HIGH-VOLTAGE GENERATION

A few readily available components and some technical know-how is all that's required to produce very high DC voltages from a relatively low AC voltage source.

BILL CODY

Although the trend in modern electronics is toward lower-power circuitry, there is simply no getting around the fact that many of the latest electronic gadgets still require a "spritz" or two of high voltage to make them function properly. Unfortunately, many high-voltage circuits depend on relatively expensive and bulky step-up transformers to generate the "juice" that they require. That's because those circuits also have fairly hefty current requirements, as well as a "thirst" for good regulation. Other circuits, in which extensive regulation and "vast" amounts of current are not required, rely heavily on high-voltage-generating configurations that can be built around relatively inexpensive and readily available components.

Warning!! This article deals with and involves subject matter and the use of materials and substances that may be hazardous to health and life. Do not attempt to implement or use the information contained herein, unless you are experienced and skilled with respect to such subject matter, materials, and substances. Neither the publisher nor the author make any representation as for the completeness or accuracy of the information contained herein, and disclaim any liability for damages or injuries, whether caused by or arising from the lack of completeness, inaccuracies of the information, misrepresentations of the directions, misapplication of the information, or otherwise.

In order to obtain the high voltages needed for the less demanding circuit configurations, a voltage-doubler is often used. Voltage doublers, which are sometimes used in radio-frequency-actuated circuits to obtain the control voltage, allow you to generate higher voltages than would otherwise be possible with conventional power supplies. Voltage doublers are not generally used when a high degree of regulation is required or when the current drain is high.

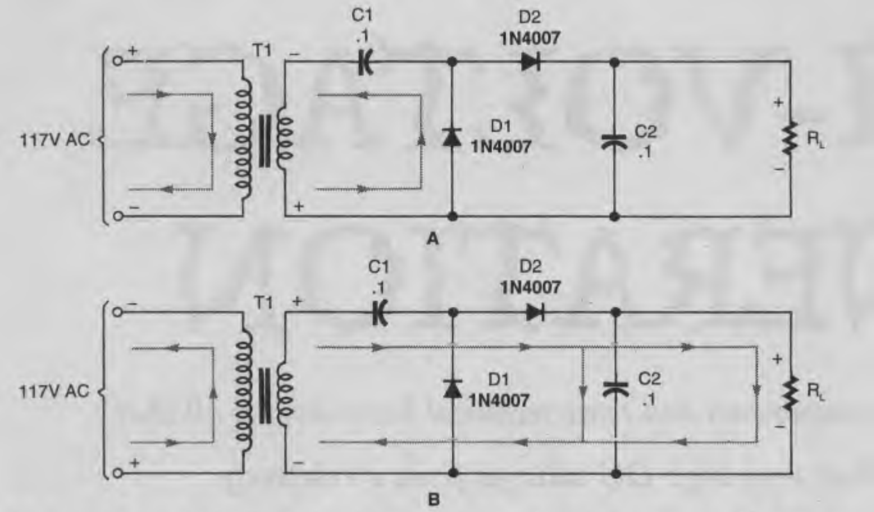


Fig. 1. Shown here is an example of a half-wave voltage doubler, which produces a DC output voltage ($V_{DC(OUT)}$) *that's twice the peak of the AC input voltage.*

Voltage-Doubler Circuits. As in conventional power-supply circuits, there are two basic voltage-doubler configurations—half-wave and full-wave. Figure 1 is an example of the half-wave voltage doubler (also referred to as a cascade voltage doubler), while Fig. 3 illustrates the full-wave version (also referred to as a conventional doubler). In both circuits, the direct-current (DC) output voltage (V,„ (0„)) is twice the peak alternating-current (AC) input voltage; i.e., VDc(oul) = 2 (1.41)VAc(, MS INPUT)' or 2.8 times the root-mean-square of the AC input voltage. That means if the circuit is fed from a 12.6-volt AC transformer, the DC output voltage (V,c(O4) would be:

$$V_{DC(OUT)} = 2(1.41)V_{AC(RMS\ INPUT)},$$

$$V_{DC(OUT)} = 2 \times 1.41 \times 12.6$$

$$V_{DC(OUT)} = 35.532$$

The conventional doubler (Fig. 3) provides superior voltage regulation and less output ripple, but the cascade circuit (Fig. 1) can be used without a transformer. In addition, two or more cascade circuits can be connected in series to form voltage multiplier circuits with various multiplication factors.

