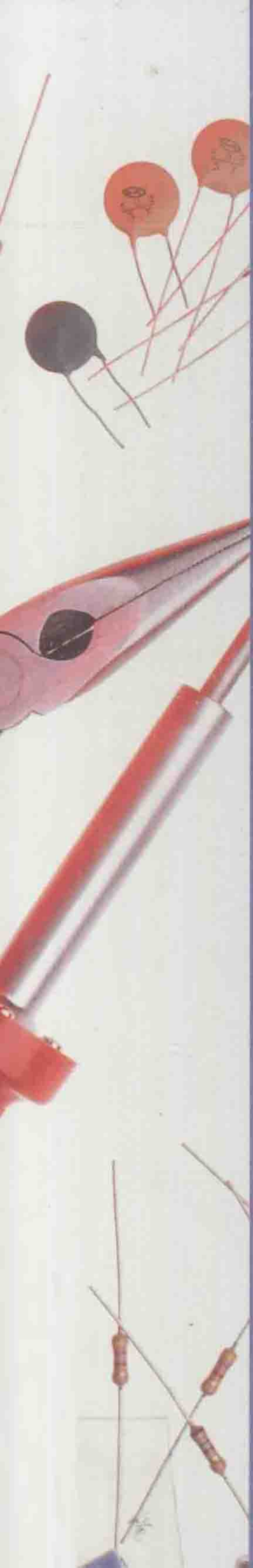

SAVE A BUNDLE

BUILD YOUR OWN

Low-Cost Signal Generator

Delton T. Horn

Build Your Own Low-Cost Signal Generator

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Build Your Own Low-Cost Signal Generator

Introduction

Few electronics systems would be of much use without signals of some sort flowing through them. Sometimes the signal is an electrified version of some non-electronic parameter. For example, a PA amplifier system uses voice and other sound signals converted into electrical form by a microphone. An electronic light meter's signal is the electrical equivalent of the intensity of the light shining on some sort of photosensor.

Often, though, the signals needed are purely electronic in origin. The circuitry must create its own signals from scratch. There are countless types of electrical signals that we might want to generate. Simply put, an electronically-generated signal may be either a dc voltage or current, or an ac waveform of some type. Both dc and ac signal generation are covered thoroughly in this book. Chapter 1 deals with dc signals, and the rest of the book explores various ac signals, including the most popular and widely used—the sine wave (chapter 2), the rectangle wave and its special forms, the square wave and the pulse wave (chapter 3), the triangle wave, the sawtooth wave, and the staircase wave.

Odd and exotic special purpose waveforms are also covered, along with white noise and pink noise. Function generators, which can generate two or more different waveforms within a single circuit, are discussed in chapter 4. White-noise and pink-noise generators are the subjects of chapter 6.

Chapter 7 explores various ways to generate nonstandard, complex ac waveforms. Amplitude modulation, frequency modulation, additive synthesis and subtractive synthesis are among the techniques discussed here. The special problems and considerations involved when working with RF (radio frequency) signals are explored in chapter 7.

Finally, chapter 8 examines the various, and often surprising ways that ac signals can be generated by digital circuitry. Usually digital circuitry only works with rectangle waves of some sort, but techniques for digitally synthesizing other analog waveforms will also be considered in this chapter.

In addition to the theoretical background and circuit design tips, this book also features sixteen inexpensive but useful projects, including sound generators, power supplies, and test equipment. Certainly, none of these projects will put any commercial manufacturers of such equipment out of business. For the most part, we won't be dealing with super-precision specifications in any of these projects. But the specs are still surprisingly good for such easy, minimal-cost projects. They should be good enough for most typical hobbyist applications. The limitations of any given project will be mentioned in the text, where relevant.

You can spend hundreds of dollars to buy a deluxe commercial signal generator. Or, you can build any one of these projects for less than $25, and it will do almost as good of a job for most noncritical applications.

With this book as your guide, you should be able to generate almost any electronic signal you'll ever need, without having to spend a bundle.

