Radio Receivers

DEPARTMENT OF THE AIR FORCE

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FOREWORD

This Manual is published to serve as a training text and guide for repairmen and technicians. It covers the field of radio receivers, in sufficient detail, to enable the student to understand the operation, repair, and adjustment of basic communications receivers. The information contained in the Manual also gives the student an adequate background for studying specific Air Force receivers.

There is a general discussion of the fundamentals of radio reception followed by explanations of tuned-radio-frequency and superheterodyne receivers. Descriptions of ordinary communications receivers, and very-high-frequency and ultra-high-frequency receivers are discussed in detail. The latest techniques in receiver design, such as the use of subminiature tubes and plug-in units, are incorporated in the next chapters, followed by explanations of frequency modulation and special purpose receivers. The Manual ends with discussions of performance tests and trouble-shooting techniques.

We invite you to send recommendations and or comments for the improvement of this Manual to the Director of Personnel Procurement and Training, Headquarters USAF, Washington 25, D. C.

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*This Manual supersedes Air Training Command Manual 52-9, December 1953.

**Commanders may requisition additional copies for issue to individuals possessing primary AFSC's in the 30- career fields whose duties require knowledge of receiver principles and circuits.

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introduction

A radio receiver is the other half of a communications network—the first half, so to speak, is the radio transmitter. The two halves are linked by radio waves that are radiated from the transmitting antenna and intercepted by the receiving antenna.

Like transmitters, receivers are usually classified and taught as a part of either airborne or ground equipment. In the airborne field, you will become either an Electronic Communications Equipment Repairman or an Electronic Navigation Equipment Repairman. In ground equipment maintenance, you will become either a Radio Repairman or a Radio Technician.

This manual is designed to serve as a basic text in both fields, since basic receiver theory applies equally well to both airborne and ground receivers.

Once you have mastered the operation of the basic receiver circuits presented in this manual, you will have little difficulty understanding the operation of any receiver that you will be required to maintain and service. Actually the only differences between receivers are frequency range, arrangement of stages, types of tubes used in the various stages, and the physical location of the various controls.

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CHAPTER 1

FUNDAMENTALS OF RADIO RECEPTION

The receiver has the job of completing the communications cycle started by the transmitter. It must intercept some of the RF (radio frequency) energy radiated by the transmitter — separate the intelligence from the RF — and reproduce the intelligence as energy in some meaningful form, such as sound, light, or mechanical energy. What a receiver is, and how it performs its communication job, is discussed in the following pages.

GENERAL REQUIREMENTS OF RECEIVERS

Frequency Coverage

The frequency coverage of a receiver is the range of RF which it can handle.

Consider frequency range from the point of view of a receiver. Radiated frequencies may range anywhere from 10 kc to above 30,000 mc. However, no practical receiver has yet been constructed that will handle this entire range successfully. This range constitutes too big a chunk of frequencies. Even talking about it clearly requires that it be divided up a bit, as shown in the frequency spectrum chart below.

Another kind of division is shown in the frequency allocation chart on page 2. This is based on the purpose for which the frequencies are used. A receiver might handle a complete band or only part of a band. At most, it will handle only two or three bands. Thus, the broadcast receiver has a frequency coverage of 550 kc to 1600 kc, a complete band, while some receivers used in Air Force communications have a frequency coverage of 225 mc to 399.9 mc, only part of a band.

Sensitivity

The *sensitivity* of a receiver is the measure of its ability to intercept weak signals and extract intelligence from them.

A receiver intercepts many radiations. These radiations may originate from transmitters operating anywhere within the radio frequency spectrum. They may originate from transmitters located anywhere in the world. They may also originate from transmitters of wide-

RADIO FREQUENCY SPECTRUM

Frequency Band		Designation	Abbreviation
KC	MC		
10-30		Very Low	VLF
30-300		Low	LF
300-3000		Medium	MF
3000-30000	3-30	High	HF
30000-300000	30-300	Very High	VHF
300000-3000000	300-3000	Ultra High	UHF
3000000-30000000	3000-30000	Super High	SHF

FREQUENCY ALLOCATION

Frequency Band	Wavelength (in meters)	Uses
400 mc	0.75	Experimental
400 mc 106 mc	2.83	Government, Aircraft, Police, Television
108 mc 88 mc	3.41	Frequency Modulation
88 mc 50 mc	6.82	Television
50 mc 1600 kc	187.5	Ship-to-Shore, Aircraft, Police, Foreign, Government, Point-to-point, Experimental
1600 kc 550 kc	545.45	Commercial broadcast
550 kc 20 kc	15,000	Government, Commercial, Maritime, Ship-to-Shore, Aircraft, Point-to-Point, High Power Government, Transoceanic

ly varying power output. Thus, the RF radiations intercepted by a receiver are of widely varying signal strength. A highly sensitive receiver does a good job of completing communication, whether signals are weak or strong.

Selectivity

Selectivity is the measure of a receiver's ability to intercept a desired signal and extract its intelligence to the exclusion of others. From the point of view of a receiver, the RF radiation that comes along is composed of a hodgepodge of various frequencies and various signal strengths. A highly selective receiver must be able to concentrate on one signal and reject all others, even those whose frequencies are close to the frequency of the desired signal.

Fidelity

While sensitivity and selectivity are the measure of radio receivers' ability to intercept a weak signal and to extract the intelligence from that signal to the exclusion of all others, *fidelity* is the measure of receivers' ability to reproduce the intelligence of the signal. A receiver designed primarily for entertainment requires a high degree of fidelity. It must reproduce faithfully the sounds and sights on which entertainment depends — for example, the music of a symphony orchestra, or the fine details of a television picture. The fidelity requirements for simple communication are not so high. Still, reproduction must be faithful enough to make the message intelligible. This means reproduction without undue distortion. Voice reproduction must be understandable. The reproduction of CW and MCW must be readable.

Physical Requirements

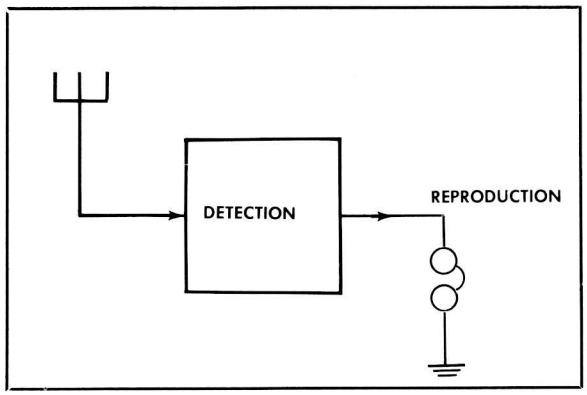
The components of a receiver are usually smaller and more compact than those of a transmitter. This is due chiefly to the fact that the power requirements of a receiver are less. As a result, power supply components are usually included right in the receiver unit. The actual size, weight, and cost of a receiver vary greatly, depending on the type and quality of operation the receiver is to perform. Communications receivers are usually of rugged construction. Receivers designed for mobile use are shock mounted.

BASIC REQUIREMENTS FOR RADIO RECEPTION

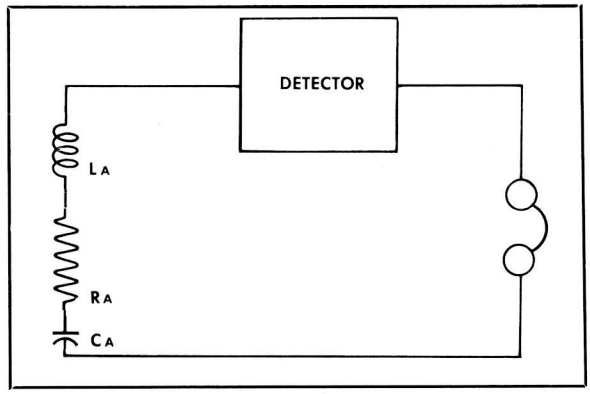
A simple practical receiver performs three essential operations — selection, detection, and reproduction. By selection, one RF signal is extracted from a multitude of RF signals. By detection, the intelligence is separated from the RF. By reproduction, the intelligence is turned into some type of energy which reproduces the intelligence. Each of these operations, with the exception of selection, is shown in the diagram, Simple Receiver.

Antenna

Actually an antenna in itself is a tuned circuit. It provides some selectivity. The Antenna Equivalent Circuit shows how an antenna can be a resonant circuit. La represents the distributed inductance of the antenna. Ca represents the distributed capacitance of the antenna. Ra represents the resistance of the antenna. The resonant frequency of an antenna



Simple Receiver



Antenna Equivalent Circuit

can be determined by the formula,

$$F\,(mc) = \frac{159}{\sqrt{LC}}$$

where L is in microhenries and C is in micro-microfarads. Substituting typical values (La = 50μh and Ca = 200 mmf) in the formula,

$$F\,(mc) = \frac{159}{\sqrt{(50)\ (200)}}$$
$$= 1.59\ mc$$

Note that frequency may be changed by varying L or C or both. When the antenna is a wire or a mast, L and C vary directly with antenna length. The longer the antenna, the lower the resonant frequency.

The resistance of the antenna will affect the sharpness of response of the tuned circuit. This is illustrated by the chart at the right, showing relative values of antenna current for varying values of resistance, with L and C remaining constant. Note that the smaller the resistance, the greater the response and the greater the selectivity of the antenna.

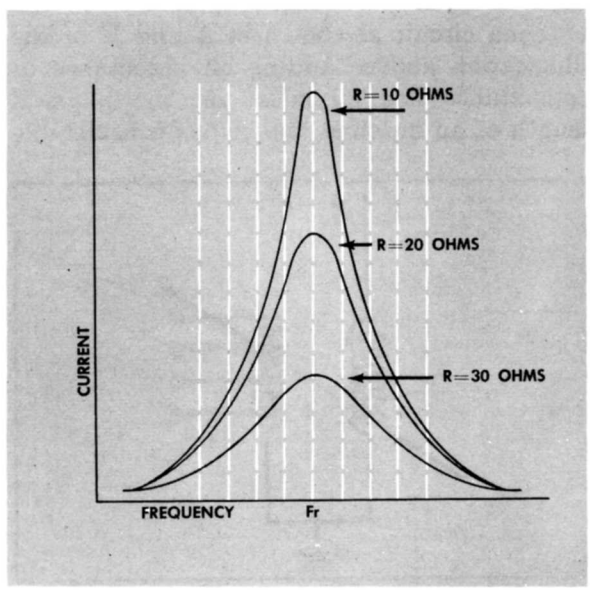
An antenna can be tuned in construction by making its length correspond to a quarter or half wavelength or a multiple of a quarter wavelength of a desired frequency. An antenna may also be provided with a means of varying its length for operational purposes.

At high frequencies, the selectivity provided by antenna tuning can be very critical and very important. At those frequencies antennas are short, and their resistance is kept as small as possible. A slightly detuned antenna may make a receiver inoperative.

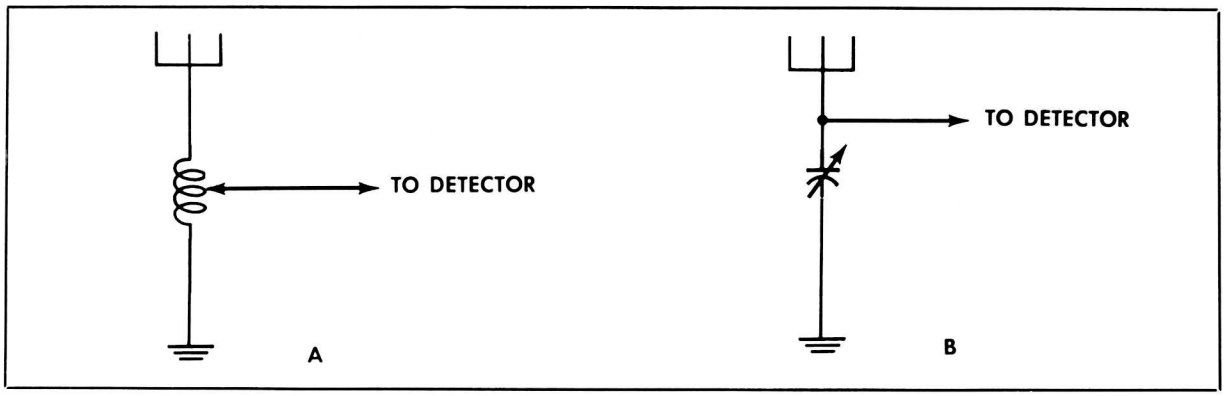
At low frequencies, antennas are long, and reduction of internal reistance is less practical. Here, antenna tuning is usually much less critical. The gain provided in a receiver by amplifier stages far surpasses the gain obtained by antenna tuning. Antenna length has little importance in broadcast receivers.

However, in simple receivers such as the one under consideration, there are no amplifier stages to provide signal amplification. Here, antenna length is important both for the sensitivity and the selectivity of the receiver.

