Experiment #6—Rectifiers and Zener References

Background

This month begins a three-part series of experiments on power supply circuits. We'll start with a basic rectifier and a Zener diode voltage reference. In the second step we'll experiment with some voltage multipliers. Finally, we'll design a linear voltage regulator.

Terms to Learn

- *Anode*—diode electrode into which current flows.[1]
- *Cathode*—diode electrode out of which current flows.
- *Half-wave or Full-wave*—rectification during one-half of or an entire ac cycle, respectively.
- *Peak Inverse or Reverse Voltage (PIV or PRV)*—the maximum voltage from cathode to anode a diode can safely withstand.
- *Avalanche Breakdown / Conduction*—current flow from cathode to anode when a diode's PIV or Zener voltage is exceeded.

The Basic Rectifier

The term *rectifier* can refer to either a semiconductor device (a diode) or to a circuit. Both convert alternating current (ac) into direct current (dc). The diode performs no other function besides controlling current flow, while the rectifier circuit may include several other functions. For this experiment, the term *rectifier* will refer to the circuit.

For a diode to be used in a power rectifier, we need to know two basic things about it: its PIV and its average forward current ratings. Diodes convert ac to dc by preventing current flow from cathode to anode. If ac is applied to a diode, current will flow only during the half-cycle in which the voltage from anode to cathode is positive.

[1]Notes appear on page 58.

During the non-conducting half-cycle, the diode blocks current flow as long as the voltage from cathode to anode does not exceed the PIV rating. At higher voltages, the diode will begin to conduct in its reverse mode and may suffer damage.

The diode's average current rating specifies how much power the diode can dissipate while conducting current without overheating. When conducting, a regular P-N silicon diode will have about 0.7 V *forward voltage drop* from anode to cathode[2] and will dissipate a power of (0.7 V × I_{avg}) W.

Now let's go on to the rectifier. Figure 1 shows three types of diode-based rectifier circuits—a half-wave, a full-wave center-tapped and a full-wave bridge. In our experiments, we'll use a function generator as an ac signal source, but the principles are the same for a transformer in a real power supply. We'll use 1 kHz (1000 Hz) as our ac frequency (because it's convenient and the filter components are smaller)—a transformer in a real power supply will usually be operating at the ac power line frequency of 60 Hz (as commonly used in the Western Hemisphere). Resistor R_L is the load.

The half-wave rectifier with its single diode can only supply current to the load during one-half of each applied ac cycle—thus the term *half-wave*. The full-wave center-tapped requires two out-of-phase voltage sources with a common center connection, such as a transformer's center-tapped secondary winding. Each source supplies current to the load on opposite half-cycles—thus the term *full-wave*—and doubling the output voltage.

The full-wave bridge achieves full-wave rectification by using an extra pair of diodes. On the first half-cycle, the full-wave bridge conducts through D1 and D3. On the next half-cycle, D1 and D3 are *reverse-biased* and don't conduct current, while D2 and D4 are *forward-biased* and supply current to the load.

