Experiment #7—Voltage Multipliers

Background

This is the second of a three-part series of experiments on power supply circuits. Last month we studied the rectifier. This month we take the rectifier one step further to create output voltages higher than that of the power source…even of the opposite polarity!

Terms to Learn

- *Commutation*—periodic switching that is synchronized to a clock signal or a time reference
- *Floating*—a voltage source is floating if neither of its output connections are connected to ground
- *Ripple*—the regular (ac) variation of rectifier output voltage at the frequency at which the output capacitor (filter) is charged
- *Surge Current*—the large inrush of current into discharged capacitors when voltage is first applied
- *Voltage Regulation*—the change in output voltage with load current (usually expressed as a percentage change in voltage for a given change in output current)

The Voltage Multiplier

There are many instances where an ac power source is available but a dc voltage is needed by a circuit that can't be obtained by using a simple rectifier. Sometimes, a circuit just needs a "dab" of higher voltage…and it's not worth the expense of using a higher-voltage transformer or adding another secondary winding to get it. For other applications, such as high-voltage supplies for amplifiers or other tube circuits, a full-voltage transformer may be too expensive (or too difficult to insulate for the high voltage needed). Voltage multiplier circuits are used to address both situations.

In the full-wave rectifiers of the previous experiment, we saw how diodes are used to route charging current into a storage capacitor. The diodes effectively double the frequency at which the capacitor can be charged. The doubling of the charge frequency also doubles the amount of current a rectifier can supply for a given voltage variation or ripple.

What if, instead of doubling the output current, there was a way to use the same diodes to double the output voltage? By arranging the diodes and capacitors properly, we can create a "bucket brigade" effect where the voltages of the capacitors can be added together.

Figure 1A shows the simplest voltage multiplier—a half-wave doubler—supplied from a source with an RMS voltage of V_{RMS} and whose peak voltage is 1.4 V_{RMS}. Starting with both capacitors discharged, a negative half-cycle from the voltage source charges C1 to 1.4 V_{RMS} through D1, as shown in Figure 1B. On the following half-cycle, in Figure 1C, the output capacitor C2 is charged through D2 but, like an acrobat
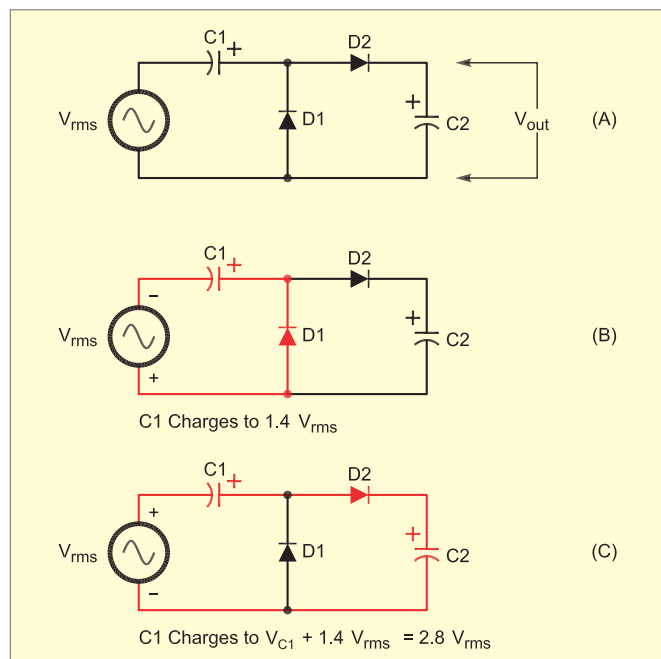

Figure 1—The half-wave voltage doubler circuit. Figures 1B and 1C show how the capacitors charge on alternating half-cycles. The voltages of C1 and C2 are added together as C2 is charged.
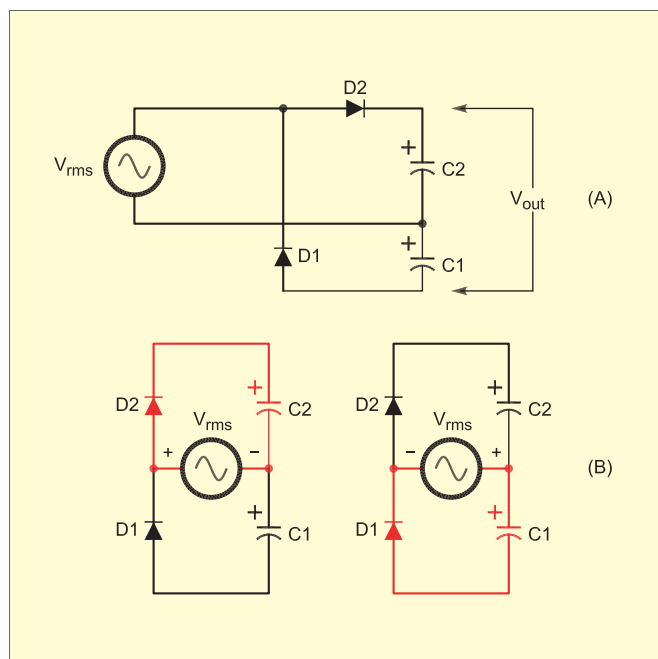

Figure 2—The full-wave voltage doubler. Figure 2A shows the usual schematic for the circuit. Figure 2B redraws the circuit for clarity and illustrates how the capacitors charge on alternate half-cycles.

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springing onto another's shoulders, the voltage of C1 adds to the source voltage and C2 is charged to 2.8 V_{RMS}. Because one diode is always in the current path, the actual output voltage is less by one diode's forward voltage drop, V_f, of 0.7 V.