The receiver antenna intercepts the signal by being in the path of the radiated RF. When



Effect of Resistance on Selectivity

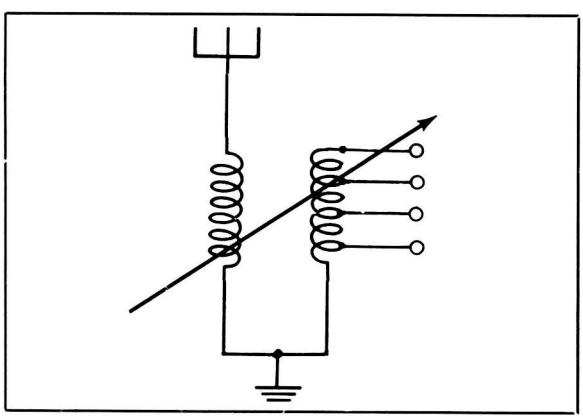


Variable Antenna Circuits

magnetic lines of force cut a conductor (the antenna) an emf is induced in the conductor. This induced voltage reproduces both the RF and any frequency or amplitude variations of the inducing voltage. The induced voltage is greatest when the antenna is tuned to the frequency of the inducing voltage. The induced voltage represents the intercepted energy needed for the first steps in the receiving process — interception and selection.

Tuning for Selectivity

As stated before, the resonant frequency of an antenna can be changed by varying antenna inductance, antenna capacitance, or both. This can be done by placing a variable inductance or a variable capacitance in the antenna circuit as shown in A and B of the illustration above. Adding an inductance or capacitance has no effect on the physical length of an antenna, but it has considerable effect on the electrical length. It is the electrical length which determines the resonant frequency of the antenna. When the added inductance or capacitance is variable, the electrical length of the antenna can be changed to achieve exact tuning for a desired signal.



Variometer Tuning

The variometer, shown below, provides another means of changing antenna resonance by varying inductance. The taps on the secondary can be used to increase the tuning range.

Finally, higher selectivity can be obtained by coupling the received signal into a separate tuned circuit, as shown at the right. With such a selector circuit added, selection may be regarded as a separate step, distinct from antenna tuning. The antenna may then be regarded as being primarily for interception.

The use of a transformer improves both sensitivity and selectivity. The transformer steps up the voltage and isolates the tuned circuit from the resistance of the antenna. For tuning, either the capacitor or the coil could be made variable.

Detection

The process of separating the intelligence from the modulated RF signal is called *detection*. In the simple receiver shown, detection is accomplished with the help of a crystal detector. Detection is the opposite of modulation, and is sometimes called demodulation. In the receiver, here, detection separates the amplitude modulation from the carrier. The process of separating frequency modulation

from the carrier is somewhat different. It is discussed in chapter 6.

All detectors are essentially rectifiers. The crystal detector, shown in the illustration, conducts effectively only in one direction. Thus, when it is connected across the selector tank circuit, the crystal acts as a rectifier. Its output is a pulsating direct current, pulsing at the RF rate but at the AF (modulation) amplitude.

This is the first step in detection. The process is completed by filtering the pulsating DC. In the simple circuit shown here, the coils in the headset form part of the filter. They offer little impedance to AF but high impedance to RF. A capacitor across the headset completes the filter. It offers little impedance to RF but high impedance to AF. Thus the capacitor bypasses the RF around the headset while the AF signal goes through the headset.

Reproduction

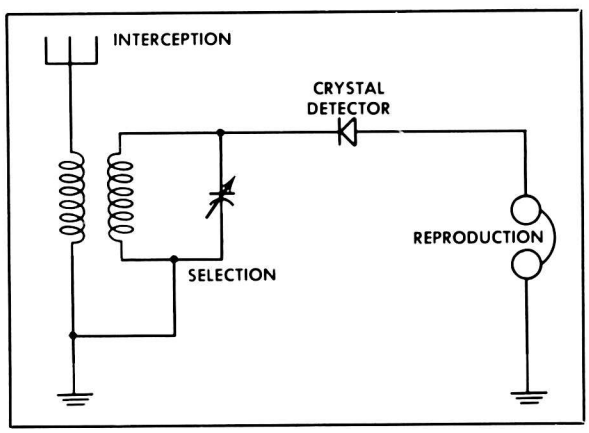
The current flowing through the coils of the headset varies at an audio rate. If the current can cause vibrations in the air at the same rate, the vibrations will constitute sound. For the reproduction of sound, the energy of the magnetic field which surrounds the coils is used. The strength of the magnetic field varies as the current varies. In turn, it causes a metal diaphragm to move back and forth at the same rate. This sets up vibrations in the air and produces corresponding sound waves.

OPERATIONAL ANALYSIS OF A SIMPLE RADIO RECEIVER

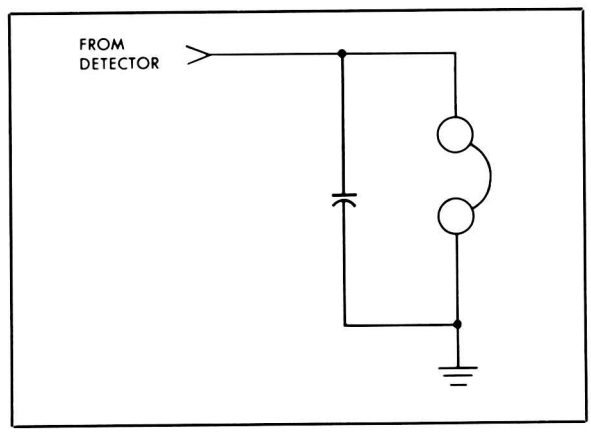
To analyze the simple radio receiver, study the schematic diagram shown on page 6. In this schematic, are gathered together all the steps just discussed. The points to be considered in the analysis are — What are the essential components? — What are the functions of each component? — What are the changes made in the radio waves as they pass through the receiver?

The illustration shows the conventional connections of the components. It also gives a graphic representation of the wave as it passes through the receiver. When the radio wave passes or cuts across the antenna, RF voltage is induced across the antenna, and consequently across the primary of T1. The current flow in the primary of T1 (L1) induces current flow in the secondary. The antenna transformer usually has an air core and a step-up ratio. This allows a small amount of signal gain.

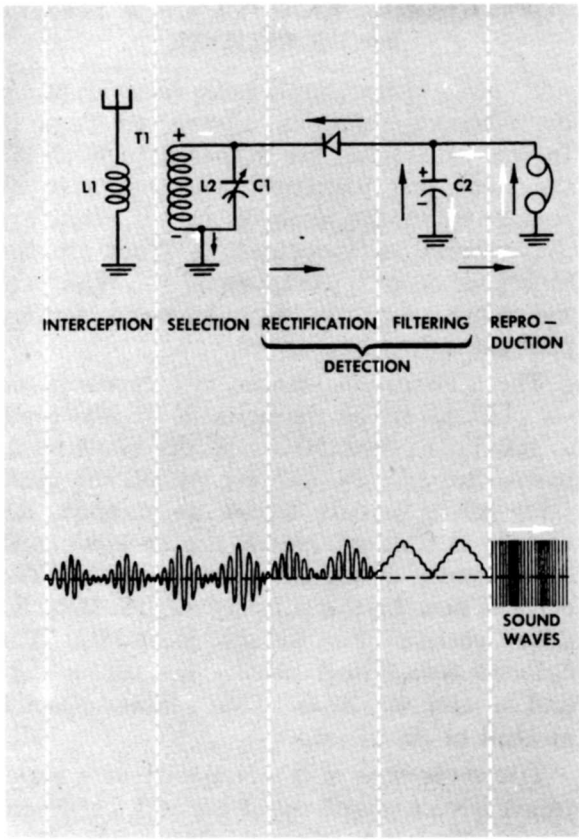
The secondary of T1 is a part of a series tuned circuit, made up of L2 and C1. Maximum circulating current flows through a series tuned circuit when the resonant frequency is applied. In addition, since maximum current flows at resonance, maximum reactive voltage is developed across each component. For maximum output from the headset, maximum voltage must be applied to the rectifier and the parallel combination of C2 and the headset. This results in a maximum



Simple Tunable Receiver



Detector Output Filtering



Simple Tunable Receiver Analysis

amount of current through the headset, and since the headset is a current device, there will be a maximum audio output. Actually, the tuned circuit (L2-C1) appears as a parallel circuit to the rectifier and the parallel-connected capacitor and headset, and one characteristic of a parallel circuit at resonance is that maximum voltage is developed across it.

The polarity at the extremities of the transformer changes with changes in the incoming signal. When the top of the tank circuit is positive, current flows through the circuit as indicated by the solid black arrows. When the top of the tank is negative, the crystal does not conduct, and the capacitor discharges as shown by the white arrows. Thus, the waveform is rectified, and the signal is changed to a pulsating DC. Note that the pulses still bear the imprint of the modulation after filtering, but this does not affect the intelligence.

Part of the filter is C2, a small capacitor, usually about 250 mmf. It filters the RF component of the pulsating DC. The capacitor charges during the half cycles that the crystal conducts and discharges partially when the crystal is not conducting. In its charging and discharging, it absorbs almost all the swing of the RF pulses and follows the pattern of the modulation envelope, as the waveform shows.

A headset changes current pulses to sound waves by application of the electromagnetic principle. Each receiver contains two coils, a U-shaped permanent magnet which serves as the core of the coils, and a flexible diaphragm. As current travels through the coils, a changing magnetic field is developed. The strength of this field determines how much the diaphragm is attracted. When the field strength decreases, the diaphragm pulls away. The mechanical vibrations of the diaphragm cause the sound which is the intelligence.

LIMITATIONS OF A SIMPLE RADIO RECEIVER

The simple receiver just described has its limitations. There is only one tuned circuit to improve the selectivity of the antenna. The slight step-up of the antenna transformer does little to improve the sensitivity of the receiver. This limits the effectiveness of the receiver to strong signals from nearby stations. On other signals, the output of the detector is not strong enough to develop magnetic fields around the headset coils to produce diaphragm vibrations.

An effective receiver needs more than the basic requirements. It must include circuits and stages to improve performance in terms of selectivity and sensitivity. It needs additional tuned circuits for selectivity. It needs RF amplifier stages to improve sensitivity. It needs AF amplifiers to increase audio output so that a speaker can be used to reproduce the intelligence. Such a receiver is shown in the block diagram of a tuned radio frequency receiver (TRF) on page 7. Typical stages of a TRF are discussed in chapter 2.

CHAPTER 2

TRF RECEIVER

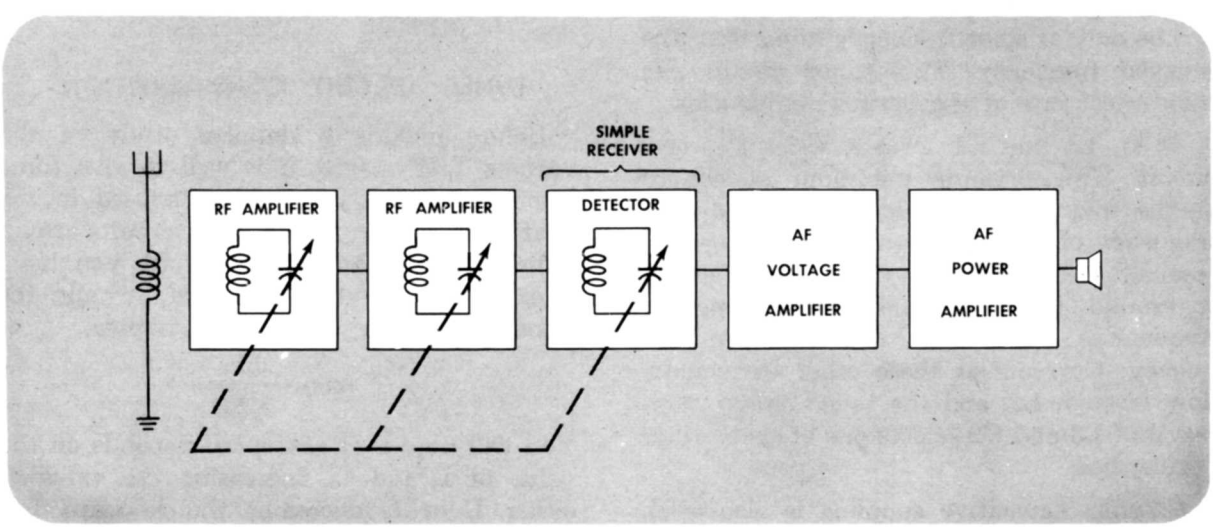
The simple receiver studied in the previous chapter is classified as a single stage receiver, since neither the antenna nor the headset can be called a stage. The TRF receiver, on the other hand, is a multistage receiver. As shown in the block diagram, the detector of the TRF is the equivalent of the single stage of the simple receiver. The TRF is the more useful receiver because it has two RF amplifier stages, an AF (audio frequency) voltage amplifier stage, and an AF power amplifier stage.

In performance, the TRF far surpasses the simple receiver. The use of electron tubes makes the big difference. With the help of tubes, the number of steps which the receiver performs is expanded. The steps now are interception, selection, RF amplification, detection, AF amplification, and reproduction. Amplification, both of RF and AF, is the great advantage gained by using tubes.

