satisfactory method of determining whether some of the tube elements are shorted, and whether the tube's emission or transconductance characteristics are normal for its type, is to use a well designed tube tester. However, it should be noted that the tube tester cannot always be looked upon as a final authority for determining whether or not a particular tube will operate satisfactorily in a given receiver. This is due to the fact that this tube might be operating in the receiver on a portion of its characteristic curve which is not covered in the tube tester, or it might be operating in the set with voltages much higher or lower than those used in the tube tester. All deviations from normal readings should make a tube liable to suspicion. An excessively high reading may indicate a defective tube as readily as one that is too low.

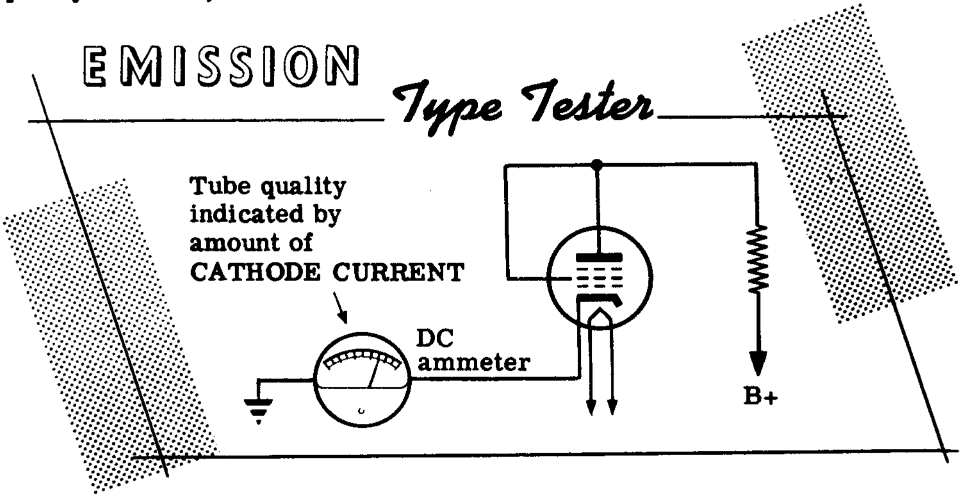
The check for filament continuity and for shorted tube elements is generally performed as the first part of the testing procedure. If the filament is found to be open, it is useless to attempt further testing of that tube. If shorted elements are discovered, it is not advisable to test further, as the shorted elements may blow fuses or damage instruments in later tests. Filament continuity and shorted elements are usually indicated by the lighting of a small neon or pilot lamp on the instrument panel.

If the tube passes the short and filament continuity test, it is next tested for merit or quality. The greatest difference between various types of tube testers is in the selection of a suitable characteristic for the quality test. Testers are divided on this basis into two great classes, the emission type and the transconductance type.

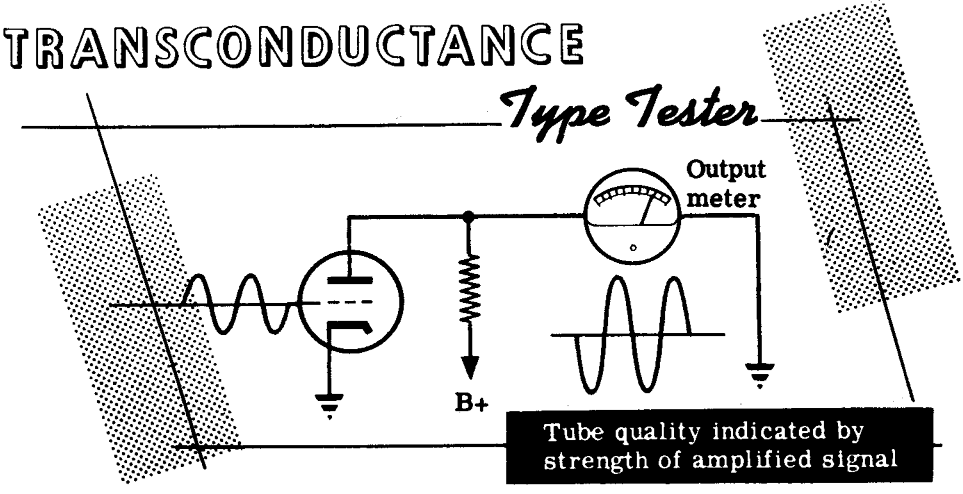


Vacuum Tube Testing (continued)

