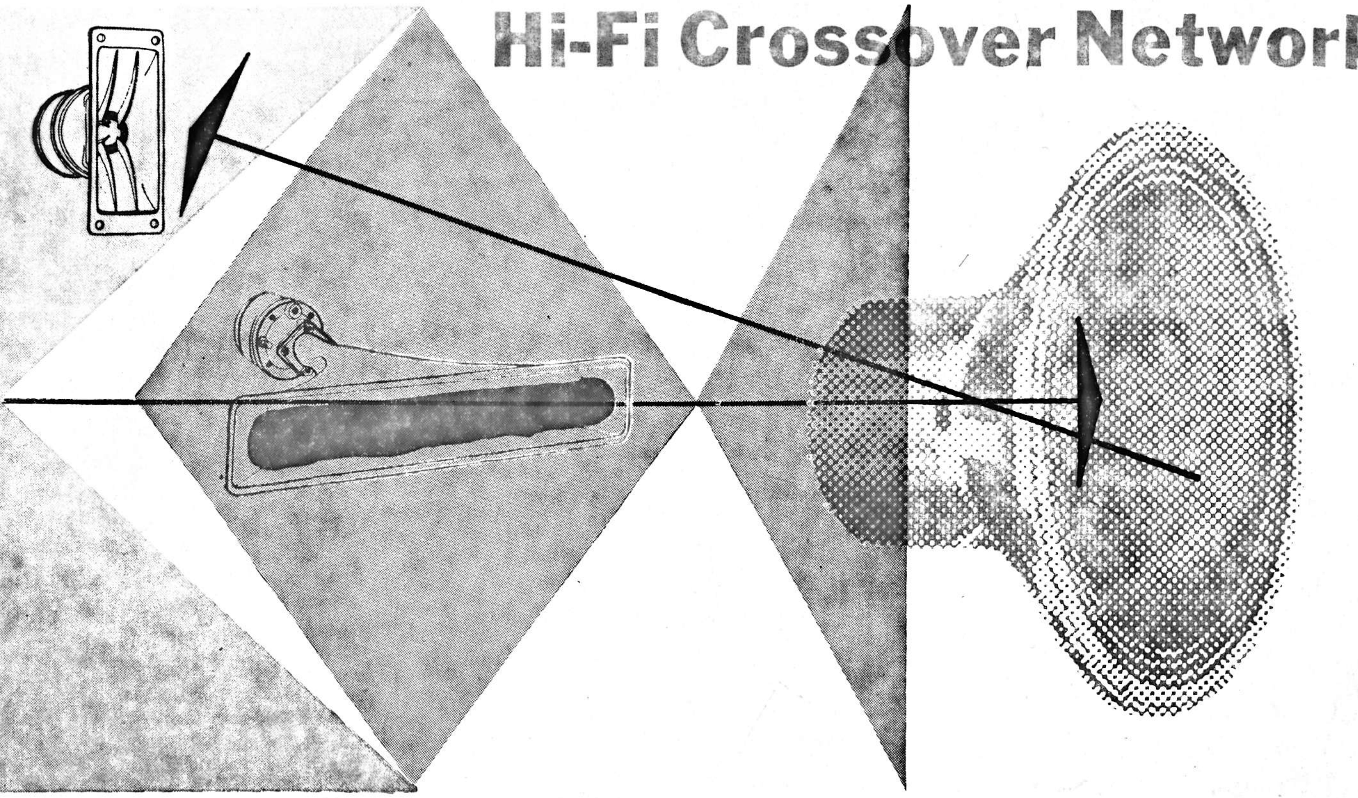
Hi-Fi Crossover Networks

General Principles



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Part 1. Here are the facts you need to know about these important circuits before building or buying.

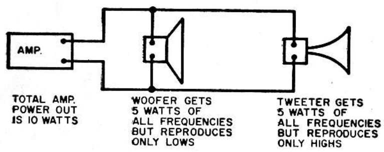
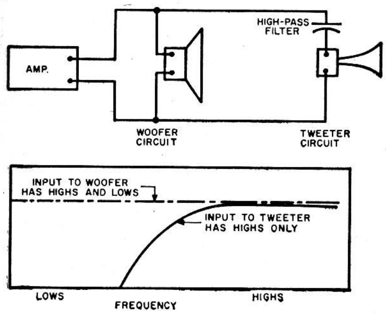
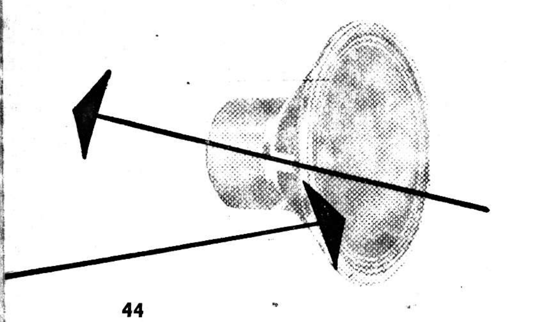


Fig. 1. Lack of network wastes power.

