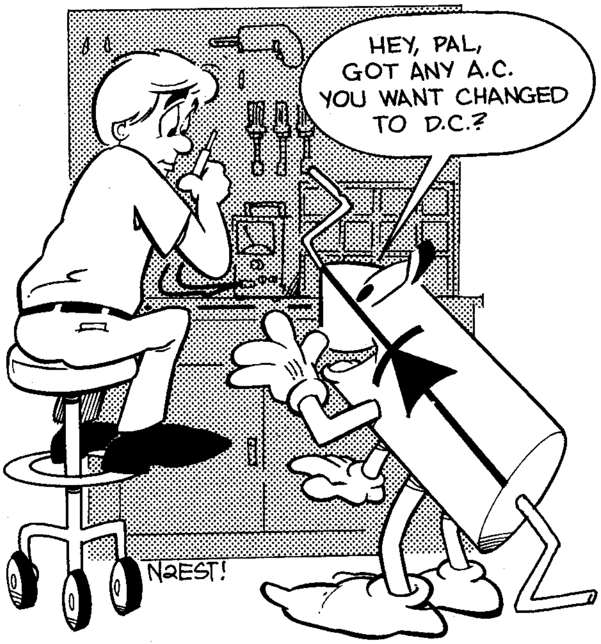

• *First Steps In Radio*

Diodes and How They Are Used

Part 15: However simple diodes may be, you'll use them again and again in Amateur Radio.

By Doug DeMaw,* W1FB

Could there be an electronics technology without diodes? Probably not — at least not as we know the technology today. It is incredible that so simple a device can play such an important role in radio circuits. The first radio signals were detected by means of diodes: Diodes were used in "crystal sets" to detect standard AM broadcast signals in the early days of radio. There are many new types of diodes, but a diode remains a diode with respect to the function. A diode is a device that has a cathode and an anode, and passes current in one direction only.

The combination of the galena crystal and "catwhisker," used to detect AM (amplitude modulated) radio signals, was, in fact, a solid-state diode. The galena serves as one half of the diode, and the tip of the catwhisker (fine wire) comprises the remaining half. When the two objects are in contact with one another, it is possible to rectify the incoming radio signal and create pulsating dc that would activate a pair of earphones at an audio rate, thereby enabling a person to listen to a favorite radio program. A number of other materials, such as carborundum, were used to form a diode for signal detection. The idea is to provide a poorly conducting junction that causes rectification (changing ac to dc) of the radio signals.

The irony of having solid-state diodes in the old days is that vacuum-tube diodes were used for nearly every other diode application until copper-oxide and selenium rectifiers were introduced, prior to World War II. The large-signal semiconductor diode (silicon or germanium) came into being in the early 1950s. Germanium small-signal (low-power) diodes were used prior to 1940 for various detector circuits, and were a vital part of radar receivers during WWII.

Modern Diodes

Fig. 1 illustrates the progression of diodes since the first days of radio. We went from the tube diode and galena crystal to selenium diodes, low-power point-contact (germanium) diodes and, finally, to germanium or silicon junction diodes. Germanium has fallen out of popularity as a power-diode material; silicon is the principal material used today. We now have rectifier diodes that can accommodate many amperes at relatively high peak voltages (e.g., 50 A at 100 V). The larger diodes are used extensively in such devices as electroplating rectifiers, welding machines and automobile alternators.

The small-signal diode has come a long way, also. There are many types of internal structures for these diodes, and each is created to perform a specific job in electronic circuits. We will examine some of these interesting applications later in this article.

One of the principal differences between germanium and silicon diodes (apart from the difference in crystal material) is the "barrier voltage." If we apply a current to a diode, it will not commence to conduct until a particular voltage is developed across the diode junction. Therefore, this level of voltage functions as a *barrier*. For germanium diodes, the barrier voltage is approximately 0.4. It is on the order of

