

Experimenter's Corner

By Forrest M. Mims

THE VOLTAGE MULTIPLIER

THIS MONTH, we're going to look at the diode-capacitor voltage multiplier, an extremely simple but very useful power-supply circuit. The diode-capacitor voltage multiplier allows the user to obtain a larger dc voltage than that available from his battery or transformer/rectifier supply. In ac circuits, this voltage multiplication is readily accomplished by transformers, so you can consider the voltage multiplier as a solid-state, dc step-up transformer with very limited current regulation capability.

These networks have found many applications in semiconductor electronics. They are commonly used in digital wrist-watches to derive required operating voltages from a single mercury cell. Voltage multipliers are also employed to obtain the relatively high voltages needed for powering neon glow lamps, electrofluorescent displays and semiconductor lasers. Heavily insulated voltage multipliers are frequently found in the high-voltage sections of color television receivers and infrared-to-visible light conversion systems.

Although there are several basic voltage multiplier designs, they are all based on the principle of charging and discharging capacitors with the help of steering diodes. Let's look at a few representative circuits. All inputs are ac.

Typical Voltage Multipliers. Figure 1 is the schematic diagram of the traditional voltage doubler. In operation, an ac voltage is applied across the input terminals. During the negative half-cycle of the input signal (BP2 positive with respect to BP1), C2 charges to the peak

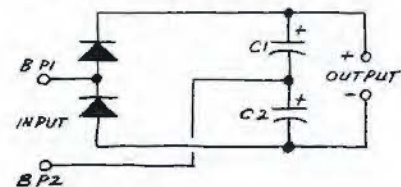


Fig. 1. Traditional diode-capacitor voltage multiplier.

value of the input voltage. During the positive half-cycle, C1 charges up to the peak value of the input voltage. Since C1 and C2 are in series, the output voltage is double the peak input voltage if the output is lightly loaded. Therefore, the capacitors must be rated to withstand the peak value of the input voltage and the diodes twice that value.

Figure 2 shows two other ways to make a voltage doubler. The cascade doubler (A) isn't as efficient or as well-regulated as either the traditional or bridge doubler, but it can easily be expanded to many stages. (Component voltage ratings are given in parentheses.) It's possible to obtain outputs of many thousands of volts from multistage cascade voltage multipliers. Figure 3 shows both a full-wave voltage tripler (A) and quadrupler (B).

You can duplicate any of the circuits in Figs. 1 through 3 using ordinary silicon rectifiers and suitably rated capacitors.

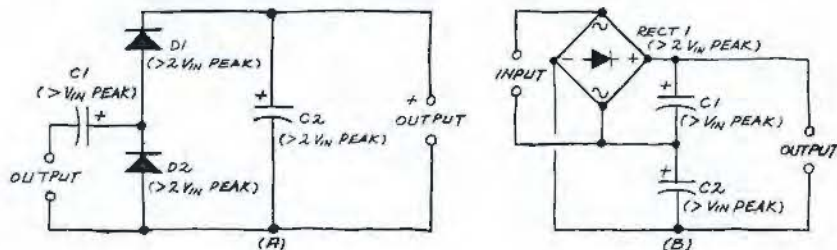


Fig. 2. Two different ways to make a voltage divider.

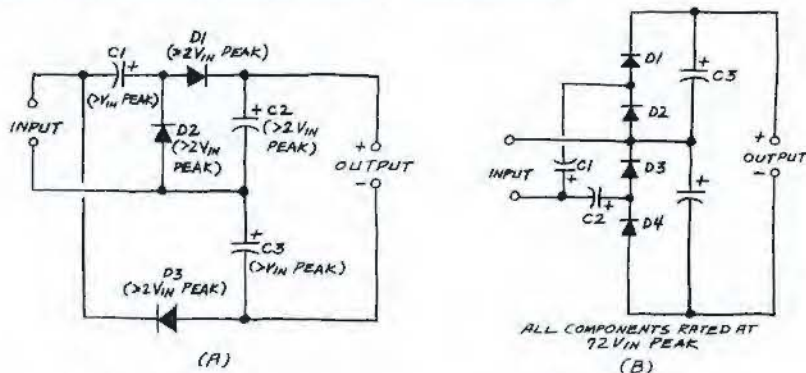


Fig. 3. Full-wave voltage tripler and quadrupler circuits.

