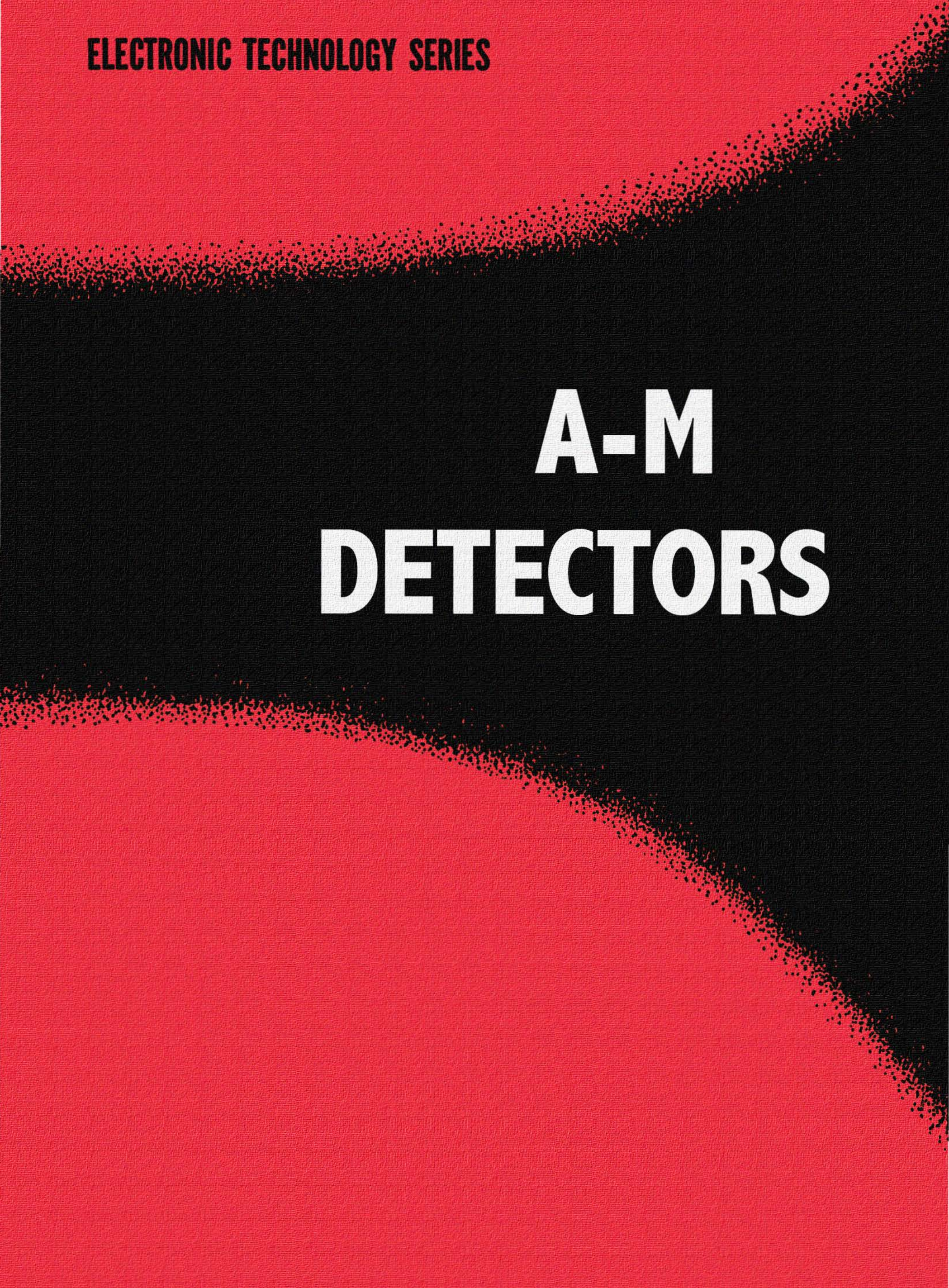
ELECTRONIC TECHNOLOGY SERIES



A-M
DETECTORS

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A-M
DETECTORS

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PREFACE

A-m detectors are an integral and important part of most communications and electronic equipment. Therefore, presentation of the concepts and fundamentals of a-m detectors should occupy a correspondingly important place in any complete program of electronics instruction. The subject can be a deceptive one, for many texts deliberately oversimplify the concepts involved, omitting the details necessary to present a truly rigorous definition and analysis of a-m demodulation and detector circuits.

It is the intent of this booklet to provide a thorough and detailed explanation for both the detection processes and the various important circuits of a-m detectors. Therefore, all of the classical types of a-m detectors are described. After a specific discussion of the requirements for detector action, fundamental detector considerations are developed in terms of crystal and vacuum diode, plate circuit, grid-leak, infinite impedance, oscillating, non-oscillating, and superregenerative types of detector. Linear detection and square law detection are also discussed.

Because automatic volume control circuits are commonly associated with various practical a-m detector circuits, an entire chapter has been devoted to the functions and explanation of avc action and the circuitry required to provide it. Delayed automatic volume control is also covered.

Perusal of this booklet should permit the advanced student, technician, or practicing engineer to review the concepts and basic applications of these types of circuits to advantage. The review questions given at the end of each chapter have been carefully designed to facilitate adequate self testing, offering in addition to theoretical problems several that are typical of those met in everyday work situations.

Grateful acknowledgement is made to the staff of the New York Technical Institute for its assistance in the preparation of the manuscript for this booklet.

New York, N. Y. *A. S.*
December, 1955

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Chapter 1

FUNDAMENTALS OF A-M DETECTORS

1. A Rigorous Definition of Detection

Intelligence is transmitted in radio communication by means of a *keyed* or *modulated* continuous electromagnetic wave. To interpret keying at the receiver, certain special circuits are required.[1] Since these additions are not involved in the reception of a modulated wave, the initial discussions of detection and detectors in this book are confined to explanations of circuitry used for the recovery of audio frequency amplitude modulation from the radio frequency carrier.

An unmodulated carrier consists of a single frequency component. When modulation by a single pure tone occurs—the simplest form of amplitude modulation—*three distinct and separate frequency components* immediately appear: (a) The original component of carrier frequency, (b) a second component of frequency higher than the carrier, and (c) a third component of frequency lower than the carrier. The two new ones are called, respectively, the *upper and lower side frequency components.*

Before presenting numerical examples, it is advisable to clarify the relationship between the conventional representation of an amplitude modulated wave such as that shown in Fig. 1 (A) and the same wave divided into its component parts. Fig. 1 (A) pictures an a-m wave of a *single frequency* (the carrier frequency) whose amplitude changes in conformity with the impressed audio modulation. This is a convenient picture of the sum of the three components—carrier component, upper side frequency component, and lower side frequency component—as it would appear when displayed, for example, on the screen of a cathode-ray oscilloscope.

Consider an example in which a 1500-kc carrier is modulated by a sinusoidal audio tone of 7500 cps. After modulation the emitted component frequencies are:

Carrier	1500 kc	
Upper side frequency	1507.5 kc	(1,500,000 cps + 7500 cps)
Lower side frequency	1492.5 kc	(1,500,000 cps — 7500 cps)

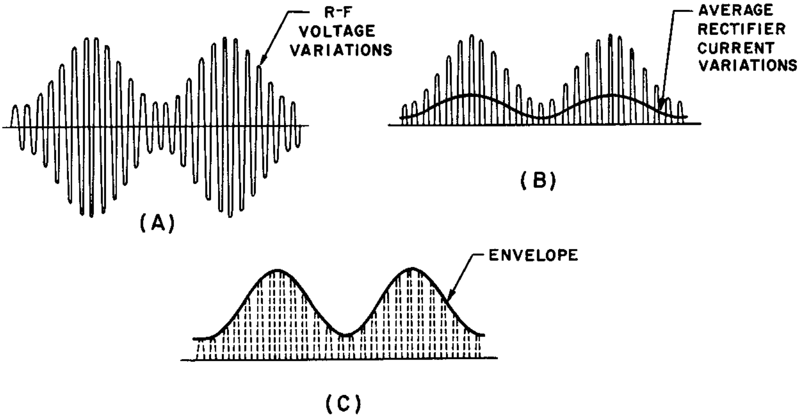

Fig. 1. Modification of modulated signal waveform (A), after rectification (B), and filtering out of carrier-frequency variations (C).

It is important to note the simple relationship between the actual components produced: the upper side frequency (usf) = carrier frequency + the modulation frequency, and the lower side frequency (lsf) = the carrier frequency — the modulation frequency.

Since these three individual components move through space together, they must recombine in the detector in such a manner as to yield the original audio frequency signal used for modulation. This is accomplished by having the carrier *beat with* or *heterodyne* the two side-frequency components in exactly the same way that the initial modulating signal heterodyned the carrier to produce the two side-frequency components. Thus, in the example above, either the usf component may heterodyne the carrier alone in the

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[1] See paragraphs 29 and 34.

detector to yield the original audio frequency signal (1507.5 — 1500 = 7.5 kc or 7500 cps), or the lsf component may do so (1500 — 1492.5 = 7.5 kc), or both side-frequency components together may accomplish the same result by simultaneously heterodyning the carrier. When both side-frequency components heterodyne the carrier, the difference frequencies are in phase with each other and merely add together in the final audio output.

It may be shown that the production of sum and difference frequencies may occur only in a *nonlinear device,* or a device in which the output is not proportional to the input. For instance, if two frequency components are mixed in a wire or a resistor, sum and difference frequency components are not obtained; i.e., the two original signals exist independently of each other without interaction. On the other hand, the same two frequency components, applied to a rectifier or any other device whose output is not proportional to its input, do heterodyne each other with the consequent yield of additional signal components of sum and difference frequencies.

Program information as provided by broadcast and communications stations does not consist of single tone modulation. The use of complex audio voltages does not alter the foregoing principles, except that one must think in terms of sidebands rather than side frequencies. Each distinct audio frequency component gives rise to its side frequency component with the combination of all of the individual side frequency components constituting the sidebands. A numerical example follows:

A 1000-kc carrier is modulated by a signal having a band of audio frequencies extending from 40 cps to 5000 cps. The transmitter output then consists of:

The carrier	1000 kc
The upper sideband	1000.04 kc to 1005.0 kc
The lower sideband	999.96 kc to 995.0 kc

As mentioned above, a rectifier is a nonlinear device. This nonlinearity arises from the unidirectional characteristics of a rectifier in which an a-c input results in a pulsating d-c output, certainly a process in which severe distortion is occurring. It is just this ability to distort the incoming signal that makes a rectifier a nonlinear device and hence a potential detector.

Referring to Fig. 1 (A) once again, it should now be evident that this portrayal is a graphical representation of the resultant waveform obtained by adding the three basic components that are radiated from the antenna.

As such a representation, it lends itself particularly well to simplified explanations of detector action. As long as one is aware of the fact that it is merely a representation on paper, one may use it freely to describe the steps that are followed in any detection process. In a book of this kind—or even in advanced engineering texts—constant reference to side-frequencies, heterodyne action, and the sum/difference frequencies resulting therefrom is space-consuming and entirely unnecessary. Therefore, all the theoretical and practical considerations involving detectors in this book are handled by utilizing the more convenient concept of a radio-frequency wave whose amplitude varies with modulation.

Making use of this point of view enables us to set up the conditions necessary for detection in two simple steps:

a. Starting with the sinusoidally modulated carrier as shown in Fig. 1 (A), a detector must first remove, either partially or completely, alternate half-cycles of the transmitted r-f wave. The product of this action is given in Fig. 1 (B). After rectification, the waveform of the current averaged over each r-f half-cycle is the same as the waveform of the audio frequency signal voltage modulating the r-f carrier at the transmitter source.

b. By means of a suitable filter network, usually consisting of a resistor and a capacitor properly chosen as to time constant, the detector must next develop an output voltage that follows closely the gentle rise and fall of the rectified r-f peaks. Stating this in other words, the output of the detector, instead of comprising rapid r-f variations as in Fig. 1 (B), must be in the form of a voltage which corresponds to the *envelope* that can be generated by connecting the peaks of the r-f variations by a smooth curve. This is shown in Fig. 1 (C). In the process of creating this envelope—and the word *creating* is used advisedly here because the envelope has no real existence until it is born in the filter circuit of the detector —the r-f variations are eliminated. Thus only the audio voltage represented by the envelope is passed on to the reproducer or other audio amplifier stages which might follow.

2. The Crystal Detector

Some crystalline materials possess the property of allowing an electric current to flow through them more easily in one direction than another. Examples of such substances are silicon, selenium, galena (crystalline lead sulphide), and germanium. The average crystal detector is an "imperfect diode" because a small current can pass in the reverse or nonconducting direction, as indicated in Fig. 2 (A). The assumption is made, however, that the crystal is theoretically perfect, with the characteristics shown in Fig. 2 (B) and is connected into the simple circuit of Fig. 2 (C). The reverse conduction of the crystal is insignificant, and can be disregarded in practice.

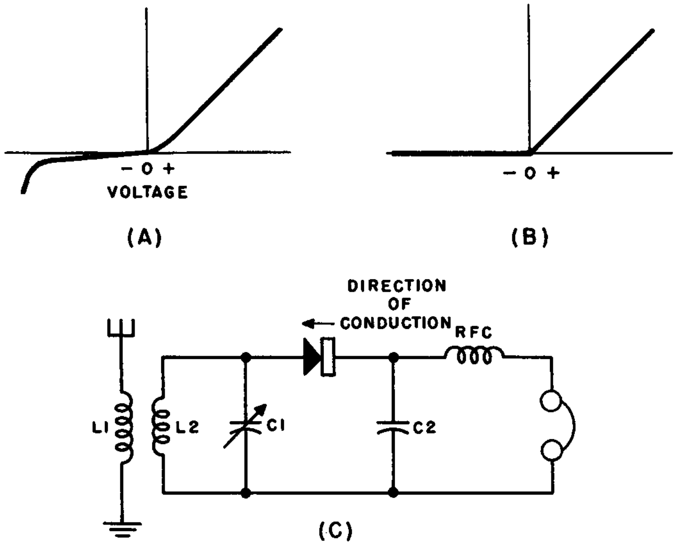


Fig. 2. (A) Current-versus-voltage characteristics of a crystal diode. (B) Assumed ideal diode characteristic. (C) Crystal detector receiver circuit.