Half-Wave Doubler. Refer to the half-wave voltage-doubler circuit shown in Fig. 1A, and assume thai CI and C2 are both initially discharged. During the first half-cycle of the AC input, the upper input terminal of Ti's primary winding is positive with respect to the lower terminal (as illustrated in Fig. 1A), causing an oppositely polarized voltage to be induced in Ti's secondary winding. Under that condition, D1 begins to conduct, causing CI to charge. At the same time, diode D2 is reverse biased, preventing its conduction, so C2 discharges through R_L. The analysis is similar in the second half-cycle, except (as illustrated in Fig. 1B) that D2 conducts and C2 charges, while D1 is cut off and CI discharges into R_L.

The circuit is really a transformerless voltage amplifier. While Ti can provide isolation, as well as increase the AC voltage initially going into the doubler, the amplification due to the doubling action would occur without it. When the polarity reverses, both the input voltage and the charge across CI behave like two batteries connected in series, with their voltages combining to produce a DC output of about 36 volts peak. One problem, though, is that a half-wave doubler cannot be used with a current-hungry load.

One way of increasing the circuit's current capacity is to use a full-wave voltage doubler.

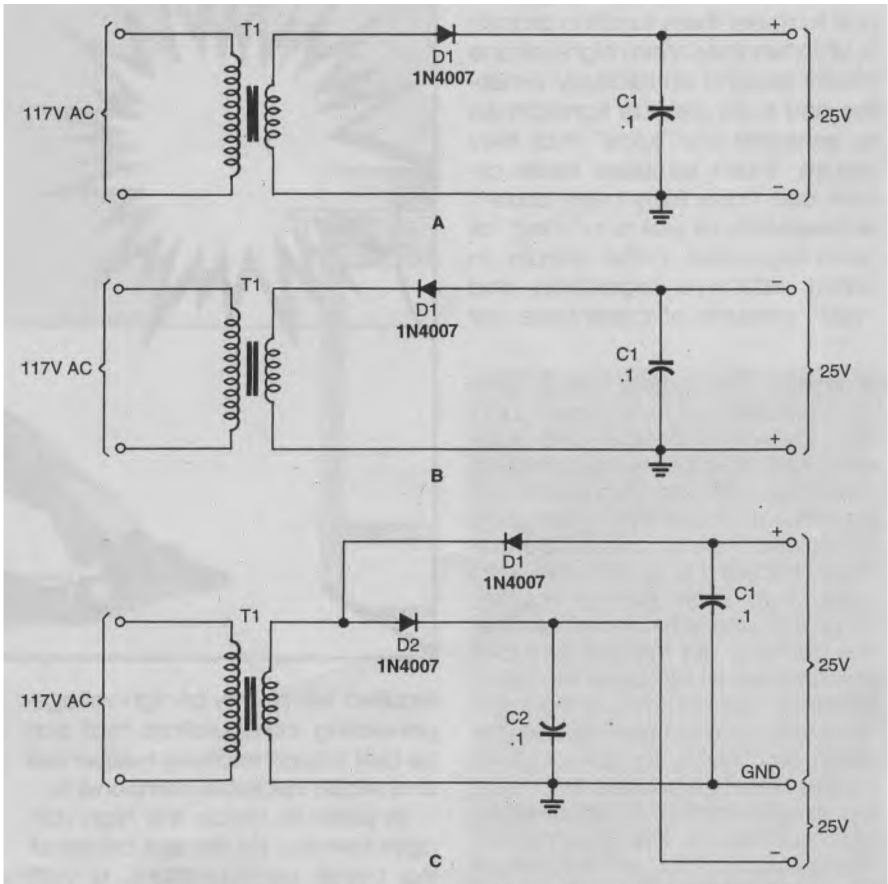


Fig. 2. The half-wave rectifier circuits shown in A and B can be combined, as shown in C, to form a full-wave voltage doubler.