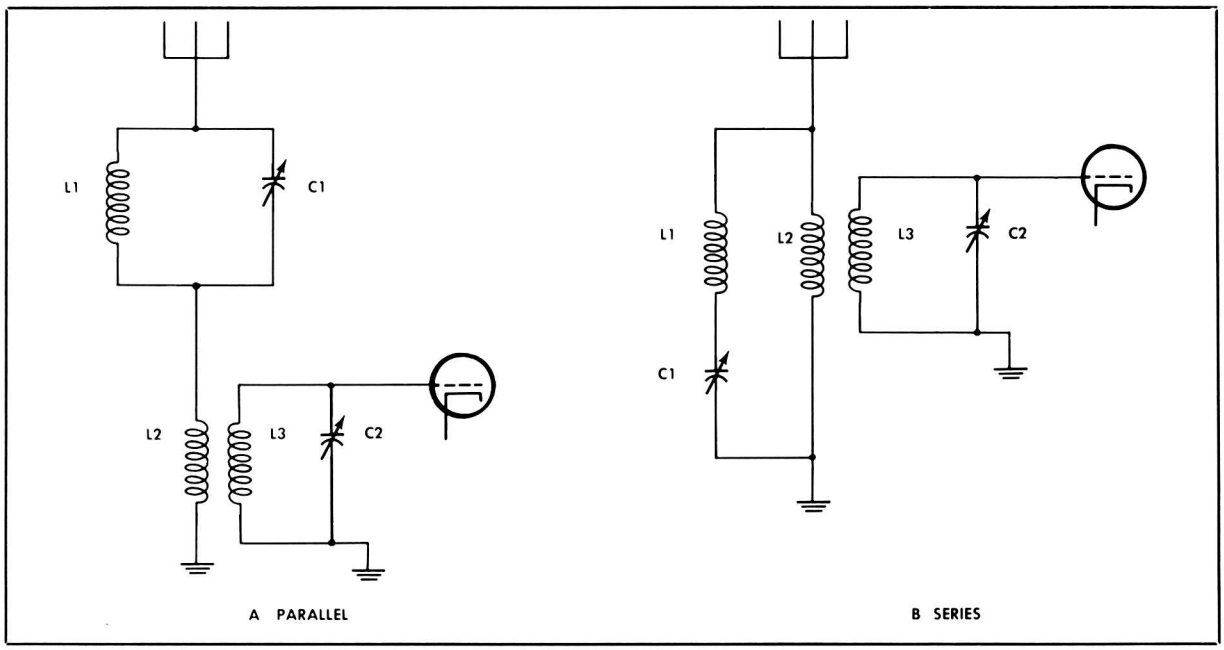
ANTENNA CIRCUITS

The antenna coupling circuits used in connection with the TRF receiver are similar to those you studied in connection with the simple receiver. Usually, though, they are more elaborate. The RF energy which the antenna intercepts is applied to the grid of the first RF amplifier stage. In most cases, transformer coupling is used. This method offers the advantages of signal gain through the step-up action of the transformer.

Sometimes wavetraps are used with transformer coupling. A wavetrap is a device for preventing undesired signals from nearby transmitters or from extra powerful transmitters from drowning out desired signals



TRF Receiver



Wavetraps in Antenna Circuits

from weaker or more distant transmitters. As shown above, these wavetraps may be parallel or series resonant circuits. Their use increases selectivity.

At A in the illustration, notice that L1 and C1 form a tunable parallel resonant circuit which presents maximum impedance to the frequency to which it is tuned—the frequency of the undesired signal. Thus, it rejects the unwanted signal. The current through L2 and the voltage across the tuned circuit, L3-C2, can be only at some frequency other than the rejected frequency. This tuned circuit can then select one of the desired frequencies.

At B, L1 and C1 form a series resonant circuit. This presents minimum impedance to the frequency to which it is tuned—the frequency of the undesired signal. This series resonant circuit bypasses the undesired signal to ground, but presents high impedance to frequencies other than the undesired frequency. Currents at these other frequencies flow through L2, and the tuned circuit composed of L3 and C2 selects one of these other frequencies.

Antenna capacitive coupling is also used, especially with a variable coupling capacitor. In the capacitive coupling illustration on page 9, the capacitor couples the antenna to the tuned circuit. This variable capacitor makes it possible to match antenna impedance to the impedance of the grid circuit to obtain maximum signal input.

In many modern broadcast receivers, a loop antenna is used. The loop circuit is a tuned circuit, for the inductance of the loop combines with the capacitance of the variable capacitor to form a tuned circuit.

TUNED CIRCUIT CONSIDERATIONS

Before making a detailed study of the various TRF stages, it is well to give some attention to the tuned circuits used in the TRF. Essentially, these tuned circuits are no different from the tuned circuits you have already studied. Recalling the formula for resonant frequency in the last chapter,

$$F\ (mc) = \frac{159}{\sqrt{LC}}$$

You will note that resonance depends on the value of L and C. Increasing the value of either L or C decreases the resonant frequency. Decreasing the value of either L or

C increases the resonant frequency. Changing the value of both may change the resonant frequency—or it may not. It depends on whether the *product* of L and C is changed. If L and C are changed so that their product remains the same, the frequency will remain the same. Thus, for the same frequency, L may be high and C low, or L may be low and C high.

You remember, though, that the L/C ratio is important to the Q of a tuned circuit. Since $Q=\frac{Z}{R}$, the ratio of impedance to resistance affects the Q.

If the resistance remains the same, raising L and lowering C gives a higher ratio of impedance to resistance and a higher Q. Lowering L and raising C gives a lower ratio of impedance to resistance and a lower Q. A high Q has the advantage of providing sharp tuning and high gain, thus improving selectivity and sensitivity. If the Q is too high, though, tuning is so sharp that it eliminates part of the sidebands and introduces distortion.

This all means that the makeup of the tuned circuit, in terms of L, C, and R, is of considerable importance.

The tuned circuits in the TRF are tunable, usually by means of variable capacitors. The capacitors are ganged so that they may be varied simultaneously by one control. The fact that the capacitors can be varied permits exact tuning for a desired frequency. The fact that the capacitors can be tuned over a range of frequencies provides the receiver with its frequency coverage.

Another way of tuning is by use of variable inductances. They can be ganged in the same way as the variable capacitors.

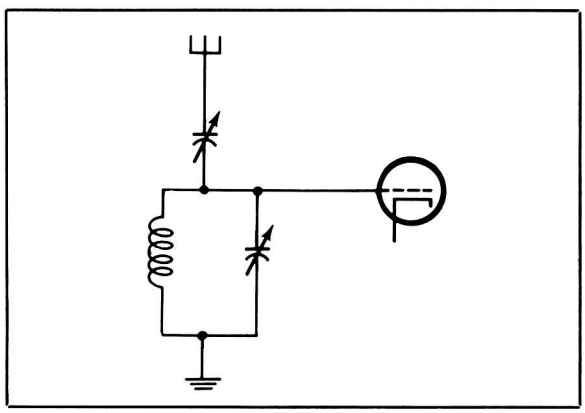
The tuned circuits used for the TRF receiver are essentially the same as the tuned circuits you have studied. Their individual parts, though, are modified to adapt them to the TRF.

RF Coils

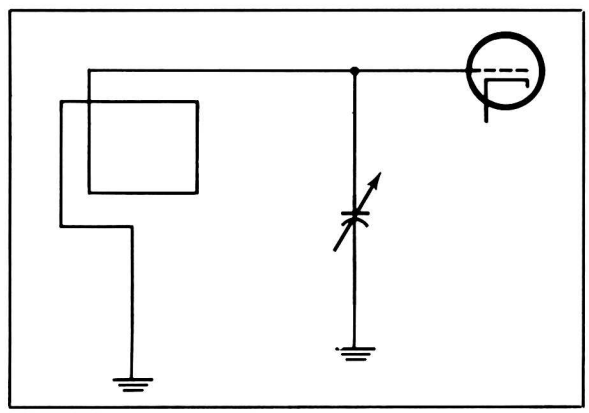
An RF coil, such as the one shown on page 10, is designed for minimum loss. It uses a multistrand wire called "Litz" wire. This wire is made by weaving together a large number of fine insulated wires. Its AC resistance is low, and therefore the Q of the coil is high.

Very light cardboard is used for the coil form. The form is varnished both before and after winding, to prevent absorption of moisture. The physical size of coil and form is kept as small as possible. The width of the mass of wound wire is usually about equal to its depth, as shown. The form contains both primary and secondary windings. The primary may be wound near the secondary or directly over the secondary.

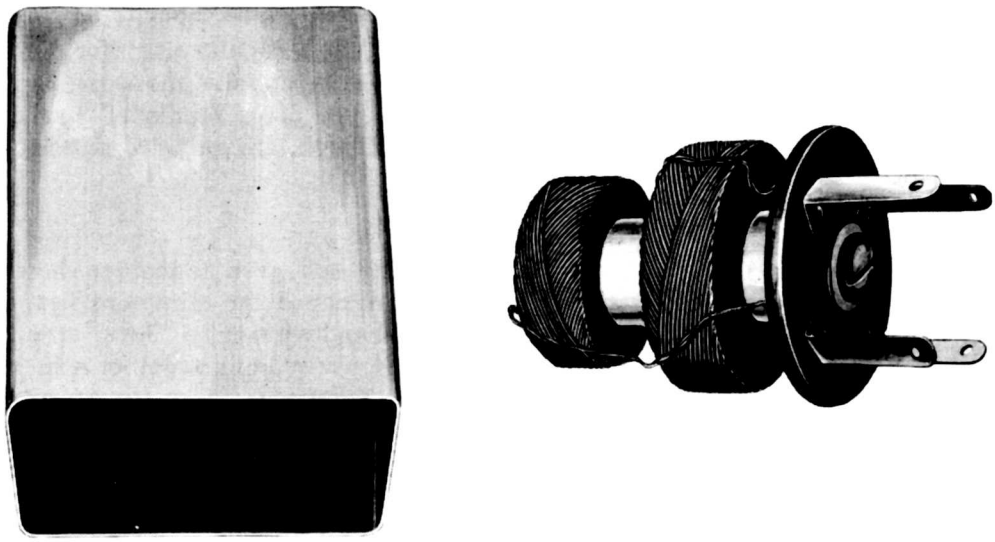
A shield covers the coil and shields it from electric and/or magnetic fields which might induce unwanted voltages. The shield must be a good conductor to shield against electric fields. Aluminum is usually used because it is light, cheap, and a good conductor. Shielding of coils results in some reduction of efficiency, due to eddy currents induced in the shield by the magnetic field of the coil. These eddy currents produce a magnetic field of their own



Capacitive Coupling From Antenna



Loop Antenna



Typical RF Coil with Shield

which opposes the field of the coil. The loss of efficiency due to eddy currents is limited to approximately 15% by using a shield with a diameter twice the diameter of the coil. The shield should be well grounded.

RF coils usually have air cores. A few designed for low and medium frequencies have powdered iron cores. The cores are sometimes adjustable. As the iron core moves into the coil, inductance increases and the frequency of the tuned circuit decreases. A brass core can be used for the opposite effect. As the brass core is moved into the coil, inductance decreases and frequency increases. In either case, the circuit can be tuned by moving the core. This is called *permeability tuning.*

Variable Capacitors

Variable capacitors for RF tuned circuits are somewhat bulky. The plates, both rotor and stator, are usually aluminum, but better receivers sometimes use silver-plated brass capacitors for improved RF conductivity.

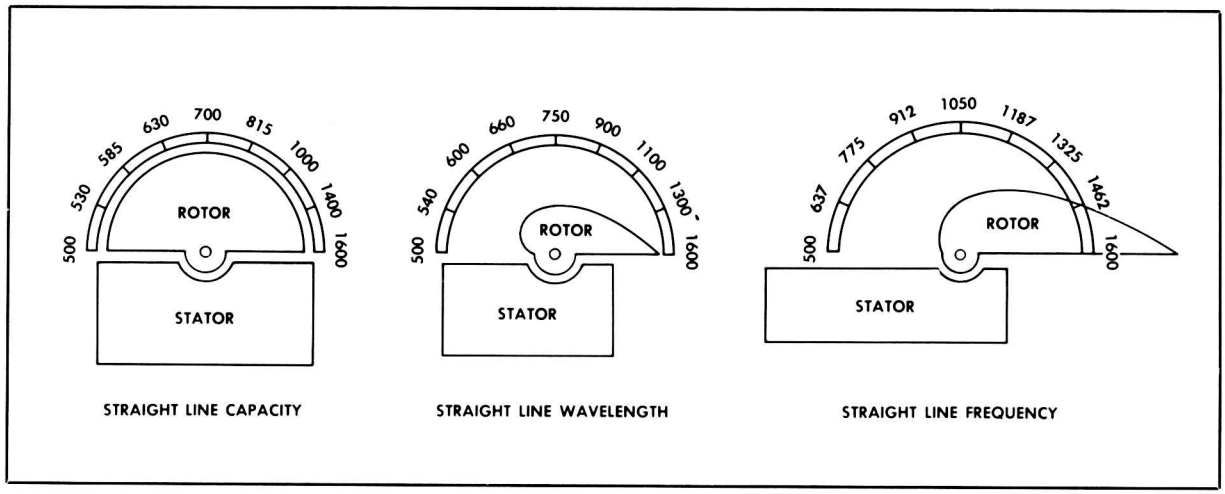
The calibration pattern of a variable capacitor depends on the shape of its rotor, as shown on page 11. For calibration, capacitors fall into three classifications — straight line capacity, straight line wavelength, and straight line frequency.

With the straight line capacity type, capacity increases directly with the amount of rotation. Since frequency does not increase directly with the decrease in capacitance, calibration puts the upper half of a frequency band in about one-eighth of the dial rotation.

With the straight line wavelength type, wavelength increases directly with the amount of rotation. In this type, the upper half of the band appears on one-third of the dial rotation.

With the straight line frequency type, frequency varies directly with the amount of rotation. This permits linear dial calibration. With this type variable capacitor, a tuned circuit has the same sharpness of tuning over its whole band.