To understand the action of this simple diode detector let us analyze its operation when receiving an amplitude-modulated radio wave whose 1000-kc carrier is modulated by a 1-kc audio signal. The carrier induces an a-c voltage in the antenna, which results in an alternating current of the same frequency flowing to ground through *L1*, inducing a similar voltage across *L2*. When *L2C1* is tuned to form a resonant combination at 1000 kc, a relatively large 1000-kc voltage appears across the tuned circuit. This voltage is applied to the crystal through the r-f choke (*RFC*) and headphones. The first requisite of detection (rectification) takes place as shown in Fig. 3, current flowing only on the r-f half-cycles on whose polarity the crystal is conductive. The second requisite, eliminating the r-f component in the output signal, is accomplished by the filter circuit composed of *C2* and the *RFC*. The value of *C2* is such as to permit bypassing the radio frequency component by presenting an r-f path whose reactance is low compared to the reactance of *RFC* plus the headphones. The capacitance is too small, however, to pass an appreciable amount of the 1-kc audio frequency variations. Similarly, the *RFC* offers a high impedance to r-f and a low impedance to the a-f signals. The audio frequency currents flow through the r-f choke, through the headphones, and back to the tuned circuit.

3. Fundamental Detector Considerations

Crystal detectors are used in modern radio systems, particularly in the higher frequency ranges. To evaluate their performance accurately, a number of considerations are necessary:

a. The linearity of the detector is of importance because, of all the possible flaws or faults in detector design, nonlinear distortion of the audio component is the most difficult to correct. In the broadcast receiver, the distortion introduced by the detector circuit is *the* prime consideration before a detector is placed into service. Because the crystal detector is not very linear, it tends to introduce appreciable distortion. The first measure of performance, then, is detector *linearity,* the ability of the detector to reproduce the exact form of the modulation on the incoming signal.

b. Another factor is the *detector sensitivity,* which is the ratio of the useful detector output to the signal input. The sensitivity of a detector is determined largely by the amount of amplification occuring during the detection process, or in the detector circuit. The sensitivity of the crystal detector is poor because it does not amplify the input signal.

c. The *selectivity* of a detector is its ability to discriminate between signals of adjacent frequencies. Detector selectivity is important in receiver design. When the detector consumes appreciable power, which must be furnished by the preceding stage, the selectivity is lowered in proportion to the loading effect. Detector selectivity is thus related to the resistance the detector presents to the tuned circuits to which it is connected. It is determined by the effective Q of the tuned circuit. Effective Q is the Q with all circuit components connected, including crystal diodes and vacuum tubes with heaters operating. When the loading effect of a detector across a tuned circuit is increased, the Q of the circuit is decreased. The effect of a lowered Q is to broaden the resonance peak, which, essentially, is the same as lowering the selectivity. Since the crystal detector draws power from the tuned circuit, its selectivity tends to be poor.

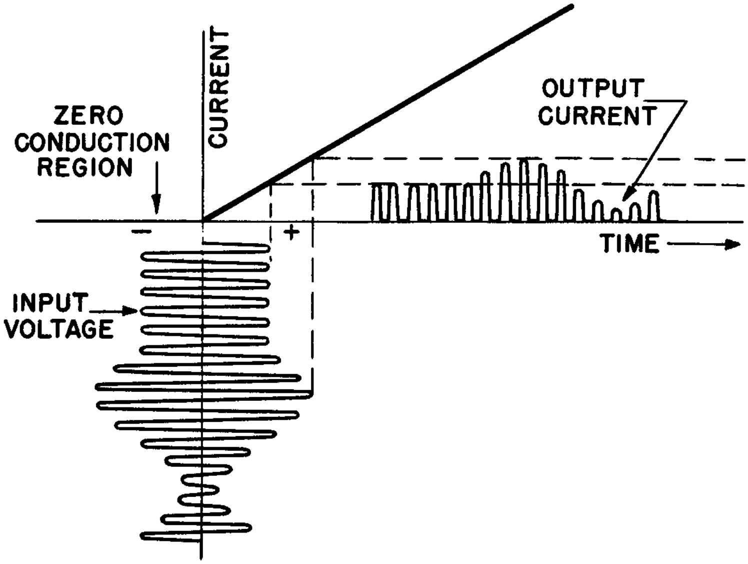


Fig. 3. Crystal detector action on a modulated r-f input signal.

d. The *signal handling capability* of a detector is its ability to accept signals of a given amplitude without distortion. A detector that overloads easily with large signal input produces distortion on any but low-level or relatively constant amplitude signals. A crystal detector does not overload except at extremely high signal amplitudes, and consequently has high signal handling ability.

4. Linear and Square-Law Detectors

Types of detectors are often distinguished by whether they are designed for strong signals or weak signals. Diode detectors have a wide amplitude range of linearity. They are sometimes called *linear* detectors, and are of the "strong signal" class. Other types of detectors employ a "bend" in a characteristic curve for demodulating action. These are "weak signal" detectors. Because the bend in the characteristic curve represents a square relation (current proportional to the square of applied voltage) these are often referred to as *square-law* detectors. Their amplitude range is small; unless operated on weak signals, they overload and cause distortion. However, they have the advantage that they provide amplification, and are thus more sensitive than diodes. The circuits and the operation of both linear and square-law detectors are covered in a later section of this book.

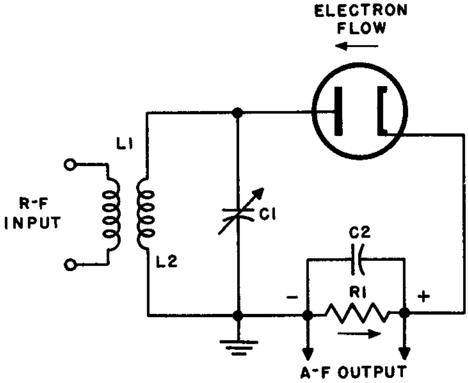


Fig. 4. Basic circuit diagram of vacuum tube diode detector.

5. The Simple Vacuum Tube Diode Detector

Vacuum tube diodes serve as rectifiers because current can flow in the plate circuit only when the plate has a positive potential with respect to the cathode. Since detection involves rectification, vacuum tubes are used as detectors.

The simplest vacuum tube detector is the elementary half-wave diode tube circuit shown in Fig. 4. The circuit *L2C1* is tuned to the signal frequency. Typical values for *R1* and *C2* in a-m broadcast receivers are 250,000 ohms and 250 $\mu\mu$f respectively. Let us assume that, as in the crystal detector example, a radio frequency carrier of 1000 kc modulated by a 1000-cycle audio signal is being received. If the tank circuit, *L2C1,* is tuned to resonance at 1000 kc, a large voltage of this frequency is developed across the tuned circuit. This r-f voltage is applied between the plate of the tube and ground, and is the input signal.

When the input r-f voltage drives the plate of the diode positive, electrons emitted by the cathode are attracted to the plate, causing a current flow. These electrons complete their circuit by flowing through the tank coil, *L1,* and the load resistor, *R1.* During the negative half of the r-f signal input cycle, the plate is negative with respect to the cathode and no current can flow through the external plate circuit. Since the output current can flow through the load resistor, *R1,* in only one direction, with the polarity indicated in Fig. 4, rectification of the input signal voltage has taken place. The additional requisite, that of filtering the r-f variations, is accomplished by capacitor *C2* and resistor *R1.* Figure 5 illustrates the manner in which this is accomplished.

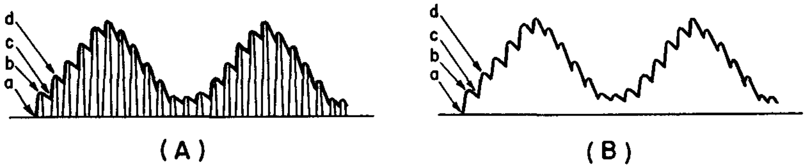


Fig. 5. Waveforms showing how detector filter removes carrier fluctuations.

In Fig. 5 (A), the r-f voltage applied as input has been sketched lightly, while the output voltage across capacitor *C2* is shown in heavy lines. On the first positive r-f half-cycle of the input wave, *C2* charges to the peak value of the r-f voltage indicated by the portion between points *a* and *b* on the diagram. As the applied r-f voltage drops off from its peak value, the capacitor begins to discharge through the load resistor (between *b* and *c* on the diagram), keeping the voltage on the cathode more positive than the voltage applied to the anode of the diode. The current flow in the diode is thus momentarily shut off. It is to be emphasized that *C2* discharges through *R1* at a very slow rate determined by the time constant of the combination. The time constant of this *RC* circuit is much longer than the short time required for the r-f voltage to change from point *b* to point *c.* For this reason, the capacitor voltage loss is small, and between points *b* and *c* there is no current flow in the plate circuit. When the r-f voltage on the plate during the positive half of the next r-f cycle rises high enough to bring the plate to a higher voltage then the plate-to-cathode voltage resulting from the capacitor's discharge emf, current flows again in the plate circuit. The capacitor charges up to the peak value of the second positive half cycle, shown as *d.* Each of the succeeding r-f voltage alternations cause the same actions to repeat. The voltage across the capacitor follows the peak values of the applied r-f voltage, and the audio frequency modulation is reproduced. In spite of the irregularity of the peaks in Fig. 5 (B), which represent a radio frequency component in the voltage applied across the capacitor, the r-f voltage component across *C1* is negligible in an actual circuit. The diode detector output, across *C2* and *R1,* is the electrical audio signal corresponding to the music or speech at the transmitting station.

6. Verification of the Filter Time Constant

Some simple calculations should help in understanding the operation of the circuits described. Since the resonant frequency of *L2C1* is 1000 kc, the time necessary for the r-f wave to complete one cycle is $t = \frac{1}{1{,}000{,}000}$ second $= 1 \times 10^{-6}$ seconds. The time constant for $R1C2$ is $T = RC = .25 \times 10^{6} \times 250 \times 10^{12} = 62.5 \times 10^{-6}$ seconds, which is 62.5 times $(\frac{T}{t_1})$ as great as the time of one cycle of the r-f wave. This then is the reason why the capacitor loses only a small portion of its voltage during the interval between decay and growth of the r-f wave from point *b* to point *c.*

7. Characteristics of the Vacuum Tube Diode Detector

The vacuum tube diode detector can be evaluated with respect to the essential characteristics of a detector as follows:

a. Freedom from distortion. This is essentially dependent upon the linearity of a tube's characteristic curve which, for the average vacuum tube diode, is excellent. The output waveform of the diode will be a virtual duplicate of the envelope of the input voltage, with a small distortion factor. Distortion in the vacuum tube diode detector is normally low.

b. Signal handling ability. The same characteristic curve of the diode, long and straight, with the upper saturation bend occurring only at high plate voltages, permits the application of a large input voltage without distortion. The diode does not saturate easily. Its signal handling ability, therefore, is excellent.

c. Sensitivity. There is no amplification in the diode. Thus its sensitivity is low.

d. Selectivity. Like the crystal diode the vacuum tube diode detector draws current from the tuned circuit during its operation.

The loading effect produced upon the tuned circuit reduces its *Q*, resulting in broader tuning. This is a disadvantage, because the diode detector, operating alone, cannot separate signals of closely adjacent frequencies. The selectivity of the diode detector is, therefore, poor.

In practice, the disadvantages of low sensitivity and poor selectivity are easily overcome by the addition of one or more stages of r-f amplification preceding the detector. The required gain and selectivity are obtained by the additional circuits. The advantages of the diode detector make it one of the most frequently used types of detectors in modern broadcast receivers. Besides the previously mentioned advantages, there is the fact that automatic volume control circuits (avc) may be developed easily from the diode detector. Avc circuits are covered in Chap. 2.

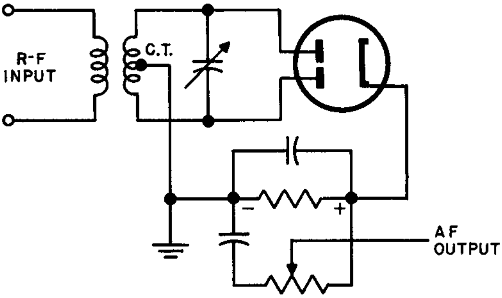


Fig. 6. Full-wave detector circuit.

Design factors for the simple diode detector call for low distortion, high input resistance, and high efficiency. A fairly large carrier voltage of 10 volts or more and a proper time constant of the load resistor, *R1*, and the shunting capacitor, *C2*, are required to effect these results. The capacitance of *C2* should be from five to ten times that of the cathode-to-plate value of the diode. At the same time, *C2* must be as small as possible (usually 50 to 250 $\mu\mu$f) in order to present a suitably high reactance to the modulation frequency. With the value of *C2* fixed by these considerations, *R1* is given the highest value possible to satisfy the time constant requirements.

8. The Full-Wave Diode Detector

The full-wave diode detector shown in Fig. 6 differs from the simple half-wave detector of Fig. 4 by utilizing both halves of the input r-f voltage cycle. A rectified current pulse flows in the cathode circuit twice for each r-f input cycle. R-f filtering is simpler in this circuit than in the half-wave arrangement because the half-cycles of carrier current through the diode have twice the input carrier frequency. This type of circuit is rarely used, the extra circuit complications outweighing its advantages.

