CROSSOVER BASICS

Knowing crossover characteristics can help you predict a speaker system's sound

IT'S hard to know what a speaker sounds like without hearing it. You can get some idea if you know something about its drivers. For example, a big speaker with two 15-inch woofers is likely to have better bass than a small speaker with one 6-inch woofer.

Drivers aren't the only parts in a speaker, however. When a speaker has different drivers to handle different parts of the frequency range, something else is necessary—a *crossover network.*

A crossover network divides the audio signal coming from a receiver or amplifier and sends the right parts of it to the right drivers. In a three-way speaker, it sends the lows to a woofer, middle frequencies to a midrange, and highs to a tweeter (see Figure 1). To know what frequencies each driver handles, you have to know the speaker system's *crossover frequencies*—the point(s) at which a rising or falling note will *cross over* from one driver to another. In addition to crossover frequency, other important features of crossover networks are the rate and shape of its attenuation *slopes*, which determine how the frequencies fade out from one driver and fade in to the next.

Because crossovers are designed for specific drivers in multiway speakers, they are usually built into each speaker. But they can also be purchased as separate components, especially for three-piece satellite/subwoofer systems or for biamplified and triamplified systems.

Whether a crossover comes with the speaker or is separate, knowing its characteristics can tell you something about the speaker's sound before you hear it. Different types of crossovers have different advantages and disadvantages. Some are hard on drivers (making them handle a wide range of frequencies), while others have problems with phase coherence (giving two drivers the same signal out of phase) or time alignment (causing the drivers to produce the same sounds at slightly different times).

Sonic Effects of Crossovers

Many multiway speakers have level controls for the midrange and the tweeter that act like broadband tone controls. The so-called *turnover points* of these controls are the crossover frequencies. Obviously, adjusting these controls can dramatically change the sound of a speaker.

A more subtle crossover effect is caused by the different distortion characteristics of different drivers. A crossover frequency that is too low or too high can send signals to a driver that it can't reproduce without distortion, and this distortion will get worse at higher volumes.

The amount of overlap a crossover network allows between drivers—that is, when a signal is reproduced by two drivers because its frequency is in the high part of one driver's range and in the low part of the other's—can also make a difference in the system's sound. Some speakers, such as those made by Bose, are touted for their large overlap (nearly an octave in the Bose 601 III's), while others, such as the JSE Infinite Slopes, are touted for their minimal overlap (with slopes over 100 dB per octave).

Crossovers and Drivers

Typically, there is a crossover output for each driver in a speaker. Since the limiting factor is driver capability, a speaker designer's selection of drivers dictates his choice of crossover frequencies.

For example, sending too much low-frequency energy to a tweeter is an easy way to send the tweeter to an early grave. The tweeter can't move far enough to reproduce very low-bass frequencies. And even if it could survive that much motion, its voice coil will burn out first because of the excessive energy levels.

Another driver limitation that affects crossover design is how evenly a driver disperses sound. If a woofer has wide dispersion and a tweeter has narrow dispersion, the speaker may sound weird and "beamy." If the dispersion patterns of the drivers don't match well, stereo imaging is likely to be lousy, especially for the overlap frequencies produced by both drivers.

How Crossovers Work

A crossover network is nothing more than a collection of electrical filters. A two-way speaker needs a *highpass* filter to pass highs to the tweeter while holding back the lows and a *lowpass* filter to pass lows to the woofer while holding back the highs. A three-way speaker will also need a *bandpass* filter to pass the middle frequencies to the midrange driver while holding back both the highs and the lows.

Figure 2 shows the output curves of the filters in a typical three-way crossover network. Notice how the lowpass filter lets the low frequencies, up to about 200 Hz, go through untouched while reducing the level of the higher frequencies, so that a note at, say, 4,000 Hz reaches the woofer at a level about 24 dB lower than a bass note. As the frequency increases, the output level from this filter steadily decreases.

The highpass filter works the opposite way, allowing its output level to increase as the frequency increases until about 10,000 Hz, above which it passes the high-frequency signals to the tweeter unchanged. In the middle of the network, the bandpass filter attenuates both lows and highs while leaving middle frequencies unchanged.

A system's crossover frequencies are determined by the *cutoff frequencies* of its crossover filters, which are the points at which their output level is 3 dB below the maximum output (which would produce a sound only half as loud). Signals beyond the cutoff frequency—above it for a lowpass filter, below it for a highpass filter, and either way for a bandpass filter, which has two cutoff frequencies—are still allowed to go through, but at a decreasing level as the frequency changes.

In Figure 2, the cutoff frequency of the lowpass filter and the lower cutoff of the bandpass filter are just over 400 Hz, while the upper bandpass cutoff and the highpass cutoff are just over 4,000 Hz. These two points, therefore, are the crossover frequencies of the speaker system.