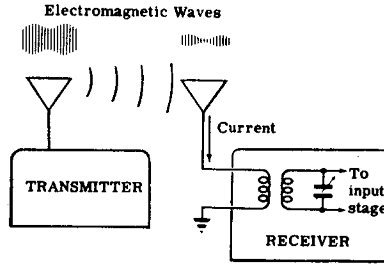
The emission-type tester determines the merit of the tube by measuring the amount of cathode current flowing when the filament is operated at its rated voltage and a positive voltage is applied to the plate. Since it is desired to measure only cathode emission in this test, the control grid, screen grid and suppressor grid are connected to the plate. Therefore, all tubes, whether they are diodes, triodes, tetrodes or pentodes, are tested as diodes. It is the simplest and cheapest method of testing the quality of a tube, but it is also the least satisfactory method.



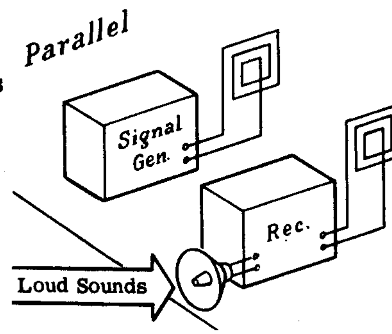
The mutual conductance or transconductance type of tester simulates the normal operation of the tube by applying a known signal to the grid and measuring the strength of the amplified signal in the plate circuit by means of an output meter. Since this procedure is performed under conditions which resemble the actual operating conditions of the tube in a receiver, the results obtained by using a transconductance-type tester give a better indication of a tube's serviceability than the results obtained from an emission-type tester.



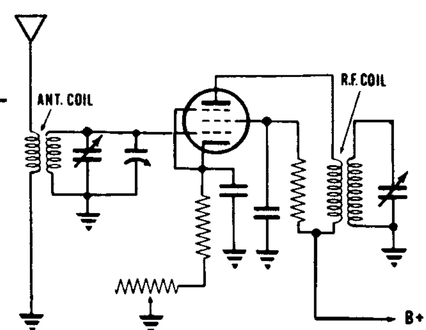
Review of Receivers



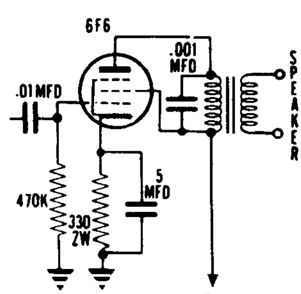
ANTENNA FUNCTION—The purpose of a receiving antenna is to pick up electromagnetic waves radiated by transmitting antennas. These waves, in cutting the antenna, induce voltages in it, causing a current to flow. The current flows into the input of the receiver, where it generates a signal which is amplified by the receiver circuits.



DIRECTIONAL CHARACTERISTICS—The position of a receiving antenna, relative to the transmitting antenna, will determine the strength of signal that it picks up. If a loop receiving antenna is broadside to a loop transmitting antenna, the signal picked up will be of maximum amplitude. If the loop is turned so that its edge faces the broad side of the transmitting antenna, a very weak signal will be picked up. Therefore, the antenna is said to have directional characteristics.

