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TECHNICIANS AND EXPERIMENTERS RECTIFIER MANUAL

By Louis E. Garner, Jr., Ph.D.

By definition, *rectifiers* are devices having non-symmetrical conduction characteristics which are used for the conversion of alternating currents into unidirectional currents. They are, basically, diodes which offer a high resistance to the flow of current in one direction and a low resistance to current flow in the opposite direction. Semiconductor rectifiers are those which utilize the electrical properties of materials with conductivities intermediate between those of true conductors, such as metals, and insulators, such as ceramics.

Today, semiconductor rectifiers are manufactured using a variety of basic materials...typically, copper oxide, copper sulphide, selenium, germanium and silicon. Of these, copper oxide and copper sulphide types are used principally in low current, low voltage applications, although a few high current types are produced. One widespread application for copper oxide types, for example, is in meter and instrument rectifiers (IR Type DD-104). Selenium, germanium and silicon types, on the other hand, are used in low, medium and high current applications at from low to very high voltages. The latter types are used principally in AC/DC power supplies, in DC/DC converters, and as protective devices.

For a number of years, selenium types were the most popular and were used extensively in all types of equipment. More recently, silicon types have increased in popularity and have replaced selenium units in many applications. In the future, silicon rectifiers will probably be the most popular general type.

Each basic type has special characteristics. Of the three most popular general types, for example, silicon rectifiers offer the highest temperature capability and, in addition, can handle high currents and voltages. Germanium types, with a medium temperature capability, also have good current and voltage characteristics, and offer the advantage of the lowest forward voltage drop per cell. Finally, selenium rectifiers are less sensitive to voltage transients than silicon or germanium types, but have a medium temperature capability, are subject to "aging," and have a limited voltage handling capacity on a per cell basis. However, all three types may be series connected for high voltage applications.

INTERNATIONAL RECTIFIER manufactures a broad selection of rectifiers to meet virtually every power supply and circuit protection requirement. These range from low-voltage, low-current types for instrument applications to high-voltage, high-current types for heavy duty power supplies. Series assemblies, plug-in types, bridge stacks, cartridges, and other types are available for special applications.

A generalized rectifier characteristic curve is illustrated in Fig. 1. When forward biased (anode positive), the device offers very little opposition to current flow once its inherent forward voltage drop is exceeded. When reverse biased (anode negative), it offers high resistance to current flow, permitting only a small "leakage" current, until its breakdown voltage is reached. At this point an avalanche condition occurs and the reverse current increases suddenly and rapidly. Unless limited, the reverse current will destroy the unit.

While semiconductor rectifiers, in general, are quite rugged, certain precautions must be followed when employing the devices.

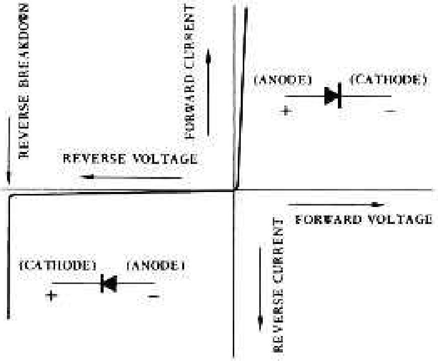

FIG. 1: Typical rectifier characteristics.

Maximum voltage and current ratings must be observed to avoid overload and subsequent deterioration. If the device is used at elevated temperatures, it must be *derated* in accordance with the manufacturer's suggestions. Overheating must be avoided, with suitable heat sinks (IR Type DD-125) provided if the units are used at high ambient temperatures or near maximum ratings ...in some cases, forced air cooling may be needed. Care must be taken to avoid voltage peaks *(transients)* or *surge* currents in excess of specified ratings. In general, transients may be eliminated by careful circuit design or by the use of "Klipcells", Zener diodes, or similar protective devices, while surge currents can be limited by the use of small series resistors.

From an applications viewpoint, a rectifier's most important specifications in addition to its maximum transient voltage and surge current ratings are its *peak inverse voltage*, PIV (or *peak reverse voltage*, PRV), its *forward voltage drop*, V_f, its reverse *leakable current*, I_r, and its maximum (DC) *current output*, I_o. Other useful specifications are its *maximum AC input voltage* (RMS) and nominal *DC output voltage*.