9. Review Questions

1. List the essential requirements for an a-m detector circuit.
2. Draw a simple crystal detector circuit from memory.
3. Explain the operation of the crystal detector.
4. Define, in terms of an a-m detector circuit, the following: (a) distortion, (b) sensitivity, (c) selectivity, (d) signal handling ability.
5. Define "linear detector" and "square law detector."
6. Draw a simple vacuum tube diode detector circuit and explain its operation.
7. Give the characteristics of a diode detector. Explain how its disadvantages are overcome.
8. Explain in detail the action of diode detector capacitor *C2* and load resistor *R1* in Fig. 5. Use the time constant equation to illustrate your explanation.
9. With the circuit constants listed in Fig. 5, calculate the r-f and a-f reactances of capacitor *C2* to a 710-kc r-f voltage modulated by a 500-cps audio frequency voltage applied to the input of the detector circuit.
10. Draw a full-wave detector circuit and explain its operation.

Chapter 2

PRACTICAL DIODE DETECTOR CIRCUITS AND AUTOMATIC VOLUME CONTROL

10. Purpose of Automatic Volume Control

The output level of a receiver may fluctuate due to signal fading or to variation of input signal levels at the receiver antenna. Circuits associated with the detector, termed automatic volume control or avc circuits, have been devised to maintain approximately the same volume from the loudspeaker for various input signal strengths without the necessity of changing the setting of the volume control. These avc circuits may be designed to operate over the entire range of strength of the incoming signal; in this case the action is referred to as *simple* avc. If the avc functions only for levels of received signals above a certain minimum, the circuits are called *delayed* automatic volume control circuits. Automatic volume control circuits are normally used with diode detection.

11. Operation of Automatic Volume Control

Satisfactory avc operation is obtained by controlling the receiver's radio frequency and intermediate frequency stages so that the gain is less for a strong signal than for a weak signal. When the input level is high, the avc circuit reduces the gain of the r-f and i-f stages (thus controlling the output volume of the loudspeaker) by increasing the negative bias of the r-f, converter, and i-f stages when the input (received) signal level increases. Similarly, for weak signal input, the bias voltages are decreased, resulting in a larger signal gain, tending to maintain constant signal voltage to the detector. The tubes preceding the detector must be of the "remote-cutoff" type to permit smooth variations in voltage amplification as the grid bias is varied. The input signal level changes appear as voltage variations in the signal to the detector. These signal variations result in similar variations of detector rectified current. The voltage drop produced by the rectified current through the diode load resistor thus varies in the same way as input received signal. The diode load resistor can be connected so the ungrounded end is negative with respect to ground, becoming more so as the signal strength increases, and less so as the signal strength decreases. (See Fig. 7.) When this voltage is applied to the control grids of the remote-cutoff tubes, increases in the avc bias voltage reduce the overall voltage amplification, holding the output essentially constant. Similarly, reduced avc bias resulting from a weak signal increases the voltage amplification, since the weak signal develops a smaller avc bias across the diode load resistor. The detector output is automatically maintained at a constant level by the avc bias. The avc action becomes more complete as the number of stages to which the avc bias is applied is increased. In practice, control of at least two stages is required for satisfactory performance.

12. AVC Circuitry

In practical detectors, it is generally necessary to provide a filter such as shown in Fig. 7 in order to prevent radio frequency voltage from reaching the detector output. Capacitors *C1* and *C2* are usually of equal value in this filter system. *RL* has a value several times that of *R1*. In ordinary broadcast receivers, *C1* and *C2* might have values of about .0001 μf, *R1* 50,000 ohms, and *RL* 500,000 ohms. Figure 8 shows the addition of a coupling capacitor, *C3*, whose capacitance is usually about 0.1 μf. *C3* transfers the audio frequency signal to potentiometer *RL*. Coupling to the gain control through a capacitor avoids any flow of direct current through the potentiometer. Direct current flowing through a high resistance volume control tends to make the control scratchy and noisy.

Figure 9 is a diode circuit with provision for obtaining voltage for automatic volume control from the i-f amplifier of a broadcast receiver. Typical values are listed in the diagram. *C1, R1,* and *C2* form the r-f filter network. The output across *RL* is the audio component of the signal plus a d-c component. The audio signal, because of its variations, cannot be used as an automatic bias voltage.

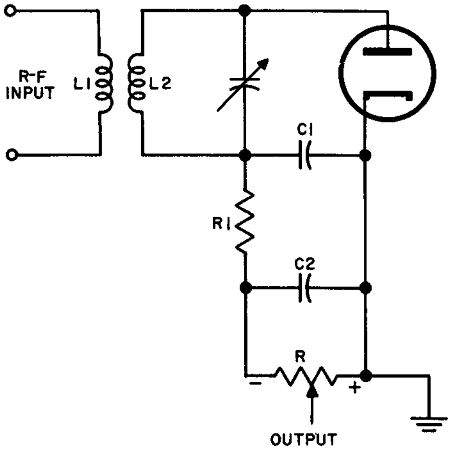


Fig. 7. Diode detector circuit with r-f filter.

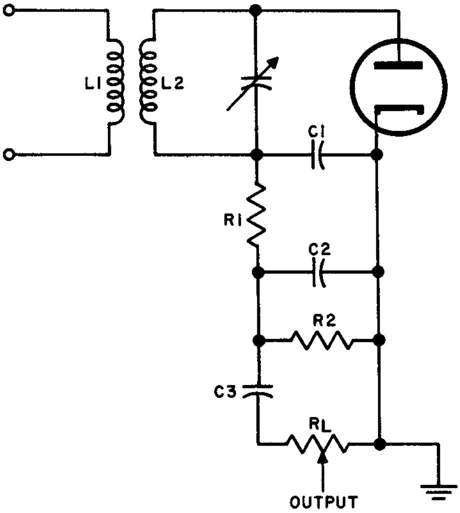


Fig. 8. Diode detector with a-f output capacitively coupled to volume control potentiometer.

Bias voltage must be pure d-c. *R3* and *C3* must be chosen to form a time constant of sufficient length so that the lowest value of audio frequency to be reproduced does not cause much charge on capacitor *C3*. On the other hand, it should not be so long that the automatic volume control cannot respond to sudden changes in signal strength. The voltage to charge capacitor *C3* through *R3* is taken from the negative side of the resistor at the point marked *X*, making the avc bias dependent upon the charge of *C3*. The time constant is usually from 1/5 to 1/20 of a second. This is sufficient to prevent variations resulting from the a-f pulsation of the detector's output from having a sizable effect and to control fluctuations due to changing signal input.

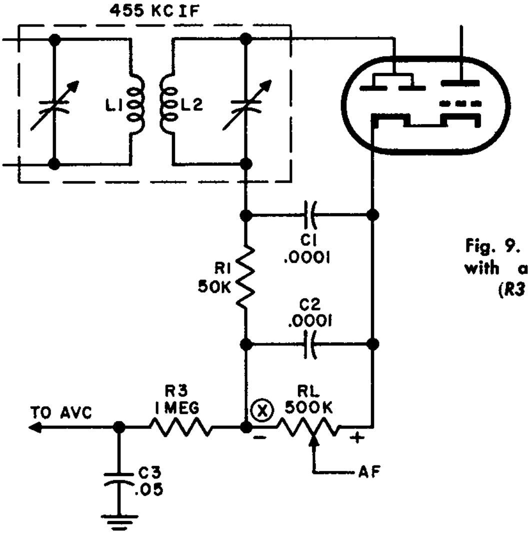


Fig. 9. Diode detector circuit with avc filter components (*R3* and C3) added.

It can be seen that the negative voltage available at *R3* is a function of the signal voltage impressed across the secondary. With strong signals, the rectified and filtered output of the detector resulting from the signal voltage present in *L1* is high, resulting in a high avc bias. The amplification of the controlled r-f and i-f tubes is therefore reduced. When the signal input is low, the voltage at the output of the i-f transformers is low, hence the avc bias voltage is reduced. This enables the gain of the controlled tubes to rise. The circuit arrangement just discussed appears in Fig. 10.

The time constant of the *RC* combination used for avc filtering (*R3* and *C3*) is:

$$TC \text{ (seconds)} = R \text{ (meg)} \times C \text{ } (\mu\text{f})$$
$$TC = 1 \times .05 = .05 \text{ seconds}$$

Most broadcast receivers of the table-top variety employ an avc filter time constant of from .05 second to .2 second. If the time constant is relatively short, the receiver responds more quickly to sudden variations in signal input level such as those encountered in mobile operation, but may not give full value to extremely low audio frequency notes (20 to 100 cps). With a small time constant, the avc circuit becomes a low-pass degenerative feedback network. A longer time constant reacts to changing signal strength more slowly, lagging somewhat behind the variations in level if they occur suddenly, but it does not cause any "washing out" of the audio lows.

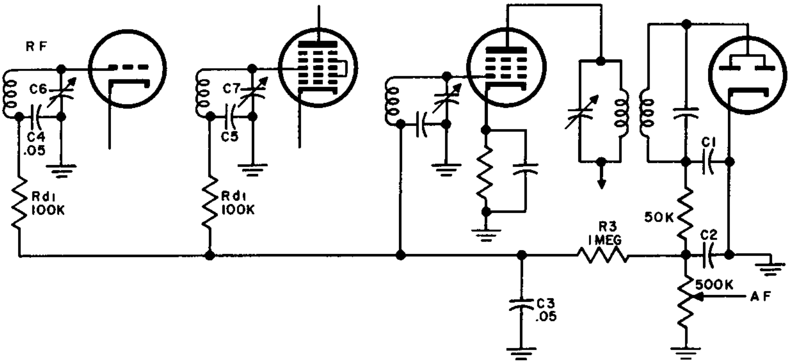


Fig. 10. Circuit showing how avc voltage is applied to r-f and i-f sections.

In summary, *C3* and *R3* are a filter system designed to prevent the avc voltage from fluctuating at an audio rate or higher. They are necessary because the voltage drop across the 500-k load potentiometer varies with the audio frequency modulation component of the carrier. If the avc voltages were taken directly from the load potentiometer without filtering, the audio variations in avc voltage would oppose the carrier modulation. When the avc voltage is taken from capacitor *C3*, which can charge and discharge at only a relatively slow rate because of the series resistor, *R3*, the avc voltage cannot vary substantially at the frequencies in the audio range. It can, however, compensate for slower signal variations caused by fading and retuning. *C4* and *C5* assist in decoupling the r-f and i-f stages and, in addition, permit the rotors of the variable and semi-variable capacitors, *C6* and *C7*, to be at ground potential without affecting the avc bias.

13. Detectors in Diode-Triode Circuits

Many a-m broadcast receivers employ combination diode-triode tubes. The elements of a diode and a triode are all contained in the same tube envelope; the diode acts as detector. The triode is the a-f voltage amplifier, whose input is obtained from the output of the detector. A typical circuit arrangement is shown in Fig. 11.

Tubes of this type commonly employed in a-m receivers provide a common cathode for both diode and triode. If cathode bias were used for the triode, it would also bias the diode. Such diode bias would allow conduction only on signal levels high enough to overcome the bias. Diode current would thus be "chopped" and distorted, and so would the a-f voltage across the load resistor.

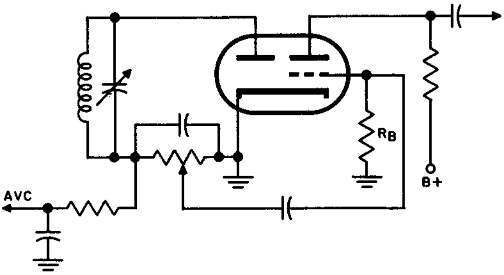


Fig. 11. Diode-triode detector amplifier circuit.

To avoid this, most a-m receivers use the circuit of Fig. 11. Bias resistor *RB* has a high value, in the order of 10 megohms. This resistance is high enough so that a minute electron current due to the velocity of the electron stream striking the grid inside the tube develops an appreciable voltage drop (1 or 2 volts). This voltage drop is adequate to bias the triode sufficiently for the low-level signal received from the detector. At the same time, the diode remains unbiased and works at full efficiency.

14. The Electron Ray Tuning Indicator

The avc voltage may be used to control a "Magic-Eye" or electron-ray tube. This tube indicates relative d-c detector output voltage, so the operator knows when the receiver is tuned for maximum carrier, the correct adjustment for a-m reception. Tuning for indicated maximum prevents distortion due to sideband cutting experienced when tuning is "off center." These tubes are designed to show the effect of a change in controlling voltage visually by the angular width of a pie-shaped shadow on a fluorescent target. The shadow deflection, widest when a low voltage is applied to the control grid, narrows as the grid voltage is increased. The connection of an electron-ray tube to the avc bus is shown in Fig. 12 (A).

Figure 12 (B) shows the indicator with and without signal at maximum avc voltage. The deflection is wide without signal, since there is no avc voltage. The deflection narrows as the signal is tuned in because the avc voltage applied to the grid rises to a maximum. The correct tuning condition causes the narrowest angle of deflection of the electron-ray tube, representing maximum response and maximum avc voltage. A receiver with an electron-ray tube has a virtual vacuum tube voltmeter connected to the output of the r-f and i-f stages, useful both as an output meter for alignment purposes and an indicator for the avc voltage.

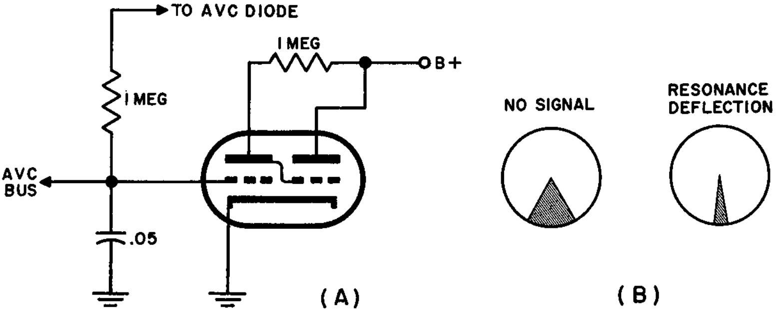


Fig. 12. (A) Electron-ray indicator tube circuit. (B) How tuning is indicated on fluorescent screen.

