The Diligent Detector

73 Staff

So far as most of us are concerned, the detector is the "forgotten man" in a communications receiver. Ultra-simple circuitry, tried and true over the years, tends to make us think of the detector (when we bother to think about it at all) as one of the most nearly perfected parts of the set.

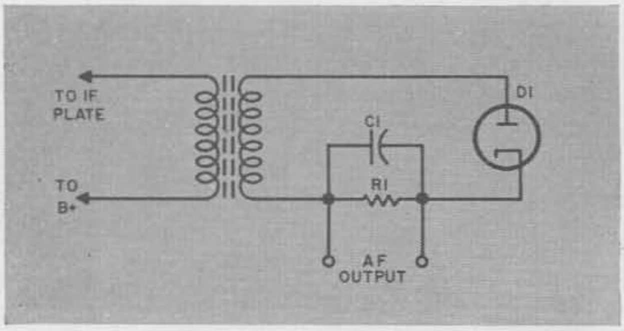
The general impression that detectors have little room for improvement isn't correct. For a few cents worth of parts and a few minutes time, you can reduce your set's detector distortion to a fraction of its previous value. This will do a near-miraculous job of cleaning up formerly-muddy signals whose only actual fault was 100 percent modulation, and may even restore broken friendships if bad signal reports caused the breach!

You can take your choice of a number of circuits to accomplish this end, thanks to the audio fraternity which devotes much of its time to reduction of distortion. Some are nearly as simple as the conventional detector, while others involve addition of one or more tubes to the set.

Each of these circuits has its own set of advantages and disadvantages, making the choice a bit more complicated than one of mere time and complexity. The purpose of this article is to list these circuits, together with their pros and cons, to make it easy for you to pick the one best suited to your own needs.

Before going into the newer and more-sophisticated detector circuits, a brief review of the conventional detector is in order. To clarify the approach used in this review, you know that an ordinary AM signal may be visualized in either of two ways: It may be considered to be a single, steady carrier wave varying in amplitude, or it may be thought of as an unvarying carrier accompanied by sidebands of varying strength which are later mixed with the carrier to produce sound.

Fig. 1. This basic circuit, or slight variations of it, is the second-detector in use in nearly every radio receiver on the market today. Except for the filter, the circuit is identical to a half-wave power supply but operates in a completely different fashion.



While the second visualization is more correct in the mathematical and physical sense, there is no measurable difference between the two. To avoid complicating this article with exotic mathematics, the first (and older) visualization has been used in explaining diode-detector action.

Since the most common detector in use today is the diode, let's look at it first. Most diode detector circuits are similar to that shown in Fig. 1. You may find a crystal diode instead of the tube in some receivers, but the principles of operation remain unchanged.

Similarity between this circuit and an ordinary half-wave power supply (less filter) is evident. However, the two circuits differ drastically in several important operational details.

In a power supply, the design factors are chosen so that current will flow over as much of the cycle as possible without flowing during the reverse half-cycle. This reduces ripple voltage in the output to a minimum.

In the detector, however, the objective is to make current flow through the diode in a series of extremely short pulses. This is accomplished by making the resistance of R1 very large compared to the diode's forward resistance, and by making the applied signal voltage as large as possible without running into overload.

Under these conditions, C1 is charged by the short pulses, and if the time constant is properly chosen the capacitor voltage will rise almost to the peak value of the applied signal. The voltage will vary in a linear manner with the strength of the applied signal as measured at the peak. For this reason the circuit is known to engineers as a "peak-linear" detector.

Note that the voltage impressed on C1 will follow the signal modulation envelope only if the tube voltage drop is negligible compared to applied voltage. At low signal levels, every rectifier becomes a "square-law" device whose voltage output varies with the square of input voltage rather than varying linearly. Square-law detectors produce excessive distortion of AM signals, but are useful as mixers.