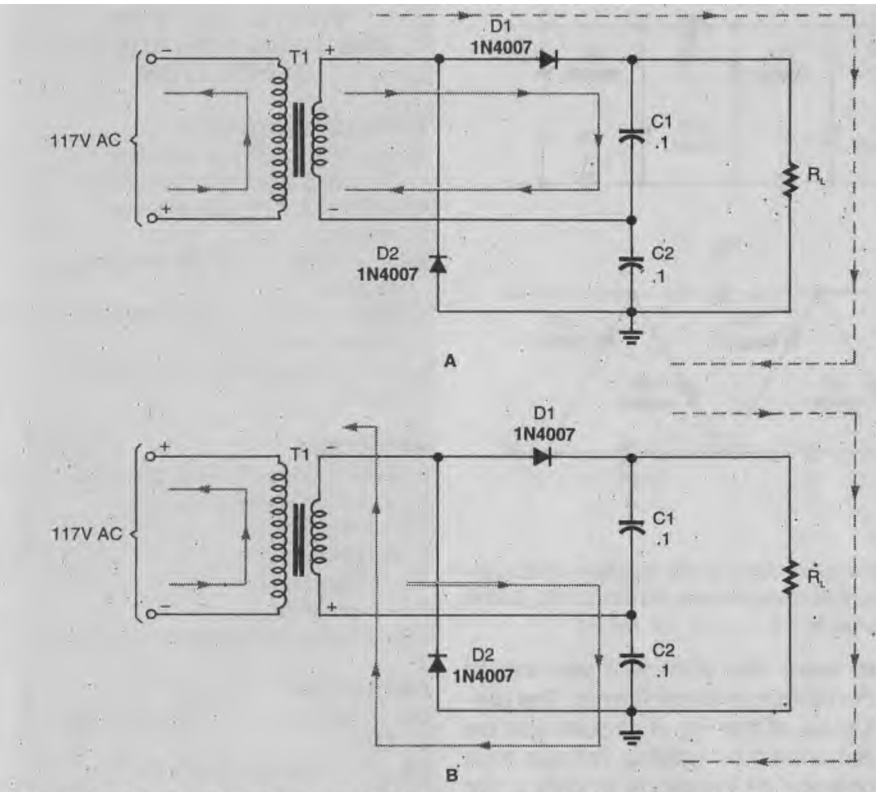


Fig. 3. For the sake of greater clarity, the full-wave voltage doubler illustrated in Fig. 2C can be redrawn as shown here. The full-wave voltage-doubler circuit has better regulation, is easier to filter, and produces nearly double the peak AC voltage of the half-wave version.

Full-Wave Doubler. A full-wave voltage doubler, unlike the half-wave version, is designed to take advantage of both positive and negative half-cycles of the input AC voltage. Figure 2A shows a half-wave rectifier with a positive output, Fig. 2B shows the same circuit redrawn with a negative output. Those half-wave rectifier circuits can be combined (as shown in Fig. 2C) to form a full-wave voltage doubler.

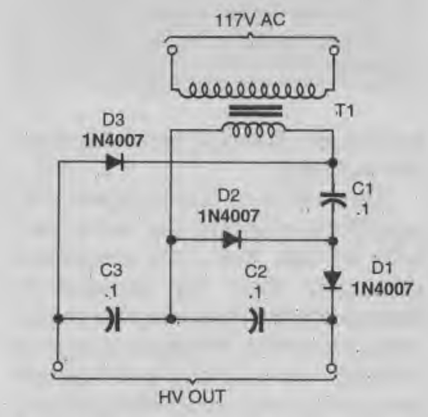


Fig. 4. Here is a voltage-multiplication configuration based on the circuit in Fig. 3 that can be used to generate a DC output voltage three times that of the AC input to the circuit.