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CHAPTER
dc power supplies

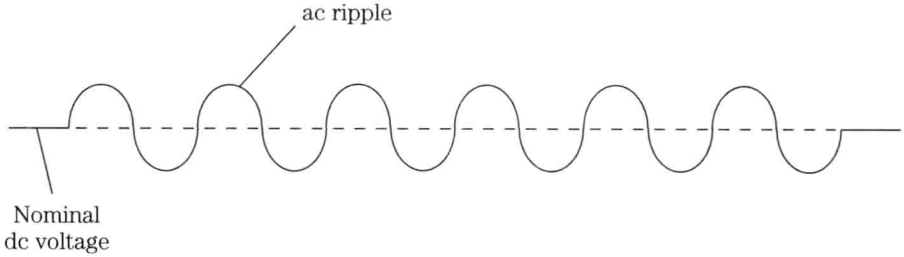
A *dc voltage* usually isn't thought of as a *signal*, even though it is as much of a signal as any ac waveform. It is just a steady-state signal, rather than a fluctuating signal.

dc voltages probably aren't normally considered to be signals because of the way they are used. When used to power a circuit, the dc voltage does not really function as a signal. However, in many circuits, dc voltages are used as control signals. For example, in a PLL or servo circuit, a dc signal is fed back to make automatic self-correction adjustments. In older analog music synthesizers, almost all functional parameters were set by various control voltages, a clear case of dc voltages being used as signals.

We are beginning with dc voltages in this book because they are the simplest possible type of signal. The *waveform* is simply a straight line. The polarity doesn't change, and the voltage value is constant (until the signal is changed to a new value). The frequency is always 0 Hz. All ac signals are necessarily more complex. We'll get to them in later chapters of this book.

In most modern electronics work, two basic sources are used to obtain dc voltages—batteries and ac-to-dc power supplies. *Batteries* are perfectly straight-forward. An internal chemical reaction of some sort generates a dc voltage, which can be used as it is, or it can be dropped to a lower value by a voltage-divider network. (Voltage-multiplier circuits also exist for increasing a dc voltage, at the expense of the available current.) For batteries, dc is the natural order of things.

An *ac-to-dc power supply* is a circuit that accepts ordinary ac house current, and converts it to a specific dc voltage. Some sort of low-pass filtering is almost always used to reduce the amount of ac fluctuations sneaking through the circuit to the nominally dc output voltage. Such ac fluctuations riding on a dc voltage are known as *ripple* (sometimes *ac ripple*, although this term is redundant), and the effect is illustrated in Fig. 1-1.



1-1 ac fluctuations riding on a dc voltage are known as ripple.

Better-quality power-supply circuits also include some form of voltage regulation, which reduces ripple effects even more than simple filtering, while minimizing the effects of loading. Without voltage regulation, the output voltage can vary (often by a very significant amount) with changes in the current drawn by the load. Such load variations are almost always highly undesirable. In most applications, we definitely want the supply voltage to remain constant, regardless of the load.

The basics of power-supply circuits

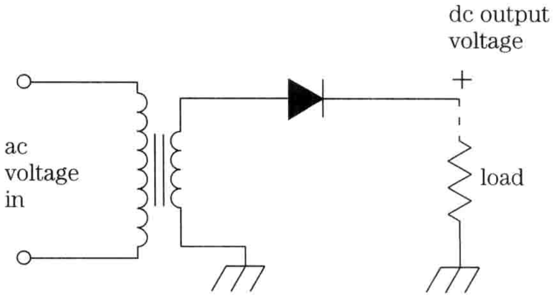
A simple power-supply circuit typically consists of three basic elements—a power transformer, a rectifier, and a filter. The *power transformer* drops the input ac voltage (nominally 120 Vac) to a lower ac voltage, closer to (but higher than) the desired output dc voltage. For example, in a power-supply circuit intended to put out 12 volts dc, the transformer might drop the ac voltage down to 13.6 Vac. When used in this way, the transformer is called a *step-down transformer*. In some special cases, a *step-up transformer* can be used to create a voltage larger than the nominal ac input. An *isolation transformer* has an output voltage exactly equal to its input voltage, but the two sections are electrically isolated from each other, maximizing safety, and almost totally eliminating loading effects on the transformer voltage.

After the transformer comes the *rectifier*. This can be a single diode, producing a half-wave rectifier circuit. Multiple diodes can be used to create more sophisticated power-supply circuits known as *full-wave rectifier* and *bridge rectifier* circuits. We will discuss each type of rectification shortly.

Finally, the filter, as already noted, reduces any stray ac content, or ripple, in the output voltage. In most simple power-supply circuits, the *filter* is simply a large-value electrolytic capacitor, which shunts any ac signal content to ground. Better quality power-supply circuits might use more sophisticated filtering, but the basic principle is the same. There is a low-resistance path to ground for ac signals, but this path presents a very high resistance to a dc voltage, so the ac content is shunted off, while the desired dc voltage has nowhere to go but to the circuit's output terminals.