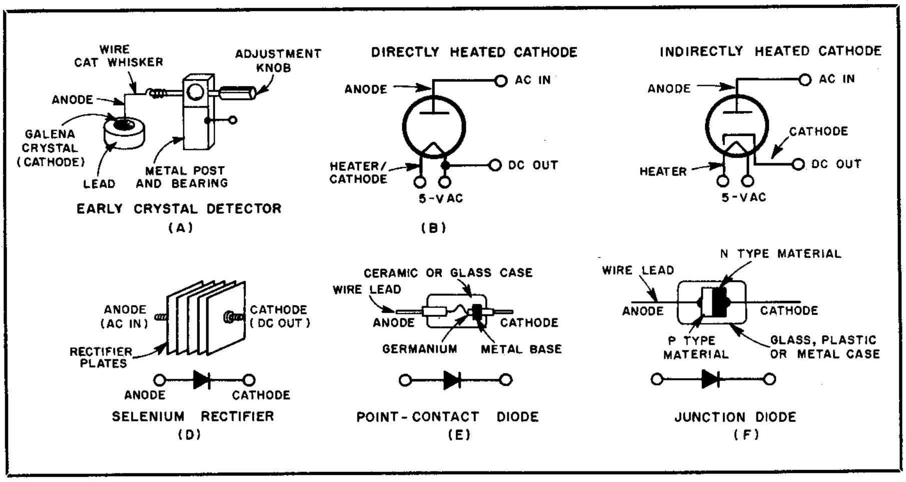

Fig. 1 — The evolution of diodes. The crystal detector at A was used for signal reception in the early days of radio. Vacuum-tube diodes (B and C) were used as rectifiers and signal detectors for many years, until selenium (D) and junction diodes (F) replaced them. Point-contact diodes remain in common use as hot-carrier diodes (E).

*ARRL Contributing Editor, P.O. Box 250, Luther, MI 49656

0.7 V for a silicon diode. In everyday language, we may think of the germanium diode as being the more *sensitive* of the two, since it will conduct at a lower voltage level than will its silicon brother.

The solar-electric (photovoltaic) cell found in solar panels utilizes the barrier concept to develop dc voltage. A solar cell is a type of diode, and when photons impinge on the cell a current will flow. The barrier voltage is approximately 0.5 per cell. Therefore, many solar cells must be wired in series to obtain a desired voltage output from a solar panel. To realize 13 V from a solar panel (with a load connected to it, such as a transmitter or receiver), we must use roughly 36 cells. Under no load this will produce about 17-18 V dc at peak sunlight.

Various packaging formats are used for the current crop of diodes. They may be housed in metal, glass or plastic cases. Fig. 2 shows a group of modern diodes in various packages. The physical characteristics may vary with the power ratings, and electrically similar diodes may look different because of the manufacturer's choice of package style. Most diodes have a band of paint around one end of the body to identify the cathode end of the diode. The cathode end of a metal-encased, stud-mount power diode is generally the stud end. The anode terminal is set in glass at the opposite end of the diode.

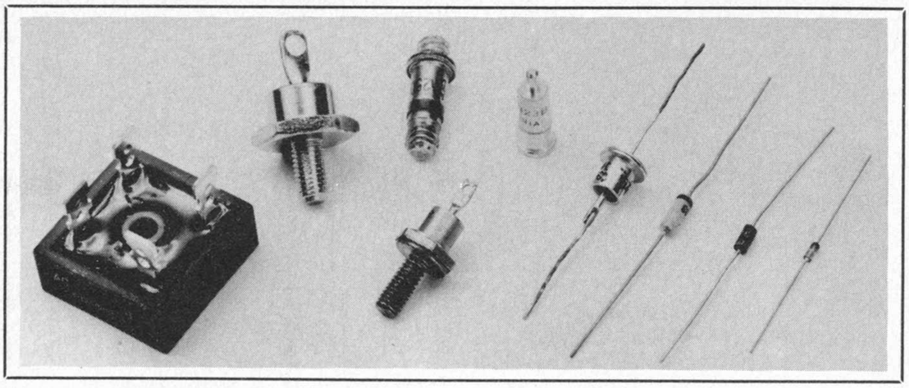

Fig. 2 — Various types of solid-state diodes. High-power units appear at the left, with small-signal diodes at the right.

