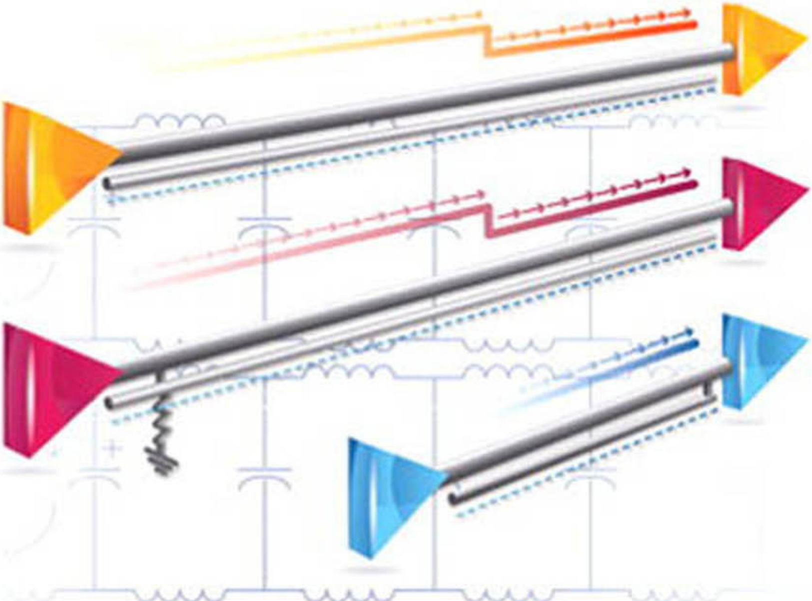
PCB Currents

How they Flow, How they React



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Modern Semiconductor Design Series

Signal Integrity Library

PCB Currents

Current rises linearly (the triangular curve) in response. When there is a positive current applied (the top half of the square wave), the voltage increases. When the current becomes negative (the bottom of the square wave), the voltage decreases. Thus, a square wave current source creates a triangular voltage wave across the capacitor.

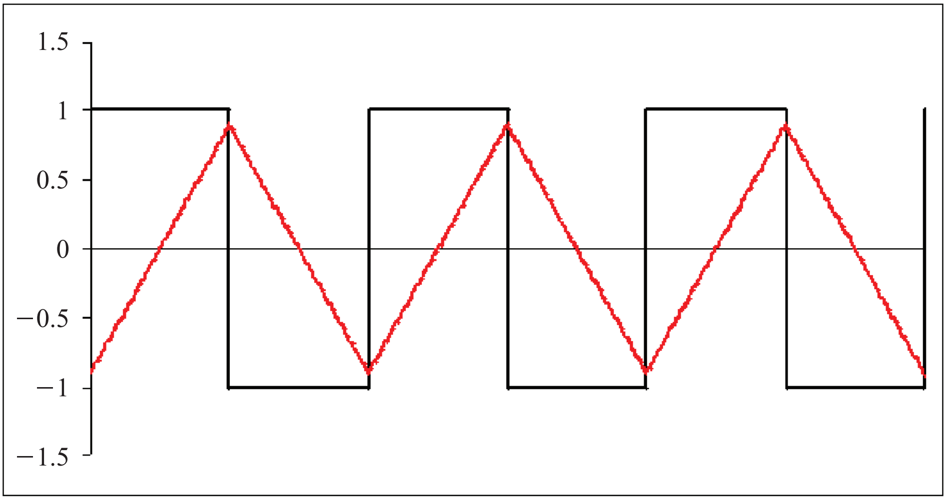

Figure 5-5 Voltage and current through a capacitor.

A fundamental relationship is revealed if we substitute a sine wave for the square wave current source in Figure 5-5 (see Figure 5-6).[2] Whenever the current through the capacitor is flowing in a positive direction, the voltage across the plates of the capacitor is increasing. As soon as the current becomes negative, the voltage begins decreasing. The current is positive during the first 180 degrees of its cycle, so the voltage is increasing during those 180 degrees. When the current is negative (between 180 and 360 degrees), the voltage is decreasing. The voltage is still positive over a part of that range because it takes a little time for the voltage to bleed off and become negative. But the voltage is decreasing whenever the sign of the current is negative.