For the sake of greater clarity, the full-wave voltage doubler illustrated in Fig. 2C is shown redrawn in Fig. 3. The full-wave voltage-doubler circuit has better regulation than the half-wave version, is easier to filter, and produces nearly double the peak AC voltage (approximately 36 volts for the previous example) across R_L. During the first half-cycle (see Fig. 3A), D2 is reverse biased and therefore cut off, while D1 is forward biased into conduction, so that the voltage across C1 (V_{C1}) is approximately 17.766 volts DC. On the next half-cycle (see Fig. 3B), the polarization of the applied voltage is reversed, forward biasing D2 into conduction, while reverse biasing D1 into cutoff. The load resistor (R_L) is wired in parallel with the C1/C2 series combination effectively creating a doubled level of about 36 volts DC.

Unlike the half-wave voltage doubler, the full-wave version has two capacitors across R_L rather than one. Whereas C1 shown in Fig. 1 is cut off and unsupplied for half of every cycle, C1 and C2 in Fig. 3 are supplied on alternate half cycles. When the capacitor corresponding to the diode that's cut off discharges, it can only do so through the capacitor being supplied, slightly decreasing both its current and the maximum voltage it has reached.

Voltage-Multiplication Circuits. There are many variations of the voltage-doubler scheme. Figure 4 illustrates a voltage-multiplication configuration based on the circuit in Fig. 3 that can be used to generate a DC output voltage three times that of the AC input to the circuit. That circuit, a voltage tripler, operates in essentially the same manner as the doubler circuit of Fig. 3. Like the circuit's operation, the formula for calculating the output voltage of the tripler circuit is very similar to that for the doubler: $V_{DC(OUT)} = 3(1.41)V_{AC(RMS\ INPUT)}$.

Another circuit—a voltage quadrupler—based on the voltage-doubler of Fig. 3 is shown in Fig. 5. Like the tripler, the voltage quadrupler operates in much the same manner as the voltage doubler. By now a pattern should be beginning to emerge; *i.e.*, $V_{DC(OUT)} = 4(1.41)V_{AC(RMS\ INPUT)}$. Note the correlation between each circuit's voltage-multiplication factor and the number of diodes and capacitors in each circuit. For example, the voltage doublers in Figs. 1 and 3 use two diodes and two capacitors to provide a x2 multiplication factor, while the voltage tripler (Fig. 4) and quadrupler (Fig. 5) use three and

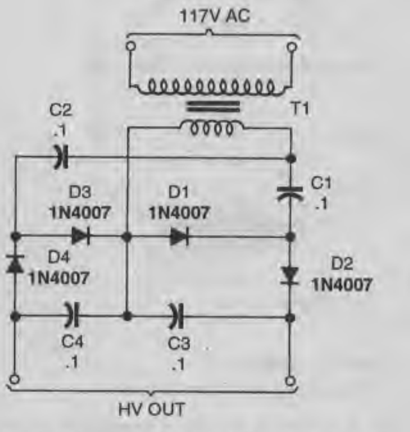


Fig. 5. Like the voltage tripler, this circuit (a voltage quadrupler) is based on the voltage-doubler of Fig. 3 and operates in much the same manner.