The TRF can use any number of RF amplifier stages, but usually it has no more than three. In each TRF there is one more tuned circuit than there are RF amplifier stages. The extra RF tuned circuit, of course, is in the detector stage. When these tuned circuits are controlled by variable capacitors, it is advantageous to have the capacitors tunable by a single control. This can be done by ganging the capacitors, as shown at the right. This means that the capacitors are mounted in line with their rotors attached to a common shaft. Grounded partitions act as shields. They

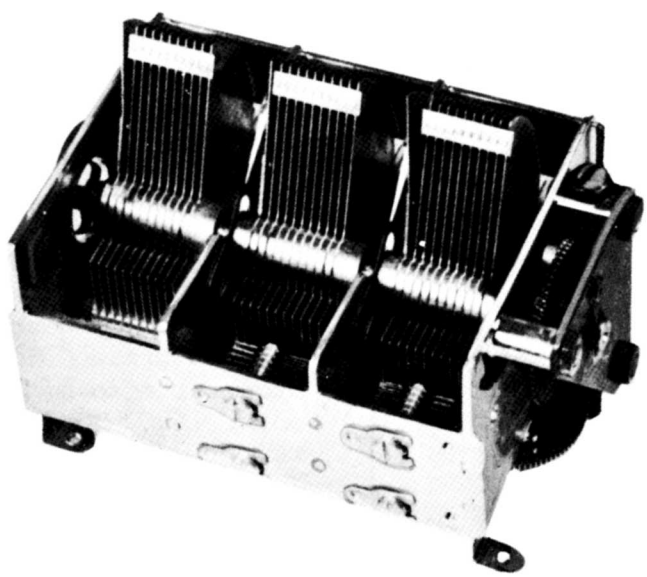


Variable Capacitors

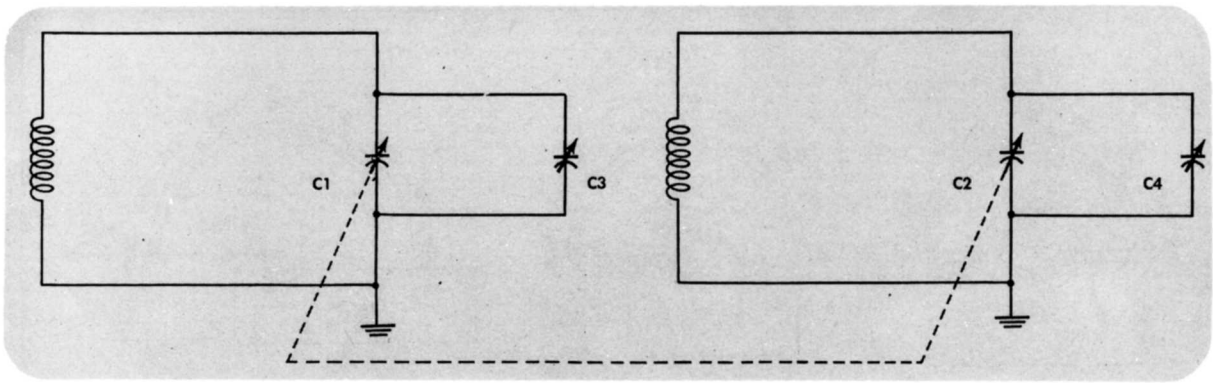
provide electrical separation between the stator sections of the ganged capacitors.

It is almost impossible to manufacture a set of ganged capacitors of exactly the same capacitance. Similarly, it is difficult to keep each one of a set of ganged capacitors at the same capacitance. Even a slight bending of a single plate of a capacitor will change its value. Still, it is necessary for capacitors to "track"—that is, to maintain equal capacitances at each setting of the rotor. To compensate for differences, therefore, each of the ganged capacitors is provided with a small additional capacitor. It is screwdriver adjustable, and is called a *trimmer*. It is connected in parallel with the main tuning capacitor section. (See illustration on top of page 12.)

To make further adjustment possible, the outer rotor plates on each section are usually slotted, as shown in the illustration of a slotted plate on page 12. The slots make it easy to bend part of a plate and slightly change the capacitance of one section.



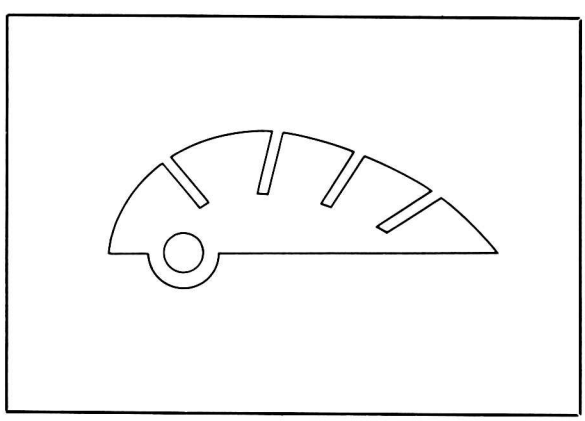
Ganged Tuning Capacitor



Trimmers Used for Tracking

Band Switching

TRF receivers frequently operate over several bands. Switching from one band to another requires switching from one set of tuned circuits to another. Usually the new set of circuits is formed partially out of the old set by substituting different components for either L or C. Since variable capacitors are bulky, it is practical to use as few as possible. Generally, therefore, it is the coils that are changed to form the tuned circuits for the new band. This can be done by use of a series of plug-in type coils, or by use of a switching arrangement. Where a switching arrangement is used, a single coil form may include windings for one, two, or three bands. A rotary wafer switch, such as the one on page 13, is used to switch in the desired set of coils. The switch connects the proper coils to the capacitor section, and, at the same time, grounds all unused coils. As you see, the switch shown has three wafers. When the shaft is turned, metal contacts fastened to the inner portion move from one contact point to another along the outside portion. Each setting of the switch makes a combination of connections for one band.



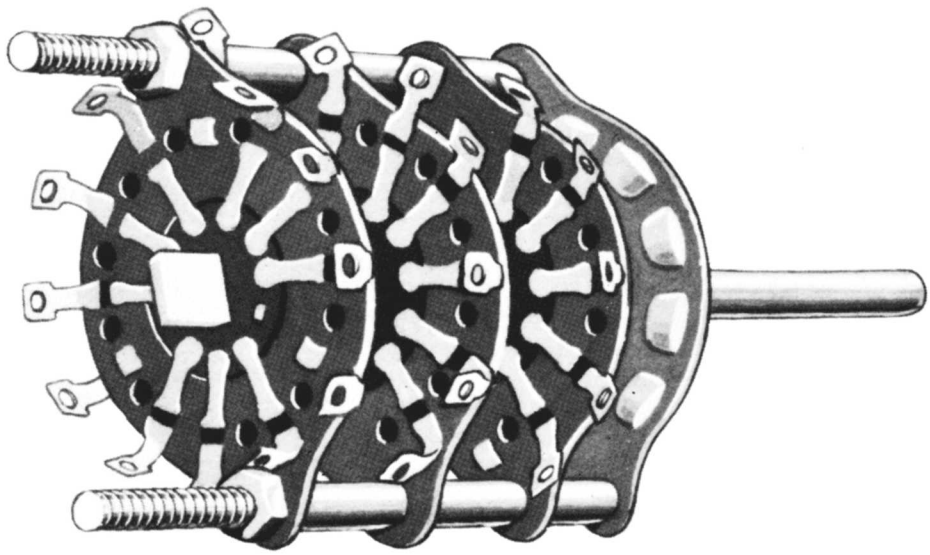
Slotted Rotor Plate

You can see the electrical equivalent of two switching arrangements at the right. A shows an arrangement for placing different coils into the circuit with one variable capacitor. B shows an arrangement for switching different capacitors in series with one variable capacitor.

Bandspreading

In a multiband receiver, each band has a different bandwidth. Still it is desirable for each band to occupy the entire range of the tuning dial. For example, the broadcast band extends from 550 kc to 1600 kc, a frequency ratio of about 3 to 1 and a frequency coverage across 1050 kc of tuning range. When a dial for this band rotates 180°, it covers about 5 kc for each degree of rotation. Shifting to a new band may bring about a situation where the tuning range occupies only a portion of the dial range and where many kilocycles of frequency are covered for each degree of rotation. This concentration of frequencies in each degree of rotation makes dial reading difficult. To correct this, the band is spread until it more closely approximates the full dial rotation.

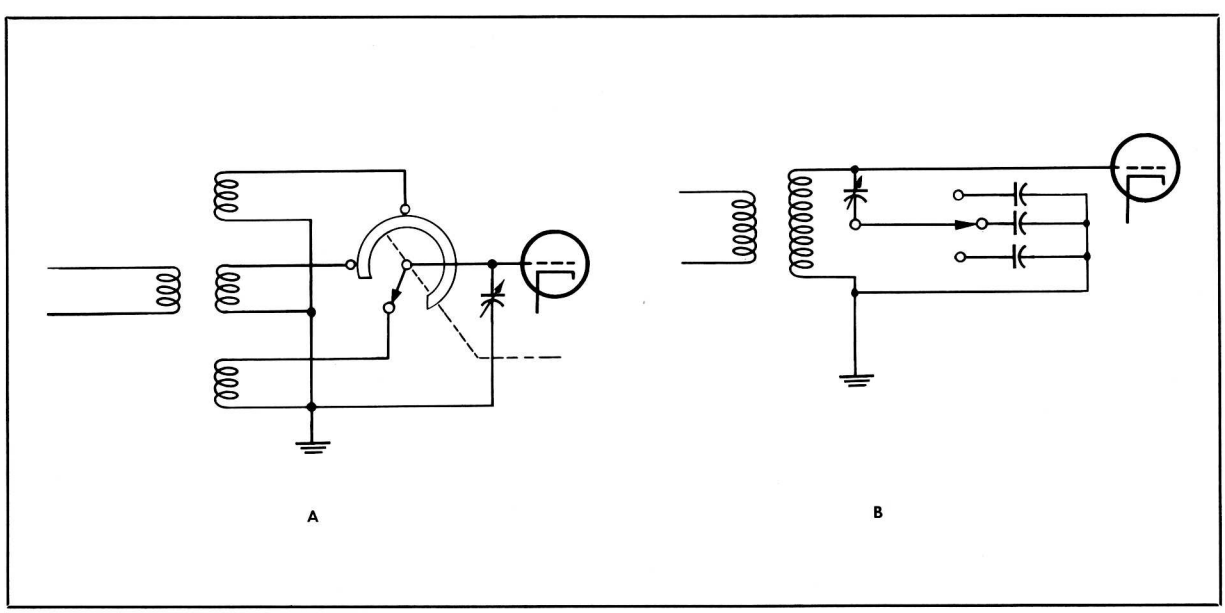
Bandspreading can be accomplished by mechanical means. The mechanical arrange-



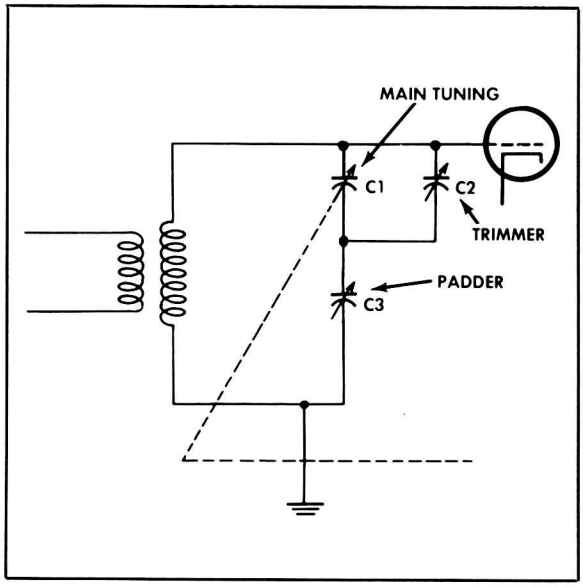
Rotary Switch for Band Switching

ment uses gears which coordinate the rotation of the dial with the rotation of the variable capacitor. But this method is expensive and is used only with precision equipment.

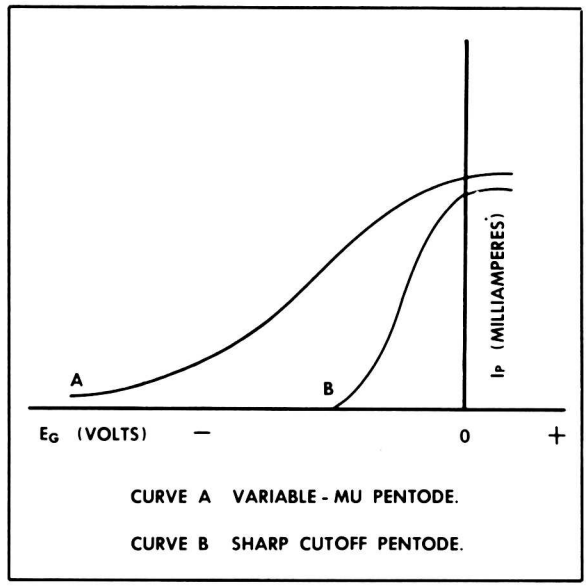
Bandspreading can also be accomplished electrically by using trimmer and padder capacitors, as shown on page 14. These capacitors can affect the minimum to maximum capacitance of a circuit. To increase the bandspread, a variable trimmer, C2, is connected in parallel with the main tuning capacitor. To decrease the maximum capacitance without changing the minimum value appreciably, a padder or series capacitor, C3, is used.