15. Delayed Automatic Volume Control

The simple avc circuits previously described have a disadvantage in that, even with weak signals, some negative bias is applied to the stages preceding the detector. For weak signals, the full sensitivity and gain of the receiver are needed, and even the small avc bias interferes with reception. Circuits have been designed that do not apply any avc bias until the input signal strength becomes greater than a predetermined value. These circuits, which permit the r-f and i-f amplifiers to operate with maximum gain for weak signals, are called delayed automatic volume control (davc) circuits. A typical circuit is shown in Fig. 13, the duo-diode detector being part of a multipurpose tube with a triode amplifier.

The diode plates are used separately, one serving solely for the detector function while the second plate is used to develop the avc voltage. In delayed automatic volume control a fixed negative delay voltage of about three volts is applied through *R4* to the avc diode plate, *P2*. This fixed voltage can be obtained by a biasing battery, a tap on the proper point of a voltage divider, by cathode biasing, or by any other appropriate means. A portion of the signal input voltage is coupled to the avc diode plate through *C1* of Fig. 13. This plate has the small negative delaying bias applied to it. It cannot rectify a signal or give rise to an avc voltage until the peak voltage through *C1* becomes sufficiently large to overcome the existing negative delay potential. The gain of the preceding stages stays high because there is no avc voltage applied to these circuits. When strong signals are received, the voltage applied through *C1* is sufficiently large to overcome the negative delay bias and to produce an avc voltage drop across *R4*.

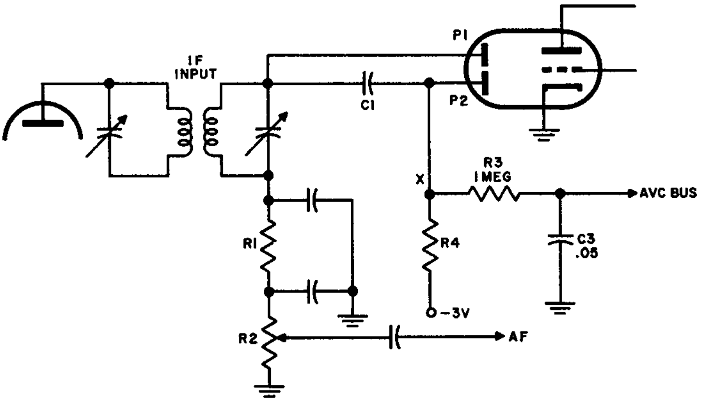


Fig. 13. Circuit of typical davc system.

The circuit action can be explained in further detail by referring to Fig. 13 again. The plate, *P1*, serves as the diode detector plate, *P2* being the section used for the development of the avc voltage. *P2* is fed by the coupling capacitor, *C1*. The applied delay (fixed) bias makes the avc diode plate, *P2*, negative with respect to cathode. The circuit operation for *P1* is exactly as described for the simple diode detector. Rectification of the incoming signal, whether weak or strong, takes place in the conventional manner on each positive half of the input signal voltage cycle. The rectified current is used to develop an audio output across the load impedance, *R2*, from which it is coupled to the grid of the next amplifier stage through an appropriate coupling capacitor.

When the input signal to diode *P2* is zero, the negative potential of approximately 3 volts is applied to the *P2* plate with respect to the cathode. When the signal voltage applied to diode plate *P2* through the diode coupling capacitor, *C1*, exceeds the value of the delay bias, *P2* is positive with respect to cathode and rectified current will flow through *P2* and *R4*. The voltage developed across diode *P2*'s load resistor, *R4*, is negative at point *X* with respect to ground. *R3* and *C3*, the avc filter, now work in the conventional manner to control any further variations in signal strength.

16. Automatic Volume Control For Continuous Wave (Code) Reception

Automatic volume control systems designed for use with continuous wave receivers (for code reception) must have long time constants to work with reception of slow speed sending. The circuits further differ from the conventional broadcast types in the use of a separate avc channel connected to an i-f amplifier stage preceding the second detector and the beat frequency oscillator. If the diode furnishing the avc voltage is not properly isolated from the beat frequency oscillator, the rectified beat frequency oscillator voltage acts like a strong received signal and cuts down the overall receiver gain. Good selectivity of the receiver is important too, poor selectivity permitting strong adjacent frequency signals to drive down the gain when the receiver is tuned to weak signals. With proper design and with clear channels, the avc circuits in a cw receiver provide a fairly constant receiver output over a varying range of signal input.

17. Review Questions

1. What is the essential purpose of automatic volume control?
2. Describe the operation of a typical avc system.
3. Draw, from memory, a circuit that will meet the requirements of Question 2 above.
4. Explain the limiting factors governing the choice of time constants of the avc filter system.
5. Give typical ranges for the time constants of an avc filter system. Would a combination of 2 megohms and 0.1 μf be suitable? Why?
6. Draw a circuit of a typical electron indicator tube such as the 6U5/6G5 connected to the avc bus as a tuning indicator. Explain the indications of the tube to maximum avc voltage; repeat fot a minimum avc voltage.

7. What is delayed avc?
8. Draw, from memory, a typical circuit for avc operation, assigning typical values for broadcast receiver operation.
9. Explain the function of each of the components of Question 8.
10. How may avc delay potentials be acquired?

Chapter 3

PLATE AND GRID CIRCUIT DETECTORS

18. Introduction

It has been shown that, despite the excellent performance to be expected from a diode detector with respect to fidelity and signal handling ability, it does have certain shortcomings that make it unsuited for use in compact, inexpensive receivers.

The diode detector is insensitive and unselective. It does not have the ability to provide amplification of the received signal either before or after detection; as a matter of fact, a definite *loss* of signal strength occurs during the detecting process. In the modern multi-tube superheterodyne receiver, more than adequate r-f amplification occurs before the diode detector, and at least two stages of audio amplification follow the diode so that the lack of sensitivity is counterbalanced. Since the objective of the broadcast radio designer is good fidelity and signal handling ability, this additional circuitry is not consdered a drawback.

At the same time, the i-f amplifiers of a superheterodyne receiver provide all the selectivity required, hence the broad-tuning characteristic of the diode becomes relatively unimportant; here again, the added expense involved in the use of additional tubes and components is justified by the excellent fidelity of the diode detector under all types of signal conditions.

The moment the designer enters the field of small, highly compact equipment in which economy in tube usage is a factor of considerable importance, the picture changes completely. Low cost amateur receivers, walkie-talkies, vest-pocket portables, headphone receivers for children, receivers for radio-controlled model airplanes and boats, garage-door actuators, etc. must be based upon economical circuit design in which few tubes are used and very little power is consumed. The need for fidelity virtually disappears in these applications and signal handling ability likewise becomes inconsequential, because most of these receivers are intended to be used under very weak signal conditions. Thus, a type of detector other than the diode is demanded, a detector that can be counted on to offer much higher sensitivity and in some cases superior selectivity without adding to the number of tubes. The answer is found in the plate and grid-leak detectors to be discussed in this chapter and even more so in the regenerative and superregenerative detectors covered in Chap. 4.

19. Plate Power Detector

This detector arrangement is also known under the names "Bias Detector," "Anode Detector," "Power Detector," and "Plate Detector." The reader is cautioned at the start to avoid confusion with regard to the differences between *power detection* and *square law detection*. The forthcoming discussions will be confined to the conditions required for power detection, unless otherwise stated. As will be reviewed later, square-law detection is *not* a process that depends upon the type of detector circuit but is one that occurs as a result of the *signal and bias conditions* set up initially.

A plate detector is an amplifier biased approximately to cutoff. When such an amplifier is supplied with a grid input voltage of comparatively large amplitude, plate current pulses flow during each positive half-cycle of the applied alternating signal voltage. Since the modern triode and sharp-cutoff pentode have more or less linear transfer characteristic curves, these plate current pulses are proportional to the excitation voltage applied to the control grid of the tube and, if this input is modulated, the average amplitude of the plate current varies in accordance with the modulation envelope. Thus the intelligence present in the original may be recovered. This action is illustrated in Fig. 14, and the circuit diagram of a typical plate detector is given in Fig. 15. Either a triode or pentode may be used. For the first, transformer coupling between the detector and the succeeding audio amplifier is generally preferred. In the case of the pentode, resistance coupling is more practical, due to the high plate impedance in this type of tube.

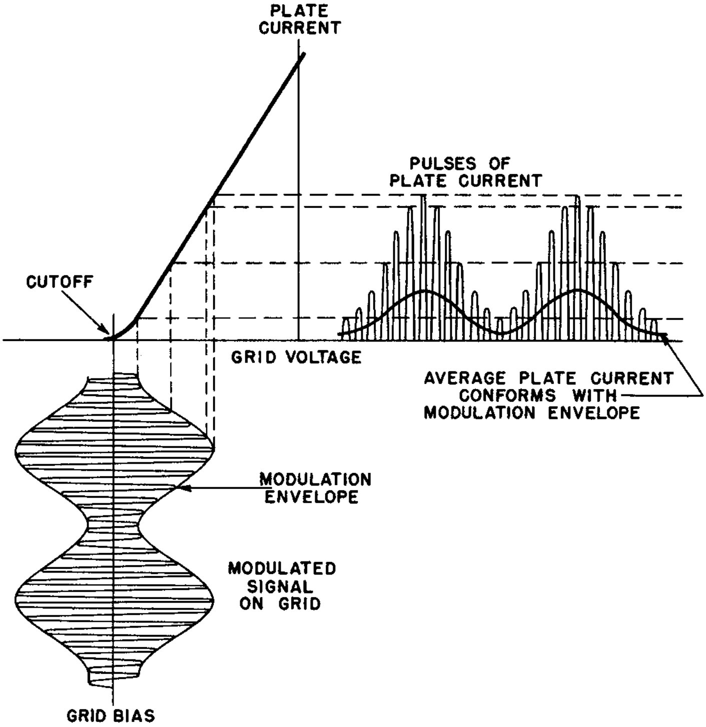


Fig. 14. The demodulating action of the plate detector

20. Circuit Analysis of the Plate Detector

The behavior of the antenna coupling coil, *L1*, and the tuned circuit, *L2C2*, is identical with that of the crystal and vacuum tube diode detectors discussed in previous chapters, with one important exception: the value of *R1* is intentionally made high so that the tube is biased practically to cutoff. If the signal is maintained at a sufficiently low level so that the grid is never driven positive with respect to the cathode, *grid current cannot flow.* Without grid current, power is not taken from the tuned circuit; i.e., it is not "loaded down." Accordingly, its *Q* remains effectively at the same value with or without signal. If careful consideration is given to the design of the tuned circuit, keeping its resistance as low as possible in comparison with its inductive reactance, its *Q* is initially high and, because it is not reduced by loading, the detector's selectivity is much improved.

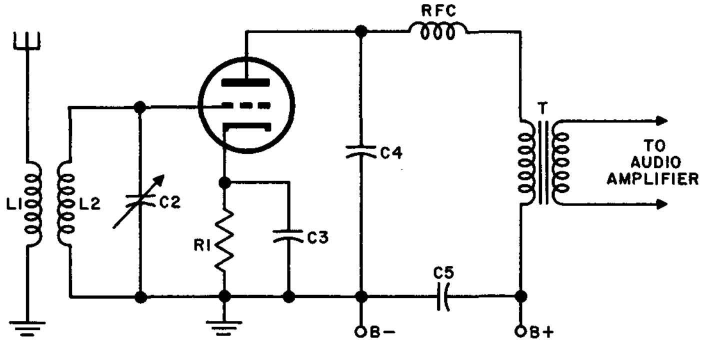


Fig. 15. Plate detector circuit.

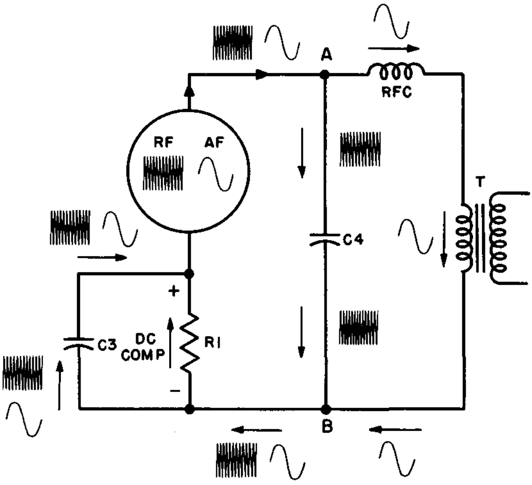


Fig. 16. R-f and a-f signal paths in plate detector.

The plate current contains r-f pulses of changing amplitude as shown in Fig. 14. The rate of change of these pulses is governed by the modulation frequency. Thus, the plate current may be viewed as being composed of two alternating components: the r-f variations and the slower audio variations represented by the average plate current changes.

Consider the tube as a generator whose output contains these two components. Figure 16 shows the paths of the component currents through the various parts that make up the "generator" circuit. In addition to the two alternating components, account must be taken of the d-c component that must be present in the plate current, since all of the pulses are above the horizontal axis in the curve of Fig. 14. That is, the plate current is unidirectional and, regardless of its variations, must have a definitely measurable d-c component. This component has been omitted from Fig. 16 for the sake of clarity. The only part of its path that is significant is through *R1*, the cathode bias resistor, as explained more fully below.

a. Both the r-f and a-f portions of the signal proceed together to point *A*, Fig. 16. At this juncture, the r-f component passes through the low reactance of *C4*, while the audio component finds an easier (lower impedance) route through the *RFC*. Hence, only the a-f portion finds its way into the primary of coupling transformer *T* and is passed on to the audio amplifier system.

b. The two components again join at point *B*. Capacitor *C3* is chosen so that its reactance is low for both r-f and a-f (0.1 μf and up). Both alternating signals pass through this capacitor and return to the generator.

c. The d-c component, however, is forced to flow through *R1*, producing a voltage drop having the polarity indicated in the figure. The cathode of the tube, therefore, is positive with respect to ground, while the control grid is at d-c ground potential at all times due to its connection through *L2*, Fig. 15. Thus, the tube is negatively biased and, if *R1* is large enough, the bias may be brought close to plate current cutoff as the operating conditions for this type of detector require.

