Like an inductor, the voltage and current are out of phase by 90°. But for a capacitor, the current reaches its peaks $\frac{1}{4}$ cycle before the voltage does, so we say that the

current leads the voltage by 90° in a capacitor.

Capacitor: current leads voltage

Because the current and voltage are out of phase, the average power dissipated is zero, just as for an inductor. Thus *only a resistance will dissipate energy* as thermal energy in an ac circuit.

Only R (not C or L) dissipates energy

A relationship between the applied voltage and the current in a capacitor can be written just as for an inductance:

$$V = IX_C, \qquad \left[\begin{array}{l}\text{rms or peak}\\ \text{values}\end{array}\right] \qquad \textbf{(21–12a)}$$

where X_C is the **capacitive reactance** and has units of ohms. V and I can both be rms or both maximum (V_0 and I_0); X_C depends on both the capacitance C and the frequency f:

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}, \qquad \textbf{(21–12b)}$$

Capacitive reactance

where $\omega = 2\pi f$. For dc conditions, $f = 0$ and X_C becomes infinite, as it should because a capacitor does not pass dc current.

EXAMPLE 21–17 Capacitor reactance. What is the rms current in the circuit of Fig. 21–37a if $C = 1.0\,\mu\text{F}$ and $V_{\text{rms}} = 120\,\text{V}$? Calculate for (*a*) $f = 60\,\text{Hz}$, and then for (*b*) $f = 6.0 \times 10^5\,\text{Hz}$.

APPROACH We find the reactance using Eq. 21–12b, and solve for current in the equivalent form of Ohm's law, Eq. 21–12a.

SOLUTION (*a*) $X_C = 1/2\pi f C = 1/(6.28)(60\,\text{s}^{-1})(1.0 \times 10^{-6}\,\text{F}) = 2.7\,\text{k}\Omega$. The rms current is (Eq. 21–12a):

$$I_{\text{rms}} = \frac{V_{\text{rms}}}{X_C} = \frac{120\,\text{V}}{2.7 \times 10^3\,\Omega} = 44\,\text{mA}.$$

(*b*) For $f = 6.0 \times 10^5\,\text{Hz}$, X_C will be $0.27\,\Omega$ and $I_{\text{rms}} = 440\,\text{A}$, vastly larger!

NOTE The dependence on f is dramatic. For high frequencies, the capacitive reactance is very small.

Two common applications of capacitors are illustrated in Fig. 21–38a and b. In Fig. 21–38a, circuit A is said to be capacitively coupled to circuit B. The purpose of the capacitor is to prevent a dc voltage from passing from A to B but allowing an ac signal to pass relatively unimpeded (if C is sufficiently large). In Fig. 21–38b, the

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Capacitors as filters

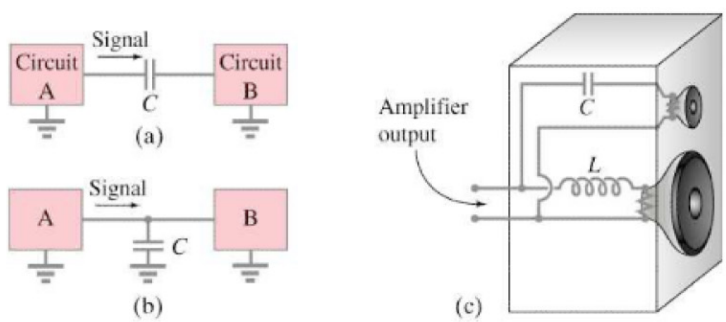

FIGURE 21–38 (a) (b) Two common uses for a capacitor. (c) Simple loudspeaker cross-over.

capacitor also passes ac but not dc. In this case, a dc voltage can be maintained between circuits A and B, but an ac signal leaving A passes to ground instead of into B. Thus the capacitor in Fig. 21–38b acts like a *filter* when a constant dc voltage is required; any sharp variation in voltage will pass to ground instead of into circuit B.

Loudspeakers having separate "woofer" (low-frequency speaker) and "tweeter" (high-frequency speaker) may use a simple "cross-over" that consists of a capacitor in the tweeter circuit to impede low-frequency signals, and an inductor in the woofer circuit to impede high-frequency signals $(X_L = 2\pi f L)$. Hence mainly low-frequency sounds reach and are emitted by the woofer. See Fig. 21–38c.

PHYSICS APPLIED
Loudspeaker cross-over