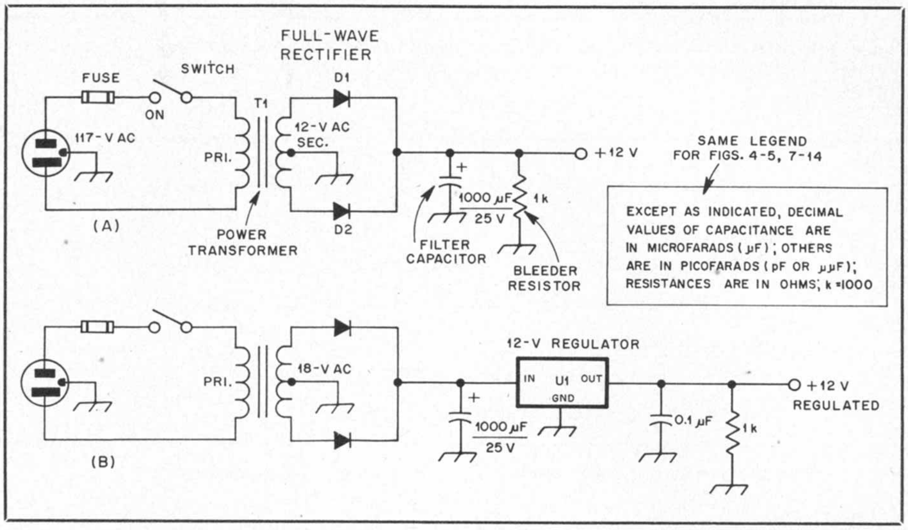

Fig. 3 — Diagram A shows a simple, unregulated 12-V dc power supply in which D1 and D2 serve as rectifiers. A regulator (U1) has been added in circuit B to stabilize the output voltage at +12.

Diodes as Power Rectifiers

Whenever we apply ac voltage to a diode and extract dc voltage from it, we are using the diode as a *rectifier*. Even though the diode may be used in a specific application to change a radio-frequency voltage (signal) to audible, pulsating dc voltage, it is still acting as a rectifier.

Few pieces of electronic equipment operate without some form of ac power supply. Among the exceptions are portable radios, watches, calculators, car radios, and some portable and mobile Amateur Radio gear. Most indoor appliances are plugged into the ac outlets of our homes. When this is done, we must have provisions, within or outside the equipment, to not only increase or decrease the wall-outlet voltage to a level suitable for the item it will power, but to change the ac voltage to dc.

As we learned earlier in this series, a transformer is used to change the voltage amount. Let's suppose that we wanted to power a CW keyer from the ac wall outlet. The keyer is designed to operate from 12-V dc. What type of power supply would be suitable to satisfy our requirements? A circuit for accomplishing our goal is shown in Fig. 3A. However, we will find that the dc voltage will shift up and down somewhat as the CW keyer is activated (no load to full load). Some circuits are not sensitive to small voltage changes, while others are very intolerant of voltage shifts (poor regulation). The no-load, full-load voltage changes can be stopped if we add a voltage regulator, as shown in Fig. 3B. I don't wish to get involved with a discussion of voltage regulators in this installment, but you should be aware that they exist and that they are used frequently to ensure a nearly constant output voltage from a power supply.

The power supply at A of Fig. 3 will produce approximately 17-V dc while no external load is attached to it. The output voltage will drop to roughly 12 with the load connected. D1 and D2 are the rectifier diodes that change the ac to dc.

A voltage regulator has been added to our power supply, as shown at Fig. 3B. Another change is the power-transformer secondary voltage. It has been increased to 18 V. This is necessary in order to permit U1 to work as a regulator: A regulator needs more input voltage than the output voltage it delivers. Actually, this circuit delivers 25.3-V dc to the input side of the regulator. This is because when a filter capacitor is used immediately after a rectifier, the no-load voltage from the diodes is 1.41 times the secondary ac voltage of the power transformer when a full-wave rectifier is used. The input voltage to a regulator must be high for another reason: For the regulator to prevent the power supply output voltage from falling *below* the desired amount, more than the required output voltage must be present in the first place (25.3 V versus 12 V).