Crossover Types

Ideally, the acoustic output of a speaker with more than one driver should be the same as the output of a speaker with just one perfect full-range driver. In practice, however, it is difficult to make different drivers work together in perfect harmony. The speaker's designer must choose the right crossover frequencies as well as the right shapes and rolloff rates for the filter slopes if the system is going to sound anything like the ideal.

A crossover filter's characteristics are described mathematically in an equation that represents a curve like those in Figures 2 through 6. Filter curves have three parts: the *passband* section, which is where the curve is level (or flat) because the filter is passing all signals in that frequency range; the *stopband* section, which is the part of the curve beyond the cutoff point that appears as a straight line with a certain constant angle, or slope; and the *transition region* between the passband and the stopband, which is the part that is truly curved.

The slope of a filter is the *rate* at which it rolls off, or attenuates, its output beyond the cutoff point given a constant-level input. It is usually expressed in decibels per octave, and for mathematical reasons the figures are almost always multiples of six. As the slope of a filter gets steeper and steeper, it approaches the ideal limit of a so-called "brick-

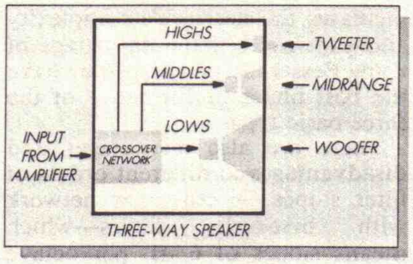

Figure 1. The crossover network in a three-way speaker system needs three filters: a highpass filter to send the high frequencies to the tweeter, a bandpass filter to send the middle frequencies to the midrange driver, and a lowpass filter to send the bass frequencies to the woofer. Different types of crossovers will provide more or less overlap between the signals sent to drivers in adjacent ranges.

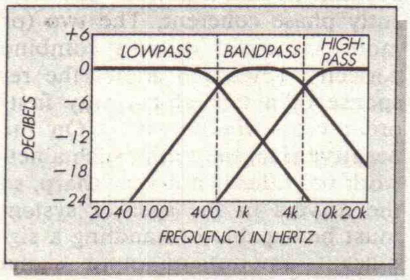

Figure 2. Response curve for the crossover network in a typical three-way system. Each of the three filters lets a certain range of frequencies pass through to its associated driver unaltered while rolling off the unwanted frequencies beyond its range. The crossover points for the system are where the filter outputs are 3 dB down from their maximum levels.

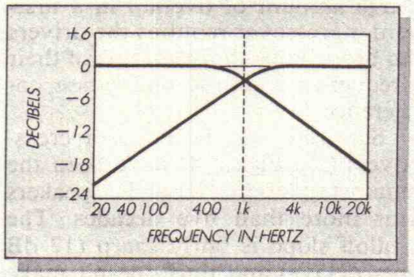

Figure 3. Response of a first-order crossover for a two-way system. The slope beyond the crossover point is a gentle 6 dB per octave, creating a wide overlap in the frequency ranges sent to each driver.

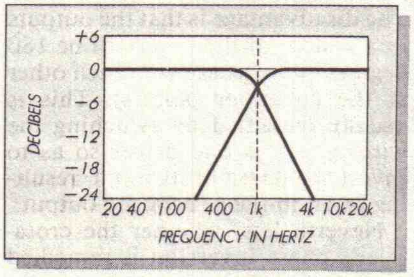

Figure 4. Response of a two-way, second-order Butterworth crossover. The rolloff slope is 12 dB per octave.

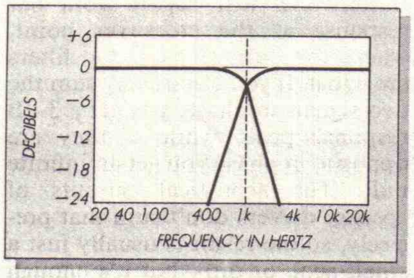

Figure. 5. Response of a two-way, third-order Butterworth crossover, with a slope of 18 dB per octave.

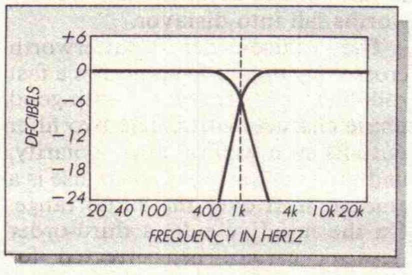

Figure 6. Response of a two-way, fourth-order Linkwitz-Riley crossover. In this special case of a Butterworth crossover, the rolloff curve is sharper and the crossover point is at −6 dB instead of the usual −3 dB. Beyond the crossover point, the slope is the same 24 dB per octave as with any fourth-order filter.