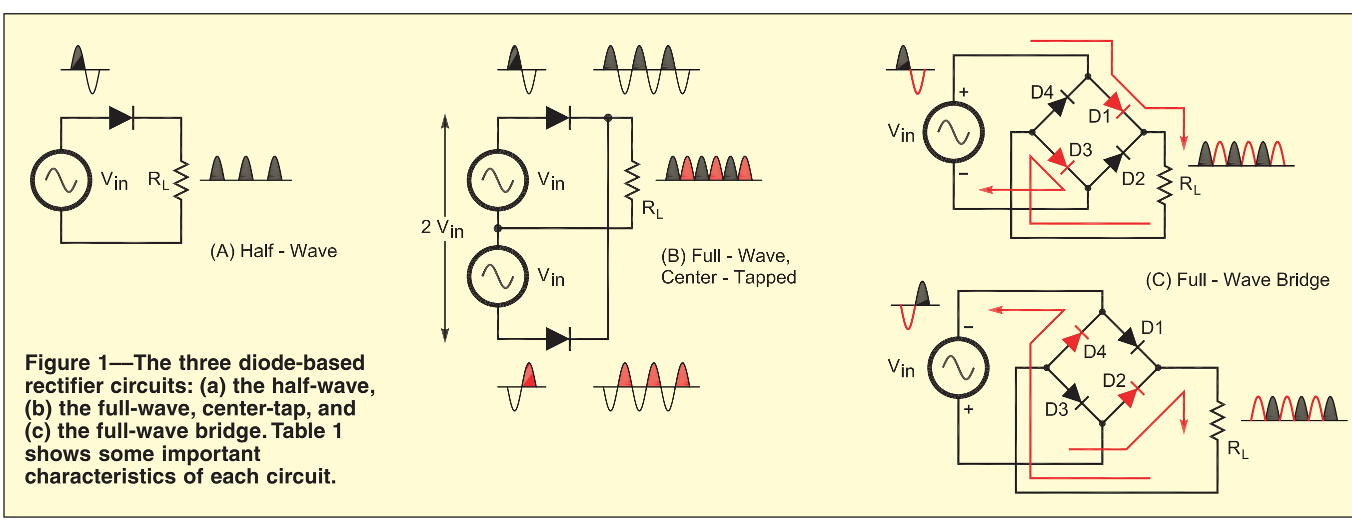

Figure 1—The three diode-based rectifier circuits: (a) the half-wave, (b) the full-wave, center-tap, and (c) the full-wave bridge. Table 1 shows some important characteristics of each circuit.

Table 1

Important Characteristics of Rectifier Circuits (V_{in} is the input RMS voltage and I_{avg} is the average load current)

Rectifier Type	*Number of Diodes*	*Average Output Voltage*	*Power Loss*	*Diode PIV Required*
Half-Wave	1	0.45 V_{in}	0.7 × I_{avg}	2.8 V_{in}
Full-Wave, Center-Tap	2	0.9 V_{in}	0.7 × I_{avg}	2.8 V_{in}
Full-Wave Bridge	4	0.9 V_{in}	2 × 0.7 × I_{avg}	1.4 V_{in}

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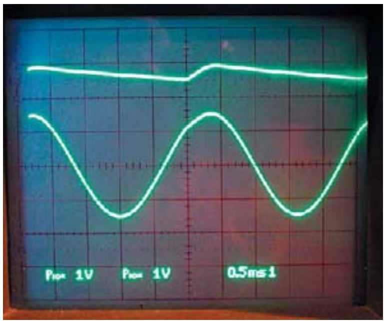

Figure 2—The bottom trace in this photograph shows the sine wave input from the signal generator. The upper trace shows the voltage across the load with a 1 µF capacitor. Note that the charging peaks in the upper trace correspond to the positive peaks of the input voltage.

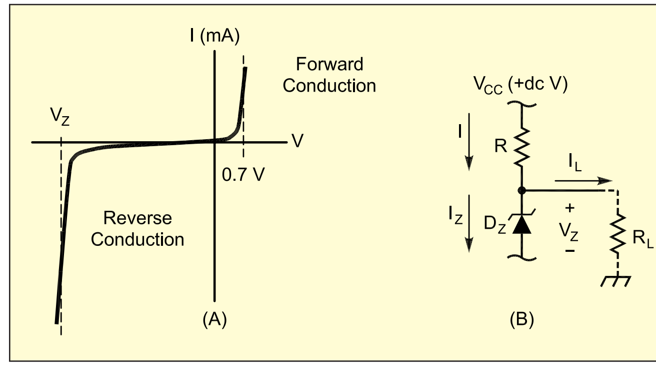

Figure 3 (A)—The Zener diode's current-voltage characteristics. Current from anode to cathode is considered to be positive or forward current and voltage from anode to cathode is positive. (B)—A common circuit for making a voltage reference with a Zener diode.

Testing the Half-Wave Rectifier

- Because function generator outputs usually have a ground-referenced output, we will only test the half-wave rectifier. Build the half-wave circuit of Figure 1a using a 1N4148 diode and a 3.9 kΩ load resistor.
- Set the function generator to output a sine wave of 5 V_{peak} (3.5 V_{rms} on the DMM's ac scale) at 1 kHz. The DMM will show about 1.3 V dc across the load resistor. An oscilloscope will show the load voltage pulsing on every positive half-cycle of the input sine wave. Note that the diode doesn't conduct for exactly one-half cycle because of the 0.7 V forward drop.
- Connect a 1 µF capacitor with at least a 10 V rating in parallel with the resistor. The DMM will show a load voltage of about 3.6 V dc because the capacitor stores energy during the non-conducting half-cycles. The 'scope will show the load voltage as a series of short ramps (as the capacitor charges through the diode) followed by long ramps (as the capacitor discharges through the resistor). This can be seen in Figure 2.
- Experiment by trying different input voltages, load resistors, and capacitors. Try different input waveforms—square and triangle waves, for example. Observe the shape of the charging ramp as you try different waveforms. If you have a function generator with a ground-independent (or *floating*) output, try building the full-wave bridge rectifier.