Under normal conditions, the output of an ordinary diode detector contains about 5 percent harmonic distortion. While signals are perfectly readable with this amount of distortion, reception can become extremely tiring to the ears—as anyone who has ever operated in a contest knows.

In addition to introducing distortion, the peak-linear detector plays another sneaky trick on the signal—it cuts down the effective modulation percentage.

This can happen because the *if* amplifier feeding the detector has very poor voltage regulation. Output of the *if* transformer, with the same signal applied to the amplifier, is considerably less under load than it is with no load—and the diode detector represents a very appreciable load.

What's more, this load varies with strength of the applied signal since the diode's impedance will vary with voltage applied. This means that the *if* amplifier is under a heavier load for the sidebands of a signal than it is for the carrier, and the ratio of sideband power to carrier power as measured at the detector is reduced.

Bad as this sounds, it's actually no loss—since a peak-linear detector is not capable of reproducing a 100 percent modulated signal without severe distortion. In one typical case, breakup of the signal became objectionable at 75 percent modulation. Other authorities claim the effect is severe at 70 percent. By reducing effective modulation percentage, the diode makes itself able to handle a more-deeply-modulated signal than could otherwise be accommodated.

Distortion in a peak-linear detector is caused by three major factors. One—curvature of diode characteristics—is outside the control of the designer or the set owner. The other two can be controlled to some degree, but the control always represents a compromise.

Whenever the dc component of the signal and the ac component meet different load lines, distortion is sure to result. This situation occurs if AVC is derived from the detector, if an S-meter is connected to the detector circuit, if an automatic noise limiter is incorporated, or if the detector feeds an audio amplifier. The last condition is necessary if you're going to hear anything out of the set!

This condition, known variously to engineers as "clipping" and as "differential distortion," is the major factor limiting acceptable modulation percentage. Distortion in conventional circuits remains under 5 percent at moderate modulation levels, but rises rapidly to 12 to 20 percent when modulation depth approaches 100 percent.

The third factor introducing distortion is the RC time constant of the detector load (R1 and C1 in Fig. 1). If the time constant is too long, "bottoming" will occur on negative half-cycles of the incoming signal, producing a raspy and most objectionable sound. If it is too short, detector output will be low and rf ripple will be too high. This is not usually a problem, since design values found in most sets represent a highly acceptable compromise between output level and distortion.

With this background established, we're ready to examine some low-distortion circuits and to compare them to existing detectors in your receiver.

One of the simplest of the low-distortion circuits is the "diode integrator" described a couple of years ago by Leonard Geisler. It's shown in Fig. 2.

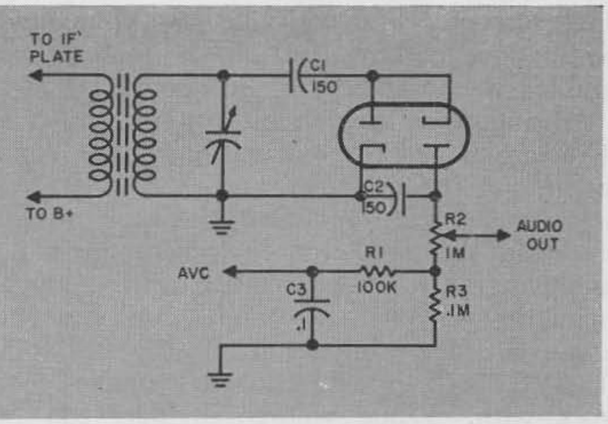


Fig. 2. The diode integrator, sometimes called a peak-to-peak detector, provides a virtually open-circuit load to the *if* transformer secondary. All distortion resulting from assymetrical transformer loading is thereby eliminated, and detector efficiency is increased.

Instead of being patterned after a half-wave rectifier, this circuit is an adaptation of the full-wave voltage doubler. Since it is a full-wave device, it utilizes both halves of the input-signal cycle rather than only one, with resulting increase in efficiency.

