

Meet the Versatile Diode



Part 7: Diode devices have been with us since the beginning of radio. But in recent years they have taken many new and sophisticated forms that make them useful for a host of applications.

By Doug DeMaw,* W1FB

Let's become acquainted with one of the most commonly used electronic devices — the diode. Diodes have long been used for changing ac to dc voltage (rectifiers), and they have been put to work for many years as *detectors* to convert radio-frequency waves to audio-frequency ones so we might listen to music and conversations that are broadcast through the ether.

Diodes were a vital part of the first radios. Those receivers consisted mainly of a galena-crystal detector (diode) with a "cat's whisker" wire that was adjusted to touch the crystal in a spot that would cause diode action. The radios also used a large coil of wire with tap points for tuning the system to the desired radio-station frequency. We knew them as "crystal sets."

Many an early-day experimenter hunted for hours with the cat's whisker knob in hand, trying to find a "hot spot" on the galena crystal. A truly good hot spot was not only hard to find, but it might never be found a second time! When it was located, the broadcast station would be much louder than when other detector spots on the crystal were used.

No longer must we deal with such crude methods for radio-wave detection. If diodes are used for that purpose, they come in tiny packages with wire leads, and we need only to solder them into our circuit. Many large diodes, designed to accommodate large amounts of current and

voltage, have threaded studs on their cases, making them easy to mount on a heat-conducting surface for cooling purposes.

Fig. 1 shows a number of diode types that are in use today. We can see that it is not always easy to identify a diode by its outward appearance. Many resemble small resistors or capacitors, while others look like transistors. The tip-off for most diodes is that they have but two terminals, whereas other semiconductor or tube devices have three or more terminals.

Whatever type of diode we may use, it is a *passive* component. That means it doesn't require an operating voltage to make it function in a circuit. This is not to say that operating voltage is not applied to some diodes in special instances, for to make specific events take place we must at

times place a voltage on the anode or cathode of a diode. More about that later.

Diode Basics

Fig. 2 shows the symbols for some of the common vacuum-tube diodes that were popular in the "tube era." Although some equipment still contains tube types of diodes, modern apparatus utilizes semiconductor (solid-state) diodes. They are more efficient and much smaller in size. You should be aware, however, of the general format for early-day diodes. The principle of operation was about the same as it is for semiconductor diodes.

Our modern diodes take the general forms illustrated in Fig. 3. Unlike the tube diodes of Fig. 2, there is no heater that must be warmed up for current to flow.

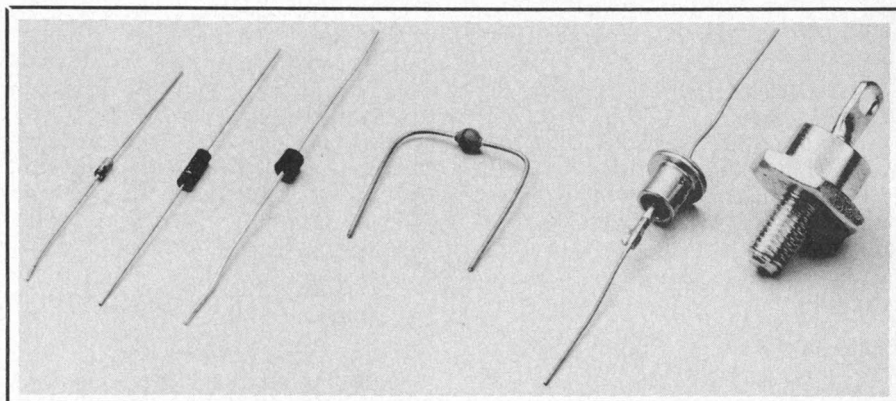


Fig. 1 — Left to right are small-signal diodes, medium-size rectifier diodes and a large stud-mount power diode. Each has one thing in common — it is a two-terminal device that can change ac into dc.