BASIC APPLICATIONS

A rectifier's primary application is the conversion of AC to pulsating DC. Hence its greatest field of use is in AC/DC or DC/DC power supplies. The two types of power supplies are basically similar as far as rectifier operation is concerned, for an oscillator or switching circuit is used to convert DC to either AC or pulsating DC for transformer step-up (or step-down) *before* rectification in DC/DC supplies. A variety of circuit arrangements may be employed, depending on individual preferences and equipment requirements. Basic power supply circuits are illustrated in Fig. 3, while typical voltage-multiplier circuits are shown in Fig. 4.

A *half-wave* rectifier circuit is shown in Fig. 3(a). The diode (RD_1) conducts only on alternate half-cycles, so that the output load current is a series of spaced half-wave pulses. With a sine-wave input voltage applied by transformer T_1, as shown in Fig. 2(a), the output waveform would be as illustrated in Fig. 2(b).

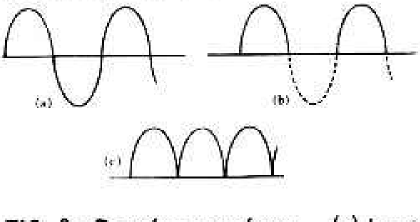

FIG. 2: Rectifier waveforms. . .(a) input sine-wave, (b) half-wave rectification, and (c) full-wave rectification.

A standard *full-wave* rectifier circuit is shown in Fig. 3(b). AC is supplied by T_1's center-tapped secondary winding. Diodes RD_1 and RD_2 conduct on alternate half-cycles, but their outputs are in parallel, so, that the output current is a continuous series of half-cycle pulses, as shown in Fig. 2(c).

The full-wave *bridge* rectifier circuit illustrated in Fig. 3(c) requires twice as many rectifier diodes as a conventional full-wave type, but does not require a center-tapped AC source.

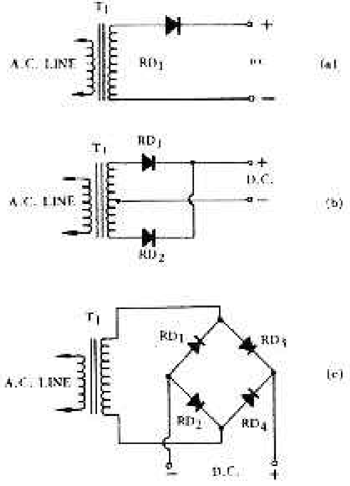

FIG. 3: Basic rectifier circuits...(a) half-wave rectifier, (b) full-wave rectifier, and (c) full-wave bridge rectifier.

Voltage-multiplier circuits are used in line-operated transformerless power supplies or where higher DC output voltages are required than can be obtained conveniently from a transformer. Voltage-doubler circuits are illustrated in Figs. 4(a) and 4(b) and a voltage-tripler in Fig. 4(c).

Referring, first, to Fig. 4(a), a *full-wave doubler* circuit is shown. In operation, RD_1 conducts on one half-cycle, charging C_1 to to peak line voltage. RD_2 conducts on the next half-cycle, charging C_2 to peak line voltage. Since C_1 and C_2 are in series as far as the output load is concerned, the DC output voltage is twice the peak line voltage.

A *half-wave voltage doubler* is illustrated schematically in Fig. 4(b). Here, C_1 is charged to peak line voltage through RD_1 on alternate half-cycles. During the remaining half-cycles, C_1's voltage is effectively in series with the line voltage, charging C_2 to twice peak line voltage through RD_2. The output load is connected across C_2.

The *voltage-tripler* circuit illustrated in Fig. 4(c) is essentially a half-wave voltage doubler combined with a conventional half-wave rectifier. In operation, C_1 is charged to peak line voltage through RD_1. As in the previous circuit, C_2 is charged to twice peak line voltage through RD_2, with C_1's voltage added to line voltage. At the same time, however, C_3 is charged to peak line voltage through RD_3. C_2 and C_3 are in series as far as the output load is concerned and thus their output voltages add, applying a DC voltage equal to three times the peak line voltage.