Half-wave rectifiers

A simplified *half-wave rectifier* circuit (without a filter) is shown in Fig. 1-2. The ac voltage from the transformer, by definition, reverses its polarity twice during each cycle. For one half of each cycle, terminal A is positive with respect to terminal

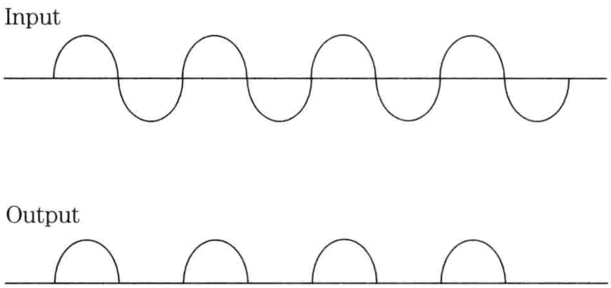


1-2 This is a simplified half-wave rectifier circuit, without an output ripple filter.

B (which is grounded here). For the other half of each cycle, terminal A is negative with respect to terminal B.

A *diode*, or rectifier is a *polarized device*. It only permits a voltage to pass through it in one direction (polarity). In the other direction (polarity), the voltage's path through the rectifier is blocked. In our half-wave rectifier circuit, when terminal A is positive, the diode is *forward-biased*, so the applied voltage can pass through it to the output.

However, when terminal A is negative, the diode is *reverse-biased*, blocking the applied voltage. Nothing at all appears at the output during the negative half-cycles. Only the positive half-cycles appear at the circuit's output, as illustrated in Fig. 1-3.

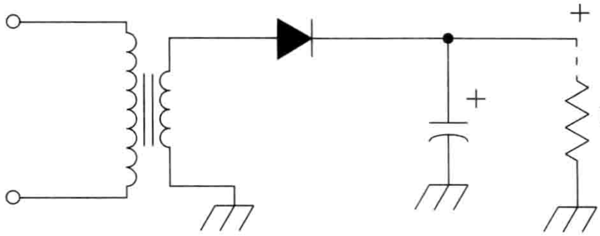


1-3 In a half-wave rectifier circuit, only the positive half-cycles appear at the output.

Of course, this is not a true dc voltage at all. Half the time, there is no output voltage at all. The rest of the time, the output voltage is either in the process of rising from zero to the maximum level, or dropping from the maximum level back down to zero. It never holds a constant value.

To achieve a closer approximation of a true dc voltage, we need to add a filter stage to our half-wave rectifier circuit. This is usually accomplished by placing a large-valued capacitor across the diode's output, as shown in Fig. 1-4.

Let's start things out at zero. The ac signal is in a negative half-cycle, so the output voltage is zero for this instant. We will assume that the capacitor is fully discharged (charge = 0). Nothing will happen until a positive half-cycle begins, and the diode starts to conduct, permitting a voltage to appear at the output. As the output voltage rises from zero to its peak value, the capacitor is charged. When the voltage drops off from its maximum level, the capacitor starts to discharge through the load, so the voltage that is seen by the load looks something like Fig. 1-5. If the capacitor



1-4 A large electrolytic capacitor can be added across the output of a half-wave rectifier circuit to filter out the worst of the ripple.

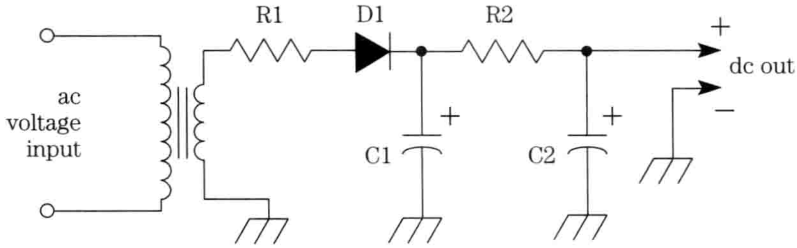
1-5 Adding a filter stage to a half-wave rectifier circuit will give a closer approximation of a true dc voltage.

is large enough, it will not fully discharge before the next positive half-cycle starts. In other words, the capacitor will be repeatedly charged and partially discharged. The less it is discharged when the new cycle begins, the less ripple there will be in the output signal.

The larger the capacitance value, the slower the discharge rate, and therefore, the shallower the discharging angle in the output waveform. That is, increasing the capacitance will give a closer approximation of a true dc voltage with less ripple. Electrolytic capacitors with values of several hundred to a few thousand microfarads are typically used.

But even with the largest imaginable capacitor, there is still going to be a fair amount of ripple in the output signal. Therefore, practical power-supply circuits typically use a somewhat more complex filter stage, as illustrated in Fig. 1-6. In this circuit, resistor R2, along with capacitors C1 and C2, comprise a low-pass filter network that smooths out the output signal more efficiently than a single capacitor can by itself. There will still be some ripple, but it will not be as pronounced.