Rectifier diodes can be used in other forms of power supplies. For example, we may use what is called a half-wave rectifier (Fig. 4A), but the load-no-load shift in voltage will be greater than with a full-wave rectifier. Also, the ripple (hum) from a half-wave rectifier is much harder to filter out. Fig. 4B shows a full-wave bridge rectifier. The dc voltage characteristics from this rectifier are the same as for the simple full-wave rectifier of Fig. 3. When the four diodes are used, however, the power transformer does not require a center tap on the secondary winding.

We can employ diodes in other types of

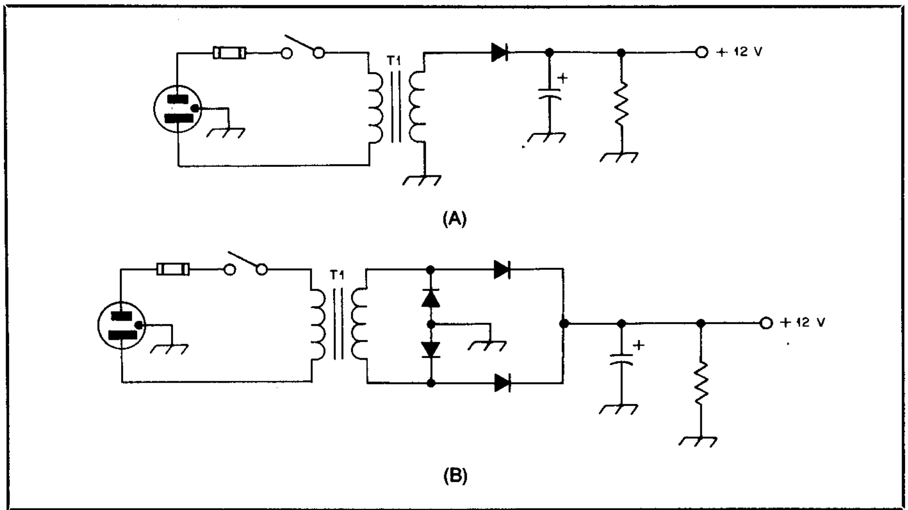

Fig. 4 — Diodes are shown here as rectifiers in a half-wave (A) and full-wave bridge (B) rectifier. T1 needs no secondary center tap when a bridge rectifier is used.

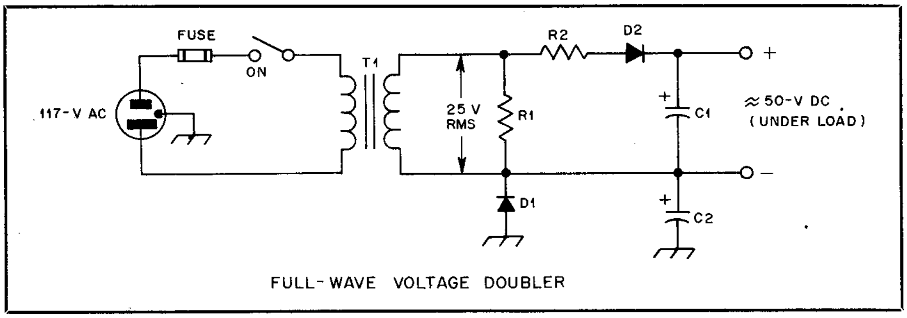

Fig. 5 — Example of how two power diodes can be used in a voltage doubler.

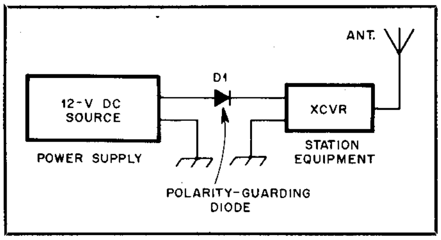

Fig. 6 — D1 functions here as a protective diode against accidental polarity reversal of the power supply (see text).

power-supply rectifiers. They can be arranged with appropriate capacitors to form a voltage doubler, as shown in Fig. 5. The resistors (R1 and R2) are chosen to protect the diodes from high-current surges when the power supply is turned on. These resistors will also protect D1 and D2 from excessive reverse voltage: Too much voltage or current can destroy a diode.

The dc output from a voltage doubler of this type will be approximately twice the RMS voltage across the secondary winding of T1. Under no-load conditions the voltage may approach 2.7 times the RMS secondary voltage.

