There are many issues involving crossovers, but let me begin with your first question, "What is the difference between active and passive crossovers?" The engineering definition is that "active" electronics (crossovers or any other type of electronics) include amplifiers in their circuits while passive ones do not.

But when audiophiles use the term "active" with respect to crossovers, they usually mean "electronic" crossovers, which are low level and active compared to "passive" crossovers, which are high level and passive. Since this is all rather confusing, allow me to dig into crossover theory and design a bit, with their pros and cons, and it will all soon make sense.

By way of review, there is no speaker type that can reproduce all the frequencies in the audio bandwidth well. So crossovers must be used to split the audio frequencies into bands that can be reproduced well by the various types of drivers (usually woofers, midranges, and tweeters).

This is rather easy to do using passive components like capacitors and inductors. A capacitor inherently will roll off the bass into a tweeter at 6 dB/octave. An inductor inherently will roll off the highs into a woofer at 6 dB/octave. The circuit is very simple as you need only put a capacitor in series with the tweeter and an inductor in series with the woofer.

You may have heard about the number of "poles" in a crossover. A pole is the inherent 6 dB/octave roll off in capacitors and inductors. A single pole crossover would operate at 6 dB/octave. A two pole crossover would be 12 dB/octave, three poles would be 18 dB/octave, etc.

A simple, passive crossover is made of inductors and capacitors that are placed in the speaker cabinet along with the drivers. A single amplifier can be connected to the crossover and the crossover will then energize the various drivers in the speaker cabinet. This is simple, cheap, and easy, so that is what most manufacturers used at the start of the high fidelity industry -- and most continue to use these passive, high-level crossovers to this day.

This type of crossover is passive because its components have no ability to amplify or control the musical signal. It is "high level" because it handles the relatively high power (hundreds of watts), high voltages (up to several hundred volts), and currents (up to a few tens of amps) found at the output of an amplifier.

But passive crossovers have many problems and limitations. The major ones are poor precision, distortion, phase shift, the inability to produce steep crossover slopes, and no buffering. Let me address these in some detail.

It is important to understand that different types of drivers should not reproduce the same frequencies. No two drivers are identical or behave identically, so if multiple drivers are used to reproduce the same frequencies, there will be various distortions and errors introduced as the two drivers interact with each other at the shared frequencies.

This is particularly true when woofers and tweeters are combined. A woofer is extremely limited in its ability to produce high frequencies and will not sound at all the same as a tweeter at those same high frequencies. While operating a woofer at high frequencies only messes up the sound, operating a tweeter at low frequencies will destroy it. So it is very important to confine a woofer to the bass and a tweeter to the highs.

Audiophiles tend to think that the various drivers pretty much stop operating at the crossover point, which technically is defined as that frequency where the signal is 3 dB below the reference or baseline level. But this is not at all true. The output from a driver only starts to roll off at the crossover point. It continues to contribute a substantial amount of energy to the sound far beyond the crossover point.

The output of a driver needs to be at least 48 dB below the reference level before its output is low enough that it can be ignored. So crossover slopes are very important.

A capacitor or inductor inherently rolls off the sound at 6 dB/octave. Therefore, a driver that is driven by a single-pole, passive crossover will continue to operate and produce useful sound output for fully eight octaves above (or below) the crossover point before its output will have diminished by 48 dB.

To put this in proper perspective, let's examine the woofer's contribution to the sound if it has a crossover point of 1 KHz using a crossover with a 6 dB/octave slope. Since an octave is double the fundamental frequency, one octave above 1 KHz will be 2 KHz. The second octave will be at 4 KHz, the third will be at 8 KHz, the fourth octave will be at 16 KHz, the fifth octave will be at 32 KHz, etc.

So you can see in this case, that the woofer's output level will only be reduced by 18 dB at 8 KHz. This means that it will still be generating a lot of output at frequencies that should be produced only by the tweeter. Therefore, a single-pole, 6 dB/octave crossover is virtually useless at keeping the woofer out of the treble region. The woofer's sound will remain a major contributor to the highs and will degrade them significantly.

