By now, the symmetry of filtering leaves no surprise that a bandpass topology can be rearranged to form a *band-reject* filter, often called a *notch* filter. Whereas the bandpass filter passes a narrow range of frequencies, a band-reject filter attenuates a narrow range of frequencies. The two basic second-order band-reject filter topologies are shown in Fig. 12.26. In the reverse of a bandpass filter, the series topology takes advantage of the LC circuit's high impedance at its resonant frequency to block the incoming signal. Similarly, the shunt topology's low combined impedance at a narrow range of frequencies diverts that energy to ground.

Digital systems often require only that a filter attenuate unwanted frequencies, typically noise, to the point at which the digital circuitry is not adversely impacted by that noise. Clock generators and clock circuits are usually the digital components that are most sensitive to noise. Alternatively, digital systems that incorporate sensitive analog interface components may require filters to separate and "clean up" the power, data, and control signals that pass between the digital and analog circuitry. Such applications often require only a first-order of approximation to determine cutoff or center frequencies for filters.

Designing filters for analog applications where specific characteristics of transfer functions have a major impact on circuit performance requires far more detailing and circuit analysis theory than has been presented here. If your filter is more analog than digital in its application, you are strongly advised to spend time in obtaining a thorough understanding of AC circuit analysis and filter design.

12.11 TRANSFORMERS

When two inductors are placed together in close proximity, they exhibit mutual inductance where one coil's magnetic field couples onto the other coil and vice-versa. This behavior may be undesired in many situations and can be largely avoided by physically separating individual inductors. However, the phenomenon of mutual inductance has great benefit when two or more coils are assembled together to form a *transformer*. Mutual inductance is enhanced not only by close physical proximity, but also by winding the transformer's coils around common cores made from ferrous metals that conduct magnetic fields. Transformers have many uses, but their basic function is to transfer AC energy from one coil to another without having a DC connection between the two ends. A transformer does not pass DC because there is no direct connection between the two coils.

Neglecting losses resulting from finite resistance and less-than-ideal efficiency in magnetic field coupling, the voltage excited in one coil winding is related to that created in another winding by the proportion of the number of winding turns (N) in each coil. A transformer with two windings is said to have a *primary* and a *secondary* winding. The voltage relationship of each winding in an ideal transformer is as follows:

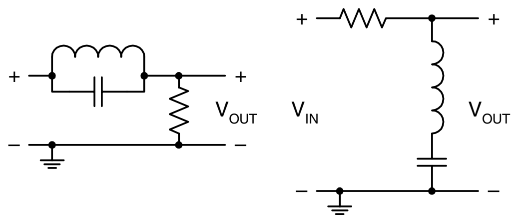

FIGURE 12.26 Second-order band-reject filter topologies.

$$\frac{V_{PRIMARY}}{V_{SECONDARY}} = \frac{N_{PRIMARY}}{N_{SECONDARY}}$$

A transformer is a passive component; it has no capability of amplifying a signal. Consequently, an ideal transformer passes 100 percent of the power applied to it and satisfies the equation $V_S I_S = V_P I_P$. If the primary coil has more windings than the secondary coil, an AC signal of lesser magnitude will be induced on the secondary coil when an AC signal is applied to the primary coil. The current flowing through the secondary coil will be higher than that in the primary so that conservation of energy is preserved. In reality, of course, a transformer has less than 100 percent efficiency as a result of parasitic properties, including finite resistance of the coils and less-than-perfect magnetic coupling.

One of the most common uses of a transformer is in power distribution in which AC power is either stepped up or stepped down, depending on the application. Figure 12.27 shows a basic transformer with a 120 VAC signal injected into the primary coil and a load resistor on the secondary coil. The ratio of the primary to secondary windings is 10:1; perhaps the primary coil has 1,000 windings whereas the secondary has 100. The result is a step-down of high-voltage power from a wall outlet to a more manageable 12 VAC. This illustrates why AC power distribution is so convenient: voltages can be arbitrarily transformed without any complicated electronic circuits. It is advantageous to distribute power at a higher voltage to reduce the current draw for a given power level. Lower current means lower I^2R power losses in the distribution wiring. The 12 VAC transformer output may power the voltage regulator of a digital circuit. If the digital circuit draws 10 A at 12 VAC, it will draw only 1 A at 120 VAC.

Transformers are critical to power distribution both at the system level and at the generation and utility levels. Power is stepped up at generating plants with transformers to as high as 765,000 V for efficient long-distance distribution. As the power gets closer to your home or office, it is stepped down to intermediate levels and finally enters the premises at 120 and 240 VAC.

Aside from power supply applications, transformers are also used for filtering and impedance matching of interface signals. The use of a transformer as a filter requires knowledge of the physical orientations of the primary and secondary windings with respect to one another. Each winding in a transformer has two terminals. When a signal is applied to the primary coil, a decision is made as to which terminal is connected to the positive portion of the circuit and which is connected to the negative portion (ground in some applications). That signal will induce a signal of equivalent polarity on the secondary coil when the appropriate choice of positive and negative terminals is made at the other end of the transformer. Alternatively, a signal of opposite polarity will be induced if the secondary coil's positive and negative connections are swapped. The graphical convention of distinguishing the matching terminals of the primary and secondary coils is by placing matching reference dots next to one terminal of each coil as shown in Fig. 12.28. The coils may be drawn with their dots on the same side or on opposite ends of the transformer.

The relative polarity of the primary and secondary windings is important for filtering applications to ensure that magnetic fields in each coil either add to or cancel each other as appropriate. Trans-

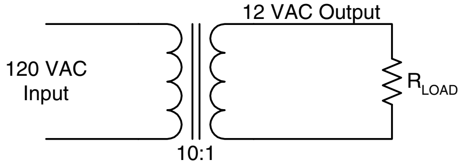

FIGURE 12.27 Basic transformer operation.