Implementing a Crossover

Crossover filters combine matched high- and low-pass filters to separate low- and high-frequency signals and direct the signals to separate outputs. Manufacturers often use crossover networks in audio systems to direct the frequency components of audio signals to the appropriate driver (e.g., tweeter, woofer, and midrange) in a loudspeaker. Although there are many ways of implementing crossover filters, one interesting and nonintuitive method is to use a single, low-pass element, such as an integrator, as the starting point. Figure 10 shows a feedback loop with an amplifier acting as the feed-forward element and an op-amp integrator providing feedback.

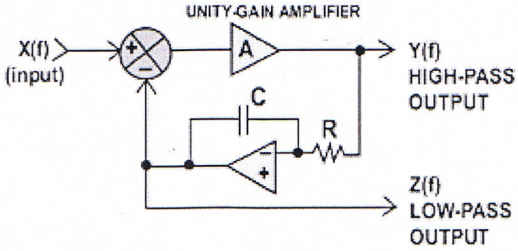

Figure 10. Wrapping a feedback loop around an integrator results in both low-pass and high-pass filter functions.

For simple feedback loops, such as the one shown in Figure 10, the general relation between input (X) and output (Y) is given by:

$$\frac{Y}{X} = \frac{a}{1+ab} \tag{15}$$

where:
a = the gain of the feedforward path
b = the gain of the feedback path

In this case, a is constant (1) and b is the complex gain provided by an integrator ($^1/_2\pi$fRCj). Substituting these expressions for a and b yields the following expression for gain at the Y output:

$$\frac{Y(f)}{X(f)} = \frac{1}{1+\frac{1}{2\pi fRCj}} = \frac{2\pi fRCj}{2\pi fRCj+1} \tag{16}$$

This expression describes a first-order high-pass filter with a corner frequency $F_C = 2\pi RC$.

You can also obtain a low-pass filter by simply taking the output at another point in the circuit. The output of the integrator (Z) represents the high-pass function appearing at output Y, multiplied by the gain of the integrator. The resulting relation between Z and X is given by:

$$\frac{Z(f)}{X(f)} = \left[\frac{2\pi fRCj}{2\pi fRC+1}\right] \times \left[\frac{1}{2\pi fRCj}\right] = \left[\frac{1}{2\pi fRCj+1}\right] \tag{17}$$

This is recognizable as the gain function for a low-pass filter with a corner frequency $F_C = 2\pi RC$. Note that both the high-pass and the low-pass corner frequencies match each other because they are both ultimately derived from the integrator's gain function.

Although this circuit can be built from discrete components, it can also be implemented with a Lattice ispPAC10 programmable analog circuit (see Figure 12).

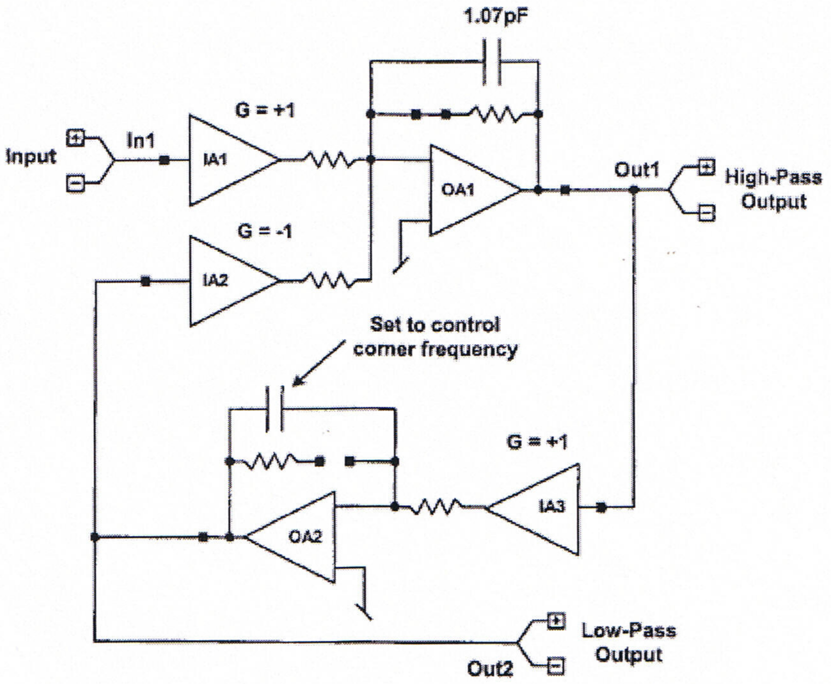

Figure 12. The Lattice ispPAC10 can directly implement the crossover filter using no external components.

This device provides adjustable corner frequencies and a single-component realization.

The onchip programmable capacitor associated with OA2 can be used to set the filter crossover frequency over a range of roughly 10–200 kHz. The actual corner frequency for both filter functions will vary slightly from that calculated for a given capacitor value because of finite bandwidth in the other amplifiers used in this circuit.

Another effect of finite bandwidth is that the high-pass response curve will begin to roll off around 500 kHz, in actuality being a band-pass filter with an adjustable lower limit (see Figure 13).

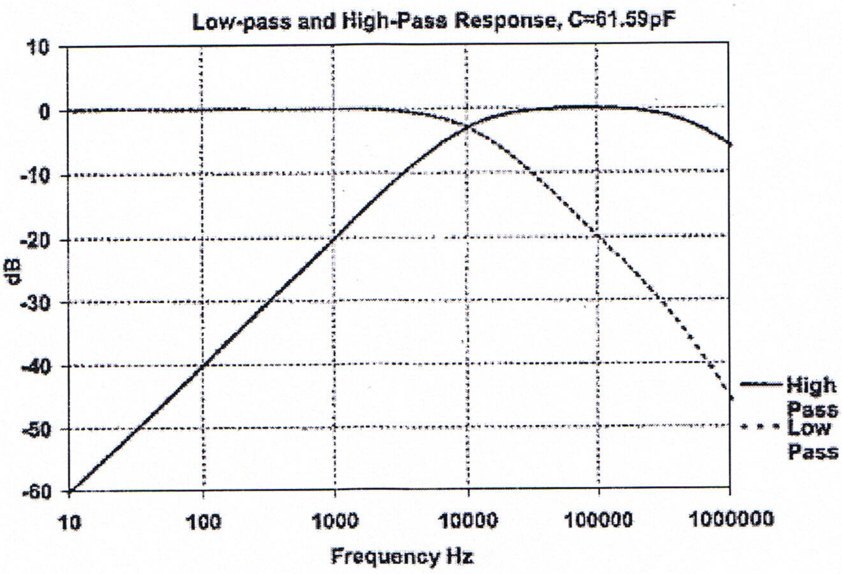

Figure 13. The crossover filter provides both high-pass and low-pass functions with the same -3 dB frequencies.