Rectifiers may be connected in series to handle higher voltages or in parallel to furnish larger currents, as shown in Figs. 5(a) and 5(b), respectively. For proper

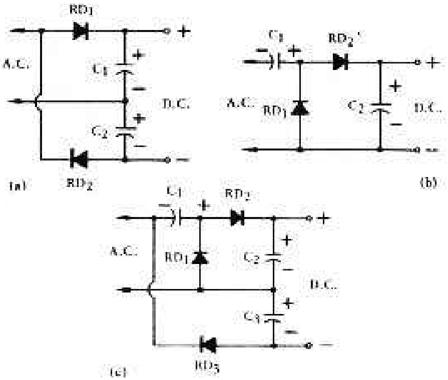

FIG. 4: Voltage multiplier circuits. . .(a) basic voltage-doubler, (b) cascaded volt age doubler, and (c) voltage-tripler.

operation, the individual rectifier "cells" in either a series or parallel arrangement must have identical characteristics. In practice, selected identical units are used in factory-assembled stacks and in multi-cell high-voltage cartridges. Where a series arrangement is assembled in the field, however, resistors should be connected across each element to equalize voltage drops. By the same token, small resistors should be connected in series with each cell in a parallel stack to equalize leg currents.

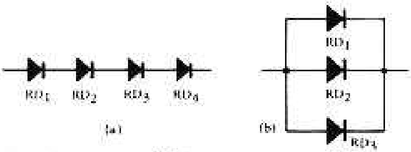

FIG. 5: Series (a) and parallel (b) rectifier connections. . .see text for details.

The basic rectifier circuits described above furnish a pulsating DC output. . .that is, a current with both (pure) DC and AC (ripple) components. For most applications, the ripple component must be removed. This is accomplished by means of a suitable *filter network.* Typical filter circuits are illustrated in Fig. 6.

As shown in Figs. 6(a) and 6(b), respectively, a simple choke (L_1) is an effective filter where large load currents are required, while a shunt capacitor (C_1) provides good filtering for very light loads. Unfortunately, a discharged capacitor acts like a short-circuit when voltage is first applied. This characteristic may result in excessive surge currents. To prevent diode damage, then, it is common practice to connect small current limiting resistors in series with capacitors which are connected directly to semiconductor rectifiers. This technique is used in both conventional and voltage-multiplier power supply circuits. A typical arrangement is shown in Fig. 6(c); here, R_1 serves to limit surge currents to C_1. As a general rule, surge limiting resistors have values of 50 ohms or less.

A combination L-C circuit provides better filtering than either a choke or a capacitor used alone. Filter networks of this general type are illustrated in Figs. 6(d), 6(e) and 6(f). A choke-input or "L type" filter is illustrated in Fig. 6(d), a capacitor-input or "pi-type" filter in Fig. 6(e), and a two-section filter in Fig. 6(f). Of these, the "pi-type" is by far the most popular, for it provides maximum output voltage coupled with acceptable regulation and good ripple removal. The choke-input circuits provide better regulation, however, while maximum filtering is provided by the two-section network. Although somewhat more costly due to the use of two choke coils (L_1 and L_2), the latter circuit is used where good regulation and minimum ripple is required.

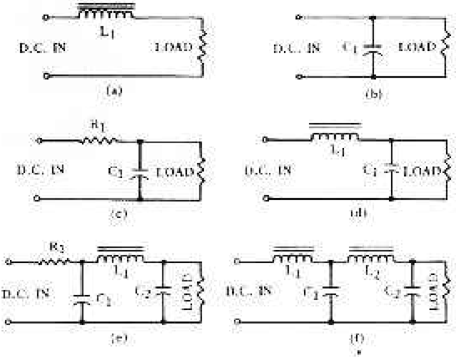

FIG. 6: Typical filter networks...(a) choke, (b) capacitor, (c) capacitor with surge limiting resistor, (d) "L" filter, (e) basic "pi" filter, and (f) two-section filter.

In summary, practical power supply circuits include an AC source, suitable rectifiers, and a filter network. The AC source may be a power line, a transformer, or the output of a DC powered oscillator or switching circuit. The rectifiers may be arranged for either half-wave or full-wave rectification. Full-wave rectification, where feasible, is preferred, for it provides better regulation and, with twice the ripple frequency of half-wave circuits, requires a less costly filter network. The filter network, finally, may be either choke or capacitor-input. Where capacitor input circuits are used, however, suitable surge limiting resistors are required to prevent diode damage.

SPECIAL APPLICATIONS

Although rectifier diodes are used primarily in power supply circuits, these are by no means their only applications. Other applications are illustrated schematically in Figs. 7 through 10. These circuits have been selected with particular reference to experimenter and hobbyist interests.