It was shown in the first part of this paragraph that the unloaded tuned circuit makes good selectivity possible. The foregoing analysis indicates that the plate detector is capable of good sensitivity as well, because advantage is taken of the amplifying properties of a triode. When the a-f component of the signal current passes through the plate load impedance (transformer *T*, primary winding), a considerably greater signal voltage is possible here than was available at the input to the tube. This action is exactly the same as in an ordinary amplifier.

21. Grid-Leak Power Detector

This detector, as illustrated in Fig. 17, corresponds in many respects to an ordinary diode rectifier plus one stage of audio amplification. Although this is not the only method of analysis that may be applied to the grid-leak circuit, it is probably the easiest to understand and will therefore be used in this section.

The group of drawings in Fig. 18 illustrates the transfer from the straightforward diode circuit to the grid system of the grid-leak detector. In (A), a standard diode detector arrangement is shown to yield audio output in the form of a voltage drop across the load resistor, *R*. Capacitor *C* is the r-f bypass path and serves to prevent a radio-frequency voltage from appearing across *R*.

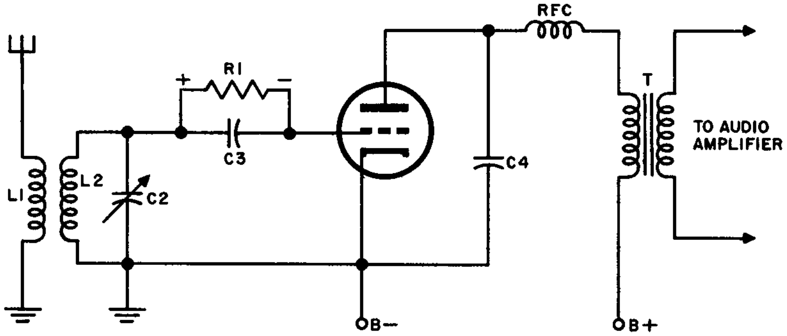


Fig. 17. Grid leak detector.

Since the tuned circuit, the diode, and the *RC* pair in the output are all in series with each other, the capacitor and resistor might, if desired, be moved into the new position shown in (B). This is not normally done in diode detectors because it is preferable to keep one leg of the output at ground potential in a multi-tube receiver (as in A), but the circuit modification in (B) provides just as much audio output as that of (A) if the component values are the same.

The diode plate is replaced by the control grid of a triode in (C). If connections were made across *R* in this case, audio output would again be obtained. This signifies, of course, that an audio potential appears across both *R* and *C*; in the grid-leak detector no attempt is made to utilize this potential at this point. Instead, the fluctuating voltage that appears across *C* is permitted to swing the grid of the triode so that amplified plate output may be realized.

22. Circuit Analysis of the Grid-Leak Detector

With no signal input, the control grid and cathode of the grid-leak detector are at ground potential (Fig. 17). As the steady d-c plate current flows from cathode to plate, a small percentage of the electrons will strike the grid structure and flow back to the cathode through *R1*, causing a small voltage drop having the polarity shown in the figure. Capacitor *C3* then charges to this voltage and maintains the control grid very slightly negative with respect to the cathode. Thus, the triode is biased under zero signal conditions, the magnitude of the bias being of the order of a fraction of a volt.

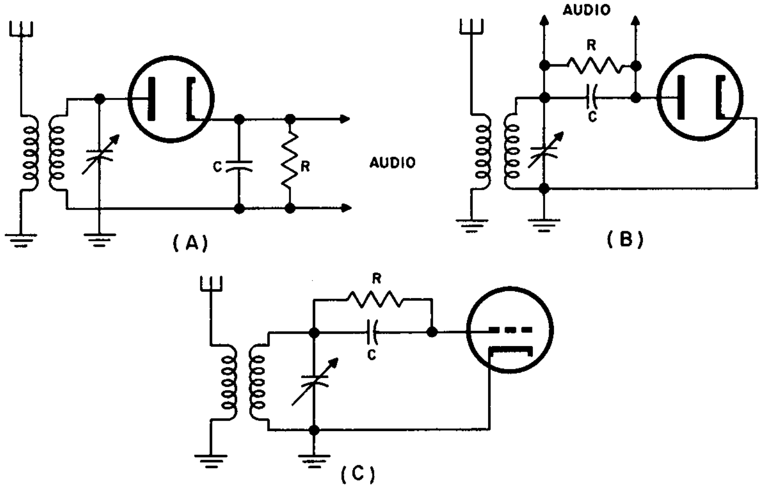


Fig. 18. Evolution from diode detector to grid-leak detector grid circuit.

When a signal appears across the tuned circuit, *L2C2*, the grid is driven into the conducting region by the positive half-cycles of the exciting voltage just as in the diode detector. The control grid thus draws additional current through *R1* and the voltage drop across this component increases, making the bias somewhat more negative. The time constant of *R1* and *C3* acting together is so chosen that the capacitor can charge and discharge at an *audio* rate but cannot follow the much more rapid variations of the r-f carrier. Hence, as the amplitude of the carrier rises and falls in accordance with the original modulation, the charge across *C3* fluctuates in the same proportion. Since the voltage on this capacitor *is* the triode bias, the latter also shifts toward and away from the zero axis (Fig. 19), producing an equivalent plate current change, which represents audio output.

The plate current of the triode during modulation has a varying r-f waveform (the rf is not shown in Fig. 19) with an average value that has audio frequency characteristics; it is this average current which flows through the primary of transformer *T* (Fig. 17) after the rf has been filtered out by the *RFC* and capacitor *C4*. At the same time, the d-c component of the average plate current also changes value during modulation as compared with the zero-modulation condition. As the diagram shows, the d-c component (as would be read on a d-c milliammeter connected in series with the plate and power source) drops with modulation to a lower value, this value being maintained as long as the modulation amplitude remains the same. For instance, if the carrier is 100 percent modulated by a sinusoidal signal of unvarying intensity, the d-c component of the average plate current is a fixed size and somewhat lower than the unmodulated value. As the modulation intensity changes, the d-c component likewise changes betwen the 100 percent modulation value and the unmodulated value.

23. Values of Grid-Leak Resistor and Grid Capacitor

As a result of the flow of grid current through *R1* in Fig. 17, grid capacitor *C3* becomes charged almost to the peak value of the unmodulated carrier, this charge becoming the operating bias of the triode. The grid potential remains fixed as long as the r-f input voltage does not vary. Now, if the r-f carrier amplitude should begin increasing due to modulation, the grid current would increase and a larger negative voltage would appear across *R1* and *C3*. During the process wherein *C3* becomes charged, the only resistance in series with the capacitor is the cathode-to-plate impedance of the tube itself. Since this may be considered to be of the order of 1000 ohms, remaining fixed throughout the detection process as long as the grid is being driven positive, the time constant of the circuit is quite low and *C3* can charge almost instantaneously.

As the amplitude of the r-f carrier begins to drop on the descending half-cycle of the modulation, the capacitor must start to discharge through *R1*. The rate at which this discharge occurs is a very important factor in the operation of the detector, because it must lose its charge fast enough during each r-f cycle to follow the decreasing audio amplitude contained in the modulation component of the carrier. On the other hand, it should not discharge too quickly, or severe distortion is likely to occur.

Since the discharge rate is determined by the values of both *R1* and *C3* (time constant $= R \times C$), these components must be selected judiciously with a view toward minimizing frequency dis-

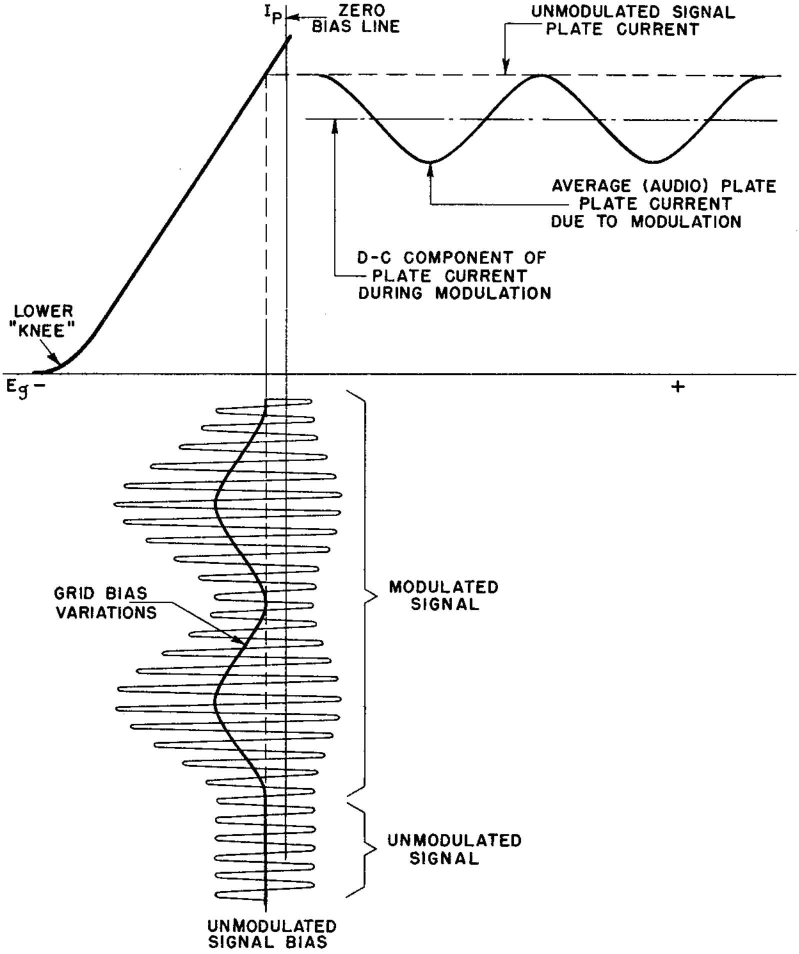


Fig. 19. Action in a grid-leak detector.

tortion and achieving the greatest possible detector efficiency. Although the radio frequency upon which the detector is expected to operate contributes toward the choice of *R1* and *C3*, a given set of values covers a very wide band. Typical combinations are as follows:

	C	*R*
Broadcast band (550 to 1600 kc)	.00015 μf	2 megohms
High frequency communications (3000 kc to 30 mc)	.0001 μf	1 megohm
Very-high and ultra-high frequencies (above 30 mc)	.00005 μf	.5 megohm

24. Power and Square-Law Detectors

Any type of detector may operate square law. This term merely refers to the effect of the lower knee of either the grid voltage-plate current characteristic curve or the grid voltage-grid current curve, depending upon the kind of detector concerned. Grid-leak detectors are sometimes referred to as square-law detectors because they have been used this way more often than plate detectors, but the conception that all grid-leak detectors are square law, or that no other detector may operate square law is completely erroneous.

Square-Law Plate Detector. If a plate detector is biased just beyond cutoff (Fig. 20) and a very small signal is applied, the curvature of the E_g-I_p characteristic makes it possible to obtain an output plate current that effectively varies as the square of the input grid voltage. Such a detector may be adjusted so that the lower knee is very close to parabolic in shape. The general equation for a parabola ($y = kx^2$) shows at once that the output (obtained along the y or vertical axis) is proportional to the square of the input (obtained along the x or horizontal axis). This relationship accounts for the increased sensitivity to be expected from square-law action in the case of the plate detector, but it must be borne in mind that the input signal must be very weak for this effect to occur with the bias conditions given. Thus, this square-law plate detector is characterized by greater sensitivity, but unfortunately the same effect that contributes to increased gain also raises the second-harmonic distortion content of the output signal.

Square-Law Grid-Leak Detector. Since this detector rectifies the input signal in the grid circuit, the explanation for square-law behavior must be sought by examining its E_g-I_g curve rather than the E_g-I_p curve as in the case of the plate detector. Here again, a weak signal is a necessary condition for square-law response. Such a weak-signal detector makes use of the curved relationship existing between grid current and grid voltage in the region of zero bias. At this operating point—a point that is normal for grid-leak detectors—the grid current is almost proportional to the square of the instantaneous grid input voltage. In flowing through the grid-leak resistor, a larger voltage drop for the modulation component is developed than would normally occur if the curvature were not present. Thus, the bias varies over a greater range and the amplified output is increased substantially.

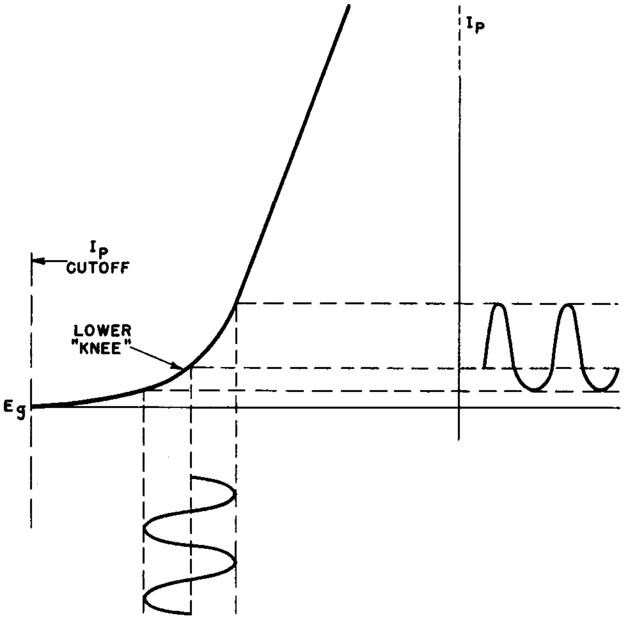


Fig. 20. Operation of the square-law plate detector.

Square-law action is encouraged in this detector by making the grid-leak resistor and the grid capacitor higher in value than in the power detector, .00025 μf for *C3* and 5 megohms for *R1* being very common. Except for the regenerative and superregenerative detectors to be discussed in the next chapter, a square-law grid-leak detector is the most sensitive arrangement of all, and also the one that causes the most distortion of the detected signal.