There are also voltage triplers and quadruplers. A full explanation of power-supply rectifiers and their applications can be found in the power-supply chapter of the ARRL *Handbook*. I urge you to go beyond this simple discussion of diodes by studying the *Handbook*.

Other Uses for Diodes

A diode can be used as a protective gate. An example of this is shown in Fig. 6. D1 is inserted between the dc power supply and the equipment with which it will be used. If we were to reverse the power-supply terminals (reverse polarity), we could instantly destroy the solid-state devices in our transceiver or other equipment. Such mistakes are made frequently. We may prevent damage resulting from human error by using D1 of Fig. 6. It will permit current to flow through it when the power-supply polarity is correct. Current will not pass through D1 if the polarity is reversed, thereby protecting the station equipment. There will be a 0.7-V drop through D1 (the barrier voltage), so the power supply should have an output of 12.7 or 13 V to ensure that 12 V reaches the equipment. The diode must be chosen to safely pass the current of the transceiver or other gear with which it is used. Similarly, we must select a diode that has a voltage rating somewhat greater than 12 V for this example.

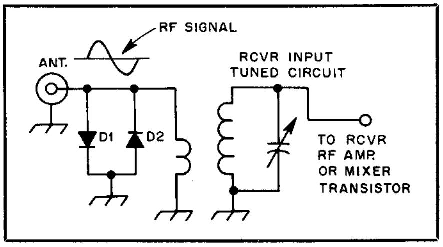

Fig. 7 — Small-signal diodes can be used as shown to prevent damage to the front end of a receiver from excessive input signal voltage.

Another protective circuit in which diodes can be used is found in Fig. 7. Here we show two diodes reverse-connected in parallel across the 50-ohm receiver input line. They will not conduct until the incoming signal voltage (ac) reaches approximately 0.7. They will create a short circuit for all input signal voltages in excess of 0.7. D1 and D2 will prevent damage to the input stage of the receiver. Arranged as shown in Fig. 7, D1 and D2 will conduct on both the negative and positive peaks of the incoming RF signal. We may wish to use two diodes in series for each leg of the protective circuit. The barrier voltage will then be 1.4, which will still ensure safety for the receiver. Series diodes are sometimes necessary when very strong commercial signals are present. They could cause D1 and D2 of Fig. 6 to conduct, which would result in rectification of unwanted signals. This would create many spurious signals and "hash" to appear in the receiver output. By using two diodes in series for each branch of the protective circuit, we would raise the barrier voltage above the signal level of the strong commercial station.

Fig. 8 shows how we can use a silicon power diode to establish a 0.7-V positive potential that is used as bias for a solid-state linear amplifier. R1 is used to limit the current through D1, thereby preventing the diode from burning out from excessive heat. Here again, we have taken advantage of the barrier voltage of the diode to establish a +0.7-V reference for the base of Q2.

Diodes are commonly used as electronic switches. We can see how this is done by referring to Fig. 9. The advantage is that S1 can be located a long distance from the three crystals, Y1, Y2 and Y3. The leads going to the diodes carry only dc voltage. The three 4.7-kΩ resistors provide RF isolation between S1 and the crystals, while serving as current-limiting devices for the diodes. As each diode is made to conduct, via application of dc voltage from S1, the related crystal is connected to the oscillator circuit. Low-power silicon diodes of the high-speed switching variety are suitable for this type of circuit. This same general switching technique is used for selecting