Switching diodes (IN914 or IN4148) work fine in low-voltage applications. Rectifiers in the IN4000 series are a good choice for circuits with higher working voltages. Here are the voltage ratings for these rectifiers: IN4001, 50 volts; IN4002, 100 volts; IN4003, 200 volts; IN4004, 400 volts; IN4005, 600 volts; IN4006, 800 volts; IN4007, 1000 volts. Be sure to observe the polarities of diodes and electrolytic capacitors.

A Word of Caution. The sample voltage multiplier circuits that follow produce relatively low voltages. Voltage multipliers, however, can easily produce very high output voltages. If you decide to experiment with high-voltage multipliers, use caution and always make sure the capacitor chain is fully discharged before touching any circuit nodes. The capacitors in an unloaded voltage multiplier chain can retain a dangerous charge for hours after the power supply has been turned off.

Op-Amp Voltage Multiplier. It's very easy to generate square waves with an operational amplifier, so an op-amp oscillator makes an ideal input for a voltage multiplier. Figure 4 shows one possible circuit.

Virtually any op amp will work as a square-wave generator, but I've selected the RCA CA3078, a micropower op amp that will operate with power-supply voltages as low as ± 0.75 volt. With the component values shown in Fig. 4, the

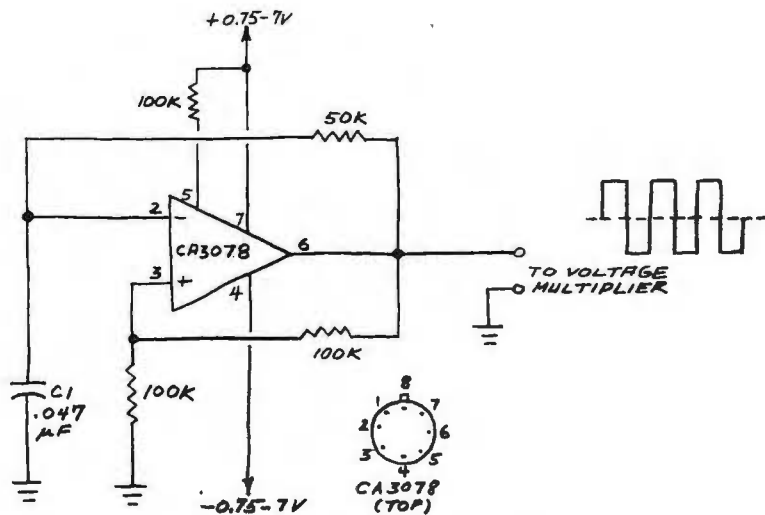


Fig. 4. Micropower op-amp oscillator circuit.

oscillator produces square pulses approximately four milliseconds wide at a frequency of 144 Hz. Increasing the value of $C1$ will increase the pulse width and reduce the oscillation frequency.

You can use the basic op-amp square-wave generator as an ac source for any voltage multiplier circuit. Figure 5 shows the results for a ten-stage cascade multiplier. Don't use a supply voltage greater than ± 7 volts if you use a CA3078 as the square-wave generator. For higher output voltages, add more multiplier stages or an op amp such as the 741 that will accept a higher supply voltage.

CMOS Voltage Multiplier. It's easy to build CMOS oscillator circuits that provide a square-wave output. Figure 6 shows one way to connect a voltage doubler to a typical CMOS oscillator comprising a clock followed by a 4013 D flip-flop. The clock is an astable multivibrator made from two of the four NAND gates in a 4011 integrated circuit. The flip-flop is operated as a toggle by feeding the not-Q output back to the D input.

Note that only half of each IC is used in this circuit. Because unterminated CMOS inputs can bias the gates into the linear operating region, it is essential to connect all unused inputs to either V_{DD} (the positive supply) or V_{SS} (ground). If your circuitry suddenly stops operating and one of the IC's becomes very hot, chances are you've left one or more inputs floating!