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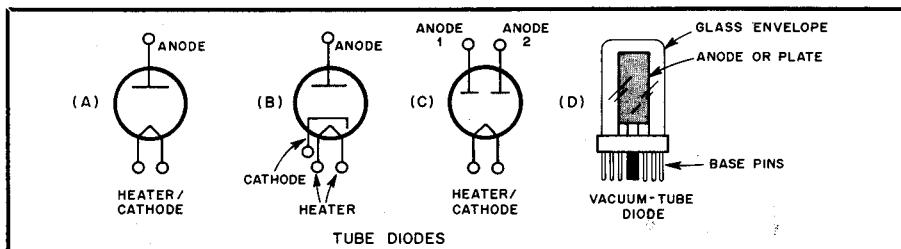


Fig. 2 — Early-day radio circuits used tube-style diodes for converting ac to dc. Although some tube diodes are still in use, they have been replaced for the most part by solid-state diodes.

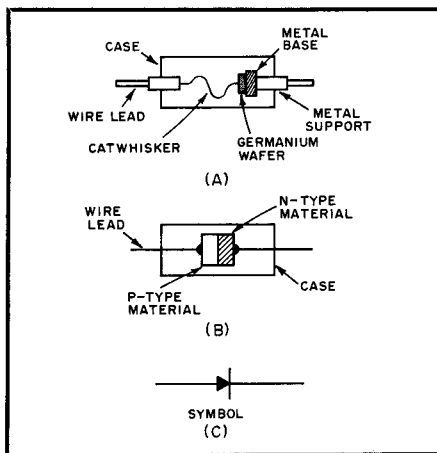


Fig. 3 — The point-contact diode is shown at A. A junction diode is at B, and the standard electrical symbol for a solid-state diode is at C.

The heater also served as the cathode in some tube diodes, while others contained a separate cathode that was warmed up by a heater. There is no warm-up time for a solid-state diode: It begins its function the moment energy is applied to it. Ironically, the galena (and carborundum) crystals of early radios were solid-state diodes, but the concept languished for many years before progress was made. The need for good detector diodes in radar systems served as the springboard for advances in the technology during WW II.

The early type of solid-state diode was the point-contact variety, as shown at Fig. 3A. A tiny wire contacts the germanium material to form the equivalent of a galena crystal and cat's whisker from days gone by. Although point-contact diodes are still available, the major usage is for junction diodes of the kind shown at Fig. 3B. Two types of semiconductor material (P and N) are formed into a sandwich to provide a rectifying junction that will permit diode action. The electrical symbol for a semiconductor diode is presented at Fig. 3C. The end with the arrowhead is the anode, and the part with the single line is the cathode.

There are two fundamental types of semiconductor diode — silicon and germanium. The essential difference is that it takes slightly more applied voltage (roughly 0.7 V) to make the silicon diode conduct

and commence functioning. The majority of our modern diodes contain silicon junction material. The 1N914 small-signal diode is an example of a silicon unit, whereas the almost generic 1N34A small-signal diode is made from germanium material. You will see many circuit examples that call for those two diodes. The approximate conduction or barrier voltage of a germanium diode is 0.3 V, compared to the 0.7 V of a silicon diode. That is, the diode must have at least 0.3 or 0.7 V across it in the correct polarity before current will flow.

How Diodes are Used as Power-Supply Rectifiers

We mentioned earlier that diodes can change ac to dc. Nearly every power supply (exclusive of those that use batteries) contains diodes that serve as rectifiers for changing ac to dc. Let's look at Fig. 4 to see how the diodes might be connected in a circuit to serve our need.

Let's suppose we wanted to develop +12 V for powering a small CW transmitter. We would have to step down the wall-outlet voltage from 117- to 12-V ac. T1 of Fig. 4 would accomplish that. But we still need to change the ac to dc. If we did not rectify the ac voltage, our transmitter signal would have a bad hum on it, caused by the

60-Hz ac wave from the wall outlet or transformer secondary winding. Similarly, we would hear a raucous hum in the speaker if we used an ac voltage to power our receiver.