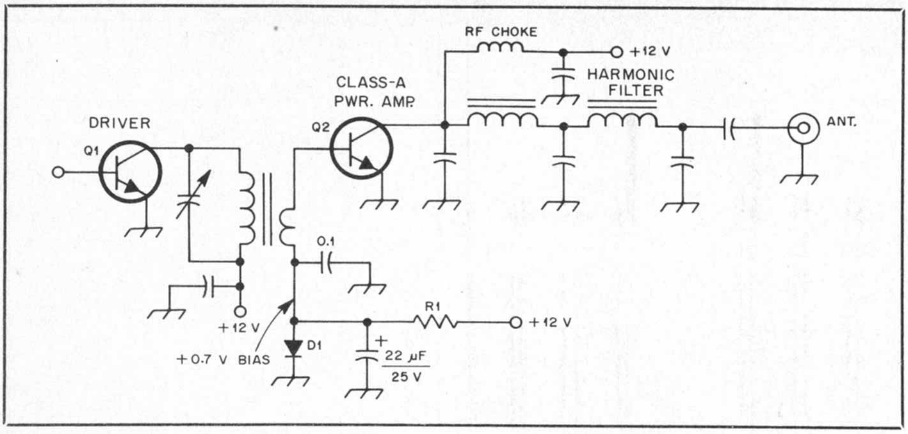

Fig. 8 — The barrier voltage of a silicon diode can be used to establish a +0.7-V bias for linear operation of an RF power transistor.

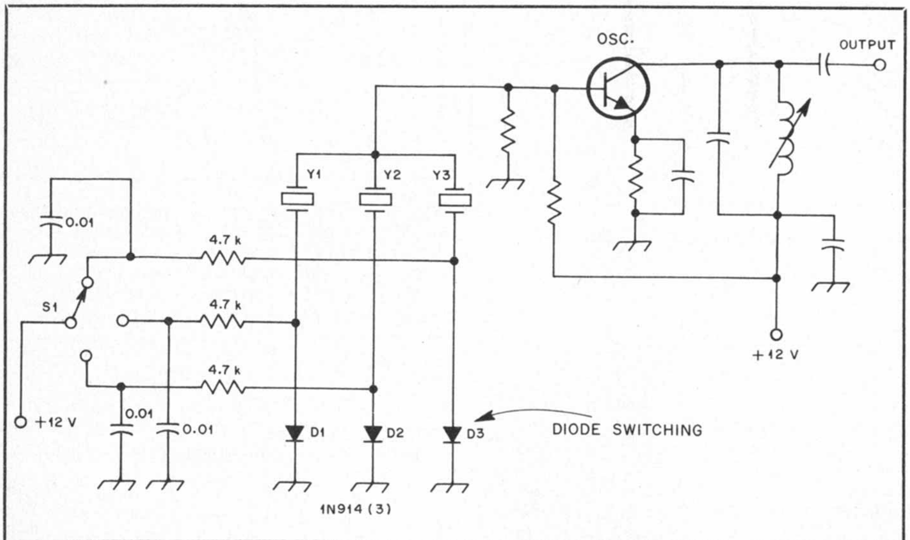

Fig. 9 — Diodes (D1, D2 and D3) are used here as switches to select one of three crystals.

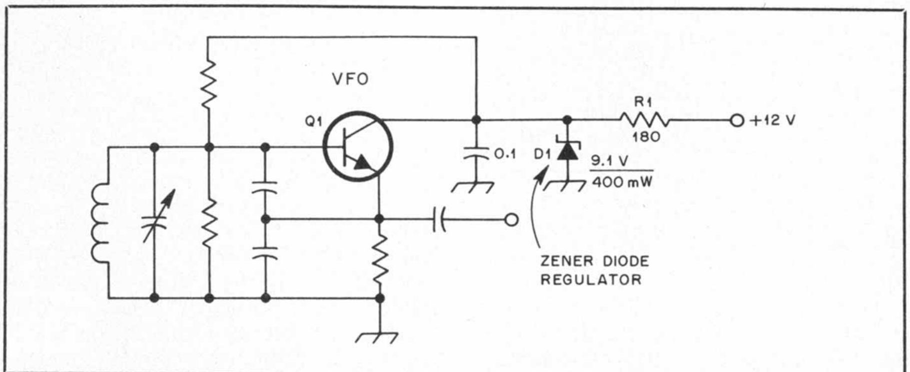

Fig. 10 — Zener diodes serve as regulators when connected as shown. They are available in a host of voltages and power ratings.

various tuned circuits and filters in radio equipment.

Still More Applications

Applications for diodes are limited only by your imagination. We are barely touching the surface in this article, but let's examine a few more common uses for diodes. A special type of diode is shown in Fig. 10. D1 is known as a Zener diode, and you can observe that the symbol has two little hooks on the cathode end. Only a Zener diode has this symbol. We see D1 serving as a voltage regulator for a VFO. R1 is a current-limiting resistor that prevents D1 from passing too much current through its junction. The formula for selecting the correct R1 value is given in the *Handbook.* In this circuit, D1 maintains the Q1 operating voltage at 9.1, despite variations in the 12-V supply line. Severe voltage changes would cause the VFO to change frequency unexpectedly, so we have used a Zener diode to stabilize the dc voltage at Q1. Zener diodes are available in various operating voltages and power ratings.