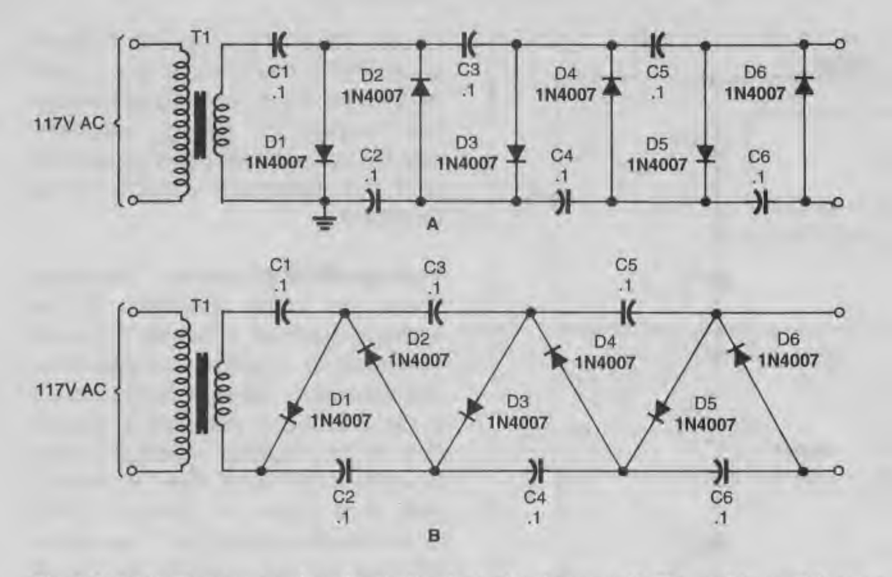


Fig. 6. Note that the circuit in A is electrically identical to the one in B. The usefulness of these circuits can be enhanced by adding voltage taps at each of the diode junctions (D1/D2, D2/D3, D3/D4, D4/D5, and D5/D6) to provide for multiplication factors of ×1, ×2, ×3, ×4, and ×5.

tour diode/capacitors pairs (respectively), to achieve multiplication factors of x3 and x4.

Figures 6-8 show a few additional voltage-multiplication circuits. The voltage multipliers shown in Fig. 6 are the most straightforward. Note that the circuit in Fig. 6A is electrically identical to the one in Fig. 6B, so keep mat in mind it you silo= come across either format. The usefulness of the Fig. 6 circuits can be enhanced by adding voltage taps at each of the diode junctions. For example, referring to Fig. 6B, voltage taps can be added at the D1 /D2, D2/D3, D3/D4, D4/D5, and D5/D6 junctions, for multiplication factors of x 1, x2, x3, x4, and x5. Plus, another tap can be connected to the anode of D6 for a multiplication factor of x6, or VDc(ouD= 6(1 .41)VAC(RMS INPUT)• Thus the circuit is able to provide six levels of DC voltage. Additional stages can be added to the circuit to generate multiplication factors of x10 or more. Note, however, that as the voltage multiplication factor increases, the available current that can be drawn from the circuit decreases by a similar factor. For example, feeding a 12.6-volt, 1-amp AC source through a voltage doubler yields a DC output of approximately 36 volts at about 0.5-amps.

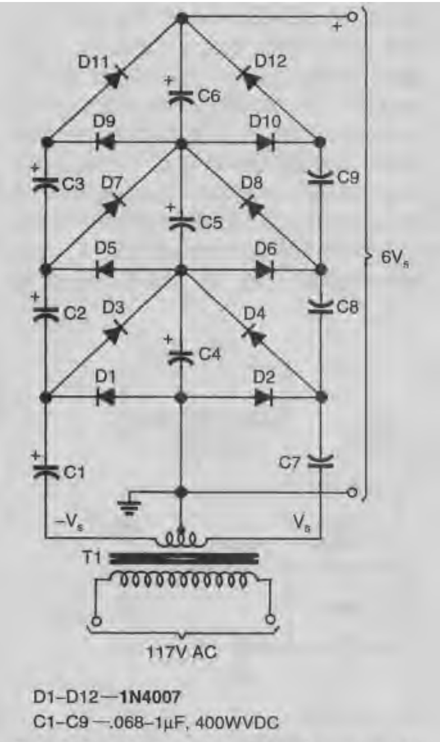


Fig. 7. Based on the Fig. 6 configuration, this circuit—known as either a Cockcroft-Walton or Greinacher cascaded voltage doubler—offers better stabilization than previous circuits for moderate-current applications.