It is common practice to use relatively low plate voltages for both grid-leak and plate square-law detectors. In the first case, low plate voltage is necessary to prevent excessive plate current because the tube operates at practically zero bias; in the second case, low plate voltage increases the curvature of the lower knee of theE_g-I_p curve, improving the square-law response.

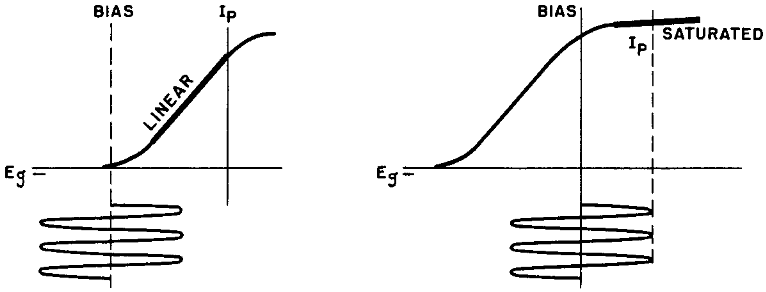


Fig. 21. Comparison between operating range of plate detector (left) and grid-leak detector (right).

25. Signal Handling Ability of Plate and Grid Detectors

That the plate detector, square-law or power, is capable of handling larger signals than the grid-leak detector without distortion comes as no surprise if their respective modes of operation are well-understood.

The positions of the respective operating bias lines explains this difference (Fig. 21). Since the plate detector is biased at or close to plate current cutoff, a wide input signal swing does no harm because it merely utilizes more and more of the linear portion of the transfer curve (within limits, of course) in producing its output.

A similar driving voltage applied to the grid of the grid-leak detector quickly drives the tube into saturation. The same effect occurs in the grid circuit as the grid voltage-grid current curve also reaches saturation quickly.

The obvious conclusion is that a grid-leak detector is best suited for use in applications where high sensitivity is needed for weak signals and where distortion of output is not a serious handicap. A plate detector is most applicable in circuits which do not require high sensitivity but do demand large signal handling ability and better fidelity.

26. Review Questions

1. List the types of equipment and circuits that might utilize (a) plate, and (b) grid circuit detectors.
2. Draw, from memory, a typical triode plate detector circuit; a typical pentode circuit. How does coupling between each detector drawn and the succeeding audio stage differ?
3. Analyze the circuit action of the plate detector when the signal input is low. Explain the function of *R1*, the *RFC*, and *C4* in Fig. 16.
4. What is the difference between power detection and square-law detection?
5. Draw, from memory, the circuit of a grid-leak detector. Give typical values and explain the operation of each component for a detector in the high frequency communications range.
6. Analyze the circuit of Question 5. Explain the factors determining the selection of time constant for the grid-leak capacitor and resistor.
7. Explain the fluctuation of the d-c component of the average plate current with changing modulation conditions, in a grid-leak detector.
8. Explain the operation of the plate detector when operated as a square-law plate detector.
9. Explain the operation of the grid-leak detector as a square-law grid-leak detector.
10. Compare the signal handling abilities of plate and grid detectors.

Chapter 4

REGENERATIVE AND SUPERREGENERATIVE DETECTORS

27. The Meaning of Regeneration

Regeneration is a general term that implies, whatever the sense of its usage, *feedback* from the output of a vacuum tube stage to the input of the same or a previous stage. Regenerative feedback is the transfer of energy from output to input of one or more stages, in such phases as to increase gain or amplification. If regeneration is great enough, it causes oscillation.

Unless the phase of the energy transferred from the output coincides with the phase of the input energy, regeneration does not occur. The process may be viewed as one of reinforcement of successive cycles of voltage, current, or power in which a small amount of signal energy is first amplified, usually by an electron tube, and is then partially used to build up the intensity of the input signal by feeding back a small percentage of the amplified energy in phase with the incoming signal.

Although regeneration in amplifiers is generally undesirable because it leads to instability and oscillation, it is intentionally introduced in the circuits of some detectors to provide a substantial increase in sensitivity and, in special cases, to bring about sustained oscillation for making code (cw or continuous waves with no modulation) signals audible.

28. Advantages and Disadvantages of Regeneration in Detectors

The most important advantage of regenerative detection is that it offers a very economical means of obtaining a considerable amount of radio-frequency amplification without the use of preamplifiers. The second item in its favor relates directly to its application in the reception of cw (code). Since such transmissions are unmodulated in the usual sense, they contain no audio components riding on the radio-frequency carrier and are, therefore, inaudible after detection. If the detector oscillates, however, the received unmodulated signal is heterodyned by the r-f signal generated by the detector to produce an audible note. The heterodyne or "beat" process is discussed in greater detail later.

The disadvantages of regeneration so outweigh the advantages insofar as the average public user is concerned that it is seldom included in equipment intended for this market. For the radio amateur and the expert commercial operator, regeneration does not offer severe handicaps despite these disadvantages: (a) very critical adjustments are necessary to obtain exactly the amount of regeneration desired, (b) improper adjustment results in oscillation when it is not wanted, and (c) an oscillating detector radiates a signal that may cause interference in other nearby receivers.

During the last two decades the trend has been away from regenerative detectors, even though this has meant more complex and more costly equipment. Nevertheless, the principles underlying regeneration are important enough to justify devoting a large part of this chapter to their analysis.

29. Methods of Obtaining Regeneration in Detectors

Undesirable or unintended regeneration may usually be traced to one of two basic causes: the presence of stray capacitance between the grid and plate circuits of the amplifier tubes, or impedances common to two or more stages of amplification. Regenerative dedectors, however, almost universally employ inductive feedback for this purpose because it is more easily controlled.

A typical circuit is given in Fig. 22. When a radio-frequency carrier induces a voltage in the antenna, a current of this frequency flows down to ground through *L1*, inducing a voltage of similar frequency across *L2*. If *L2* and *C2* are resonant at this frequency, a large r-f voltage appears at the grid of the tube. For the time being, *C1* may be considered as a coupling capacitor that transfers the signal from the resonant circuit to the tube grid.

As the grid voltage fluctuates with the signal, the plate current of the electron tube varies in the same manner and, since the plate current flows through the "tickler" coil, *L3*, a fluctuating magnetic field having the frequency of the original signal appears around this inductor. *L3* is physically close to *L2* so that its magnetic field can induce a voltage in the *L2-C2* resonant combination; furthermore, the direction of its winding is such that the phase of the induced voltage is the same as that of the original signal. Thus, the induced voltage adds to the intensity of the signal voltage, is reamplified, and again fed back to the grid circuit via the electromagnetic path between *L3* and *L2*, thus increasing the signal voltage still further.

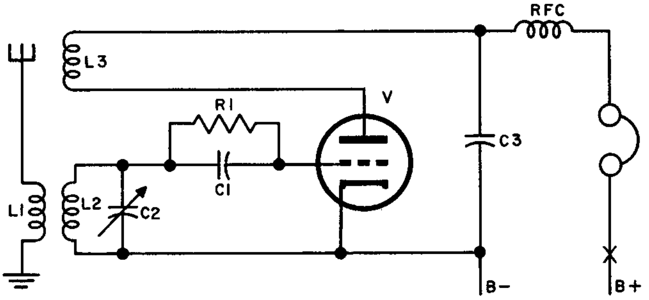


Fig. 22. Triode regenerative detector.

Two effects are possible from this cyclic feedback and amplification: (a) a large increase in gain, or (b) oscillation. Which one occurs depends upon the ratio between the signal voltage and the feedback voltage but, before comparing these, it is wise to analyze the circuit action further.

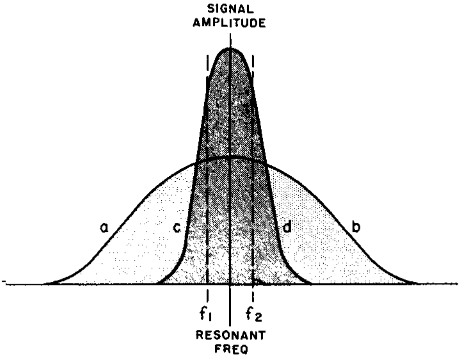
30. Analysis of Regenerative Detector Action

Regeneration produced as described in the preceding paragraph has the effect of changing the reactance of the input circuit, due to the coupling between *L2* and *L3*. This alteration of reactance changes the resonant frequency of the *L2-C2* circuit slightly, but this effect is small because it amounts to only a few ohms—a tiny percentage of the total reactance present in the tuned circuit. Hence, for analysis purposes, it may be ignored.

A tuned circuit has inductive reactance, capacitive reactance, and resistance. It is the last that causes an oscillation to "damp out" once it has started; theoretically, at least, a tuned circuit of zero resistance will oscillate forever once oscillation begins, because no loss of power occurs in a pure inductance or a perfect capacitance. When the energy is fed back in the proper phase to reinforce the applied signal, the effect is to cancel out a part of the resistance of the tuned circuit. Since the characteristics of a resonant circuit depend primarily upon the ratio of inductive reactance, X_L, to resistance, R, this reduction of resistance has a profound effect upon the Q of the circuit.

Q, it will be remembered, is defined as X_L/R. When the R factor is reduced by regeneration, the circuit Q rises. This results in both an increase in gain and a significant improvement in selectivity (Fig. 23). Curve *ab* is the response pattern obtained when the Q of the tuned circuit is low; i.e., although the largest voltage appearing across the tuned circuit occurs at the resonant frequency, it is not much of an improvement over the voltages obtained at f_1 and f_2, frequencies adjacent to that of resonance. Nor is the absolute magnitude of the voltage much in excess of those obtained at considerable distances from resonance. For a tuned circuit of high Q, curve *cd* exhibits two important changes for the better: first, the curve is steeper, causing the response to drop off sharply above and below resonance. This, of course, makes for better selectivity. Second, the amplitude of the voltage at resonance is much greater than for the low Q circuit.

Fig. 23. Response of tuned circuit when Q is low *(ab)* and when it is high *(cd)* as a result of regenerative feedback, which reduces effective resistance.



In neutralizing part of the resistance of the resonant pair, *L2* and *C2*, regeneration thus improves both sensitivity and selectivity by raising the Q of the circuit. When the regeneration is carried as far as possible, without causing oscillation, i.e., to the point where the resistance of the tuned circuit approaches zero, the resulting amplification is very great, particularly for weak signals. Oscillation begins when the feedback voltage exceeds the original signal voltage before amplification. Under these conditions, the resistance of the tuned circuit has been made negative in the sense that regeneration has been carried beyond the point where the circuit resistance became zero. Then oscillations, once started, are sustained by energy fed back from the output of the tube to its input.

31. Regeneration Control

As the performance of a regenerative detector depends so much upon the *amount* of feedback, various methods have been developed for controlling the strength of the signal induced in the tuned circuit. One af the most obvious is the system that permits the distance between (or relative positions of) *L3* and *L2* to be changed. This, of course, has a direct effect upon the magnitude of the emf induced in *L2* by the electromagnetic field surrounding *L3*. In the earliest radio receivers using regenerative detectors, the tickler coil (*L3*) was mounted inside the tuning coil (*L2*) in such a manner as to permit the tickler to rotate as the regeneration control knob was turned. When the axis of the tickler coil coincides with the axis of the tuning coil, and the coil connections are in proper phase, regeneration is maximum; at the other extreme position (with the two axes at right angles) feedback is close to zero.

A less cumbersome way to accomplish the same effect is to make *C3* a variable capacitor while *L1*, *L2*, and *L3* are all fixed on one coil form. The feedback current magnitude through *L3* is determined by the impedance presented by the series circuit comprising the plate resistance of the tube, the reactance of *L3*, and the reactance of *C3*. At minimum capacitance, with the plates fully unmeshed, *C3* should possess enough capacitive reactance to keep the feedback current at a low level so that oscillation does not occur; as the capacitance is raised the feedback current increases until the tuned circuit resistance is effectively zero and oscillation begins.

A third system for the control of regeneration involves the use of a series rheostat to vary the plate potential of the tube. Low values of plate voltage reduce amplification, with an accompanying decrease of feedback. The disadvantage of this method lies in the fact that the tube is always working under less than optimum plate voltage, so that fullest amplification is not realized. To install such a rheostat, the circuit would be opened between the source of B+ and the plate load of the tube (in the case of Fig. 22, the headphones act as the plate load) and the resistance inserted at point *X*.

Control of regeneration by varying tube element d-c voltages offers several advantages, among which are economy, smoothness of operation, and freedom from body capacitance. To this end, a pentode may be used as a regenerative detector with substantial improvement in performance, the feedback control being used to govern the screen potential. Such a detector is pictured in Fig. 24. The gain of a pentode, such as the 6SJ7 or 6AU6, is largely a function of the screen voltage, increasing voltage causing rising amplification. As the amount of regeneration is materially affected by the gain of the tube, resistive control of screen voltage offers a positive means of controlling feedback. In designing such a detector, account must be taken of the critical components to obtain good operation. In particular, the coupling between the tickler coil, *L3*, and the tuning coil, *L2*, must be adjusted so that oscillation begins when the screen voltage is between 20 and 40 volts. If the starting point is above 40 volts, oscillation is likely to begin with an annoying thump; when the critical point is below 20 volts, the efficiency of the detector deteriorates and the output is low. Coupling is affected by both the number of turns in *L3* and the spacing between the two coils. In general, *L3* should have about 1/4 the number of turns on *L2* and the spacing between them should be about 10 percent of the length of the *L2* winding.

The values of *R2* and *R3* may be computed easily as follows:

a. the range of voltages that *R2* should be capable of yielding is approximately 0 volts to 50 volts.

b. the B supply potential should be known; assume it to be 250 volts under normal load.

c. thus the voltage drop across *R2* is one-fifth of the supply voltage and its resistance should be one-fifth of the total resistance of *R2* and *R3* in series.

d. If a standard 1/2-watt resistor of 250 k ohms is used for *R3*, *R2* should be a 50-k potentiometer.

e. Thus the total series resistance is 300 k ohms and, since the applied voltage is 250 volts, the bleeder current is 250/300,000 = 0.8 ma, which is well below the 1/2-watt ratings of the fixed resistor and potentiometer.

