Crossovers as used in Pro Audio Systems

All conventional speaker systems, whether PA, hi-fi or studio monitors, have crossover circuits to ensure that each type of driver is only asked to handle the frequency range for which it was designed. If you have either an active or as passive system with crossovers built in, you may never give them a second thought, but understanding how they work can help you use your system more effectively and may also help you to protect your system from damage.

Lift & Separate

With the exception of specialist speaker systems such as those from Bose that use multiple small, identical drivers, it is normal to build PA systems using different driver types to cover different parts of the audio spectrum. A simple vocal PA, for example, may have a 12-inch or 15-inch bass/mid driver, then a horn-loaded tweeter to handle the top few octaves.

Larger PAs, or those with separate sub-bass cabinets, may split the audio into three or more bands, leaving the bass speaker to handle frequencies typically from 120Hz downwards. This way each driver reproduces only the frequency range over which it works well. It’s also interesting to note that in a typical music signal the level of bass energy is significantly greater than in the upper parts of the spectrum, so while a system might have, for example, a 1000W sub-bass speaker, the mid range may only need to be 200-300W and the tweeters 50-100W.

A crossover circuit must be incorporated somewhere in the system, in order to send just the relevant part of the audio spectrum to each driver, but there are two distinct types of crossover: active and passive filters built into the speaker cabinet – much as in a typical hi-fi speaker. These passive crossovers are connected between the power amplifier and the speakers, so they have to be able to pass all the audio power feeding your speakers. In a two-way system the frequency range is split into two, with the low frequencies to the high-frequency driver, or tweeter. In three-way systems there may be additional speakers handling the mid-range, and these are known simply as mid-range drivers.

Not only are crossovers essential for achieving the best sound from a system, they also prevent potentially damaging low-frequency signals from being fed into the tweeters. Bass and mid drivers will not be damaged by high frequencies, but the sound quality and the directivity of the speakers will be adversely affected if they are fed frequencies higher than those they are designed to handle will seriously compromise the quality and accuracy of the overall sound. They only exception is where very small drivers are used, but this approach brings its own technical problems and still does not address the problem of low bass, which is why such systems are often used with subwoofers, unless they are only handling vocals. Additional equalisers are also often necessary to flatten the frequency response of the system and these can, in turn, reduce the available power handling at lower frequencies.

Passive Crossovers

We have seen that, at its simplest, a crossover is a series of passive electrical filter elements, comprising resistors, capacitors and inductors (coils), and these are usually built into the speaker cabinets so that all you need do is feed them full-range audio from a suitable power amplifier. In a three-way speaker system comprising bass, mid and tweeter units, the bass speaker would be fed from a low-pass filter (one that only allows through frequencies below the filter’s cut off point) while the tweeter would be fed from a high-pass filter. The filter characteristics are carefully designed so that the bass driver ‘hands over’ smoothly to the tweeter at the crossover point. A mid-range speaker has both upper and lower limits of frequency handling, so it has to be fed using both high- and low-pass filters to ensure that it receives only mid-range frequencies. (The combination of a low-pass and high-pass filter produces a ‘band-pass’ response) Because no filter has an abrupt cut off, but rather a slope, the various driver ranges overlap slightly in frequency and the crossover must be designed to provide a smooth transition from one driver to the next.

Passive crossovers of the type just described are simple (because the user does not need to get involved), they are reliable (as they do not include any active components, such as transistors or op-amps), and they are cost-effective – at least, for small to medium-sized systems. However, at higher powers the components start to get bulky and expensive, as they have to withstand greater voltages and more current. In addition, passive crossovers are, by they very nature, wasteful of energy. Some of the amplifier power is always absorbed by the passive crossover circuit rather than being passed on to the speakers, so you need more amplifier power than if this loss did not take place. What is more, unless all three drivers are equally efficient at converting electrical energy into acoustic energy – and they seldom, if ever, are – the more efficient drivers have to be fed with a reduced level of signal in order to maintain a flat frequency response. In other works, the designer has to deliberately waste some power by adding resistive crossover components in order to get the combined drivers to produce a flat response across the full audio spectrum.