The reduction in distortion is brought about by the fact that one of the two diodes is conducting at all times, and both diodes never conduct simultaneously. With both C1 and C2 set at the same value, the *if* transformer always sees a capacitive load—and under this

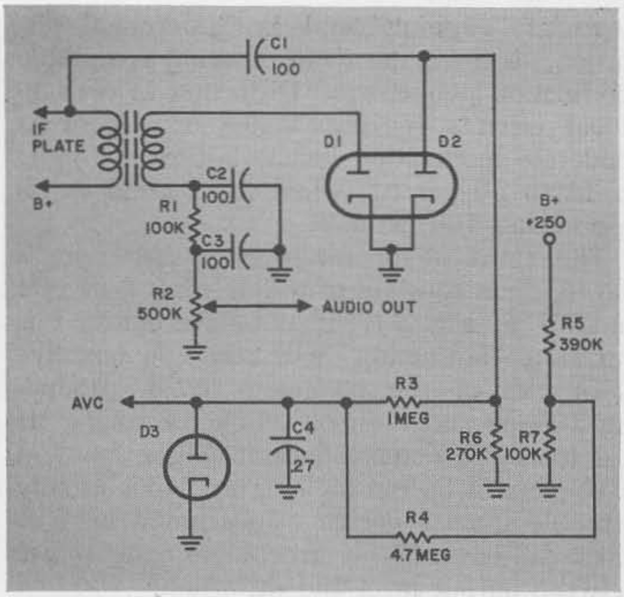


Fig. 3. Most complex of the detector circuits shown here is the "sinking diode" arrangement which includes delayed AVC and reduces distortion. Crystal diodes can be substituted for D1 and D2, but D3 must be a tube to achieve extremely high reverse resistance.

condition, the capacitance can be trimmed out by returning the *if* transformer to resonance. This results in an effective load of nothing at all; at one fell swoop you have eliminated modulation cutting and have more than doubled the efficiency of the detector.

Advantages of this circuit are the reduction of distortion and the removal of loading from the output *if* transformer.

Its major disadvantage is the high output produced; in new-design equipment this is no handicap, but when you modify existing equipment the 35-volt peak-to-peak audio which comes out of the integrator and the 100 volts of AVC both prove somewhat unhandy to work with. While voltage dividers can be used to trim them back to more conventional values, the dividers will then introduce frequency distortion and differential loading effects which may cancel out the advantages of the circuit.

Another low-distortion circuit is the "sinking diode" arrangement described by Langford-Smith and shown in Fig. 3. This circuit eliminates differential distortion and also produces delayed AVC, at the cost of several additional components. It has been applied in at least one receiver-updating technique, and excellent results have been reported.

This circuit is identical to the peak-linear circuit insofar as the detector itself is concerned. The only departure from conventional techniques is use of a voltage divider and a clamping diode (D3) to first apply a positive bias to the AVC line and then to clamp the line to ground.

The result is that the AVC line must overcome the positive bias to become effective, but can never go positive itself. The voltage-divider circuitry provides a constant load for the AVC diode, preventing interaction with the detector diode coupled to the same transformer and thus eliminating differential distortion due to the AVC action.

The advantage of the circuit is its reduction of distortion, coupled with DAVC provision.

Major disadvantage is the requirement for added components. A secondary disadvantage is the requirement for "cut-and-try" tailoring of component values in the AVC circuitry.

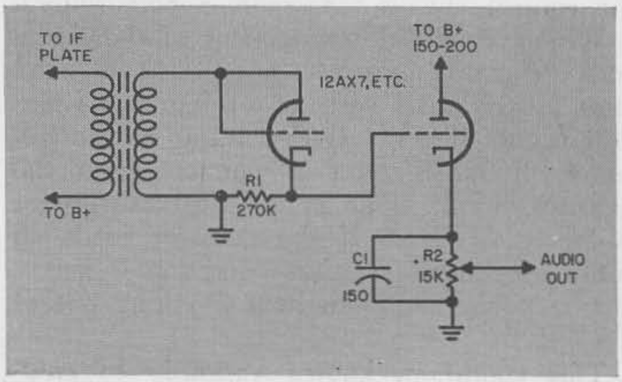
Since much of the distortion in a peak-linear detector is caused by interaction with associated circuits, use of some sort of isolation device appears to be a natural to eliminate the distortion. One of the simplest and most popular such devices is the cathode follower.