Other component values are: *R1* = 1 to 5 megohms; *C2* = 100 μμf; *C3* = 1 to 2 μf; *C4* = 100 μμf; *C5* = 100 μf; *C6* = 0.1 μf; *L4* = 500-henry audio choke; *RFC* = 2.5 to 10-mh r-f choke, *V* = 6SJ7, 6AU6, or equivalent sharp cutoff pentode. Note that *C3* serves a dual function in that it not only maintains the screen at constant r-f potential with respect to ground but also serves as a "scratch" filter to remove noise caused by the movement of the potentiometer wiper. The construction of *L1, L2,* and *L3* and the size of *C2* are dependent upon the range of frequencies the detector is expected to receive.

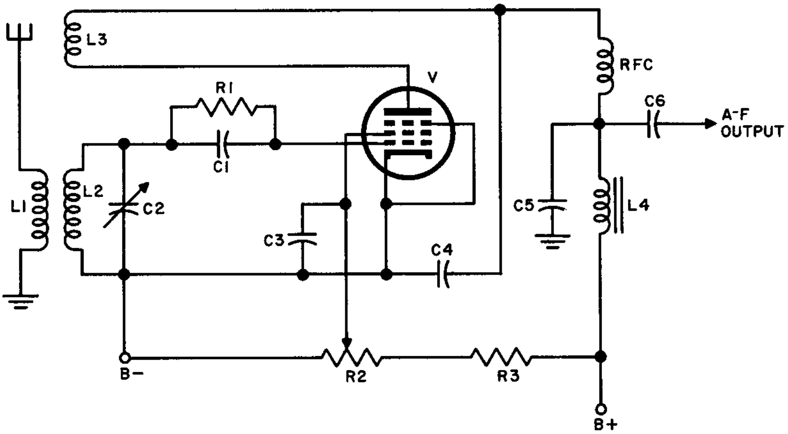
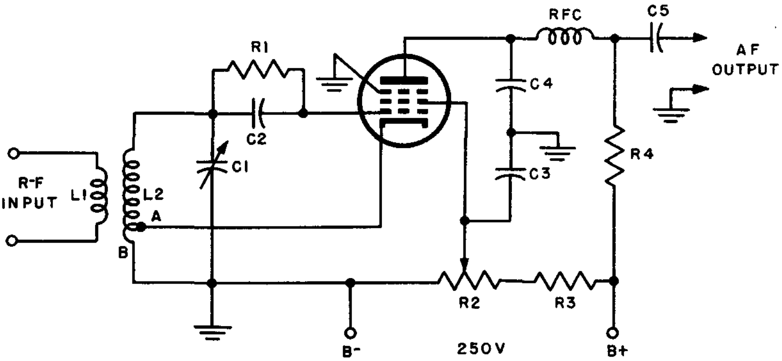


Fig. 24. Pentode regenerative detector with regeneration control in the screen circuit.

32. Analysis of Oscillating Detector Action

When the incoming signal has exactly the same frequency as that of the oscillating signal produced by the regenerative detector, the result is the complete absence of sound or "zero beat." Detuning the detector slightly, either above or below the received frequency, gives rise to an audible tone whose frequency is determined by the difference between the two r-f signals. For example, an oscillating detector adjusted to 4400 kc produces a beat note of 1000 cps while receiving a signal of ither 4401 kc or 4399 kc.

To analyze the action further, consider that the phase of the signal with respect to the phase of the oscillation voltage goes from zero to 360 degrees through all the intermediate phase angles at a rate corresponding to the difference between the two frequencies. The amplitude of the voltage applied to the grid of the tube varies just as though there were no applied signal at all, but in such a manner as to indicate that the regeneration of the oscillating detector is rising and falling at a rate corresponding to the beat frequency. This means that the detector is most sensitive when a tiny change in the amount of regeneration produces a large change in the amplitude of the oscillation. This condition exists at the setting of the regeneration control where the feedback has the *smallest* value needed for sustained oscillation and where the circuit Q is the highest.



A-B = 10% OF TURNS IN L2

R1 = 1-5 MEG
R2 = 50K OHMS
R3 = 250K
R4 = 250K

C2 = 100 $\mu\mu$F
C3 = 1-2 μF
C4 = 100 $\mu\mu$F
C5 = 0.1 μF

Fig. 25. Practical regenerative detector with screen-grid regeneration control and resistance coupling.

This explains why an oscillating detector should be adjusted close to the point where oscillation is about to cease if the best sensitivity is to be realized. Unfortunately, trouble in the form of an audio howl (fringe howl, threshold howl) is often encountered at just this setting. Threshold howl affects triodes more often than pentodes and is caused by the inductive load in the plate circuit of the detector (*L4* in Fig. 24). This objectionable effect may be cured by using resistance coupling or by shunting the coupling inductor with a sufficiently low resistance.

A somewhat different arrangement of parts for the construction of a thoroughly practical detector is given in Fig. 25. Resistance coupling as used here prevents threshold howl.

33. Superregeneration

A non-oscillating regenerative detector is far more sensitive than an ordinary grid-leak detector. However, it is limited in sensitivity because, while a modulated signal is being received, regeneration cannot be carried beyond the point where oscillation starts. If it is, the quality of the modulation is destroyed. There is another important factor that creates a limitation on the amount of regenerative sensitivity, however. This was explained in Par. 32, where it was demonstrated that the greatest sensitivity of the receiver occurs when the feedback has the smallest value needed for sustained oscillation. This occurs just as long as the oscillation is sustained and unvarying.

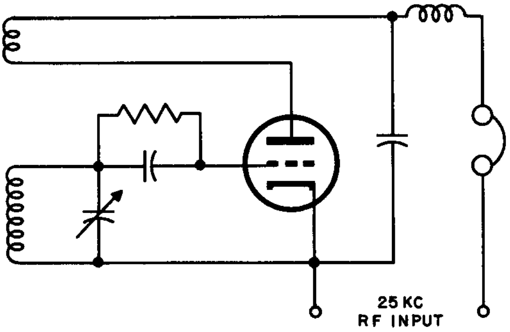


Fig. 26. Simple regenerative detector with 25-kc a-c source of plate voltage, to make it a superregenerative detector.

An enormous increase in sensitivity may be attained by periodically quenching the oscillation while the detector is in operation. Essentially, this process, called superregeneration, involves the use of a low radio frequency plate voltage, screen voltage, or control grid bias, which serves to turn the oscillation on and off at the rate of the varying potential.

Figure 26 is a representation of the condition in which an ordinary regenerative detector is powered with 25-kc plate supply voltage instead of dc. As the supply voltage makes the plate positive with respect to the cathode, the circuit oscillates freely; on the following half-cycle, when the plate goes negative the oscillations in the tuning circuit die out as a damped wave. To perform correctly, the oscillations must decay completely before they start to build up again so that the quenching rate must be adjusted to permit this to occur (Fig. 27).

In the absence of an incoming signal, oscillation in the tuning circuit is triggered into existence by random effects, such as thermal agitation, changes of cathode emission, shot effect, etc. The extent to which the oscillations build up and, consequently, the time required for them to die down depend almost entirely upon the amplitude of the triggering pulse. Since these pulses are purely random, successive groups of oscillations may vary in amplitude by considerable amounts (Fig. 28). Hence, when no signal is arriving, the ragged envelope compounded of the individual, irregular envelopes of the successive groups is detected as a hissing noise that is always characteristic of superregenerative detectors.

Upon the arrival of a signal—let us say an unmodulated carrier—each successive group of oscillations is initiated by a pulse of the same amplitude, resulting in an unchanging compounded envelope; thus, when a signal is received, the hiss either disappears completely or becomes much subdued, depending upon the strength of the signal. As modulation is applied, the amplitudes of the groups change slowly with the audio just as the carrier amplitude is changing, yielding a compounded enevelope, which contains the audio component. This component is, of course, recovered by grid-leak detection.

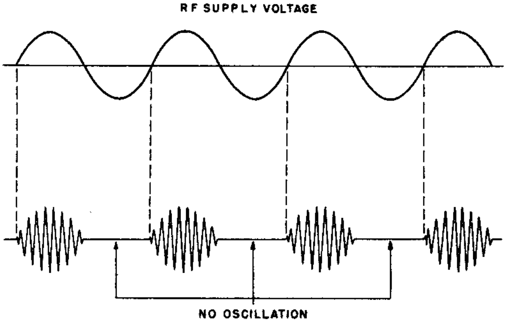


Fig. 27. Waveforms showing how oscillation is interrupted in a superregenerative detector.

As mentioned earlier in this paragraph, the quench frequency may neither be too high nor too low. If it is too high, oscillations cannot build up to full size before being squelched; too low a quench frequency results in a loss of sensitivity since there is an insufficient number of groups of oscillations per unit time. Furthermore, the quench frequency must never approach the audio range;

if it did, it would be heard as a high-pitched squeal of constant amplitude.

34. Superregenerative Detectors

The simplest type of superregenerator is identical in circuit arrangement with the ordinary regenerative detector as illustrated in Fig. 22. The only difference lies in the choice of the grid-leak and grid capacitors. If both of these are made considerably larger, the *RC* time constant becomes great enough to cause slow bias decay, a form of self-quenching. The sequence of events in this form of grid-squelching runs somewhat as follows: oscillation first builds up to the condition in which the amplitude of the oscillatory voltage is such as to establish equilibrium between the gain of the tube, the grid bias produced, and the magnitude of the oscillations. Normally, should any transient effect occur that would tend to reduce the amplitude of the oscillatory voltage, the grid bias would immediately drop to counteract the effect, thus maintaining equilibrium. Now, however, with the *RC* time constant in the grid circuit so large, oscillations may begin to die out, but the bias does not follow because the grid capacitor holds its charge much longer. Thus, if the grid capacitor and grid leak are correctly proportioned, the oscillations will die out and will not start again until the grid capacitor has discharged, allowing the bias to drop to the point where any triggering pulse can start the process once more.

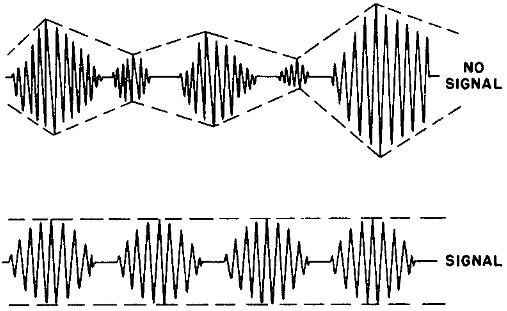


Fig. 28. Difference between signal and no-signal conditions in superregenerative detector.

A separately quenched circuit is preferred by some. The circuit shown in Fig. 29 utilizes an additional tube and quenching transformer to raise and lower the screen voltage at a radio frequency rate. The d-c screen voltage is fed to the superregenerator through the tank coil of the quench oscillator so that, effectively, the screen of one tube is in parallel with the plate of the other. Thus, as the quench tube oscillates, its plate potential rises and falls, causing the screen voltage on the superregenerator to follow suit. This alternating increase and reduction of tube amplification produces the desired squelching action.

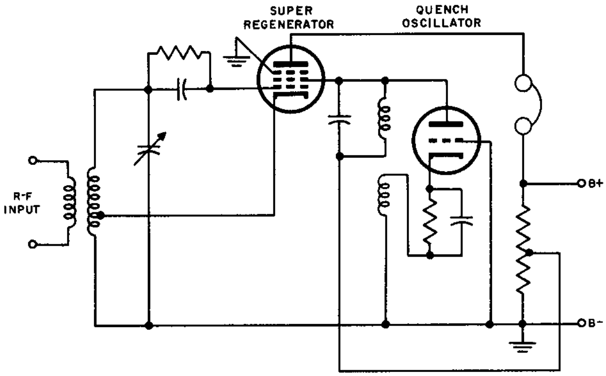


Fig. 29. Superregenerative detector employing a separate quenching tube.

35. Evaluation of Superregenerative Detectors

Three factors encourage the continued use of the superregenerator particularly at the ultra-high frequencies: (a) its sensitivity is very great, (b) it is economical to build and use, and (c) it is relatively immune to such interference as ignition noises, spark discharges, and atmospheric static.

At the same time it is subject to certain severe limitations: its characteristic hiss is annoying and does not disappear entirely except in the presence of a very strong signal; the superregenerator is relatively unselective in tuning; and the circuit radiates energy that could readily cause interference.

The development of adequate superheterodyne design and components has made the superregenerator all but obsolete even for the ultra-high frequencies except in the most compact and inexpensive equipment.

36. Review Questions

1. Define regeneration. For regeneration, what must be the phase of the feedback?

2. What are the advantages of regeneration? The disadvantages?
3. Draw a simple regenerative detector circuit. Explain the action of the circuit.
4. Explain the effect of variation in the Q of the tuned circuit of a regenerative detector.
5. Modify or complete the drawing of Question 3 to provide control of regeneration by varying the tube element d-c voltages.
6. What advantages does the circuit of Question 5 have?
7. What values might you assign to the components in the circuit of Question 5?
8. What circuit modifications would *greatly* increase the sensitivity of a regenerative detector? What is this process called?
9. Explain how the quench action of the superregenerative detector is obtained.
10. Evaluate the performance of a superregenerative detector. What disadvantages do superregenerative detectors have?

Chapter 5

SPECIAL A-M DETECTORS

37. The Infinite Impedance Detector

The importance of a high impedance input circuit to the detector has been emphasized previously; unless the circuit conditions are arranged so that the grid does not draw current during operation, the tuned circuit is "loaded" and its *Q* drops appreciably. This, as has been demonstrated, broadens the tuning and results in unsatisfactory selectivity.

The diode and grid-leak detectors suffer from this shortcoming. Even in the case of the plate detector, a strong r-f signal can drive into conduction, thus loading the tuned circuit and broadening the response.