Band Change Circuits



Bandspread Circuit



Pentode Response Curves

THE TUNED CIRCUIT AT VHF AND UHF

The use of the ordinary tuned circuit for VHF and UHF is impractical. At such frequencies, both L and C become so small that the connecting leads of the coil may have more inductance than the coil itself, and the distributed capacitance of the coil may exceed the capacitance of the variable capacitor. Under such conditions, successful tuning is impractical. Thus, it is common practice to use resonant sections of transmission lines for tuning frequencies above 100 mc. A quarter wavelength resonant line has capacitance and inductance. It is a tuned circuit. This type of tuned circuit will be discussed further in the chapter on VHF and UHF receivers.

AMPLIFIER TUBE CONSIDERATIONS

Triodes, tetrodes, or pentodes may be used in TRF receivers. The use of pentodes is most common, for pentodes provide much greater amplification, with little danger of oscillation.

Remote cutoff (variable-mu) or sharp cutoff tubes may be used. Notice the difference in response of these two types as shown above.

The remote cutoff tube is used in circuits with adjustable bias for controlling the gain of a stage without impairing linearity of amplification. With a remote cutoff tube, signal strength may vary considerably without danger of distortion. Some useful remote cutoff tubes are the 6K7, 6SK7, 6SG7, 6BE6, 6AV6, and 6AB7. These tubes cut off at bias voltages of −15 to −45 volts. Class A operation is possible up to the cutoff point.

The sharp cutoff tubes, such as the 6SJ7, 6SH7, or 7V7, have higher transconductances than remote cutoff tubes. They can be used where signal strength is low and high gain is desired, as in the first amplifier stage. They can also be used where signal strength is relatively constant.

TRF AMPLIFIER TUBES AT VHF AND UHF

In the VHF and UHF ranges, specially constructed tubes are used. Input impedance must be high, or gain is limited and tuning is broadened. At 60 mc, a normal RF amplifier tube may have an input impedance of 2500 ohms, while a specially constructed tube may have an input impedance of 54,000 ohms.

The specially constructed tube is very small physically, with closely spaced electrodes and no base. To reduce interelectrode capacitance and lead inductance, tube connections are brought out to short wire pins sealed in the glass envelope. The close electrode spacing keeps transit time down to the point necessary for UHF operation. The reduced electrode area

means reduced interelectrode capacitance. These tubes can be used for frequencies as high as 600 mc. Some examples are acorn tubes 954 and 956.

TRF AMPLIFIER CIRCUIT

Examine the typical RF amplifier stage shown below. The tube is a remote cutoff pentode. The antenna is transformer coupled through a tuned circuit to the grid of the pentode. Cathode bias is provided. The variable resistor in the cathode circuit permits adjustment of the operating bias. The output of the stage is transformer coupled to the next stage.

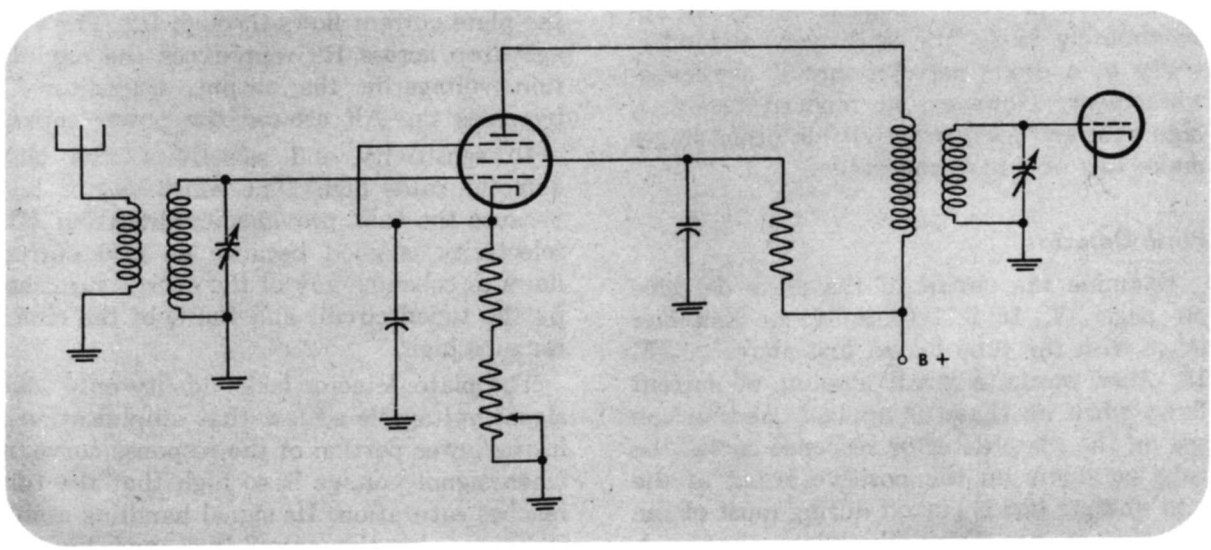
The RF signal is passed through several such TRF amplifier stages before it is applied to the detector stage. As the signal goes through the three or four tuned circuits, selectivity is greatly improved because each tuned circuit passes the resonant frequency and attenuates the other frequencies. The sensitivity is greatly increased because each tube amplifies the signal.

DETECTOR CIRCUITS

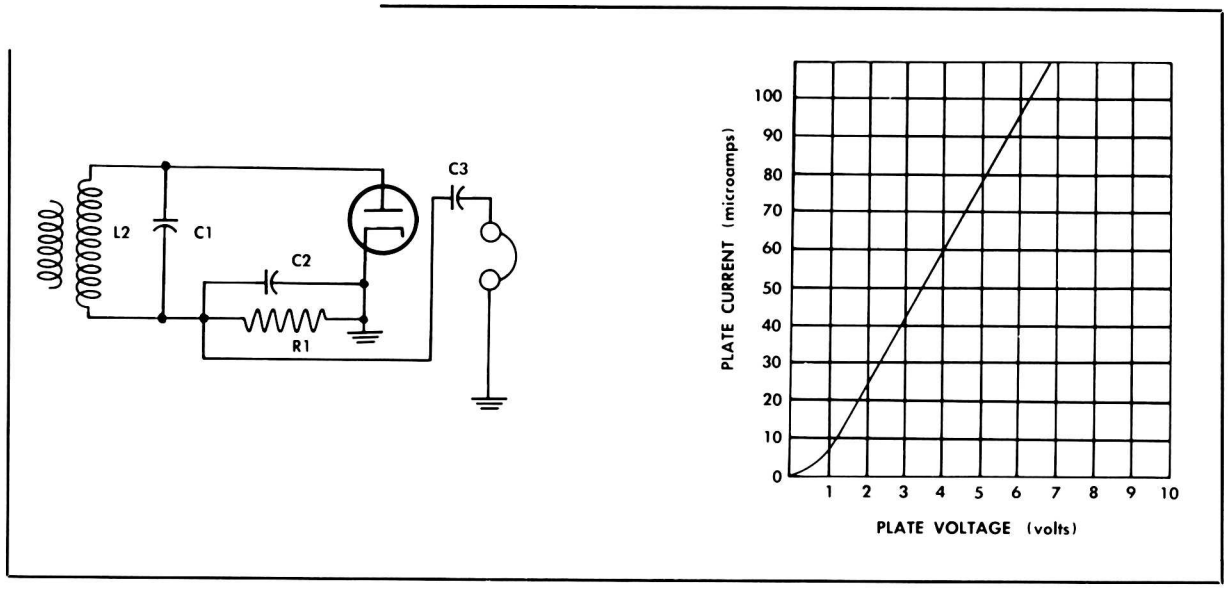
Detection involves rectification and filtering, as explained before in the simple receiver analysis. In most modern receivers, the detector uses an electron tube for rectification. Six types of tube circuits are used: diode detector, plate detector, infinite impedance detector, grid leak detector, regenerative detector, and superregenerative detector. The diode detector is the most common.

Diode Detector

Examine the diode detector circuit shown on page 16. Note that no DC plate voltage is used. The RF voltage across the tuned circuit, L2-C1, is applied across the diode. Since current flows only when the plate is positive in respect to the cathode, the RF voltage is rectified. When the plate is positive, the diode conducts and the capacitor in the filter circuit, C2, charges. When the plate is negative, no current flows in the tube, and C2 partially discharges through R1, the load resistor. However, the value of R1 is so high that the capacitor discharges only slightly before the tube again conducts. This means that the charge on the capacitor follows the positive peaks of the RF voltage. Since the shape of the modulation envelope can be traced in the variations of the RF peaks, the charge on the capacitor reproduces the AF modulation voltages.



RF Amplifier



Diode Detector and Response Curve

As you can see from the graph in B, the voltage-current response of a diode is linear except when plate voltage is very low. This means that with any reasonable signal strength, diode response is always linear, up to the point of plate saturation. Fidelity is high, even for signals that approach 100% modulation. The signal handling ability of a diode is very high. It can handle signals of almost any amplitude. The efficiency of a diode, in a properly designed circuit, is approximately 90%. The sensitivity and selectivity of a diode detector circuit are somewhat poor. However, in modern receivers, high gain and good selectivity in other stages make this of minor importance.

Plate Detector

Examine the circuit of the plate detector on page 17. It is essentially an amplifier stage with the tube biased just above cutoff. In other words, a small amount of current flows when no signal is applied. As you can see on the plate detector response curve, the tube conducts on the positive swing of the grid voltage but is cut off during most of the negative swing. Thus, the plate current is DC, pulsating at an RF rate. The amplitude of these pulses follows the amplitude of the modulation (AF) voltage.

Cathode bias for the tube is provided by R1 and C2. C3 and L3 form a filter circuit. C3 presents high impedance to the AF component of the plate current, and low impedance to the RF. L3 presents low impedance to AF and high impedance to RF. Thus, the filter bypasses RF around the load resistor but passes AF to the output circuit.

R2 is the load resistor. The AF portion of the plate current flows through R2. The voltage drop across R2 reproduces the modulation voltage in the output. Capacitor C4 bypasses the AF around the power supply.

In sensitivity and selectivity, the plate detector rates high. The sensitivity is high because the tube provides amplification. The selectivity is good because no grid current flows to consume any of the energy furnished by the tuned circuit and the Q of the circuit remains high.

The plate detector lacks fidelity only when signal voltage is so low that amplification is in the lower portion of the response curve, or when signal voltage is so high that the tube reaches saturation. Its signal handling ability is limited by the cutoff bias, and by tube saturation. For most tubes, though, the signal handling ability may be considered good.

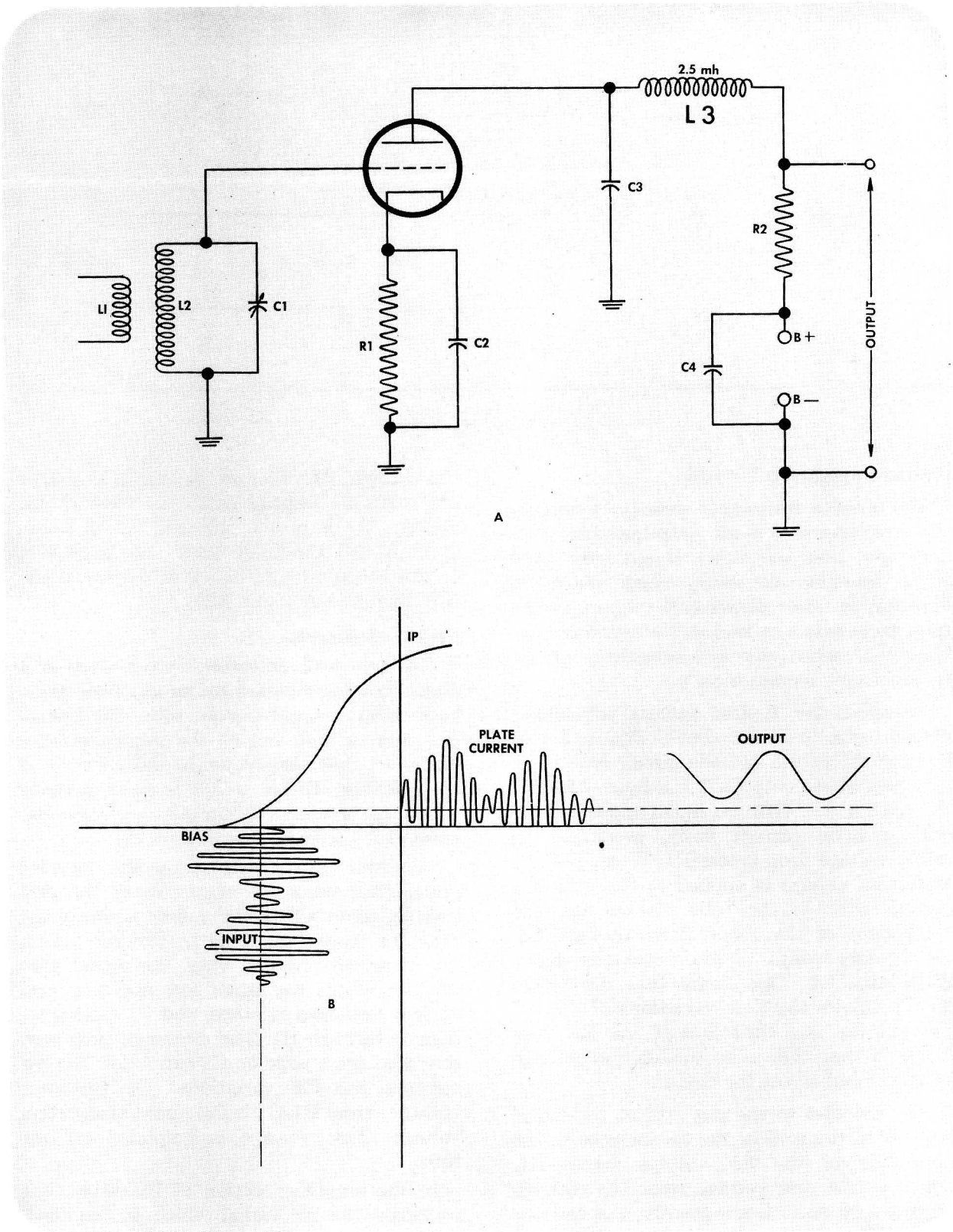
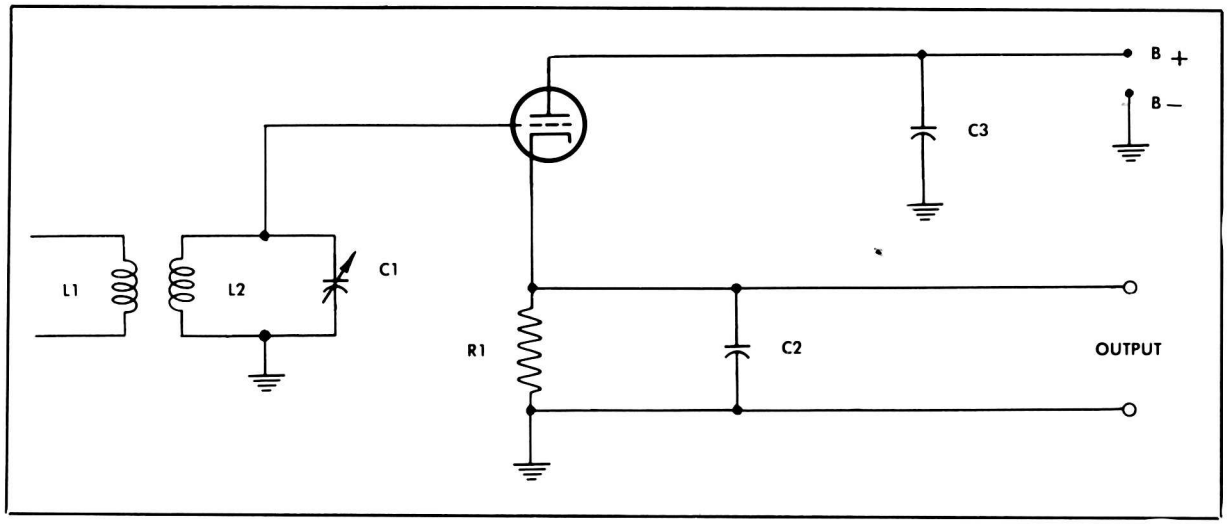