The half-wave doubler only charges the output capacitor once every other half-cycle, limiting the amount of current that can be drawn from the supply. Each diode and capacitor in the half-wave doubler must be rated to handle the full output voltage. These limitations can be a problem at high output voltages.

To increase the amount of output current and reduce the necessary ratings of individual components, the diodes and capacitors can be rearranged as shown in the full-wave doubler circuit of Figure 2. For the half-wave doubler, one side of the voltage source may be grounded, but for the full-wave doubler, the source must be floating.

Figure 2A shows the customary way of drawing the full-wave doubler circuit on a schematic, where the voltage source is usually a transformer secondary winding. However, it's a little easier to understand when redrawn as in Figure 2B. On alternate half-cycles, the source charges each capacitor to its peak voltage, 1.4 V_{RMS}. The output voltage is developed across C1 and C2 in series. This also means that the value of output capacitance that supplies current to the load is less than C1 or C2 by the equation:

$$C_{output} = (C1 \times C2) / (C1 + C2)$$

In addition, one diode drop is subtracted from the charging voltage of each capacitor, so the actual output voltage will be 2.8 V_{RMS} − [2×0.7 V].

Note that when using these voltage multiplier circuits for powering actual equipment at higher power, it is necessary to limit the surge current into the capacitors when the supply is first powered up. The discharged capacitors look like short circuits to the transformer secondary and diodes and can blow a fuse or damage components on those first few cycles of charging. That is why, in *The ARRL Handbook*, the discussion of voltage multipliers includes surge-limiting resistors. In our experiments, the surge currents are quite small and can be ignored.

Testing a Pair of Voltage Multipliers

Let's start with the half-wave doubler. As with last month's experiment, use your function generator as the voltage source. Construct the circuit as shown in Figure 1 taking care to observe the polarities of the capacitors.

• Set the function generator to output a 1 kHz sine wave at 5 V_{RMS}. Use your voltmeter to measure the dc voltage across C1 and C2. With no load to drain charge from either capacitor, you should measure nearly 2.8 × 5 V = 14 V dc across both C1 and C2.

• Connect a 10 kΩ load resistor across C2 and re-measure the capacitor voltages. You will see the voltage across C1 drop to just below 1.4 × 5 V = 7 V dc while the voltage across C2 stays about one diode forward voltage drop (0.7 V) below 14 V dc. If you are using an oscilloscope you should see waveforms like those of Figure 3.

• You can experiment with the doubler by varying the load resistance or capacitance values. Less load resistance (a heavier load) or less capacitance will drop the output voltage dramatically as C2 is discharged more during each half-cycle. Vary the frequency of the source. Raising the source frequency also charges the capacitors more frequently, so for a given load resistance, this will increase output voltage.

• Make a voltage inverter by switching the polarity of the diodes and capacitors.

• Construct a full-wave doubler, as in Figure 2, using the
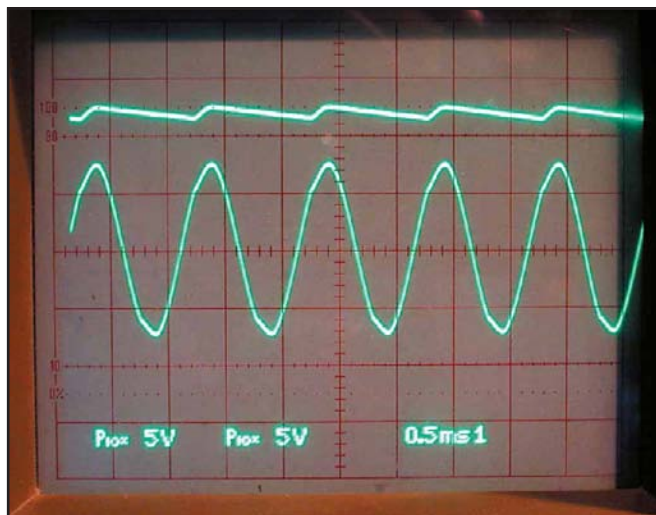

Figure 3—The photo shows the input sine wave to a half-wave voltage doubler and the output waveform across C2. Note that capacitor C2 is charged once every other half-cycle. Ground potential for both channels is at the center of the sine wave.

same diodes and capacitors as for the half-wave doubler. You won't be able to use the oscilloscope unless the function generator output is floating, so rely on your voltmeter.

• With no load resistor connected, the output voltage will be close to 14 V dc, but with the 10 kΩ load, the output voltage will be lower than for the half-wave doubler because the effective output capacitance is less—C1 in series with C2—and there is an extra diode forward voltage drop. However, the *voltage regulation* of the full-wave doubler is better than the half-wave circuit because the output capacitors are charged more frequently, doubling the ripple frequency.

• If you add a 1 µF capacitor in parallel with both C1 and C2, the output voltage should increase.

It should be obvious from your experiments that the voltage regulation of these voltage multiplier circuits is not outstanding. They should not be used where large variations in load current are to be expected. They are useful circuits, however, and can be used effectively where load currents are low and where "stiff" voltage regulation is not important.

Suggested Reading

• Chapter 11 (rectifier circuits) of *The ARRL Handbook* has an excellent section on voltage multipliers, including triplers and quadruplers. A set of graphs is provided to aid in figuring how much capacitance is needed for given loads with a 60 Hz ac supply.

• And don't forget our Web site for this series is **www.arrl.org/tis/info/html/hands-on-radio/**.

Shopping List

• 2—1N4148 diodes (any silicon rectifier will do)
• 10 kΩ, 1/4 W resistor
• 4—1 µF and 2—10 µF capacitors, 25 V dc or higher

Next Month

So what do you do with all these power supplies? To get the best results from most circuits, it's necessary to power them with a smooth, constant voltage. Next month, we'll design and build a voltage regulator to do just that.