Figure 7 shows an enhanced version of the Fig. 6 circuit—known as either a Cockcroft-Walton or Greinacher cascaded voltage doubler—that offers better stabilization for moderate-current applications.

A sewing needle can be used as an emitter for the voltage doubler shown in Fig. 8 to generate "corona wind," which sounds like a hissing noise. The circuit is capable of delivering 3.75 kV (kilovolts) DC when powered from 117-volt AC source, or 7.5 kV DC when fed from 240 volts AC.

The output of a cascaded voltage doubler should be terminated with no less than 200 megohms, and only then be allowed to extend beyond a protective plastic case, for safety. Voltages as high as 5 megavolts DC have been generated using cascaded voltage doublers, especially when operating in a pressurized atmosphere. The biggest advantage to using voltage doublers is that they use inexpensive

PARTS LIST FOR THE HIGH-VOLTAGE DC GENERATOR

SEMICONDUCTORS

IC1—4584 CMOS hex inverting Schmitt trigger, integrated circuit
Q1—TIP31A NPN silicon power transistor
BR1—6-amp, 50-PIV full-wave bridge rectifier
D1–D21—1N4007 1-amp, 1000-PIV, silicon rectifier diode
LED1—Jumbo green light-emitting diode

RESISTORS

(All resistors are 1/4-watt, 5% units, unless otherwise noted.)
R1—1500-ohm
R2—300-ohm
R3—220-ohm
R4—1-megohm
R5—10,000-ohm potentiometer

CAPACITORS

C1—0.022-µF, 50-WVDC, metallized-film
C2, C13—220-µF, 16-WVDC, electrolytic
C3–C12—0.001-µF, 2000-WVDC, ceramic-disc
C14—4700-µF, 35-WVDC, electrolytic

ADDITIONAL PARTS AND MATERIALS

NE1—NE-2 neon lamp
T1—Ferrite core step-up transformer (see source below)
T2—12-volt, 2-amp step-down power transformer
PL1—117-volt AC plug with line cord
Perfboard materials, enclosure, heat sink, IC socket, banana jack, hook-up wire, solder, hardware, etc.

Note: Transformer T1 (part # HVM-COR-B2) is available from Allegro Electronic Systems, Dept. HVM, 3 Mine Mountain Road, Cornwell Bridge, CT 06754

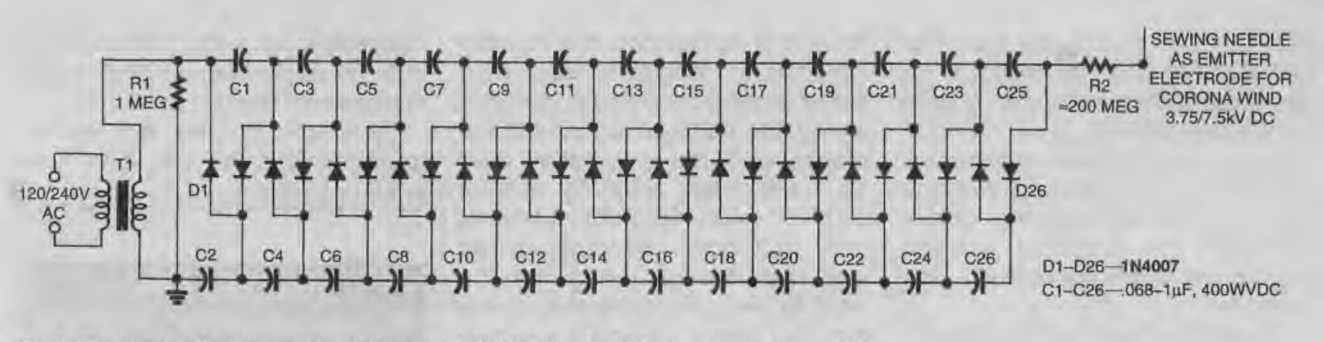


Fig. 8. This circuit, which is capable of delivering 3.75 kV (kilovolts) DC when powered from 117-volt AC source or 7.5 kV DC when fed from 240 volts AC, can be used to generate "corona wind," which sounds like a hissing noise.