The circuit given in Fig. 30 resembles that of the plate detector and is often referred to as an *infinite impedance* detector. Typical values for the parts important to this discussion are: *C3*-270 $\mu\mu$f; *R1*-100 k ohms; *C1*-0.5 μf or more; and *R2*-50 k ohms.

Audio output is taken from across the cathode bias resistor and, since this resistor is common to both grid and plate circuits as far as audio is concerned, it provides degeneration (negative feedback) for these frequencies. The consequence of this is that even sudden bursts of heavy modulation cannot drive the grid into conduction because, as the instantaneous plate current tends to rise excessively under these conditions, the voltage drop across *R1* likewise increases and biases the grid more negatively to counterbalance the effect of the positive half-cycle of the r-f input.

The plate current is very low with no signal, increasing with signal as in the case of the plate detector. The drop across *R1* increases with signal whether or not the latter is modulated. This fact, plus the large initial voltage drop across the bias resistor, makes it difficult to drive the grid positive even with an unmodulated signal. Add to this the fact that degenerative action occurs when modulation begins, and it is clear that only under the most adverse conditions does the grid circuit draw current.

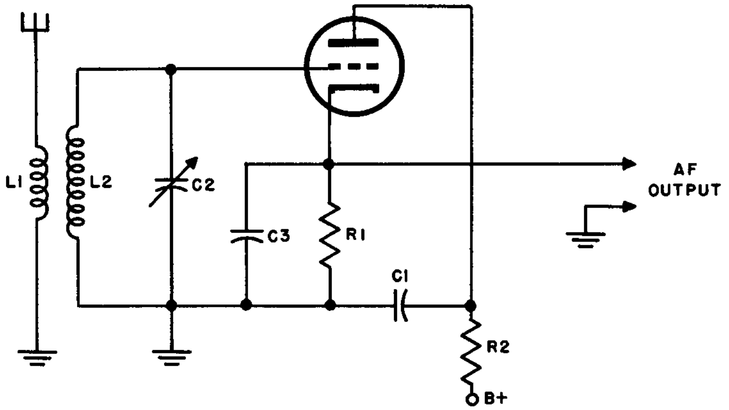


Fig. 30. Infinite impedance detector circuit.

The name *infinite impedance* is derived from this behavior. A circuit that does not permit current to flow even under the pressure of relatively high emf must have an extremely high impedance. Thus, this detector is characterized by large signal handling ability, very little distortion, and good selectivity.

38. The Heterodyne Detector

Heterodyne detection offers a means of converting an alternating voltage or current of a given frequency to a new alternating voltage or current of a lower frequency. The process involves mixing the signal to be converted with another locally generated signal whose frequency may be higher or lower by an amount equal to the frequency of the new heterodyne signal produced.

The use of a numerical example should be of help in clarifying this notion.

A ship radio transmitter, using cw or code signals, emits a carrier whose frequency is 5000 kc. This carrier is keyed by hand in the characters of the International Morse Code. Such transmission consists of groups of wave trains (Fig. 31), which start and stop abruptly but which maintain constant amplitude while the wave train is in existence. No audible result is obtained if an attempt is made to listen to this signal with any of the detector circuits thus far discussed. Code characters can be properly "copied" (transcribed as letters) by the receiving operator only if a dot is heard as an audible note of short duration and a dash as a similar note of greater duration. (The exception to this is the process of copying telegraphy from the old-fashioned sounder by means of which a dot is transmitted as a *short space* between two clicks and a dash as a longer space between two similar clicks. The same thing is occasionally done with a radio receiver, but a tone is preferable.) In the reception of radio code, it is customary to convert the radio frequency voltage—5000 kc in this example—to an audio frequency of, say, 1000 cps within the receiver itself so that the dots and dashes are heard as long and short whistling sounds.

Fig. 31. The letter *R* in international Code, reperesented in keyed r-f carrier.

Suppose that an oscillator is set up in the receiver to produce a steady output of 5001 kc while the above transmission is being received and that the oscillatory voltage is coupled to a circuit that mixes the incoming signal with it. If the mixer is a *non-linear device,* its output contains components of four different frequencies: the original signal, 5000 kc; the oscillatory frequency, 5001 kc; the difference frequency, 1 kc (1000 cps); and the sum frequency, 10,001 kc. Of these, only the difference frequency is of interest because it lies within the audio spectrum; the other three may be eliminated by suitable filters and only the audio voltage passed on to the amplifiers that follow. Thus, the original 5000-kc wave trains have been reduced in frequency to 1000-cps wave trains in the same dot-dash pattern they had when keyed at the transmitter. In the converted reception of code signals, the local oscillator is called a beat frequency oscillator (or BFO) and the audible difference frequency is termed the beat frequency. In the example just cited, it would be necessary to retune the oscillator for each new received frequency to establish an audible beat frequency, i.e., to maintain a constant difference between the two. This is accomplished automatically in the oscillating regenerative detector (see Par. 32) because the oscillatory frequency is tuned by the same circuit that is used for station selection. If the receiver is a superheterodyne, a BFO of constant frequency may be used because all incoming signals are previously converted to a single radio-frequency (the intermediate frequency) by the receiver's mixer or converter stage.[1] For instance, if the receiver IF system is aligned at 455 kc, the BFO may be adjusted to produce a steady oscillation at 455.5 kc, thus providing a beat note of 500 cps whenever a cw station is tuned in.

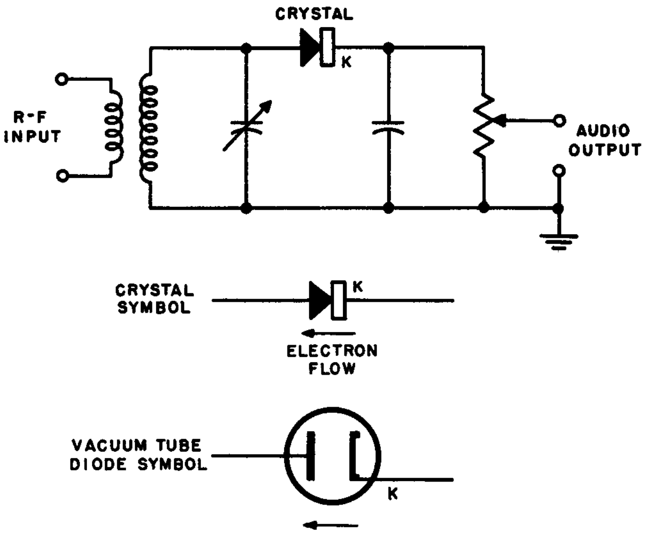


Fig. 32. Crystal diode detector, and symbolic representation of the diode.

39. Modern Crystal Diodes

Modern crystal diodes, particularly silicon and germanium, are being used in increasing numbers to replace vacuum tube diode detectors. New industrial techniques have enabled manufacturers to produce economical units having good linear characteristics, low

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[1] Frequency conversion in superheterodyne receivers is to be discussed at length in the Review Series booklet titled *Superheterodyne Conversion and I-F Systems.*

forward resistance, and high backward resistance so that their performance comes very close to the equivalent vacuum tubes. Germanium crystals, especially, operate satisfactorily even in the very high radio frequency ranges and are found in radar receiving equipment, television sets, and other high frequency gear where vacuum tubes once stood unchallenged. The circuit diagram for a typical germanium diode detector appears in Fig. 32. It duplicates the vacuum diode circuit exactly. Note should be made of the fact, however, that the diode symbol is the reverse of what one would expect it to be for representing electron flow. The terminal labeled "K" (sometimes labeled "+") is the equivalent of the cathode of a tube, hence electrons flow opposite to the direction in which the symbol's arrow points.

40. Video Detectors

Video detectors, as encountered in radar and television receivers, are the same as the a-m detectors treated earlier in this book, except for one detail that is important in picture detection but inconsequential in the recovery of the audio component from the carrier in a radio.

The upper and lower envelopes of a sound-modulated wave are identical so that it does not matter which envelope is used in the final reproduction of the original sound. Although the envelopes are of opposite phase at all times, both contain all the information present in the signal, and since the ear does not differentiate between isolated sounds of different phase, either one may be used.

A television receiver, however, makes one additional demand on the detector: the demodulated signal must present the *correct phase* of envelope to the video amplifier or amplifiers which follow. If the phase is opposite to that required by the design of the set, the picture is like a photographic negative—blacks appear where the whites should be and vice versa.

A diode detector connected as illustrated in Fig. 33 produces what is called a "negative picture phase." This expression may seem to indicate the reverse of the conditions shown in the diagram. However, it may be clarified as follows: the square portions of the signal contain the blanking and synchronizing pulses that accompany all television transmissions. These pulses, when applied to the grid of the picture tube, must carry the grid far into the *negative* region to blank out the beam current during retrace and syn-

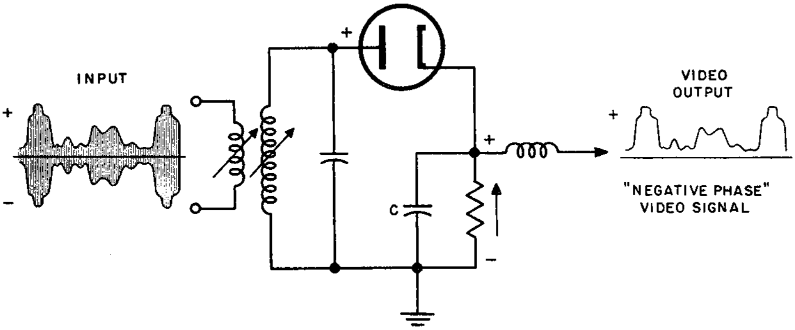

Fig. 33. Video detector with positive output.

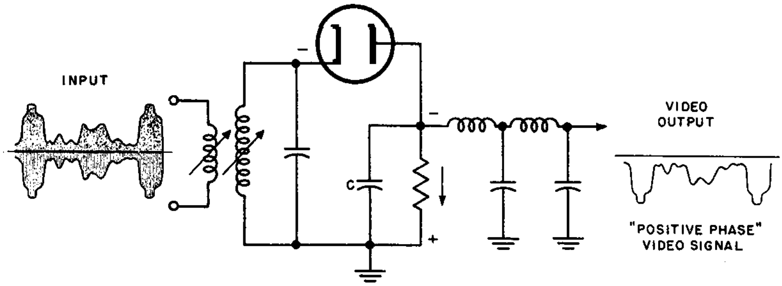

Fig. 34. Video detector with negative output.

chronization. If the pulses shown in Fig. 33 were applied directly to the picture tube grid (these are positive-going pulses) they would make the screen brighter rather than darker and produce a *negative* image, photographically speaking. Since the terms "negative" and "positive" refer, in this situation, to the photographic interpretation, a positive pulse is said to be in the *negative phase*. Such a detector is useful in a television set having an *odd* number of video amplifiers and in which the video signal is applied to the grid of the picture tube. Each video amplifier produces a 180-degree phase reversal by normal tube action. Thus, if a negative phase detector is followed by one, three, or five video amplifiers, the last amplifier output is in the positive phase as required by the picture tube.

(A negative phase detector may have an even number of video amplifiers if the signal is injected into the cathode circuit of the picture tube rather than the control grid circuit.)

The diode circuit of Fig. 33 may be converted to positive phase output by placing the diode load resistor in the plate circuit rather than the cathode as shown in Fig. 34. Here conduction occurs when the cathode is made negative with respect to the plate, the latter being held at ground potential. The voltage drop across the diode resistor (and hence the polarity of the output voltage) is reversed.

An additional difference between video detectors and radio detectors might be mentioned at this time. Due to the vast difference between audio and radio frequencies, a simple r-f bypass capacitor (*C* in Figs. 33 and 34) is sufficient to discriminate between them and filter the rf out of the audio circuits adequately. In television circuitry, however, there is not this large separation between the video intermediate frequencies and the video modulating frequencies, yet the i-f signal must be prevented from penetrating into the video amplifiers. Additional filtering is provided by the proper design and use if pi-type *LC* filters such as that shown in the output circuit in Fig. 34.

TABLE 1

CHARACTERISTICS OF DETECTORS USED IN A-M RADIOS

	Sensitivity	*Selectivity*	*Fidelity*	*Signal Handling*
Crystal Diode	Poor	Poor	Excellent*	Excellent
Vacuum Diode	Poor	Poor	Excellent	Excellent
Plate Circuit	Fair	Good	Excellent	Good
Grid Leak	Good	Poor	Poor	Poor
Regenerative (non-oscillating)	Excellent	Excellent	Poor	Poor
Regenerative (oscillating)	Excellent	Excellent	Not Applicable	Fair
Superregenerative	Best	Very Poor	Poor	Poor
Infinite Impedance	Poor	Excellent	Excellent	Excellent

* The crystal diode has a "square-law" hook at the start of its response curve and is not, therefore, particularly faithful for small signals; however, since crystals are invariably used for strong signal detection on that portion of the curve which is linear, their fidelity is considered excellent.

41. Summary of Detector Characteristics

Table 1 summarizes the characteristics of the detectors discussed in this book.

42. Review Questions

1. Draw the circuit of the infinite impedance detector from memory. Assign typical values to the components.
2. Explain why sudden bursts of heavy modulation cannot drive the grid of the infinite impedance detector into conduction.
3. What characteristic of the infinite impedance detector gives it its name?
4. How does a heterodyne detector produce an audio frequency output from an r-f unmodulated cw wave? Illustrate by assuming the carrier to have a frequency of 3500 kc.
5. Why is the phase of a video detector's output of importance?
6. What is meant by "negative phase"? "Positive phase"?
7. What is the function of the pi-type *LC* filter in Fig. 34?
8. Which types of detector would you list as excellent for sensitivity? What factors would cause poor sensitivity in a detector?
9. Which types of detector would you rate as excellent in signal handling ability.
10. Draw a comparison chart of the various types of a-m detectors analyzed in terms of sensitivity, selectivity, fidelity, and signal handling ability.

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