The reverse is true when you consider the tweeter. If the crossover is at 1 KHz, then a 6 dB/octave crossover will reduce the power to the tweeter by only 18 dB at 125 Hz. Since the energy in music is rising rapidly as you get into the bass frequencies, this 6 dB/octave crossover slope does not adequately protect the tweeter's delicate, lightweight, voice coil from being burned up by excessive power. So 6 dB/octave crossover slopes are simply unsatisfactory.

Loudspeaker manufacturers quickly learned that they needed to use steeper crossover slopes. To make a high level, passive crossover produce a 12 dB/octave slope, you need only add an inductor going to ground to the tweeter circuit and a capacitor going to ground in the woofer circuit.

Now you can see that using our earlier example of a speaker with a 1 KHz crossover point that the woofer's output will be down by 36 dB at 8 KHz and the tweeter's output will be down by 36 dB at 125 Hz. This is a vast improvement over a 6 dB/octave crossover, although there is still far too much overlap of shared frequencies from both drivers for ideal performance and the woofer still operates much too high for great sound.

It would be better to use much steeper crossover slopes. But making steeper slopes with passive inductors and capacitors becomes very difficult because the tolerance of the components is so poor that you can't get their poles to match precisely enough to work correctly.
The precision problem limits most passive crossovers to 12 dB/octave or 24 dB/octave.

The simple, common, 12 dB/octave crossover just described contains just 4 parts (2 inductors and 2 capacitors). But it has a major problem. It produces a filter type known as "Butterworth."

This means that its behavior at the crossover point is quite sharp and when both the high pass section (the tweeter) and the low pass section (the woofer) are combined, the power output at the crossover point is doubled. This produces an irregularity in the speaker's frequency response at the crossover point in the form of a bump of 3 dB. Obviously, this has adverse effects on the sound quality of the speaker and is unacceptable.

It is difficult to solve this frequency response problem by using equalization (which would be the best way to do so) because passive crossovers have no amplification with which you can produce equalization. So most manufacturers electrically invert the phase of one of the drivers.

This puts the drivers out of phase by 180 degrees and eliminates the frequency response problem. Of course, putting the drivers out of phase has adverse effects on the sound. But the adverse effects of phase are minimal in comparison to the adverse effects of a major frequency response error. So a compromise is reached where accurate phase is sacrificed for accurate frequency response.

This problem with Butterworth filters is serious and was eventually addressed by Linquitz and Riley when they jointly developed the Linquitz/Riley filter. Crossovers made to the L/R specification have flat frequency response through the crossover point and therefore, the drivers could be left in phase.

But the L/R filter was about twice as complex as a Butterworth filter, so this increased the cost of passive crossovers significantly. Still, manufacturers of quality loudspeakers adopted the L/R filter type in the interest of better performance while manufacturers of cheaper speakers continued to use Butterworth filters and suffered phase anomalies.

There are other filter types that have been developed for crossovers by Bessel and Chebyshev. I won't get into the details of these as they are rarely used and difficult to implement in passive crossovers. But for those who want special characteristics, these special filters can be incorporated into electronic crossovers.

Note that phase anomalies are most obvious when they occur in the critical midrange region. So manufacturers of quality speakers worked hard to push the crossover points out of the midrange.
Since conventional, magnetic, 2-way speaker systems usually must be crossed over at around 2 KHz, they are very bad about having crossover anomalies in the midrange. Also, it is hard to get a wide enough frequency band out of magnetic drivers to make truly high performance, 2-way systems.

So most quality magnetic speaker systems have 3 drivers (woofer, midrange, and tweeter). This allows them to move the woofer crossover frequency down to perhaps 500 Hz and the tweeter's crossover up to around 5 KHz. This really helps eliminate the problems of crossovers in the midrange, although it doesn't completely solve the problems. Having three drivers with relatively shallow crossover slopes means that at most of the midrange frequencies, you will have all three drivers contributing significant sound, which is one of the reasons that the midrange quality of magnetic speaker systems is inferior to the purity of an ESL.

A 3-way system considerably complicates the crossover. You now need 50% more parts. If those parts are used in a L/R filter, you may need twice that amount. So quality speakers end up using rather complex and expensive passive crossovers.