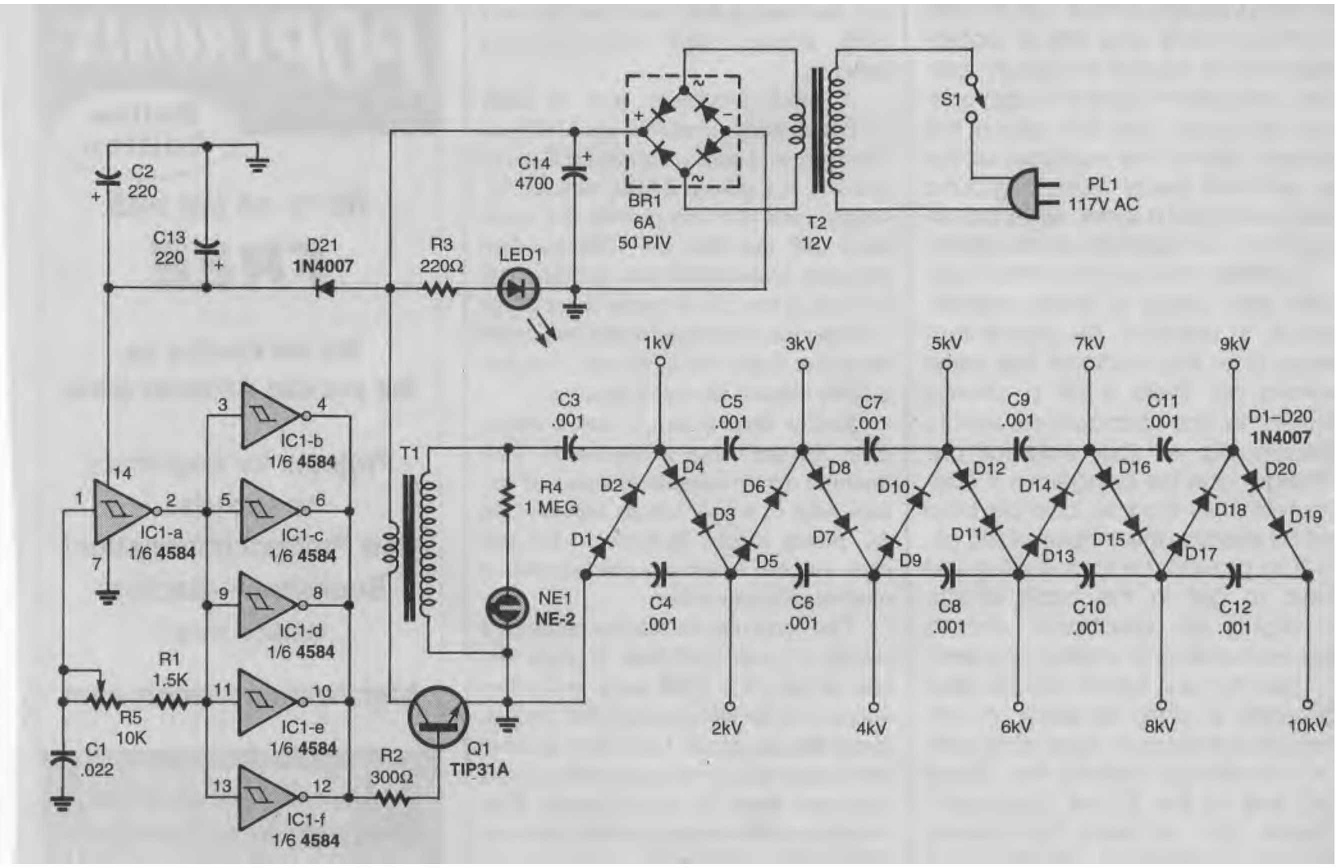
low-voltage parts. Otherwise, if all the parts had to be of the high-voltage variety, you would have to use expensive and rather large capacitors.