So, to obtain dc output from our power supply, we will add D1 and D2 of Fig. 4A. The rectifying action of the diodes will change the ac to pulsating dc, and will double the power-line frequency to 120 Hz. Remember, it is 60 Hz to start with. The pulsating dc will still cause hum on our transmitter signal, so we have to take another step in our design. Fig. 4B shows the same circuit, but we have added two filter capacitors (C1 and C2) and a filter choke (L1). These components will smooth the pulses that otherwise could cause hum.

Notice that the dc output now has but a slight ripple. This would be so small that we might not hear it on our transmitter signal or in the speaker of a receiver. We could see the ripple if we connected a sensitive instrument (such as an oscilloscope) to the output dc line. An ideal power supply would have no ripple, and only a straight line would appear on the tube face of a 'scope. These illustrations represent the basis of all power supplies, but some use four diodes in what is called a full-wave bridge circuit. Even a single diode can be used alone to form a half-wave rectifier.

Diodes as Signal Detectors

Let's return to the subject of employing diodes to change RF energy to sound energy (detectors). A diode detector is the simplest form of receiver that we might consider. To illustrate this point, look at Fig. 5. If you doubt the simplicity of the AM radio shown, I urge you to hook one up and give it a try. You will hear the loudest local station, so don't expect to hear the weaker ones (unless the strong one goes off the air).

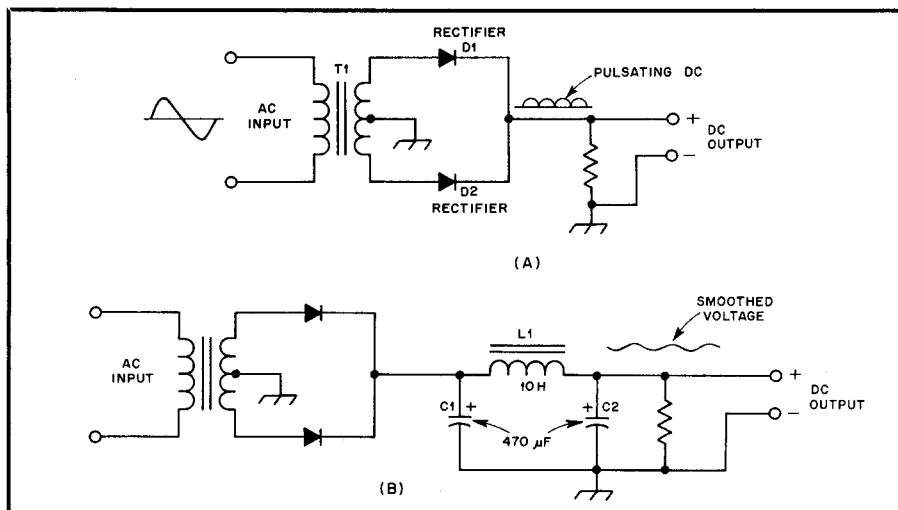


Fig. 4 — Circuit examples of diodes used as power-supply rectifiers. Pulsating dc is shown at the output of the rectifiers at A. A smoothing filter (C1, C2 and L1) has been added to the circuit (B) to minimize unwanted ripple in the dc output of the power supply.

The example of Fig. 5A has only an antenna, a diode detector (D1), a bypass capacitor and a single earphone. The more effective the earth ground and the longer the antenna wire, the louder the sound in the earphone. The circuit of Fig. 5B is a bit more complex, but will provide better performance. The combination of L1 and C1 is tuned to the desired station (you might be able to separate two or three broadcast-band stations this way). Again, the better the antenna and earth ground, the louder the signal response in the phones.

The tuned-circuit receiver is akin to the old crystal sets we mentioned earlier. The diode is coupled to L1 by means of a secondary winding that you can add. Wrap about 30 turns of fine insulated wire over the main coil winding. No. 30 or no. 32 enameled wire is suitable. You may wish to build these receivers as a workshop experiment: It is educational as well as fun.

Diode detectors are used in much more elaborate circuits than those of Fig. 5. They are used as mixers and product detectors in complex high-performance receivers, but those applications are beyond the scope of this series. The ARRL *Radio Amateur's Handbook* contains a wealth of information on that subject; likewise with ARRL's *Solid State Design for the Radio Amateur*.