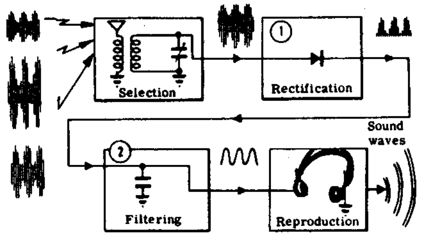


RF AMPLIFIER STAGE—An RF amplifier stage in a receiver improves the sensitivity and selectivity of the receiver. The added sensitivity is due to the amplification of the desired signal, and the added selectivity results from the use of tuned circuits which discriminate between the desired and undesired signals.

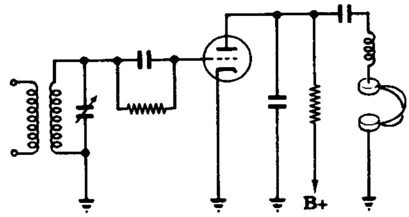


AUDIO AMPLIFIER STAGE—An audio amplifier stage in a receiver amplifies the detected audio signal. Audio stages, which precede the last stage, are voltage amplifiers whose sole function is to increase the amplitude of the audio to the level where it is large enough to drive the last stage. The last stage, called the "power stage," supplies the large current variations necessary to drive the speaker.

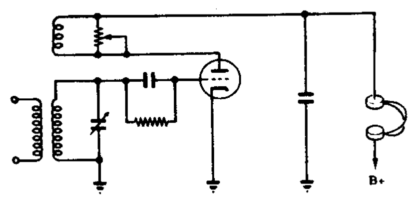
Review of Receivers (continued)



DETECTORS—The function of a detector in a receiver is to remove the audio component from a modulated RF signal so that it can be amplified by AF stages. A simple detector consists of a tuned circuit, a rectifier, and a filter. Such a detector is called a "diode detector."



GRID-LEAK DETECTOR—This type is basically a diode detector with amplification added. The grid and cathode form the diode detector with the grid acting as the plate. The rectified signal, developed across the grid-leak resistor, is amplified in the plate circuit. This detector is more sensitive than the diode type.



REGENERATIVE DETECTOR—This modified grid-leak type is still more sensitive. A feedback loop in the plate is coupled to the grid coil to provide regeneration, thus effectively increasing the gain of the stage.

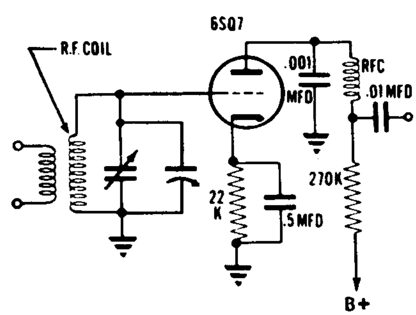
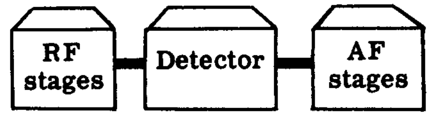


PLATE DETECTOR—This detector employs a triode or pentode, biased near cut-off. Rectification takes place in the plate circuit since the negative half of the modulated RF grid signal drives the tube into cut-off.



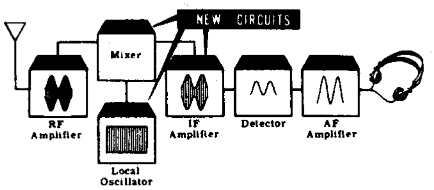
TRF RECEIVER

All tank circuits gang tuned

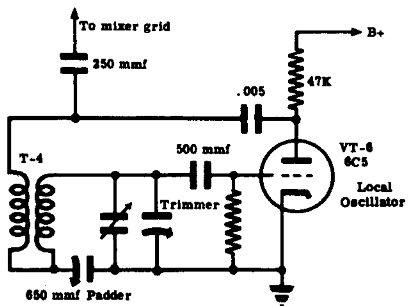
TRF RECEIVER—This receiver employs RF amplifiers, a detector and AF amplifiers. The tuned circuits are ganged-capacitor tuned. A shortcoming of the TRF is that since the tuned circuits are not fixed-tuned, constant sensitivity and selectivity cannot be realized over a tunable band.