The voltage doubler shown in Fig. 6 works quite well. With the capacitor values given and a power supply of 6 volts, the flip-flop toggles at a frequency of 170 Hz and the doubler generates 11.3 volts.

Don't hesitate to experiment with the CMOS multiplier circuit. You can easily

produce more than 100 volts by powering the CMOS clock with a 12-volt supply and connecting the flip-flop to a ten-stage voltage multiplier like the one shown in Fig. 5. That's more than enough voltage for a neon glow lamp and a 100,000-ohm series resistor between the positive output terminal of the multiplier and V_{SS} (ground). (Take care—the high voltage can easily zap one or both of the CMOS chips.)

Further Reading. The Motorola "Silicon Rectifier Handbook" (1966) has an excellent chapter on voltage multipliers (Chapter 6). Radio Shack's "Semiconductor Projects, Volume 1" (1975) has a chapter that describes an op-amp pulse generator that powers a ten-stage cascade voltage multiplier. This circuit is capable of producing a 140-volt output when the op amp is powered by a 35-volt supply. \diamond

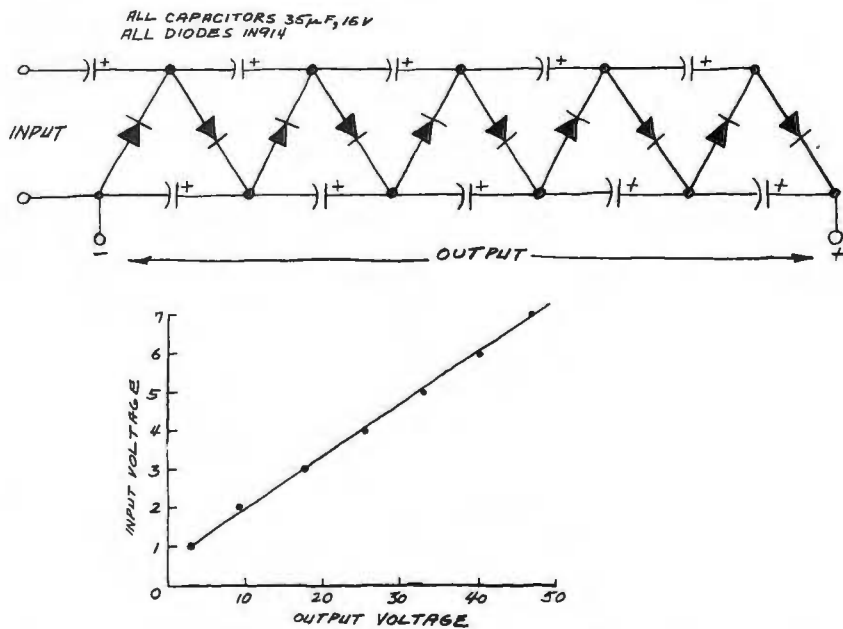


Fig. 5. Performance of op-amp oscillator and ten-stage multiplier.

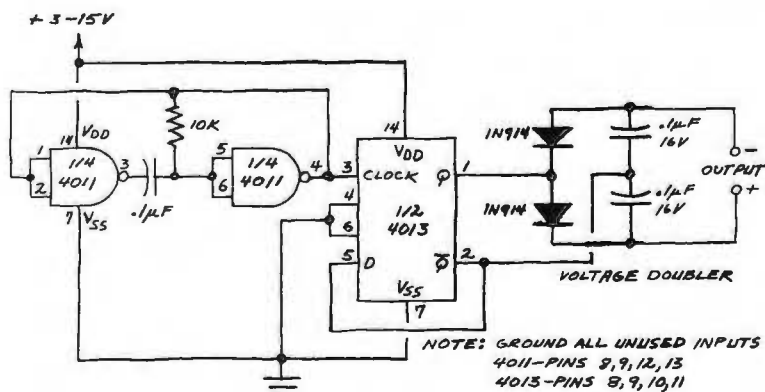


Fig. 6. CMOS oscillator and voltage doubler.