Crossover Slopes

The filter characteristic of a passive crossover cannot be made particularly steep without wasting power and using a lot of expensive components. (For example, a simple 'resistor and capacitor' filter has a slope of only 6dB per octave, whereas combining a capacitor and inductor can produce a 12dB per octave slope.) To achieve a steeper slope, multiple filter stages have to be cascaded, resulting in a further loss of electrical efficiency. The more dBs per octave, the sharper the response of the filter is said to be (using a 6dB per octave filter, the signal voltage is only halved for every octave you go beyond the cut off point, whereas a 24dB per octave beyond the cut off frequency.) The steeper the filters, the less overlap there will be between drivers handling adjacent frequency bands, which is generally desirable, as too much overlap can lead to phase problems resulting from both drivers trying to reproduce slightly different versions of the signal within the crossover's overlap region.

Because power amplifiers are now much cheaper (and often lighter) then they used to be, the power wastage issue is not as serious as it once was, so passive crossovers can be very effective in systems up to a kilowatt or so. Speakers with passive crossovers are usually fed from external power amplifiers, though a few powered designs combine internal amplifiers with passive crossovers. About a kilowatt, active crossovers start to become more appealing.

Active Crossovers

Unlike is passive counter part; the active crossover splits the audio signal into different frequency bands before it reaches the power amplifiers. Because the signal is still only at line level at this point, the crossovers do not have to handle any significant power, so no large components are used. However, it does mean that separate power amplifiers are needed to feed each frequency range. For example, in a three-way system separate power amplifiers are used to drive the bass, mid and high-frequency loudspeakers.

As the active crossover circuits deal with line-level audio signals, the filters can be built using conventional active electronic circuitry similar to that used in console equalisers, which allows much greater design flexibility. Now, instead of having to waster power to bring down the driver levels to match those of the least efficient driver in the system, the crossover outputs can be adjusted as required to achieve the correct level balance between the speakers. This gives the designers far more flexibility when selecting drive units for use in a system, and the ability to design steeper filters using active circuitry helps reduce the amount of 'out of band' signal that each driver receives.

As a bonus, active crossovers reduce the risk of tweeter damage if the system is fed with distorted signal. If the amplifier in a passive crossover system is driven into clipping distortion, as often happens when levels are high, normal low-frequency musical waveforms become approximate square waves, which contain a high level of high-frequency harmonics. These pass through the crossover to the tweeter in the same way as any other high-frequency signals and, if high enough in level or duration, they may overheat the tweeter voice coil and burn it out. Because an active crossover comes before the amplifiers, any overload at the bass end will be confirmed to the bass amplifier and hence to the bass speaker. The mid-range drivers and tweeters still receive clean signals from their own amplifiers.

Note that speakers with built-in amplifiers and crossovers have all the crossover settings matched to the drivers and cabinets being used, but if you are using a system that has external active crossovers and amplifiers the crossover frequencies and slopes may well be adjustable, and must be set in accordance with the recommendations of the speaker-cabinet designers.

Sub-Bass in Small PA Systems

Where small mid/high cabinets are augmented by an active sub-bass cabinet (of subwoofer) it is quite common for the bass bin to incorporate a crossover to feed everything above, say 120Hz to the main speakers and everything below that frequency to the sub's own amplifier. The crossovers in the main speakers then divide up their input between the bass/mid-range speaker and the tweeter. As a rule, there is no need to adjust the low-frequency response of the main speakers, as the crossover in the sub takes care of that, a side benefit being that you now have more available headroom (level) in the main speakers for the remaining mid frequencies. However, not all subs handle the filtering for the main speaker – some just pass the main audio through unfiltered, in which case the main speakers may be fitted with low-cut switches instead. Because there are so many possible options with modern PAs, reading the manual lat least once is highly recommended!