Two circuits combining the diode detector and the cathode follower have been published, and excellent results are reported with each.

The simpler of the two was developed by W. T. Selsted and B. H. Smith in the Radiation Laboratory of the University of California, and appears in Langford-Smith's writings. In it, the cathode follower follows the detector (see Fig. 4) but precedes the load capacitor and filter components.

Claimed distortion reduction is from 12 percent to less than 1 percent at total modulation. This is achieved because the isolation presents an essentially resistive load to the detector, completely eliminating all causes of distortion except diode characteristic curvature. Curavture effects are minimized by keep-

Fig. 4. Less than 1 percent distortion at 100 percent modulation is the claimed performance of this cathode-follower plus diode detector circuit. Shunt impedance is eliminated from the diode load (R1) by the direct-coupled cathode follower.



ing applied signal voltage high—greater than 10 volts in most receivers.

Major disadvantage of the circuit is its requirement for an added tube. However, should your receiver use a 6AL5 as detector, it can be replaced with a 12AX7 with little difficulty. The 6H6 can be replaced with a 6SL7.

There is no hard-and-fast rule that the isolation must be between the detector and its load. Similar advantages may be gained by isolating the detector from the *if* transformer as described by Sareda.

In this circuit (Fig. 5), two major advantages appear. Loading of the output *if* transformer is substantially reduced, since it feeds only the high-impedance input of the cathode follower. Differential distortion is also slashed by an appreciable amount, since the detector load resistor (R2) is so much lower than any associated shunt impedance. This means that any variation of shunt impedance with frequency or modulation depth becomes only a minute fraction of the impedance of R2.

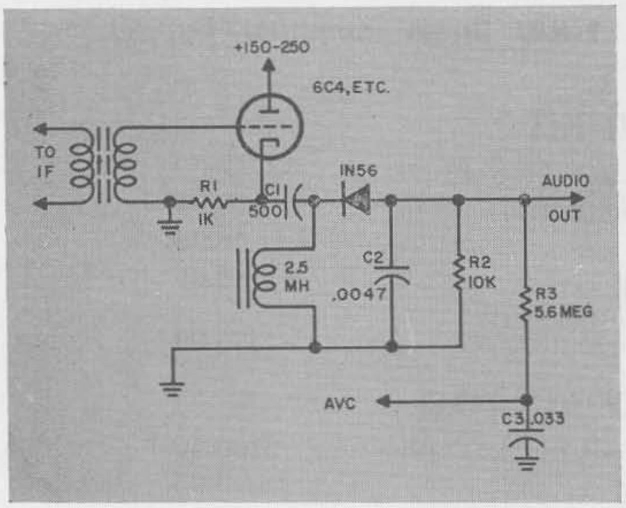


Fig. 5. This cathode-follower detector circuit provides both audio and AVC from a single diode. It eliminates differential distortion by keeping diode load resistance R2 at a low value so that all shunting impedances will have minimum effect

Use of the low-valued load resistor requires that a high-conductance crystal diode be used as detector. If a tube is employed, its forward resistance will be an appreciable fraction of the load resistance and distortion will skyrocket.

No figures for distortion reduction have been obtained for this circuit. However, it appears that its performance should be comparable to that of the diode integrator.

Major disadvantage of the circuit is its complexity, requiring addition of one triode stage and three other components to the receiver. However, it should be a natural for inclusion in a homebrew receiver.

Another approach to detection, basically different from the peak-linear diode circuit, is the "infinite-impedance" detector. Frequently used in hi-fi gear, it is seldom seen in communications receivers because it makes no provision for AVC voltage.