Easily assembled in a small metal case, the *Power Control* circuit shown in Fig. 7 may be used as an incandescent lamp dimmer, as a soldering iron or small oven heat control, or as a two-speed control for power tools or appliances employing universal (AC-DC) motors. It is *not suitable* for use with inductive loads or transformer-operated equipment. S_1 is a single-pole, 3-position rotary switch, preferably with heavy-duty contacts. RD_1 is a 200 PIV rectifier, with its maximum current rating determined by the anticipated load. Type DD176 may be used for loads under 100 watts, while type 3F20D-C should be used for loads of up to 300 watts. The line cord and plug and outlet receptacle are standard electrical hardware items.

FIG. 7: A simple Power Control circuit.

In operation, full line power is furnished to the load when S_1 is in its "Hi" position while half-wave rectified DC is supplied when the switch is in its "Lo" position, Thus, the effective RMS output voltage is reduced by approximately 30% in the "Lo" position, limiting the power supplied to the load.

A simple, but effective, *Meter Protection* circuit is illustrated in Fig. 8. RD_1 and RD_2 are "top-hat" silicon rectifiers such as type DD175. This circuit utilizes the forward voltage drop (E_f) characteristics of silicon rectifiers to protect a sensitive meter movement. In operation, neither diode conducts heavily until the effective voltage across it exceeds E_f. . .a small fraction of a volt. At this point, however, the appropriate diode (depending on voltage polarity) conducts heavily, acting as a low resistance shunt around the meter. In general, the diode's E_f is greater than the average meter voltage at full scale deflection but less than the voltage required to cause damage.

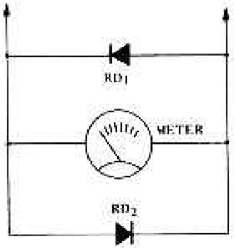

FIG. 8: A basic Meter Protection circuit.

Transistorized equipment may be damaged if connected to a power source of incorrect polarity. This fact can cause problems when installing mobile equipment such as CB transceivers and PA amplifiers, for some automobiles have negative-ground and others positive-ground systems. Damage may be avoided by using the simple *Polarity Protection* circuit illustrated in Fig. 9. In operation, the diode (RD_1) permits the direct application of DC with correct polarity, but blocks the application of power with reversed polarity. RD_1's small inherent DC voltage drop is not enough to affect circuit performance.

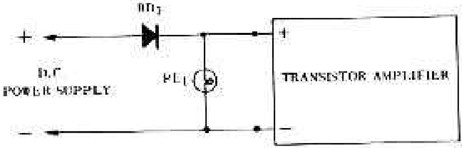

FIG. 9: A low-cost Polarity Protection circuit.

The Polarity Protection circuit may be added to almost any equipment, either as a built-in feature or as an "outboard" accessory. RD_1 is a low-voltage, high current rectifier...type 20HB5-C is suitable for most applications. The pilot lamp assembly (PL_1) is an optional feature to indicate when proper connections are made. The lamp bulb chosen should match the supply voltage (6 or 12 volts).

A *60-Cycle Stroboscope* assembled using the circuit shown in Fig. 10 can be a useful accessory for anyone working with phonographs or Hi-Fi equipment. It is used in conjunction with a standard stroboscopic disc (available through most parts suppliers) and indicates when a turntable is rotating at correct speed. In operation, the rectifier (RD_1) furnishes half-wave rectified pulses to the neon lamp through current limiting resistor R_1, causing the bulb to flash at a 60 cps rate. If desired, the instrument may be assembled as a hand-held probe in a short length of plastic or fiber tubing. RD_1 is a type DD176, SD500 or 5A4-D rectifier, R_1 is a 39K, 1 watt resistor, and the neon bulb is type NE-48.

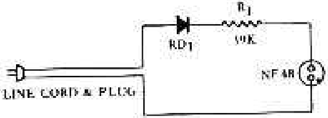

FIG. 10: An easily built 60-Cycle Strob oscope circuit.

Notes

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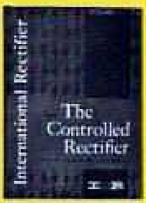

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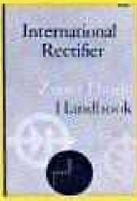

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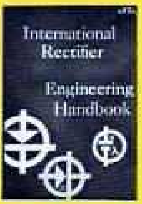

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