Basically, here's what happens with a detector diode. It rectifies the incoming RF signal voltage (also ac), converts it to pulsating dc voltage (as in the power-supply example) and causes the headphones to vibrate physically at an audible rate. This is caused by the pulsating dc flowing through the earphones. Simple receivers of this variety were fashioned from razor blades and a wire by U.S. soldiers during WW II. The carborundum in the razor blades would permit diode action for those "fox hole radios."

Other Diode Uses

We can take advantage of the ac-to-dc action of the diode in creating all manner of ham-radio gadgets. For example, we might want to build a field-strength meter for tuning our transmitters or antennas. A circuit that would do the job is shown in Fig. 6. C1 and L1 are chosen to provide resonance at the frequency of interest — say, 3.7 MHz. A short whip antenna (18 to 36 inches will suffice) is attached to the top of L1 to sample the RF energy. D1 rectifies the RF energy picked up by the whip. The pulsating dc (unfiltered) flows through a sensitive meter (M1) and causes the needle to deflect upward when L1 and C1 are tuned to the signal frequency. A strong signal could harm the meter needle by causing it to become bent, so we have added a variable resistor (R1) to control the amount of dc that reaches our meter. This would be known as a sensitivity control.

Note that this circuit is not too different from the one in Fig. 5B. Instead of routing

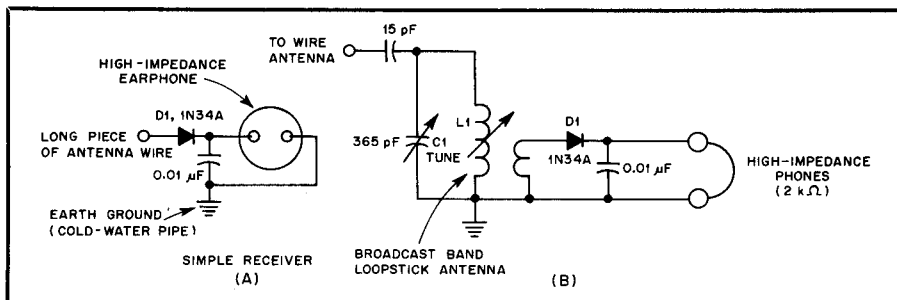


Fig. 5 — Illustration A shows the simplest form of AM receiver we might build. It consists only of a wire antenna, detector diode, capacitor, earphone and earth ground. The circuit at B has a tuned circuit that helps to separate the broadcast-band signals, but otherwise operates in the same manner as that at A.

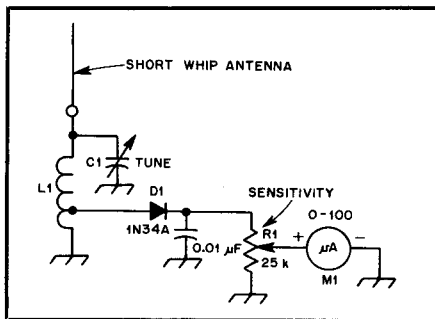


Fig. 6 — A diode detector can be used to sample RF energy. This simple field-strength meter uses rectified RF energy (pulsating dc) to cause the needle of M1 to deflect upward when C1 and L1 are tuned to the frequency of interest. R1 serves as a sensitivity control to prevent strong signals from causing damage to the meter.

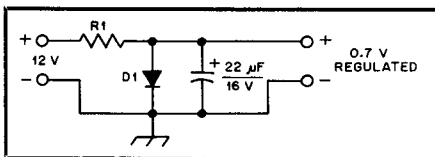


Fig. 7 — We can take advantage of the inherent barrier-voltage characteristic of a diode to provide voltage regulation (see text). R1 is chosen to limit the current through the diode junction, preventing damage to the diode.

the pulsating dc into a pair of earphones, we have sent it to a meter for visual indication. D1 is connected near the grounded end of L1 (about 25% of the total number of turns) so that it will not "load" the coil and cause a broad tuning response when C1 is adjusted.