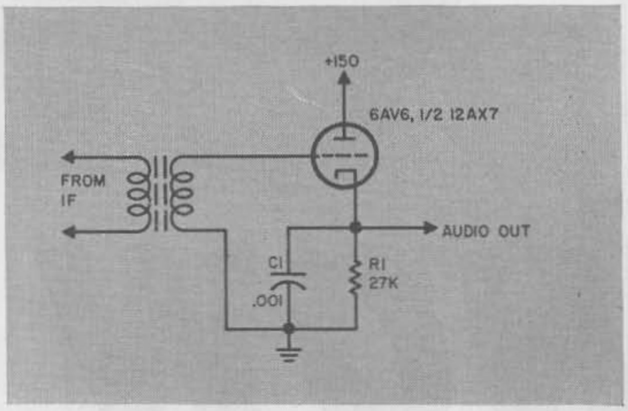


Fig. 6. The infinite-impedance detector appears similar to a cathode-follower amplifier but operates differently. It reduces distortion and increases selectivity, but can be overloaded more easily than the conventional diode circuit.

A typical infinite-impedance detector is shown in Fig. 6. You can see that it appears identical to a normal cathode follower type amplifier—and so far as the circuit goes, it is identical. The difference lies in the tube's operating point.

While circuit constants in the cathode follower are chosen so that the tube acts in a linear manner, an infinite-impedance detector is biased almost to the cutoff point. This is accomplished by the extremely large cathode resistor, R1.

With no signal, little plate current flows and the voltage drop across R1 is small and steady. When an rf signal is applied, more plate current flows at positive peaks, increasing voltage drop across R1. The voltage across R1 reproduces the signal's modulation envelope in the same manner that the envelope is reproduced in a peak-linear diode detector.

Since the tube is operated in cathode-follower configuration with a large amount of feedback, its input impedance is high. As a result, the *if* transformer is not heavily loaded and selectivity is increased. The large amount of feedback prevents overload effects until the grid is driven far into the positive region, at which time distortion suddenly becomes extreme. Since this doesn't happen until input nears 50 volts, its effect is usually absent.

Distortion level of the typical infinite-impedance detector at 100 percent modulation is in the neighborhood of 3 percent. This is not so low as some of the more sophisticated diode circuits, but appreciably lower than the 10 to 15 percent produced by the conventional diode.

Aside from circuit complexity, the major disadvantage of this detector is that it makes no provision for AVC takeoff. With the receivers using amplified AVC such as the Super-Pro and the SX-28, this poses no problem.

The only other AM detector still in anything like wide use is the superregenerative circuit, developed by Maj. Armstrong. Relegated to the UHF bands before World War II, it was brought back from obscurity for use in Class D Citizens Band equipment and, with some modifications, can find a permanent place in ham equipment.

Too many superregen circuits exist for us to list them all here. One easily-handled version is shown in Fig. 7. Note its strong resemblance to a grounded-cathode Hartley oscillator. As a matter of fact, the superregen *is* an oscillator, with its grid-circuit time constant chosen to produce "squegging" at a supersonic rate. The ear doesn't hear the oscillation or the squegging, and the nearly-infinite amplification produced when the circuit is oscillating makes it possible to hear even the weakest signals.

One major characteristic of the superregen is its characteristic hiss. At one time, they were known as "hiss-boxes." This hiss is actually the noise produced by random movement of electrons in the coil and in the antenna—indicative of its great amplification ability.