As many subs are designed to be used singly, the sub signal is summed to mono, but the 'pass-through' signal feeding the main speakers, whether filtered or not, tends to be kept in stereo. Usually the sub has its own level control, allowing the level of bass to be balanced to the rest of the frequency range. This is important, as the amount of bass needed depends on the room acoustics and the sub's location in the room. Similar results may be achieved by using the sub with passive crossovers, or by means of external active crossovers and separate power amplifiers. Having said that, for small to medium-sized systems the all-inclusive active approach is the most convenient from the set up point of view, though you have to be able to get mains power to each of the speaker cabinets.

Driver Protection

Because a loudspeaker has both mechanical and thermal limits beyond which damage occurs, some form of protection system is desirable. In passive systems it is possible to employ simple tricks, such as wiring a properly specified low-voltage light bulb in series with the tweeter (the most vulnerable driver) so that excessive signal heats up the bulb filament, thus causing its electrical resistance to increase, and consequently reducing the amount of signal fed to the tweeter. However, in an active system it is relatively easy to design in level limiters to prevent the amplifiers ever being driven into clipping. Those active speakers with everything built inside the cabinets generally also include thermal monitoring on the amplifiers that reduces the power of shuts it off completely if over-use caused the temperature to become dangerously high. Some manufacturers incorporate a nice variation on this approach, instead of the overall power being reduced, a low-cut filter comes into play to limit the amount of low-frequency energy fed into the amplifiers (which is where most of the energy is in typical pop music) until the temperature returns to normal.

All these facilities (including the basic active crossover), overall EQ, protection limiters, and more, may be built into the system controllers used with larger PA systems where the power amps are separate from the speakers.

System Controllers

Power amplifiers and loudspeaker systems differ considerable in their specifications and capabilities, and if optimum performance is to be gained from the PA system there are various parameters, which must always be under proper control. The object is to match the input signal as closely as possible to the PA system itself, to give it the opportunity to delivery maximum efficiency, and also to protect against undesirable signal content or levels. In basic terms, this can be achieved by using a crossover, compressor and/or limiter, and an equaliser. These individual functions act as shown in the table below. If all these functions could be combined in a single device, in theory that device would be all we would need, placed after the mixing desk and before the power amps and speakers, to ensure that everything ‘downstream’ is operating as effectively as it should, and is also protected as far as possible against inappropriate use, or accidents such as mains spikes.

Not too long ago this would have been something of a technical challenge, but with the advent of affordable digital signal processing it no longer represents a problem. Once the audio signal has been converted to digital form it is a relatively easy matter to process it in any way you like – exactly as if you were using software plug-ins to process a recorded signal, but instead with a live signal, and in real time. Where previously there would have been various hardware circuits performing discrete functions, all requiring proper compatibility and correct matching when connected together, and each stage potentially adding unwanted noise, modern equipment enables all the functions to be carried out within the digital domain, and the results depend only on the quality of the algorithms used. These all-in-one packages tend to be called ‘system controllers’ because they place the entire PA system under their control, and they are the last device in the signal path before the power amps. Even relatively affordable controller systems, now contain a host of useful additional facilities, such as a library of known responses of popular PA system components and the ability to store a room curve or even an entire system set up for when you return to a venue.

Function	**What it does**	**What it achieves**
Crossover	Sends the correct part of the frequency spectrum to the correct speakers	Protects against speaker damage and loss of power caused by feeding unsuitable frequencies to LF and HF drivers
Limiter	Prevents the input signal to the power amps from increasing beyond a certain level	Avoids overdriving the system and resulting damage to the speakers
Equaliser	‘Shapes’ the overall signal to match specific amp and/or speaker types	Optimum performance from the amps and speakers, plus a degree of extra protection

Summary

Most systems do not require you to know much about what type of crossover they use, but you may be able to use the system more effectively if you have some idea of the implications of passive and active systems, especially where driver protection is concerned. You only need a deeper knowledge if you are using an external configurable electronic crossover, because then you have to set it up to match the requirements of your speakers. Many of the portable systems available today have active crossovers and power amplifiers built in, and these are the easiest to use, as well as being the best protected. However, as you have probably surmised by now, there are many different options, even including hybrid systems where the sub has an active crossover but the main speakers use passive crossovers. There are also mixing consoles on the market that have ready-filtered mono sub outs, which can make adding a sub to an existing system fairly straightforward.