If you have an amateur license and a transmitter, why not build a field-strength meter and see how it works? You can use one of the broadcast-band ferrite loopstick antennas of Fig. 5 (Radio Shack sells them). Retain the 365-pF variable capacitor and remove turns from the loopstick until you get a meter response at 3.7 MHz when C1 is set at midrange. You don't have to tap the coil as shown in Fig. 6. Instead, add a secondary winding (like in Fig. 5B), but

use only about 15 turns.

Another common use for the diode is as a regulator of dc. See Fig. 7 for a typical circuit. What's happening here? Well, we need a low-level voltage that stays relatively close to the chosen amount, despite changes in load current to the right of the diode. If we use a silicon power diode for D1 (50-V, 1-A diode, for example), it will draw considerable current and provide what is known as a minimum load current. Small changes in the circuit current along the 0.7-V output line will not cause the voltage to drop appreciably. In this circuit we are taking advantage of the diode forward-voltage characteristic, or conduction voltage. You will recall that it is 0.7 V for a silicon diode. We can add diodes in series to raise the value of the regulated voltage, adding 0.7 V per diode. Fortunately for us, special diodes are available for this general application. They are called Zener (rhymes with "keener") diodes, and they are available for regulation from a few volts to more than 100 V, and at various power levels.

More Applications

Did you know that a simple junction diode can be used in place of a mechanical tuning capacitor? Many diodes are used for that purpose in miniature equipment. In fact, modern TV receivers use tuning diodes in the receiver front end to select the channels. Fig. 8 illustrates how we might use a silicon diode for tuning purposes. When a positive voltage is connected to the cathode of a diode, it acts as a variable capacitor. This is because all diodes have a junction capacitance that changes with the applied voltage.

R2 in our circuit is used to vary the applied voltage, thereby causing changes in the junction capacitance. R1 acts to isolate the tuned circuit from ground so the performance will not be impaired. L1, C1 and D1 are the significant components of the oscillator tuned circuit. Once more we are favored with good fortune, for we can purchase special diodes designed for tuning purposes. They are available under a number of trade names, such as Varicap®

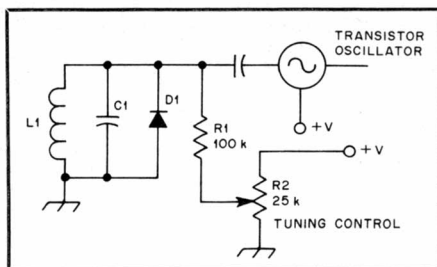


Fig. 8 — Diodes can be used to replace a mechanical variable capacitor in some instances. By applying positive voltage to the diode cathode (reverse bias), the diode internal capacitance can be made to change as the applied voltage is varied. This is an example of a tuning diode, or voltage-variable capacitor (VVC).

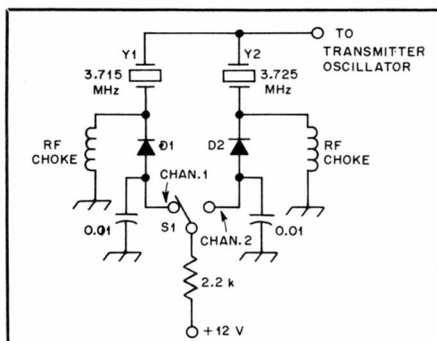


Fig. 9 — Diodes are useful also as electronic switches from dc through RF. This example shows how we might use a pair of switching diodes to select one of two or more frequency channels. When positive voltage is applied to the anode of the diode, it conducts, thereby closing the electronic switch.

and Epicap®. The generic term is *varactor diode*, which means “variable reactance” diode.

Diodes are also used as switching devices. They can be turned off and on by applying voltage and removing it, just as though we operated a mechanical switch in a voltage line. To see how this is done, look at Fig. 9. Switch leads, if long, can ruin the performance of an RF circuit. Therefore, it is convenient to use diodes as dc switches right at the point of interest in an RF circuit. The diodes can be switched by means of dc voltage that is controlled remotely with a mechanical switch (S1 of Fig. 9). When a positive voltage reaches D1 it turns on (conducts), permitting crystal Y1 to “see” a completed path to ground. Meanwhile, D2 is dormant, so Y2 is left floating, so to speak. When the diode conducts, it presents a short circuit for the current to pass through.