2. See an animation of this at www.ultracad.com/animations/square2sin.htm.

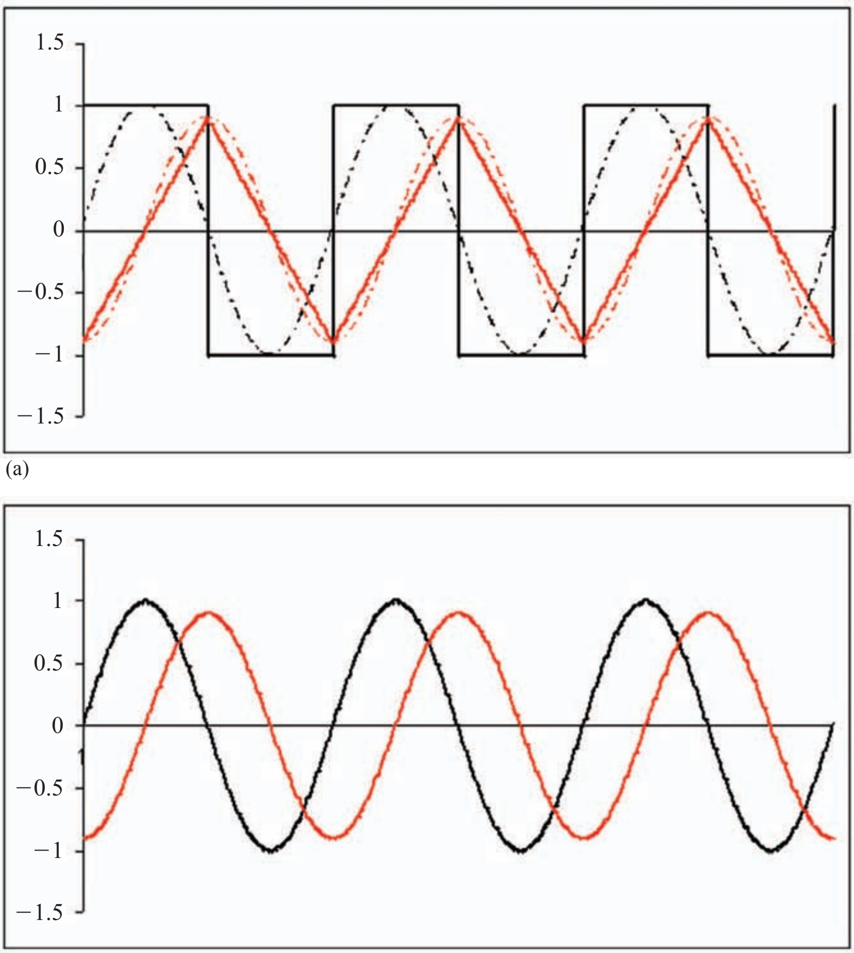

Figure 5-6 "Morphing" Figure 5-5 into sine waves. Voltage lags current by 90 degrees.

The voltage curve *lags* the current curve (or the current curve *leads* the voltage curve) in Figure 5-6 by 90 degrees. This is a fundamental relationship, and it is *always* true, with pure capacitors. The voltage curve peaks when the current changes direction (180 degrees). The voltage curve crosses the zero line when the current peaks in the negative direction (270 degrees). The negative voltage peaks when the current changes back from negative to positive (360 degrees). Figure 5-7 shows an oscilloscope curve from an actual circuit illustrating this relationship.

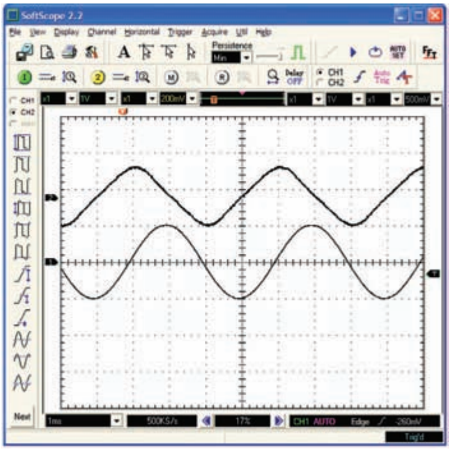

Figure 5-7 Current (top curve) leads voltage (bottom curve) through a capacitor by 90 degrees.