Review (continued)

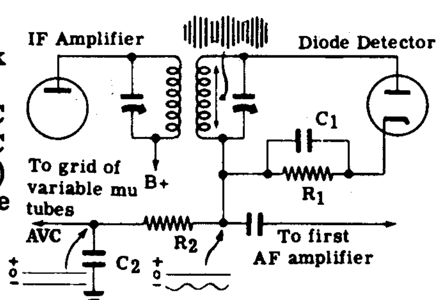
SUPERHETERODYNE RECEIVER—The aforementioned disadvantage of the TRF is overcome in the superhet receiver, in which all desired RF signals are converted to the same fixed lower signal (called the "intermediate frequency") where the signal is amplified by fixed tuned circuits before it is detected. To accomplish this, the superhet incorporates a mixer, local oscillator and IF amplifier in addition to the usual TRF stages.



OBTAINING THE IF SIGNAL—The fixed IF signal is gotten by beating the incoming signal with the signal from a local oscillator which is always a fixed amount away from the incoming signal. This is accomplished by gang tuning the oscillator and the RF amplifier so that the difference between the RF tank resonant frequency and the oscillator tank resonant frequency is constant for all settings of the tuning dial. The oscillator tank resonant frequency is said "to track" the RF tank resonant frequency.



AUTOMATIC VOLUME CONTROL—The superhet receiver incorporates an AVC circuit whose function is to equalize the receiver output for both strong and weak incoming signals. It does this using a filter circuit which charges up to the DC level of the rectified RF wave. This DC voltage (negative with respect to ground) is then applied as bias to the grids of the IF, mixer and RF stages, all of which employ variable-mu tubes. In this way the bias voltage, and therefore the gain, of the stage is directly related to the intensity of the received signal.



ALIGNING—When aligning a superhet the IF stages are adjusted first. Then the trimmers of the RF tuned circuits and local oscillator are adjusted at the high end of the band. The adjustment of the low frequency end of the band is made with the padder capacitor.

STEPS IN ALIGNING

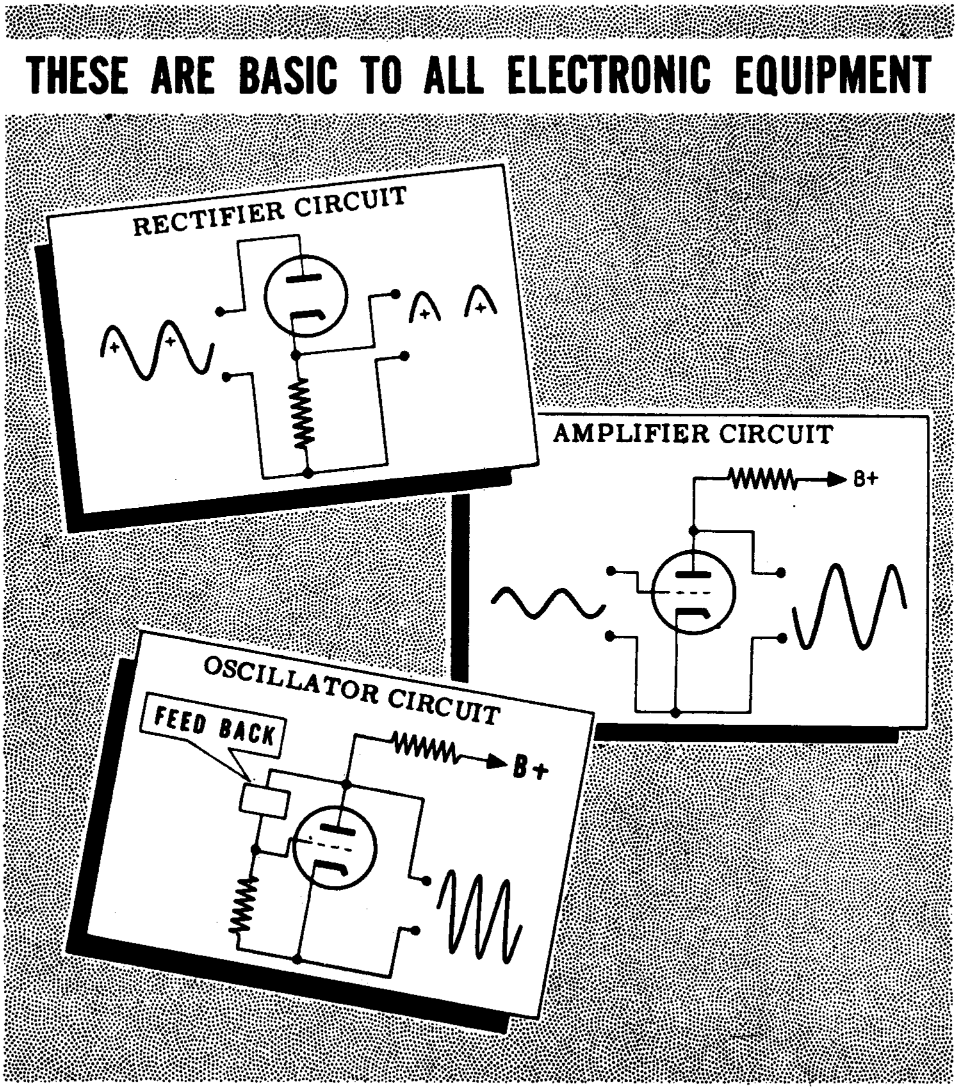
① IF trimmers.

