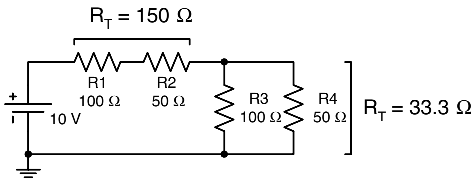

FIGURE 12.4 Combining multiple resistors.

fully simplified, its overall current flow and power dissipation can be calculated: I = 54.5 mA and P = 545 mW.

Power dissipation for the resistors in Fig. 12.4 can be determined in multiple ways: VI, I^2R, or $V^2 \div R$. Power for each resistor can be calculated individually, but care must be taken to use the true voltage drop or current through each component. R1 and R2 have the same current passing through them because both have no parallel components to divert current, but they have differing voltage drops because their resistances are not equal. In contrast, R3 and R4 have identical voltage drops because they connect the same two nodes, but differing currents because their resistances are not equal.

The two resistor pairs, R1/R2 and R3/R4, form a basic voltage divider at the intermediate node connecting R2 and R3/R4. This voltage can be calculated knowing the current through R1 and R2 (54.5 mA) by either calculating the combined voltage drop of R1 and R2 and then subtracting this from the battery voltage or by just calculating the voltage drop across R3 and R4. The parallel combination of R3 and R4 equates to 33.3 Ω, indicating a voltage drop of 1.82 V at I = 54.5 mA. This is the voltage of the intermediate node because the lower node of R3 and R4 is ground, or 0 V. The alternate approach yields the same answer.

$$V_{NODE} = V_{BATT} - I\,(\mathrm{R1} + \mathrm{R2}) = 10\text{ V} - 54.5\text{ mA }(150\ \Omega) = 10\text{ V} - 8.18\text{ V} = 1.82\text{ V}$$

12.4 CAPACITORS

Resistors respond to changes in current in a linear fashion according to Ohm's law by exhibiting changes in voltage drop. Similarly, changing the voltage across a resistor causes the current through that resistor to change linearly. Resistors behave this way because they do not store energy; they dissipate some energy as heat and pass the remainder through the circuit. *Capacitors* store energy, and, consequently, their voltage/current relationship is nonlinear.

A capacitor stores charge on parallel conductive plates, each of which is at a different arbitrary potential relative to the other. In this respect, a capacitor functions like a very small battery and holds a voltage according to how much charge is stored on its plates. Capacitance (C) is measured in *farads*. One farad of capacitance is relatively large. Most capacitors that are used in digital systems are measured in microfarads (μF) or picofarads (pF). As a capacitor builds up charge, its voltage increases in a linear fashion as defined by the equation, $Q = CV$, where Q is the charge expressed in coulombs.

One of the basic demonstrations of a capacitor's operation is in the common series resistor-capacitor (RC) circuit shown in Fig. 12.5, where a resistor controls the charging rate of the capacitor. The capacitor's voltage does not change in a linear fashion. From the relationship $Q = CV$, it is known that the voltage is a function of how much charge has been stored on the capacitor's plates. How much charge flows into the capacitor is a function of the current that flows around the circuit over a span of time (one amp is the flow of one coulomb per second). As the voltage across the capacitor in-

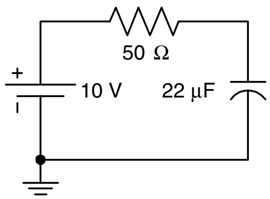

FIGURE 12.5 Simple RC circuit.

creases, the voltage drop across the resistor decreases, causing the current through the circuit to decrease as well. Therefore, the capacitor begins charging at a high rate when its voltage is 0 and the circuit's current is limited only by the resistor. The charging rate decreases as the charge on the capacitor builds up.

Normalized to 1 V, the voltage across a capacitor in an RC circuit is defined as

$$V_C = 1 - e^{-\frac{t}{RC}}$$

where *e* is the base of the natural logarithm, an irrational mathematical constant roughly equivalent to 2.718. Starting from the initial condition when the capacitor is fully discharged, $t = 0$ and $V_C = 0$. The *RC time constant*, expressed in seconds, is simply the product of R and C and is a measure of how fast the capacitor charges. Every RC seconds, the voltage across the capacitor's terminals changes by 63.2 percent of the remaining voltage differential between the initial capacitor voltage and the applied voltage to the circuit, in this case the 10-V battery. By rule of thumb, a capacitor is often considered fully charged after 5 RC seconds, at which point it achieves more than 99 percent of its full charge. In this example, RC = 1,100 µs = 1.1 ms. Therefore, the capacitor would be at nearly 10 V after 5.5 ms of connecting the battery to the circuit.

RC circuits are used in timer applications where low cost is paramount. The accuracy of an RC timer is relatively poor, because capacitors exhibit significant capacitance variation, thereby altering the time constant. A simple oscillator can be constructed using an inverter (e.g., 74LS04) and an RC as shown in Fig. 12.6. When the inverter's input is below its switching threshold, the output is high, causing the capacitor to charge through the resistor. At some point, the capacitor voltage rises above the switching threshold and causes the inverter's output to go low. This, in turn, causes the capacitor to begin discharging through the resistor. When the capacitor's voltage declines past the switching threshold, the process begins again.

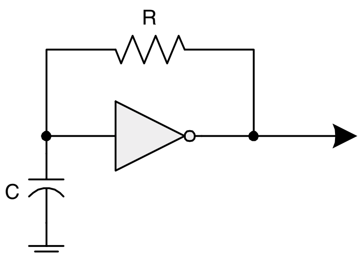

FIGURE 12.6 RC oscillator.