Passive crossovers degrade the sound by inserting parts (capacitors, resistors, and inductors) between the amplifier and the drivers. Particularly troubling are inductors. These consist of a long (many feet) of thin magnet wire wound in the shape of a coil. As a result, an inductor has significant resistance. When you put resistance between an amplifier and its woofer, you ruin the electrical damping that the amplifier could apply to the woofer to help control the woofer and stop overshoot and ringing.

As if the resistance in inductors weren't bad enough, there are often resistors in the signal path too. These are required to give you some ability to adjust the levels of the various drivers to get them to match reasonably well and get acceptable frequency response. But a resistor will ruin the amplifier's damping even worse than an inductor.

There are other problems in passive crossover involving inductors. The main one is hysteresis. Hysteresis is a problem whereby the output signal does not exactly match the input signal because there is non-linearity and phase error when producing magnetic induction in the core of the inductor.

Most inductors use iron cores to make them more smaller and more efficient. As current flows through the coil of wire in an inductor, it forms a magnetic field. This magnetic field is more powerful if it induces magnetism in an iron core.

But iron-core inductors produce a lot of distortion because they have very big hysteresis losses. To minimize this problem, most quality loudspeaker manufacturers eliminate the iron core and use air core inductors.

Due to their inefficiency, air core inductors must be much larger than iron core inductors. Longer wire must be used. More resistance is involved, which worsens amplifier damping, increases costs, and makes the crossover larger. Hysteresis losses are not totally eliminated in an air core inductor, but they are greatly reduced. But on balance, it is fair to say that inductors simply don't behave very well in audio circuits and are best avoided if possible.

Capacitors are also problematical. Large value capacitors are required, so electrolytic types are preferred because of their relatively small size compared to non-polarized caps (like polypropylene, polyester, mica, etc.).

But electrolytic capacitors have their conductors wound inside of them, so they also have a significant amount of inductance, which can alter the desired frequency response of the crossover. Therefore, non-polarized capacitors often are used in the very best speakers, even though these are expensive and take up a very large amount of room.

Passive crossovers cannot be buffered. This means that their behavior and frequency response can be influenced by the external application of inductance, capacitance, and resistance.

Where would these external factors come from? Mainly from speaker cables. Manufacturers of speaker cables know this so deliberately make their cables have various values of inductance, capacitance, and resistance to change the frequency response of speakers.

This is a real crap-shoot because they have no idea of how a particular cable will affect a particular speaker. Of course, the longer the cable, the more inductance, capacitance, and resistance it will have, so the more it will alter the frequency response of passive crossovers.
A speaker is significantly affected by room acoustics. So some cables may compensate for some of the room acoustics in pleasing ways and others may make the room interactions worse. It all depends on the speaker, the cable, the room, and the listener's taste in frequency response.

All these variables are is why there is so little agreement and so much controversy about which speaker cables are "best." Simply put, there is no "best" cable because all the variables involved prevent you from predicting the sound from a system with a particular cable.

I could go on to cover many other problems with passive crossovers. But the main point is simple -- passive crossovers have very serious flaws for which there are no good cures.

Speaker manufacturers know very well that the solution to all these problems are active, low-level, "electronic" crossovers. Such crossovers are actually small preamplifiers that have crossover filters built into them. Think of the "tone controls" that used to be available on preamps and receivers. These could be used to roll off the highs or lows just like crossovers do.

Electronic crossovers operate at low levels ("line level", which is about 1 volt and essentially no power). They operate on the signal from the preamp rather than being fed by an amplifier like passive, high-level crossovers.

The line-level preamp signal is split into the various frequency bands by the electronic crossover and each is then fed to an amplifier that energizes its respective driver directly. There are no inductors, capacitors, or resistors between the amplifier and its driver that would cause distortion, phase shift, or ruin the damping.

Electronic crossovers don't need to use inductors with all their problems as all the frequency filtering can be done with just tiny capacitors and resistors. These capacitors and resistors can be made to very high tolerance with resistors being accurate to better than 1% and capacitors to around 2%. So multi-pole filters can be used to get steeper crossover slopes.

Like any good preamp, electronic crossovers have input and output buffers. So they are immune to the effects of external inductance, capacitance, and resistance.