Rectifier Characteristics

Why would one select a particular rectifier circuit over another? There are certain differences, or *trade-offs*, in the characteristics of each that make them suitable in various circumstances, as shown in Table 1.

The full-wave bridge, because it has two diodes in the current path, is dissipating twice the power of the half-wave and full-wave center-tapped rectifiers. The benefit of the full-wave bridge is that each diode needs only one-half the PIV rating of a full-wave, center-tapped circuit. The other two circuits have fewer diodes and less power dissipation, but they require higher diode PIV ratings.

Zener Diodes

Another important power supply component is the Zener diode, named after American physicist Dr Clarence M. Zener. If an ordinary diode's PIV rating is exceeded, the diode enters avalanche conduction, but the Zener is designed to conduct in the reverse direction at a low, but stable voltage. In the normal, forward direction, the Zener looks like an ordinary diode.

The Zener is a very useful voltage reference. Figure 3 shows that even though the reverse current through the Zener may change substantially, the voltage across the diode changes very little. In the circuit of Figure 3, if enough current (I_z) is supplied to the diode through R, small amounts may be drawn by R_L without affecting the Zener voltage.

Using a Zener diode as a voltage reference requires several simple design steps:

1) Add up the currents that will be used by the load—this is I_L.

2) Determine the supply voltage, V_{cc}, and the Zener's power rating, P_z.

3) Select a current I_z so that $P_z = V_z \times I_z$ is, at most, less than one-half of the Zener's rated power—this is for safety and to keep the Zener voltage from changing with temperature.

4) Find I by adding I_L and I_z. Use Ohm's Law to find R.

$R = (\text{minimum } V_{cc} - V_z) / I$

By using this procedure, R is set so that even at the minimum value of supply voltage, there is enough current to supply the Zener and the loading circuitry. Give it a try!

Testing a Voltage Reference

- Use a 12 V supply voltage (V_{cc} minimum is 12 V) and a 5.1 V 1N4733A 1 W Zener diode. (The letter following the Zener type number usually refers to the Zener's voltage tolerance, "A" being ±10%, "B" being ±5% and no following letter being ±20%.) Assume that the circuitry loading the voltage will draw 1 mA.
- Follow the design procedure, limiting the Zener's power dissipation to 100 mW.

5.1 V × I_z = 100 mW, so I_z = 19.6 mA. Now, I = 19.6 + 1 mA = 20.6 mA and R = (12 – 5.1 V) / 20.6 mA = 335 Ω; use a 330 Ω resistor.

For the load, use a 5.1 kΩ resistor connected from the Zener's cathode to ground.

- Connect the components as in Figure 3B and verify the Zener voltage is close to 5.1 V. Vary the supply voltage up and down while watching the Zener voltage on a DMM—it should remain stable until V_{cc} falls below V_z + (I × R).

Suggested Reading

- Chapters 8 (diodes) and 11 (rectifier circuits) of *The ARRL Handbook* go into great detail about rectifier circuits as do sections 1.25 through 1.28 of *The Art of Electronics*. The Web site for our series is: **www.arrl.org/tis/info/html/hands-on-radio/**.

Shopping List

- 1N4733A Zener (RadioShack 276-565) and 1N4148 signal diodes (RadioShack 276-1122)
- 1 µF, 16 V capacitor
- 330 Ω, 3.9 kΩ, 5.1 kΩ ¼ W resistors

Next month we'll learn about the voltage multiplier. From tiny diodes and capacitors, mighty voltages come!

Notes

[1]Electronics texts typically use "conventional current" or the flow of positive charge. The actual flow of electrons or "electronic current," is in the opposite direction.

[2]Other types of diodes, such as PIN, Schottky, or those made from germanium have different forward voltage drops when conducting.