Plate Detector and Response Curve



Infinite Impedance Detector

Infinite Impedance Detector

The infinite impedance detector combines the advantages of diode detection and plate detection. Like the diode, it has very good signal handling capability. Like the plate detector, it never draws grid current so the tube never acts as a load on the tuned circuit. Thus, the sensitivity and selectivity of the tuned circuit remain high.

Examine the typical infinite impedance detector circuit shown above. The action of R1 and C2 in the cathode circuit biases the tube just above cutoff. C2 is a bypass for RF but not for AF. With no signal applied to the grid, a little current flows, producing an initial voltage drop across R1. When positive excitation voltage is applied to the grid, the current through the tube due to the RF component of the signal flows through C2. On negative swings, C2 discharges only slightly through R1. This means that the charge on C2 follows the slow variations of the AF but not the fast variations of the RF. The result is that the audio modulation voltage is reproduced across the circuit.

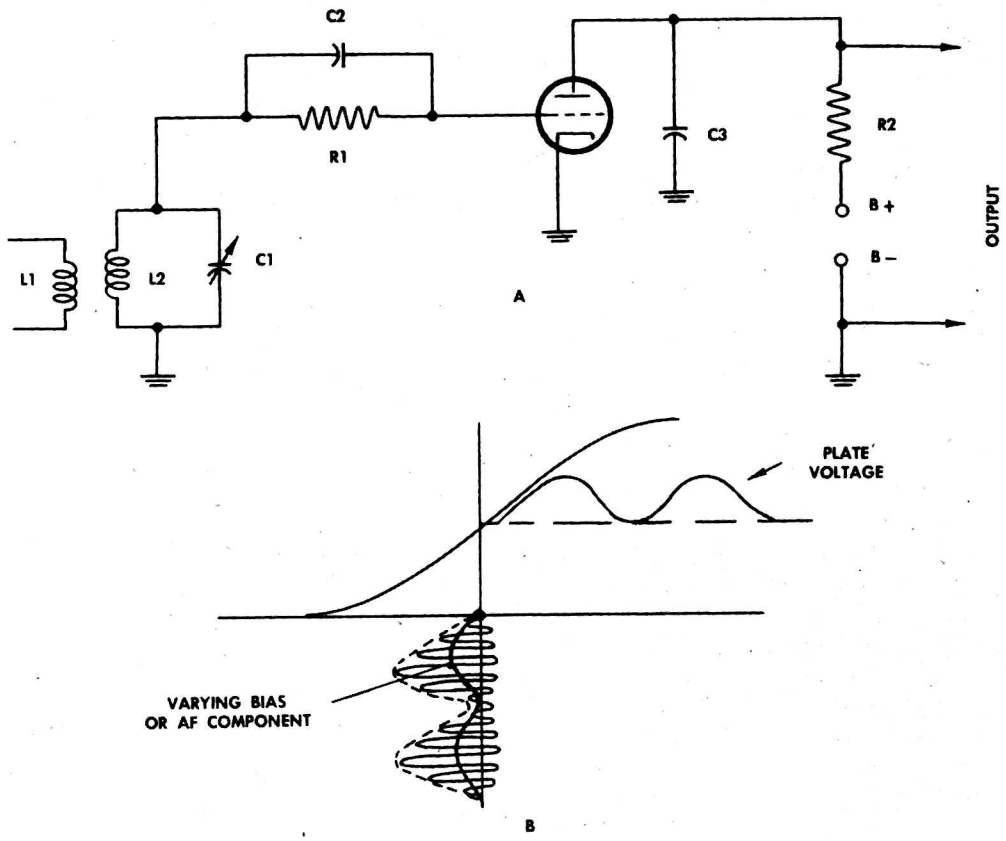
Any increase in the strength of the signal applied to the grid causes an increase in the amplitude of the AF voltage across R1. Thus, as the grid voltage rises, the cathode voltage also rises. Consequently, the cathode voltage follows the grid voltage, and the grid can never become positive with respect to the cathode. In other words, the grid always offers infinite impedance to the flow of grid current. As a result, the grid never draws current, and the tube never acts as a load on the tuned circuit. The Q of the tuned circuit therefore remains high.

Grid Leak Detector

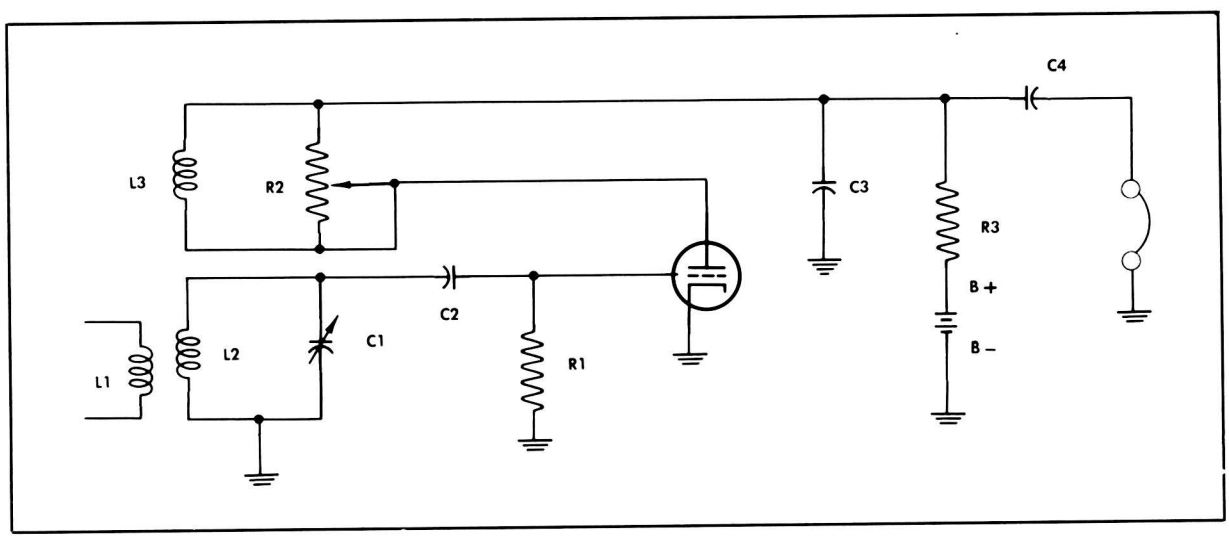
The grid leak detector is equivalent to a diode detector followed by an amplifier, with both circuits centered in one tube. The control grid and cathode act as the electrodes of a diode, yet they also act as the input circuit of an amplifier. Either a triode or a pentode tube may be used. The grid leak circuit diagram at A illustrates use of a triode.

The grid draws current on the positive grid signal. Since the reactance of the grid leak capacitor C2 to RF pulses is much less than the resistance of R1 to the RF pulses, the capacitor charges when the signal goes positive. When the signal goes negative, grid current decreases or stops, and C2 discharges slightly through R1. The discharge time is so slow that the charge on C2 can follow the AF but not the RF variations. The resultant voltage across R1-C2 is the audio modulation voltage. This voltage is amplified by the tube.

In the amplifier section of the tube, it is primarily the AF signal which is amplified. C3 bypasses the RF currents. The output is taken across the plate load resistor R2. When



Grid Leak Detector and Response Curves



Regenerative Detector

a triode is used, an audio output transformer may serve as the plate load. When a pentode is used, the high plate resistance of the tube makes it necessary to use a resistor as the plate load.

Usually the grid leak circuit is designed to operate with strong grid signals. As shown at B, the detector operates on the linear portion of the curve. This detector has good sensitivity, since the tube amplifies the input signal. Selectivity is only fair, since the grid draws current to load the tuned circuit. Linearity is fair. Signal handling ability is very good.

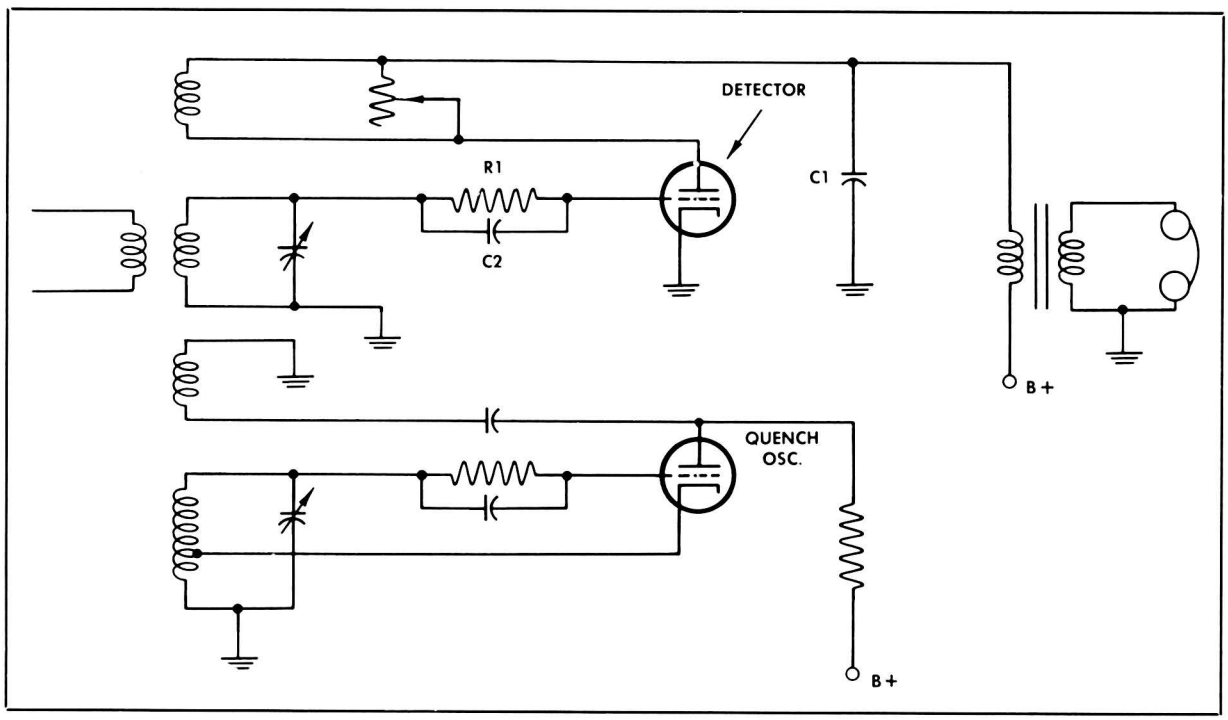
Regenerative Detector

Regenerative detectors are special types of grid leak detectors. The plate circuit of the regenerative detector (page 19) contains a feedback coil (L3) that inductively couples energy back to the tuned circuit. This coil provides feedback to reinforce the incoming signal. Thus the tube not only amplifies the signal, but it also reinforces and increases the signal on the grid. This increased signal is also amplified — and again fed back to the grid. Thus the sensitivity of this circuit is far greater than the sensitivity of the detectors already studied. However, this circuit is difficult to handle. Circuit adjustments are very critical. If feedback voltage is too great, the stage responds as an oscillator, producing squeals in the sound output of the receiver, and producing interference in other receivers.