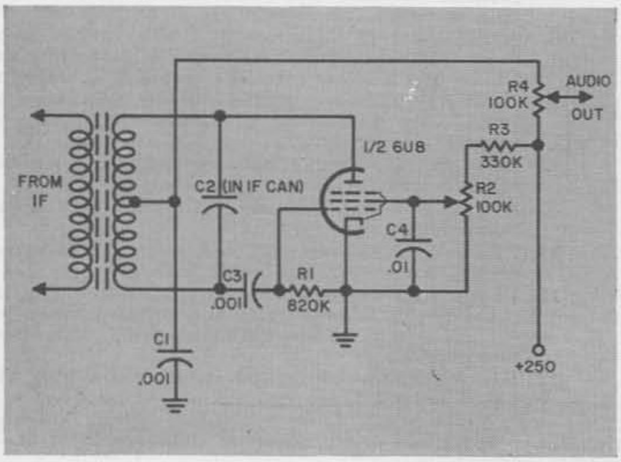


Fig. 7. This superregenerative detector for use in VHF mobile receivers combines AVC, noise rejection, and extreme amplification. R2 controls regeneration and R4 is the audio gain contol. The transformer secondary must be centertapped.

The superregen has other advantages besides extreme amplification. It automatically limits its own output, making noise limiters and AVC circuitry unnecessary.

However, in most applications its disadvantages outweigh these advantages. The superregen produces extreme noise output in absence of signal (the hiss mentioned before). It radiates an interfering signal, not only on the frequency to which it is tuned but at all integral multiples of its quench or squegging frequency for several megacycles in either direction. Its sensitivity is low despite the gain because of the high noise output. And finally, its distortion is high. The superregen is definitely not a low-distortion detector.

With a couple of modifications, though, it can fill a major need as the second detector in mobile sets designed for VHF use. In this application, its amplitude limiting and great gain become major advantages. Use of superhet configuration for the receiver eliminates the low sensitivity, interfering radiation, and broad-tuning characteristics of the superregen used alone.

Care must be taken to shield the detector completely. Otherwise, signals at the *if* will leak through and be detected because of the great gain. The *if* frequency to be used must also be chosen carefully. Quench or squegging frequency should be approximately 1/1000 the signal frequency for best results, but in no case should it be in the audio range (or even lower than twice the highest audio frequency desired in incoming signals). This means that the *if* chosen should not be lower than 10 mc and can never be lower than 5 mc if good results are to be obtained.

The circuit shown in Fig. 7 is designed for use with an *if* of 17 mc. It can be used without change through the range from 10 mc upward. Should you desire to change the quench frequency, the components which determine it are R1 and C3.

Automatic Volume Control

While AVC circuits are rightfully a subject unto themselves, they are so closely related to detectors in so many ways that they will be treated briefly here.

The basic AVC circuit is identical to the peak-linear diode detector shown in Fig. 1, except that the AVC output line includes a low-pass R-C filter to eliminate all audio components and leave only the dc voltage developed by the incoming carrier.

The time constants of this filter determine how rapidly the AVC will act, as well as the speed with which it will release after the signal stops. For communications use with normal AM signals, an overall time constant of about 0.2 second (for both attack and release) is optimum. Shorter time constants enable the receiver to follow fading more rapidly, but result in loss of bass from the audio. Longer time constants emphasize fading effects. However, in hi-fi tuners where excellent audio response is more important than freedom from fading (since most reception is local in nature), time constants for this circuit average one second.

A major disadvantage of the ordinary AVC circuit is that it applies a control voltage for weak signals as well as for large ones. In other words, it cuts back the gain of the set even when you want all the gain you can get.

To overcome this disadvantage, delayed AVC was developed. The delay refers to voltage, not to time. It means that no AVC is applied to the set until signals are above a predetermined level. Past that point, AVC action is normal. One of the best delayed AVC circuits is the sinking diode arrangement, Fig. 3. Another is included in a squelch circuit shown in "The Perfect Squelch" (73, December, 1960, pg. 26).

When receiving CW or SSB, neither conventional nor delayed AVC is in itself acceptable. Means must be found to apply AVC quickly, while retaining it even with no signal incoming. Such circuits are known generally as "hang AVC" circuits because the AVC voltage hangs on for an instant after the signal is gone. These circuits, together with detectors for CW and SSB, must form the subject for another article. 73

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