Resistor R1 is a *surge resistor* that protects the diode from any sudden increase in the current drawn through the circuit. The surge resistor typically has a fairly small value, so normally the voltage drop across it is negligible. But an increase in the current drawn through the surge resistor will cause its voltage drop to increase pro-



1-6 Most practical power-supply circuits typically use a somewhat more complex filter stage.

portionately, since according to Ohm's law, voltage equals current times resistance ($E = IR$) and the resistance is a constant in this case. Sometimes, surge resistor R1 is also fused for additional protection.

A surge resistor has uses other than for protection against unusual or abnormal circuit defects. In some circuits, it is also needed for normal operating conditions. Assume that no source (ac) voltage at all is being applied to the circuit. Any residual charge on the capacitors will soon be fully discharged through resistor R2 and the load circuit. The capacitors are now completely discharged. Now, when power is first applied, the capacitors will tend to draw a large amount of current until they are almost completely charged. Assuming the capacitance values are large enough, there won't be sufficient time for the capacitors to fully charge during a single cycle, so it takes a few cycles for ordinary operation to begin. During this time, more current will be drawn through the diode. Of course, this extra current drain will increase the voltage drops across the other components, and again, the surge resistor protects the diode from burning itself out by attempting to conduct more current than it can safely handle.

In many better-quality power-supply circuits, a *thermistor* (temperature-sensitive resistor) is used for the surge resistor. When power is first applied to the circuit, the components, including the thermistor tend to be relatively cool. The thermistor has a higher resistance when it is cold. This means that when power is first applied, there is a relatively large voltage drop across the thermistor, leaving only a relatively small voltage to pass through the diode. As current passes through the circuit, the components start to dissipate heat. The increased temperature causes the resistance of the thermistor (and thus, the voltage drop across it) to drop to a fairly low value. From then on, it acts like any ordinary (fixed-value) surge resistor.

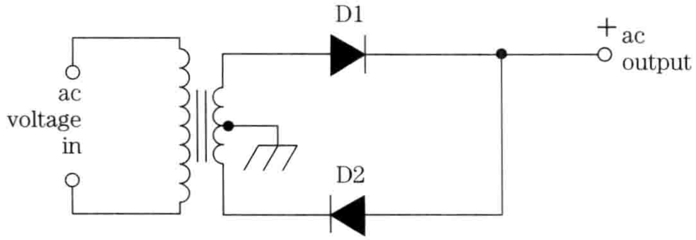
A half-wave rectifier power-supply circuit is simple and inexpensive, but it leaves much to be desired. Even with the best possible filtering, the ripple content of the output voltage will inevitably be relatively high. This type of circuit is also energy-wasteful. Half of each input cycle is completely unused. This energy is simply dissipated as heat, and does no good, even though it adds to the input power consumed by the circuit. Clearly, a more efficient type of power-supply circuit is highly desirable in many, if not most practical applications—especially if relatively large power levels are required.

Full-wave rectifiers

By using two diodes in parallel with opposing polarities, we can create a more efficient type of power-supply circuit. Since this type of circuit uses both halves of the input cycles, it is known as a *full-wave rectifier*.

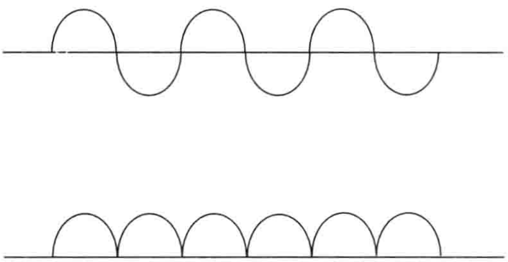
A simplified full-wave rectifier circuit (without any filter stage) is shown in Fig. 1-7. Notice that a full-wave rectifier circuit must always be used with a center-tapped transformer, with the center-tap grounded.

Remember, if the center-tap of a transformer's secondary winding is grounded, the lower half of the secondary winding will carry a signal that is equal to, but 180 degrees out-of-phase with, the signal carried by the upper half of the secondary winding. This means that in our full-wave rectifier circuit, when diode D1 is passing a positive half-cycle, diode D2 is blocking a negative half-cycle. And similarly, when diode D1 is blocking a negative half-cycle, diode D2 is passing a positive half-cycle.



1-7 This is a simplified full-wave rectifier circuit, without an output ripple filter.

One of the diodes is conducting, and the other is non-conducting at all times. This means the output signal will resemble Fig. 1-8. An actual, non-zero voltage will be present at virtually all times, except for those brief instants when the original waveform crosses through the 0 volts line, in either direction.