② RF tuned circuit trimmers and local oscillator trimmer at high end.

③ Local oscillator trimmer at low end.
   a. Rocking in.

What You Have Learned

You have just completed the course in Basic Electronics. Looking back on the weeks you have spent studying these materials, what should you be able to do with the information you have now? If you can recognize the three basic electronic circuits—the rectifier, amplifier and oscillator—in a schematic diagram, if you understand how each component functions within these circuits, and what part the entire circuit plays in a piece of equipment, then you "know your stuff".



INDEX TO VOL. 5

(Note: A cumulative index covering all five volumes in this series will be found immediately following this index to Volume 5.)

INDEX TO VOL. 5

CUMULATIVE INDEX

(Note: The first number in each entry identifies the *volume* in which the information is to be found; the second number identifies the *page*.)

CUMULATIVE INDEX

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HOW THIS OUTSTANDING COURSE WAS DEVELOPED:

In the Spring of 1951, the Chief of Naval Personnel, seeking a streamlined, more efficient method of presenting Basic Electricity and Basic Electronics to the thousands of students in Navy speciality schools, called on the graphiological engineering firm of Van Valkenburgh, Nooger & Neville, Inc., to prepare such a course. This organization, specialists in the production of complete "packaged training programs," had broad experience serving industrial organizations requiring mass-training techniques.

These were the aims of the proposed project, which came to be known as the Common-Core program: to make Basic Electricity and Basic Electronics completely understandable to every Navy student, regardless of previous education; to enable the Navy to turn out trained technicians at a faster rate (cutting the *cost* of training as well as the time required) without sacrificing subject matter.

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"Basic Electronics" consists of *five* volumes, as follows: *Vol. 1*—Introduction to Electronics, Diode Vacuum Tubes, Dry Metal Rectifiers, What a Power Supply Is, Filters, Voltage Regulators. *Vol. 2*—Introduction to Amplifiers, The Triode Tube, Tetrodes & Pentodes, Audio Voltage & Power Amplifiers. *Vol. 3*—Video Amplifiers, RF Amplifiers, Oscillators. *Vol. 4*—Transmitters, Transmission Lines & Antennas, CW Transmission & Amplitude Modulation. *Vol. 5*—Receiver Antennas, Detectors & Mixers, TRF Receivers, Superheterodyne Receivers.

•*"Basic Electricity,"* the first portion of this course, is available as a separate series of volumes.

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