High-Voltage DC Generator. A schematic diagram of a high-voltage DC generator is shown in Fig. 9. The circuit is built around a single hex inverting Schmitt trigger (101), a couple of transformers (T1 and T2), a transistor (Q1), 21 diodes, and several support components.

At the heart of the circuit is the hex Schmitt trigger. One gate of the hex Schmitt trigger (IC1 -a) is configured as a square-wave pulse generator. The output of IC 1-a (a pulsating DC voltage) at pin 2 is fed to the inputs of ICI-b to ICI-f, which are connected in parallel to increase the available drive current. The pulsating output of the paralleled gates is fed to the base of Qi through R2, causing Q1 to toggle on and off in accordance with the oscillations of 101-a. The collector of Q1 is connected in series with the primary winding of Ti. The other end of T1 is connected directly to the positive terminal of the power supply. That produces a driving wave in the primary winding of T1 that is similar to a square wave.

The on/off action of QI, caused by the pulsating signal applied to it, creates a rising and collapsing field in the primary winding of T1 (a small ferrite-core, step-up transformer). That causes a pulsating signal, of opposite polarity, to be induced in Ti's secondary winding.

The pulsating DC output at the secondary winding of T1 (ranging from 800 to 1000 volts) is applied to a 10-stage voltage-multiplier circuit, consisting of D1 through D20,



and C3 through 012. The multiplier circuit increases the voltage 10 times, producing an output of up to 10,000-volts DC—$V_{D,(O4} = 10(1.41)V_{AC(RMS\ INPUT)}$. The multiplier accomplishes its task by charging the capacitors (03-C12) through the diodes (D1-D20); the output is a series addition of all the capacitors in the multiplier.

In order for the circuit to operate efficiently, the frequency of the squarewave, and therefore the signal applied to the multiplier, must be considered. The output frequency of the oscillator (101-a) is set via the combined values of R1, R5, and CI (which with the values specified is approximately 15 kHz). Potentiometer R5 is used to fine tune the output frequency of the oscillator. The higher the frequency of the oscillator, the lower the capacitive reactance in the multiplier.

Light-emitting diode LED1 serves as an input-power indicator, while NE1 indicates an output at the secondary of Ti. A good way to get the maximum output of the multiplier is to connect an oscilloscope to its high-voltage output via a high-voltage probe and adjust potentiometer R5 for the maximum output. If you don't have the appropriate test gear, you can place the output wire of the multiplier about a half-inch away from a ground wire and draw a spark, while adjusting R5 for a maximum spark output.

Caution: The output of the multiplier can cause a strong electric shock. In addition, be aware that even after the multiplier has been turned off, there is still a charge stored in the capacitors, which, depending on the state of discharge, can be dangerous if contacted. That charge can be bled off by shorting the output of the circuit to ground. (In fact, it's a good idea to get in the habit of discharging all electronic circuits before handling or working on them.)

Also, 101 is a CMOS device and, as such, is static sensitive. It can handle a maximum input of 15 volts DC. Do not go beyond the 15-volt DC limit or the IC will "vaporize." Diode D21 is used to prevent reverse polarization of the input voltage source.

As far as the voltage multiplier goes, the diodes and the capacitors must be rated for at least twice the anticipated input voltage, So, if we have a 1000-volt input, all of the diodes and the capacitors must be, respectively, rated for at least 2000-PIV and 2000-WVDC (working volts DC) each. Because diodes with that voltage rating can be hard to find and expensive (if you can find them), pairs of series-connected 1-amp, 1000-PIV diodes were used to form 2000-Ply units. **P**

Nevertheless, I've always had great luck with Xircom products, and I don't hesitate to recommend them.

As always, feel free to e-mail me (*tneedleman@aol.com*) with your comments or questions.