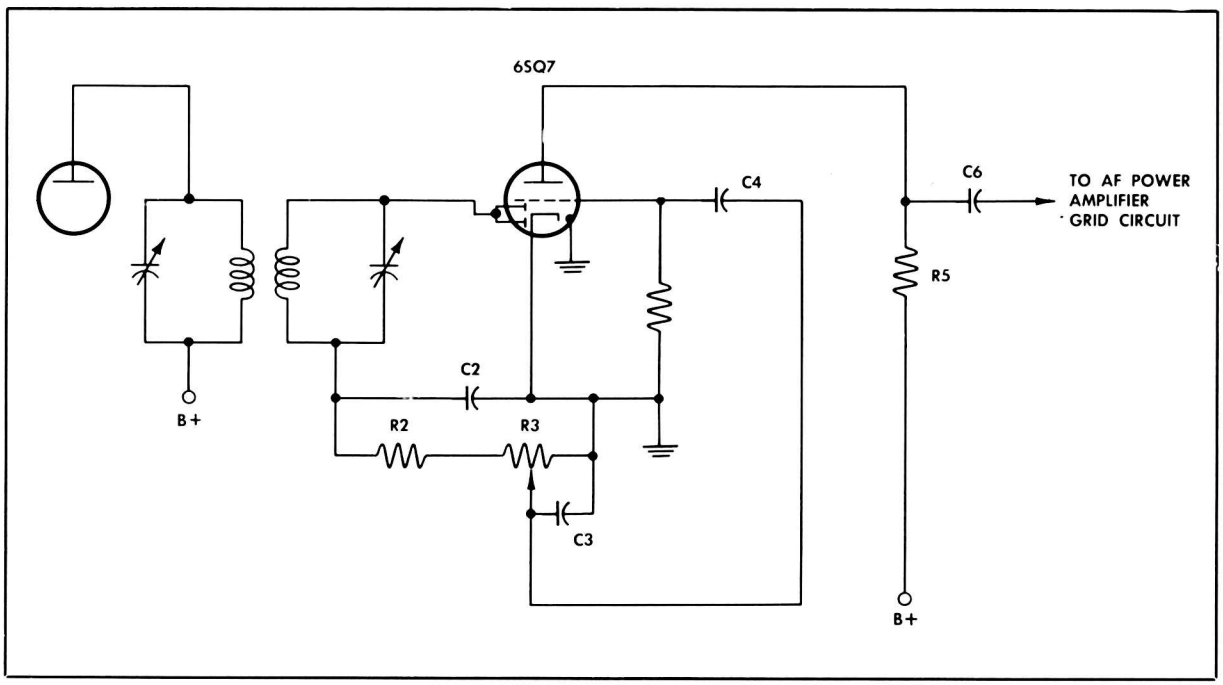
This tendency to oscillate can be used to advantage, however, in obtaining intelligence from CW transmissions. For CW reception, variable resistor R2 is adjusted so that the circuit starts to oscillate. The frequency of oscillation is slightly different from the signal frequency (to which L2-C1 is tuned) and this produces an audible beat frequency in the headset. This beat frequency can be varied by adjusting R2.

Superregenerative Detector

The operation of this type of receiver is somewhat like that of a regenerative detector receiving a CW signal. When the detector oscillates, the amplitude of oscillation is controlled by the amplitude of the RF input signals. The time that the detector oscillates is controlled by the quench oscillator, which operates at about 20 kc and applies an addi-



Superregenerative Detector



Detector-Amplifier

tional signal to the detector grid. When this signal is positive, the detector oscillates. When this signal is negative, the detector is cut off.

Each time the detector oscillates, a voltage pulse is developed in the plate circuit of the detector. The amplitude of this pulse is controlled by the amplitude of the incoming RF signal during the time of the pulse. Successive pulses, therefore, vary in amplitude according to the modulation envelope. These pulses are filtered by C1 so that only the audio voltage is applied to the primary of the output transformer.

The quench oscillator frequency must be above the audio range to prevent the quench frequency from being heard in the output. Also, the ratio of the RF input signal frequency to the quench frequency must be at least 100 to 1, to prevent a large amount of noise from developing. This means that the minimum RF frequency at which this type of receiver will operate satisfactorily is 2,000 kc. This type of circuit is especially adaptable to the VHF band, and is used in some VHF police equipment.

Superregenerative receivers are compact, light in weight, and low in cost. They consume little power, and have surprising gain for the number of tubes used. Superregenerative detectors have high sensitivity, but poor linearity. They are poor in selectivity because the grid current loads the tuned circuit. Their signal handling ability is very good.

Multielement Tube Detectors

One of the multielement special purpose tubes is the twin diode triode. Its use is shown in the detector-amplifier circuit diagram. This single tube serves simultaneously as a detector and audio amplifier. It contains a cathode, control grid, triode plate, and two diode plates. In this circuit, the diode plates are joined together and, with the cathode, they form the diode section of the tube. When the tuned circuit connected between the diode plates and cathode drives the diode plates positive with respect to the cathode, the diode section conducts.

R2 and R3 in series form the plate load resistor of the diode section. They are bypassed for RF by C2. R3 is a potentiometer which taps the AF voltage across part of the plate load and applies it to the grid of the triode amplifier section through coupling

capacitor C4. This amplifier operates as a high-mu voltage amplifier, supplying excitation voltage to the power amplifier grid. R5 is the plate load resistance for the triode section.

THE AUDIO SECTION

Two types of amplifier stages are used — voltage amplifiers and power amplifiers. When intelligence is to be reproduced by a headset, the audio section usually has one or two voltage amplifiers. When intelligence is to be reproduced by a speaker or a number of headsets in parallel, one voltage amplifier and one power amplifier are usually used.

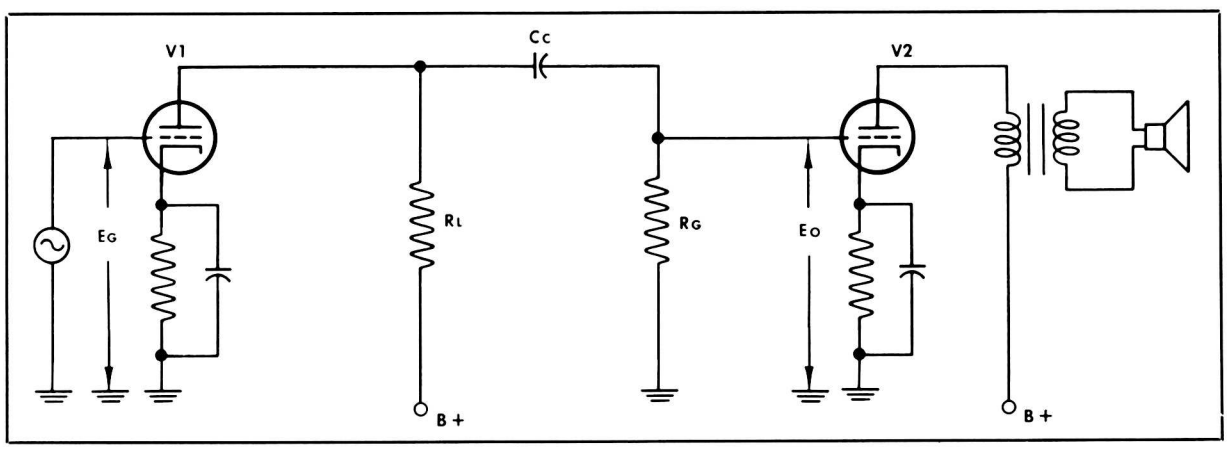
The AF voltage amplifier is used to build up the signal enough to excite the grid of the power amplifier or to energize the headset. Either a triode or pentode tube can be used as the voltage amplifier. In most cases, a medium-mu tube is used, especially when preceding RF amplifier stages provide sufficient gain. Resistance-capacitance coupling of the voltage amplifier to the power amplifier is conventional. The voltage gain for a medium-mu triode operating at frequencies around 1000 cps runs from 10 to 70. The load resistance of the voltage amplifier should be several times the plate resistance.

A power amplifier must efficiently convert DC power to AC power. If a triode is used, it should have low internal resistance. Maximum power transfer takes place when the load impedance equals the internal resistance. However, in practice, the load impedance is kept smaller than the plate resistance to prevent distortion. Power amplifiers generally use tetrodes or pentodes. These have higher power efficiency than triodes. Some tetrodes deliver nearly twice the output of a triode, even when the grid voltage of the tetrode is one-fourth that of the triode. For tetrodes and pentodes, a load impedance of about one-tenth of the plate resistance is used.

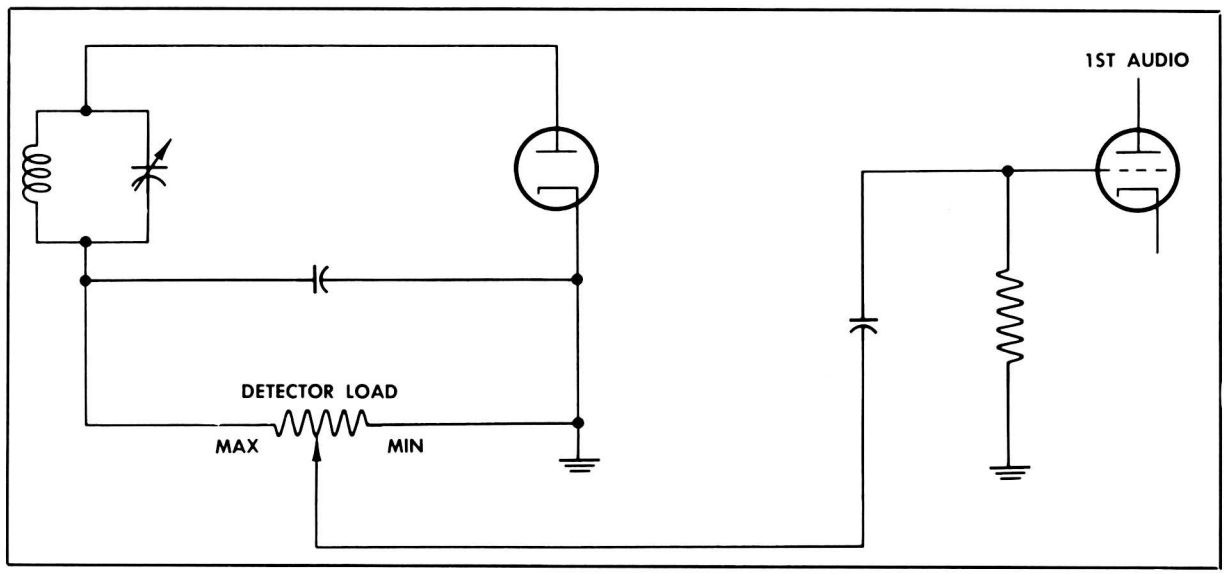
Study the voltage and power amplifier shown in the circuit diagram. The generator in the grid circuit of V1, the voltage amplifier, represents the detector stage as a source of driving energy. The voltage output of V1 is capacitively coupled to V2, the power amplifier. The output of the power amplifier is transformer coupled to the speaker so that the high impedance of the power amplifier plate circuit can be matched to the low impedance of the speaker voice coil.

VOLUME CONTROL METHODS

Since the signals intercepted by an antenna may be of widely differing strengths, the receiver should be able to handle both weak and strong signals. It is advantageous to bring both the very weak signal and the very strong signal to approximately the same level of strength for the final reproduction of the intelligence. The process of matching signal strength to desired audio output involves the use of volume controls. Three methods are in common usage — manual control of audio



Audio Amplifier Section of TRF



Manual Volume Control

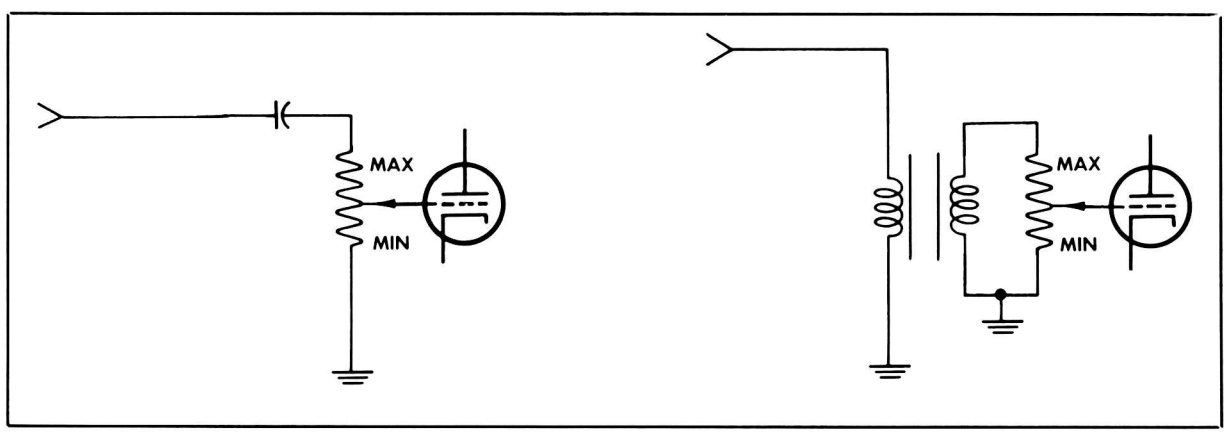
signal, manual control of RF signal, and automatic control of RF signal.