Complex filter types like Linquitz/Riley are easily and inexpensively incorporated into electronic crossovers. It is also quite easy to make the crossover infinitely adjustable in real time so that the listener can simply tweak the crossover points, slopes, gain, etc. as he wishes to get ideal sound and the flattest frequency response. This is impossible with passive crossovers.

The distortion in an electronic crossover is nearly immeasurable and is vastly lower than in any a passive crossover. The components in electronic crossovers are tiny and inexpensive, so electronic crossovers can be made at lower cost than quality passive crossovers. Since there is no large passive crossover that needs to be housed inside a speaker cabinet, electronic crossovers allow the speaker cabinet to be smaller.

Of course, nothing is perfect and electronic crossovers have their flaws. The main one is complexity and cost from the standpoint of the audiophile. This is because an electronic crossover system must be bi-amplified (for a 2-way system), or tri-amplified (for a 3-way speaker).

So the audiophile needs to buy two or more amplifiers to use with an electronic crossover. This is a major barrier for most audiophiles. But the improved performance is well worth it if you are looking for the best sound quality.

Analog electronic crossovers are still limited in their ability to produce steep crossover slopes. Although the tiny parts involved have much higher precision than the large parts in passive crossovers, they still are not precise enough to produce more than about four filter poles (24 dB/octave slopes). And while 24 dB/octave slopes are vastly better than the 12 dB/octave slopes typically found in passive crossovers, it would be nice to use steeper slopes if there were a good way to do so.

Recently, we have seen the development of digital signal processing. This makes it possible to eliminate the problems and limitation of capacitors, resistors, and inductors completely. The frequency response of the filters can be done entirely in the digital domain by computation. So digital electronic crossovers are not dependent on and limited by the behavior of special electronic parts.

Digital crossovers come with selectible crossover slopes and filter types. It is easy to use 48 dB/octave, Linquitz/Riley filters using digital crossovers, while this is virtually impossible using analog ones. These steep slopes make it possible to completely eliminate the contribution of each driver within 1 octave of the crossover point, thereby reducing the shared bandwidth to a minimum and greatly reducing the stress on the drivers.

Additionally, it is fair to say that all speakers need at least some equalization to produce the best sound. At a minimum this involves increasing the bass output below 50 Hz to compensate for radiation resistance losses that cause all woofers to roll off below 50 Hz.

Digital electronic crossovers include equalization facilities using their built-in, digital signal processor. The amount and type of equalization varies from shelving equalizers (to compensate for speaker limitations) to full-on room correction systems with parametric equalizers and built-in, real time analyzers.

Yet another advantage of digital crossovers is speaker time-alignment. You probably have noticed that some of the best speakers have their various drivers at different planes in their cabinet. This is so that they are different distances from you.

Placing the drivers in different planes is desirable because some drivers are "quicker" and their sound gets to you before others in the same cabinet. Usually the sound from the tweeter arrives before the woofer. If the sound from all drivers does not arrive simultaneously, the phase behavior of the speaker will be adversely affected -- particularly through that region where two or more drivers are reproducing the same frequencies.

Therefore, many manufacturers try to "time align" their speakers by mounting their drivers in different planes. Unfortunately, this is difficult to do with good cosmetic results and often it is impossible to mount them far enough apart to completely correct the problem.

A digital crossover solves this problem by introducing digital time delay into the early-arrival driver. You can connect a microphone to the crossover and it will automatically produce test tones that will allow it to measure the acoustical distance to each driver.

It will then take this information and automatically delay the early driver by the amount required so that all the sounds from all the drivers arrive at your ears simultaneously. The digital crossover will even compensate for temperature differences in the room that alter the speed of sound! The result will be perfect time-alignment even in speakers (most of them) where the drivers are not in the optimum planes.

At this point, you should be gaining an appreciation of why I insist that no speaker can claim to be of truly high performance if it uses passive, high-level crossovers. The performance available from electronic crossovers (particularly digital crossovers) and multi-amping is simply far better. All speakers can be made to perform better using electronic crossovers than when using passive ones.