1-8 In a full-wave rectifier circuit, one of the diodes is conducting, and the other is non-conducting at all times.

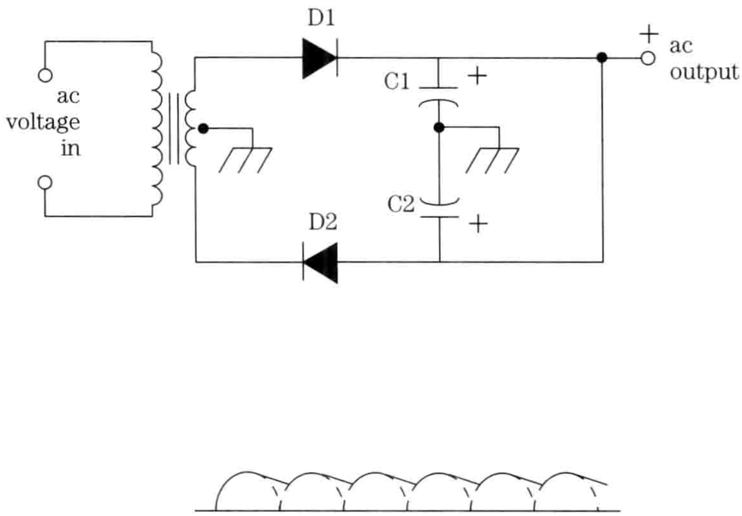
Besides wasting less input power, the output signal of a full-wave rectifier circuit is easier to filter, because there is less time for the filter capacitor to discharge before it is charged again. The simplest type of filtering for a full-wave rectifier signal, and the resulting output signal, are illustrated in Fig. 1-9. Notice that both the positive (D1) and the negative (D2) output lines need their own filter capacitor, and they are both isolated from the ac ground.

The chief disadvantage of the full-wave rectifier circuit is the requirement for a center-tapped transformer, which is usually more expensive than a non-center-tapped transformer.

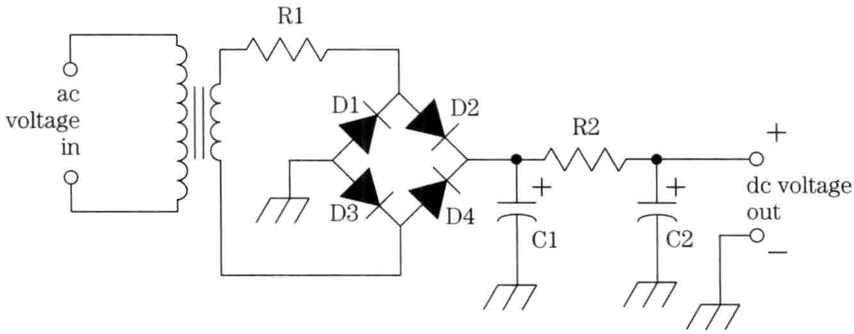
Bridge rectifiers

A *bridge rectifier* circuit, like the one shown in Fig. 1-10, combines the advantages of both a half-wave rectifier and a full-wave rectifier. Like the full-wave rectifier, the bridge rectifier uses the entire input cycle, and its output signal is fairly easy to filter.

On the other hand, like the half-wave rectifier, the bridge rectifier does not require an expensive center-tapped transformer as is necessary with the full-wave rectifier. While a bridge rectifier requires four diodes (instead of one for a half-wave rectifier, or two for a full-wave rectifier), it is still usually more economical for semiconductor circuits than a full-wave rectifier, in which the center-tapped transformer is usually the greatest expense.



1-9 This is the simplest type of filtering for a full-wave rectifier circuit, and the resulting output signal.



1-10 A bridge-rectifier circuit combines the advantages of both a half-wave circuit rectifier and a full-wave rectifier.

The bridge rectifier circuit also requires a bit less space, and produces less heat. (Bridge rectifier circuits using tube diodes are not practical.) Another potentially helpful way in which a bridge rectifier circuit resembles a half-wave rectifier circuit is that one of the output lines can be at true ground potential.

The operation of a bridge rectifier is not as obvious and straight-forward as either a half-wave rectifier or full-wave rectifier circuit. It is easiest to understand if we re-draw the circuit diagram for each half-cycle, showing only the forward-biased (conducting) diodes. At any point of the input cycle, two of the diodes in the bridge are conducting and two are reverse-biased. For the positive half-cycles, the circuit effectively acts like the modified circuit shown in Fig. 1-11. The equivalent circuit for the negative half-cycles is illustrated in Fig. 1-12.