If we want to use Channel 2, for example, we simply move S1 to the appropriate position, thus actuating D2 and turning off D1. Diode switches are used in a great many circuits, and they can be used to switch almost any circuit we have in mind. In a similar fashion they can be placed in series with a signal line to act as “gates.” When they aren’t conducting, the gate is closed.

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Glossary

- clamp — an electrical device that limits the amount of ac voltage to a specified value.
- clipper — an electrical circuit that functions like a clamp to limit the ac voltage level.
- detector — a circuit that changes ac or RF energy into an audio-frequency wave that can be comprehended visually or by the human ear.
- loopstick — a coil wound on a ferrite rod for use as a broadcast-band receiving antenna in small AM radios.
- mixer — a device that combines two ac signals to produce a third frequency, called the intermediate frequency.
- passive — a device that requires no operating voltage to make it function.
- product detector — similar to a mixer except that the output frequency or intermediate frequency is at audio frequency.
- squarer — an electrical circuit that converts sine waves to square waves.
- Zener — a class of diodes with a constant-voltage characteristic that is useful for voltage regulators. Zener diodes are available in a variety of voltages.

When voltage is applied to them, they switch to the ON mode and the gate is opened to permit passage of the signal voltage.

Diodes can be used also as “clamps.” In this type of application, they are placed between a signal line and ground to prevent the signal voltage from exceeding the barrier-voltage level of the diodes. A circuit of this kind is shown in Fig. 10. Unfortunately, the diodes cause the sine-wave audio signal to become distorted (square waves), which can make it sound unpleasant in the speaker. The malady can be corrected by adding an audio filter immediately after the diodes.

Clamping diodes are also called “clippers” or “squarers.” When silicon diodes are used in the circuit of Fig. 10, the positive and negative peaks of audio will not exceed 0.7 V. If we desire a higher clamping level, we can place diodes in series at D1 and D2, or we can use low-voltage Zener diodes for D1 and D2.

The Wide World of Diodes

We have not given a broad picture of the

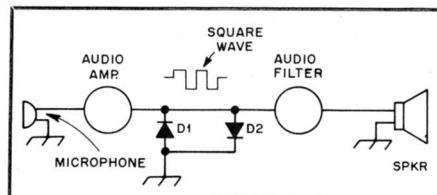


Fig. 10 — It is common practice to take advantage of the barrier voltage of a diode to limit the ac or RF voltage peaks to the barrier-voltage level. This circuit shows how we might use two reverse-connected diodes to clamp or clip the positive and negative audio-voltage peaks (to 0.7 V with silicon diodes, or 0.3 V with germanium diodes). The clipping action causes square waves (harmonics), which can cause audio distortion. A practical circuit would include a smoothing filter immediately after the diodes to restore the audio to a sine wave.

diode scene in this article. There are scores of specialized diodes available for a multitude of uses. Some of the names you will hear are Schottky, IMPATT, PIN, hot-carrier, Gunn, light-emitting (LED), tunnel and solar-electric diodes. There would scarcely be enough page space in a standard-size book to describe all of the diodes and their uses. But as you advance up the technical ladder, you will recognize these special diodes and learn how to use them.

I hope you will take the time to do some additional reading about diodes. If your soldering iron is in good working order, why not pick up a few diodes and tack some circuits together? It will aid you in understanding how diodes work. Nothing beats “learning by doing.”

QST

Strays

KV4AA — ONE FOR THE RECORD

□ In July 1982 *QST* (p. 19), we reported that Richard C. Spenceley, Sr., KV4AA, of St. Thomas, Virgin Islands, was attempting to work his way into the *Guinness Book of World Records* as the radio amateur with the most QSOs. In the April 1984 edition of that journal, Dick was posthumously awarded the first Amateur Radio entry as the “Most Assiduous Radio Ham.” Dick, who died in July 1982, achieved this distinction with a record 48,100 QSOs in 365 days (an average of over 130 a day) in 1978.

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