Now I would like to address a couple of common misconceptions regarding crossovers. The first is phase. Many audiophiles try to avoid steep crossover slopes in the belief that steep slopes cause more phase shift that degrades the sound.

While it is true that the steeper the slope, the more the phase is shifted, this is not what causes the audible phase problems in crossovers. The true cause of the phase errors that can be heard is due to the unbuffered behavior of passive crossovers. Let me explain.

I previously mentioned that because passive crossovers cannot be buffered, their frequency response can be altered by the external application of inductance, capacitance, and resistance. I stated that speaker cables were a major cause of this, which is true.

But I did not mention that passive crossovers will also have their frequency response altered by their drivers -- none of which have perfectly uniform impedance. Since the performance of a passive crossover can only be produced into a specific impedance, the expected frequency response of a passive crossover will not be perfect because the impedance of the drivers varies.

Now anytime that there is a change in frequency response, there will be a corresponding change in phase response. Look at the impedance of any speaker system with a passive crossover and you will see that it looks like a cross section of the Andes mountains.

The phase is therefore similarly altered. It is these ragged phase errors that exist across the music spectrum in passive crossover speakers that cause the adverse phase effects you hear from passive crossovers.

Note carefully that an electronic crossover is not affected by the impedance of the speaker. The speaker is driven by an amplifier, not the crossover. The frequency response of any well-designed amplifier will not be affected by the impedance of its driver. So there will be no ragged phase errors to be heard in an electronic crossover.

But what about the smooth even phase shift caused by the crossover slope? Doesn't that affect the sound too?

Actually, careful testing shows that human hearing is not very sensitive to a smooth, linear, sloping phase shift. So the effects of the phase shift caused by the crossover slope are virtually inaudible. In any case, the smooth phase shift of the crossover slope is vastly less

apparent than the phase shift caused by the impedance variations and subsequent phase anomalies in passive crossover systems.
It is also true that human hearing is only really sensitive to phase errors through the midrange frequencies. Phase errors are inaudible at bass frequencies, and quite difficult to detect in the treble. So if you can keep the crossover out of the midrange, and particularly if you can keep it below 500 Hz, the steepness of the crossover slopes becomes a non-issue.

But even if you are convinced that steeper crossover slopes produce audible phase error, you need to look at the big picture. There can be no doubt that using drivers beyond their frequency response capabilities (like using woofers in the midrange and highs) and having a lot of shared frequencies between multiple drivers that are at different distances to you, severely degrades the sound.

This degradation does far worse things to the sound than any smooth phase error can. So it is well worth trading a little smooth phase shift for the much better frequency response, tight control of the sound, and improved sound quality that you can get by using steep crossover slopes.

I am not willing to compromise the sound quality of my speakers. So I simply will not, and do not use passive crossovers. To assure that there is no adverse sound quality from the crossover, I use very low crossover points (172 Hz in the Model 10c and 220 Hz in the Model 11).

No matter how good a woofer is, it simply can't match the spectacular detail and clarity available from a single, massless ESL in the midrange. So I use 48 dB/octave slopes to assure that the woofer only operates in the bass. The ESL reproduces all the frequencies from the upper bass to beyond the treble as a single driver without any crossovers at all.

The ESL must not be operated at or near its fundamental resonance or the speaker will exhibit high Q behavior (overshoot and ringing), which sounds awful. By using very steep slopes, I am able to operate the ESL down to within an octave of this resonance without exciting it.

The equalization facilities of electronic crossovers allow me to compensate for the midrange phase cancellation inherent in all dipole radiators. This is a far better way to correct this frequency response error than by using multiple panels of different sizes and crossovers to operate them at different frequencies as is commonly done in many ESLs.

As a result of the use of electronic crossovers, particularly digital ones, the performance of my hybrid ESL is now better than a full-range, crossoverless ESL. This is because my ESL is operated nearly full range (172 Hz to 34 KHz), and yet it has a superb transmission line woofer that will produce prodigious amounts of deep bass, which a full-range ESL cannot hope to match.

In summary, electronic crossovers are essential if you want outstanding speaker performance. This is especially true of hybrid ESLs.

I hope this information, although limited in scope, has been helpful. If you have further questions, please feel free to contact me.

Great listening,
-Roger