In Fig. 11 we see a pair of low-power, high-speed diodes employed in a frequency doubler. You will notice a similarity between the hookup for T1, D1 and D2 and the circuit of Fig. 3A. A doubling action takes place also in the full-wave rectifier of a power supply. That is why the frequency changes from 60 to 120 Hz in a power supply.

Another style of diode is called a varactor (variable reactor). This diode is illustrated in Fig. 12. It can be used as a frequency doubler, tripler and quadrupler, or to generate higher-order harmonics of the driving signal. Here we depict it as a tripler. The second harmonic is removed by what is called an "idler tank," consisting of C1 and L1. Varactor diodes are quite efficient. For example, if we fed 25 W of 144-MHz energy into J1, we could obtain as much as 17.5 W of output at 432 MHz (J2). No dc operating voltage is needed.

A varactor type of diode can be used as a tuning diode. Fig. 13 contains two examples of how this is done. A single tuning diode is shown at A of Fig. 13. As the positive voltage applied to the cathode of D1 is changed by means of R1, the internal capacitance of the diode changes, thereby tuning L1 to resonance at various frequencies. Many modern TV sets use tuning diodes in the front-end section to avoid the use of a mechanical channel

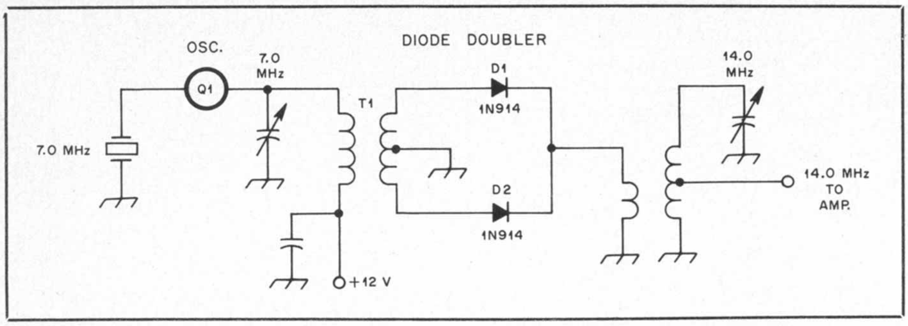

Fig. 11 — A push-push type of frequency doubler is shown here. D1 and D2 provide output at the second harmonic of the driving signal.

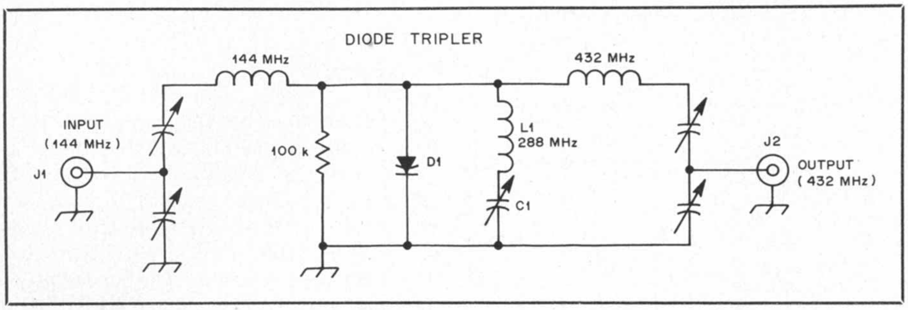

Fig. 12 — A power frequency multiplier can be made from a varactor diode. This circuit is typical of that used for tripling from VHF to UHF.