5.9 How Capacitors Combine

Capacitors combine in the exact opposite way that resistors do. Figure 5-8 shows capacitors in series (a) and in parallel (b).

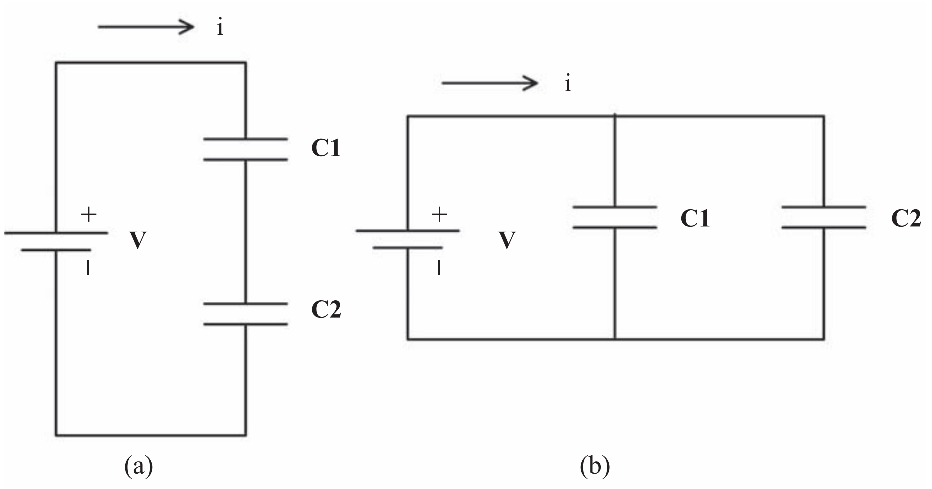

Figure 5-8 Capacitor combinations.

Capacitors in series combine according to Equation 5.12.

$$C = \frac{1}{\frac{1}{C1} + \frac{1}{C2}} \qquad [5.12]$$

Equation 5.13 is the way *parallel* resistors combine! Capacitors in parallel simply sum together, like series resistors.

$$C = C1 + C2 \qquad [5.13]$$

These relationships are easily proven using Kirchhoff's two laws, the reactance formula for capacitors (Equation 5.8), and Ohm's Law for capacitance (Equation 5.9).

5.10 Power Dissipated in a Capacitor

In an ideal capacitor, all the charge that flows onto a plate can be returned back to the source again. Referring to Figures 5-6 and 5-7, there is no apparent loss to either signal because there is no resistance in the circuit. Thus, energy is completely conserved.

If energy is completely conserved, and none is dissipated in the capacitor, then there can be no power dissipated (or lost) in a capacitor. One expression for power dissipation is i^2R. If there is no R, then there is no power lost.

This result is a general truth. Power is *never* dissipated (or lost) in a pure capacitor. Of course, no capacitor is pure. We will have more to say about real components in Chapter 9.

5.11 Formula for Capacitance

The following is the standard formula for capacitance that gives a reasonably reliable answer:

$$C_{(pf)} = \frac{0.2248 * k * A * (n - 1)}{d} \qquad [5.14]$$

where:

k = relative dielectric coefficient
air = 1; FR4 is approximately 4
A = area of plate, in^2
d = distance between plates, in
n = number of plates

When using formulas for capacitance from different sources, make sure you know which units the formula is expressed in. Different units (English vs. metric, for example) result in quite different constants that can be confusing at first.

Planar capacitance (for example, the capacitance formed when power and ground planes on a circuit board are placed close together with a thin dielectric between them) can be quite important and useful on a PC board. Equation 5.14 can give a useful estimate of planar capacitance, but be sure to adjust the area term for voids in the two planes caused by component pads and pins, vias, and so on.

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