Manual Audio Control

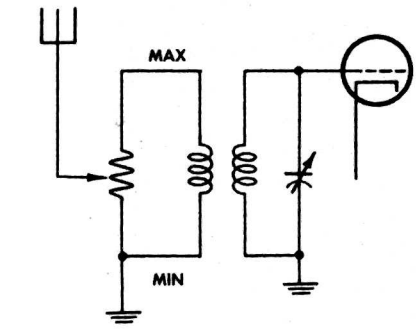
The control of signal strength in the AF section of a receiver is called manual volume control (MVC). As shown in the circuit diagram above, this type of control is accomplished by using a potentiometer as the detector load resistor. The strength of the audio signal applied to the grid of the first audio amplifier can be regulated by this means. Maximum and minimum points of volume are indicated on the circuit diagram.

For other kinds of coupling, the potentiometer arrangements are made as shown below. At A, the output is capacitively coupled to a potentiometer. The movable tap on the potentiometer is connected directly to the first audio amplifier grid. Here, the potentiometer is the grid resistor of the audio amfier. The tap selects a portion of the voltage across the resistor.

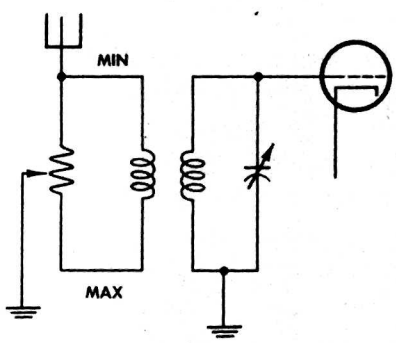
At B, the detector stage is transformer coupled to the AF amplifier. The potentiometer is across the secondary winding. The movable tap is connected directly to the grid. Here, the potentiometer is in series with the secondary of the transformer.. The tap selects a portion of the voltage across the potentiometer and applies it to the grid.



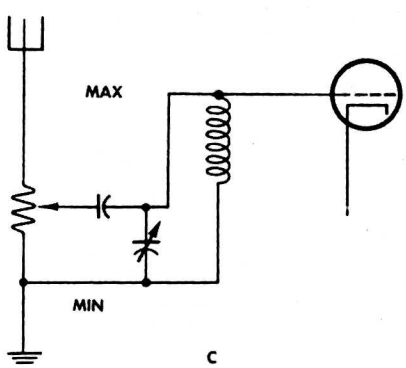
Variations of MVC



A



B



C

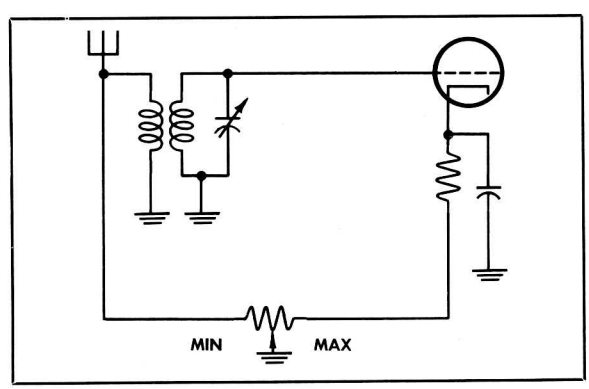
Antenna Volume Control Circuits

Manual RF Control

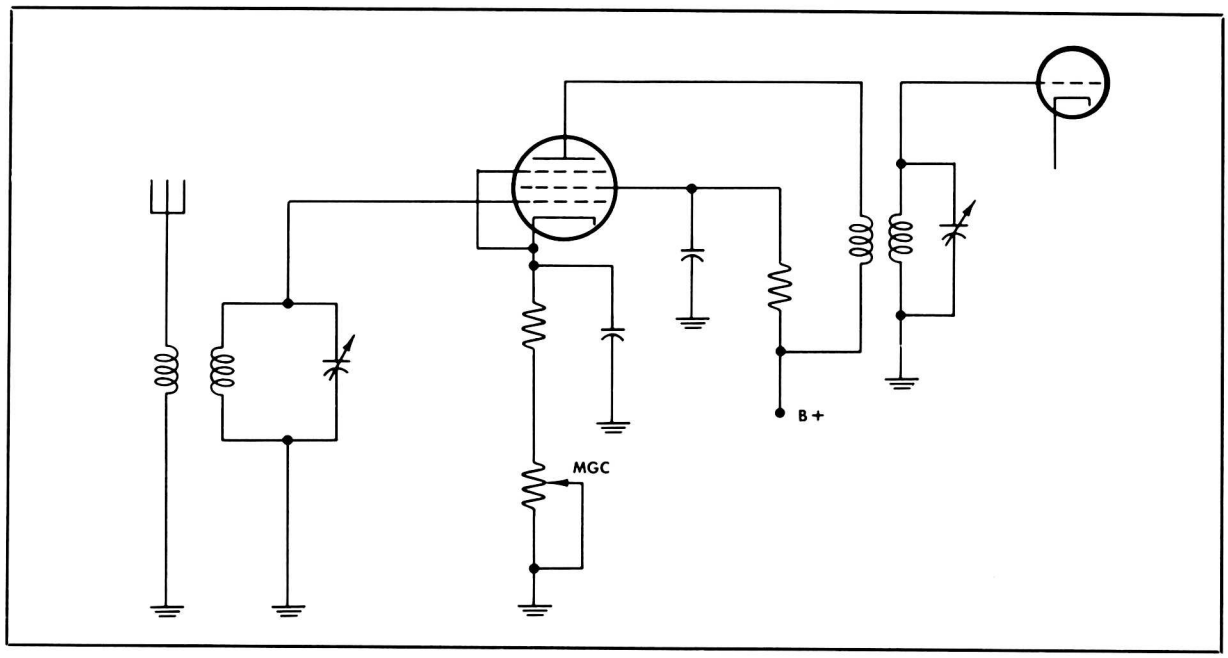
As shown in the illustration at the left, the RF signal amplitude can be controlled in the antenna circuit. At A, the antenna is connected to the movable tap of the potentiometer. At B the movable tap is connected to ground while the antenna is connected to one end of the potentiometer. At C, the movable tap is connected to the grid of the first RF amplifier while a tuned circuit is connected between the grid and ground. In each case, regulation of the potentiometer controls the amount of signal applied to the grid.

RF signal amplitude can also be controlled in the RF amplifier stages by regulating the amount of amplification of the stage. This is known as manual gain control (MGC). As shown on page 25, the variable resistor is in the cathode circuit of the RF amplifier. It is in series with a fixed resistor which provides a minimum amount of cathode bias. Adjusting the potentiometer changes the bias and thus the amount of amplification. This type of regulation is used with variable-mu pentode tubes, since these tubes permit considerable variation of bias without distortion. In actual use, the potentiometer would be in the cathode circuit of several stages. Thus, it would control the gain of several RF stages simultaneously.

Antenna volume control and manual gain control can be accomplished simultaneously by use of a single potentiometer, as shown below. The potentiometer controls both the resistance across the primary of the input transformer and the cathode resistance of the first amplifier.



Dual Antenna and Gain Control

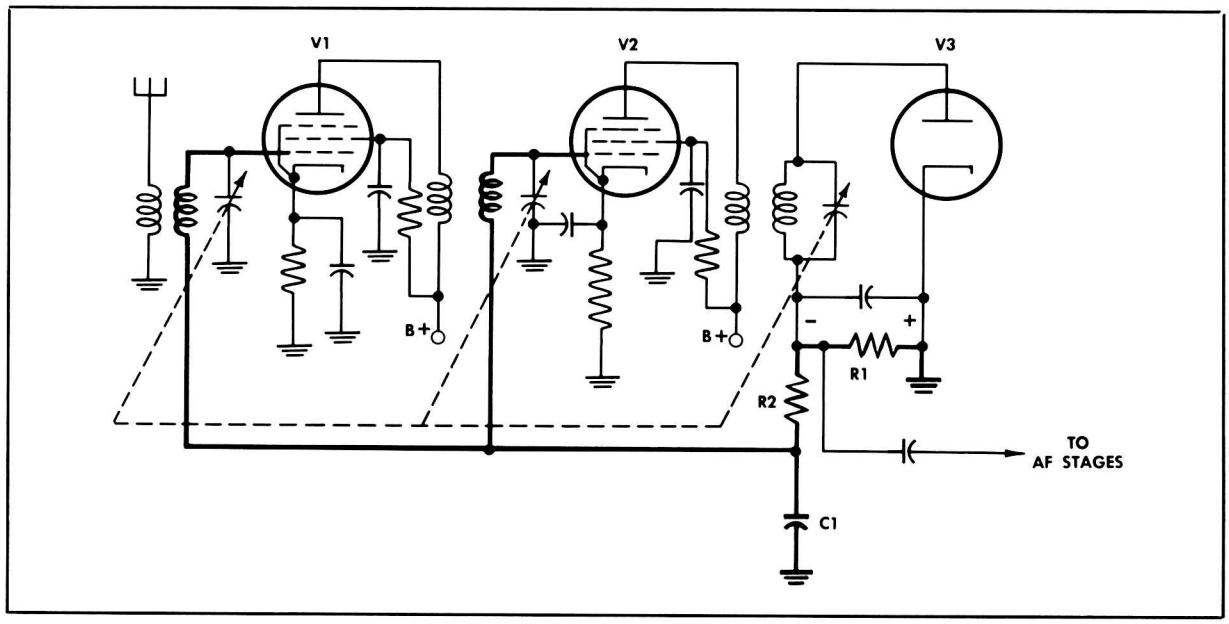


Manual Gain Control

Automatic Volume Control

A volume control permits the level of output to be kept approximately the same for both a weak signal and a strong one. However, fading causes such variations in signal strength that no single setting of the volume control gives uniform output. Automatic volume control (AVC) corrects this situation and permits uniform output for a signal of varying strength.

In general, AVC controls the gain in several amplifier stages preceding the detector. Such an arrangement is shown below. The parts



Basic AVC Circuit

of the circuit involved in AVC are drawn in heavy lines. When using AVC, these tubes are usually variable-mu tubes.

V1 and V2 are RF amplifiers. V3 is the detector. The AVC process starts with the detector and works back to the RF amplifiers. R1 is the load resistor of the detector. The voltage across R1 depends on the strength of the signal being detected by the diode. When the signal is strong, the voltage across R1 is large. Note that the voltage drop across R1 is negative in respect to ground. Note also that this negative voltage drop is applied through R2 to the grids of V1 and V2. This means a reduction in the gain of each amplifier stage. The amount of reduction depends on the size of the voltage drop across R1. If the signal is weak and the voltage across R1 is small, then the gain of the amplifier stages is reduced only a small amount. If the signal is strong and the voltage drop across R1 is large, then the reduction in gain is large. This means that AVC reduces the gain in both tubes. However, since the amount of reduction is proportional to signal strength, the output is kept fairly uniform. The general loss of gain caused by the use of AVC is small compared to the amount of gain provided by the amplifiers.

Of course, the voltage drop across R1 is DC, pulsating at an audio rate. To apply these audio variations to the RF amplifier grids would produce distortion. Therefore, the DC voltage fed back to the grids is filtered to remove the audio component by the filter made up of R2 and C1. The time constant of C1 and R2 is such that the AF pulses are filtered out, and a pure DC voltage is fed back to the amplifier grids.

TYPICAL TRF RECEIVER

You have now studied, circuit by circuit, all the parts of the TRF. You have studied various methods of detection used in the TRF, and in other receivers. You have studied various methods of volume control used in the TRF, and in other receivers. It is time now to bring the various circuits together to form one typical TRF circuit diagram. To help you understand the circuit diagram, the table on page 28 gives a description of each of the circuit components.

The antenna circuit includes a tunable parallel wavetrap for undesirable signal rejection. The antenna is inductively coupled to the input of the first RF amplifier.

There are three RF amplifier stages, followed by a detector stage. Four tuned RF circuits control the inputs to these stages. These tuned circuits are ganged—their variable capacitors, C2, C3, C4, and C5 can be adjusted by a single control. Capacitors C6, C7, C8, and C9 are trimmers They are separately adjustable and can be used for tracking the four tuned circuits. These stages, the three RF amplifiers and the detector, are transformer coupled.

The three RF amplifier stages use variable-mu pentode tubes. The detector stage provides diode detection by using a triode tube with plate and control grid connected for diode action.

The output of the detector is capacitively coupled to the audio amplifier, a pentode tube. The output of the audio amplifier is transformer coupled to the headset.

All the amplifiers use cathode bias. A single potentiometer (R4) forms part of the cathode resistance of the first two RF amplifiers. It also forms part of the antenna circuit. Adjustment of this potentiometer provides manual gain control when ganged switch SW2 is in the MGC position. In this position, one contact of the switch grounds the potentiometer so that it can be used. Another contact grounds the AVC circuit so that it can't feed voltage to the grids of the RF amplifiers. A third contact applies the entire voltage drop across the diode load resistor to the AF amplifier. This makes the adjustable part of the manual volume control inoperative.

When switch SW2 is in the MVC-AVC position, one contact grounds the top of potentiometer R4, removing it from the cathode circuit of the first two RF amplifiers, leaving all of R4 across the primary of T1. Another contact removes the ground connection which prevented AVC voltage from being fed to the amplifier grids. A third contact connects the variable arm of potentiometer R15 (the detector load resistor) to the input of the audio amplifier. Thus, the output of the