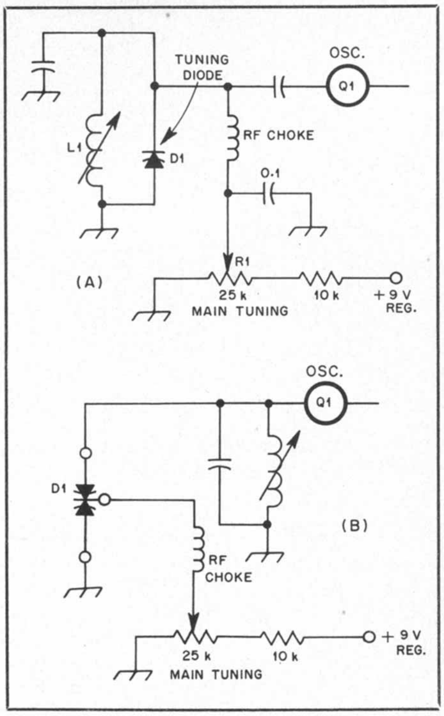

Fig. 13 — Tuning diodes can be used in place of large variable capacitors (mechanical). A single-ended tuning diode is illustrated at A, while the preferred type is shown at B (D1) in a double-ended diode format. The internal capacitance of the diode changes as the applied operating voltage is raised or lowered by means of R1.

Glossary

barrier voltage — the threshold voltage required across a diode junction to make it conduct or turn on. For germanium diodes it is roughly 0.4 V, while for silicon diodes it is 0.7 V.
full-wave rectifier — a rectifier in which the negative half of the sine-wave cycle is inverted so that the output contains two half-sine pulses for each input cycle.
half-wave rectifier — a rectifying circuit that passes only one half of the incoming sine wave, and does not pass the opposite half cycle. The output contains a single half-sine pulse for each input cycle.
LED — light-emitting diode. It illuminates when operating voltage is applied: positive to the anode, negative to the cathode.
linear amplifier — an amplifier for which the output waveform is a faithful reproduction of the input waveform, or the output quantity is essentially proportionate to the input quantity.
photovoltaic — a principle in which a photoconductive or photoemissive action takes place. Transparent conducting films are separated by semiconductor material to form a photovoltaic cell (solar cell). Electromagnetic radiation upon one of the films will create a potential difference between the films.
rectifier — a device that converts alternating current (ac) to direct current (dc). It has the characteristic of conducting current substantially in one direction only.
varactor diode — a diode for which the internal capacitance is voltage-dependent. Used for frequency multiplication and electrical tuning of LC circuits.
Zener diode — a special diode used for voltage regulation. A diode that exhibits, in the avalanche-breakdown region, a large change in reverse current over a very narrow range of reverse voltage.

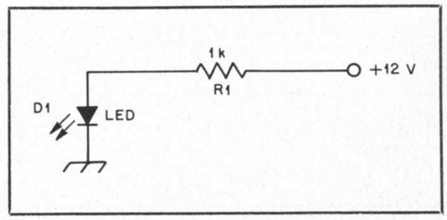

Fig. 14 — Example of an LED with operating voltage applied.

switch in the critical RF circuits.

A double tuning diode is shown in Fig. 13B. It is the preferred type of varactor in terms of linearity of the tuned circuit. One such diode is the Motorola MV104. Various capacitance ranges are available for tuning diodes. This means that we must choose the proper diode for the desired tuning range.

We must not neglect to mention a very familiar modern-day diode — the LED. LED means "light-emitting diode." They are available in many colors. When the LED is given enough current to make it conduct, it illuminates. A circuit for 12-V use is illustrated in Fig. 14. R1 is a current-limiting resistor that prevents burnout of D1. LEDs have a cathode and anode, just as do the other diodes. For this reason they will not light if the wrong polarity of voltage is applied. The electrical symbol for an LED always has two arrows pointing away from the cathode, as shown in Fig. 14.

Summary

An entire volume could be written about each of the diodes we have examined in this article. Our objective has been to familiarize you with some of the more common uses for diodes. The list of practical applications in amateur circuits goes on and on; as you continue to gather knowledge, you will become familiar with all manner of uses for diodes. I dare say you will think of some applications that have escaped me! Once again I want to urge you to pick up your *ARRL Handbook*, and study the chapter on semiconductors and power supplies. The real nitty-gritty of how diodes function and how you may use them is contained in those chapters. It will be helpful for you to wire up some simple experimental circuits that use diodes. Observing the action of diodes will help you to better understand them.