Fig. 2. Simple high-pass filter in tweeter circuit lets only highs into tweeter and provides tweeter protection, but does not keep high frequencies out of the woofer.





AUDIO dividing networks are essential components that ensure the proper functioning of multi-speaker systems. A well-designed audio dividing network, or crossover network as it is usually called, performs two functions. First, it is a traffic policeman that directs the various parts of the audio spectrum to the specialized speakers which are best able to handle specific bands such as the lows and highs. The secondary function of the crossover network is to protect the delicate tweeter mechanisms from low-frequency overload. The end *result* of these combined functions is better utilization of audio power available from the amplifier, cleaner reproduced sound from the loudspeaker, and more direct control over what comes out of the loudspeakers.

There are simple networks and there are complex networks, but they are all easily understandable when approached in a basic fashion. Before going into details of the design and construction of home-built precision networks, which will be covered in Part 2, a simple and quick recapitulation of the principles behind the network function will help the builder decide what network he should construct for his system.

Speakers Without Network

Networks, of course, are used with multi-speaker systems. The simplest multi-speaker system consists of a woofer for the reproduction of low frequencies and a tweeter for the reproduction of high frequencies. Although it would be unrealistic to connect two components such as a woofer and a tweeter directly to an amplifier without benefit of a network, we will do just that to illustrate what happens to the over-all system; then we shall progressively add network elements to the system and observe their effect upon performance.

In Fig. 1 we have connected a woofer and a tweeter directly across a 10-watt amplifier. Assuming that the amplifier is a good high-fidelity type, we may then expect that it will have full-frequency-range output. Under this condition, the full-frequency range will be fed *equally to both the woofer and tweeter*. If both speakers are of the same impedance, the woofer will get half the power and the tweeter will get the other half. But in each case, the woofer and the tweeter will both receive the same full-frequency range. Under this condition, half of the high-frequency power available from the amplifier will appear at the voice-coil terminals of the woofer. But, being a woofer, it will not be able to reproduce these high frequencies. Consequently, all the high-frequency power that is fed to the woofer (half of the total high-frequency power) is entirely wasted.

At the tweeter terminals we find a similar condition of power available but with different results. Since half of the amplifier high-frequency power has already been lost in the woofer, the tweeter already has two strikes against it. Only half of the high-frequency power from the amplifier is available to the speaker to be reproduced as useful sound. Of equal importance is the fact that half the amplifier's *low-frequency* power also finds itself at the tweeter terminals. Naturally this represents a waste of half the total low-frequency power that would normally go to the woofer. Since the tweeter cannot reproduce the low frequencies, then the lows that find themselves at the tweeter are a total loss as far as reproduction is concerned.

Of equal importance is the fact that the tweeter itself may become, physically, a total loss under these conditions. Tweeters are invariably small and delicately made so that the last drop of efficiency may be extracted from the feeble high-frequency signals. Tweeters are just not built to handle heavy low-frequency signals that should normally go to the woofer, either from a power handling capacity or from a diaphragm excursion standpoint. It might not take more than a few moments of good, loud playing of a system without a network, such as is shown in Fig. 1, to destroy the tweeter. Thus, even if one wanted to start a system in its simplest form, the use of some type of network is absolutely essential if only as far as tweeter life expectancy is concerned.

High-Pass Filter

The simplest way to protect the tweeter against low frequencies is by inserting a capacitor in its circuit—a procedure which would normally block low frequencies. In this case, as in Fig. 2, we get two effects for the price of one. Destructive low frequencies are kept out of the tweeter; and a *high-pass* filter effect is obtained. Actually, it is this high-frequency passband effect that prevents the transference of the low frequencies into the tweeter. The passband of the capacitor may be chosen to coincide with the actual high-frequency output of the tweeter itself so that only those frequencies that the tweeter will eventually reproduce will get into the tweeter. The effect of this simplest type of "network" is the conservation of all the low-frequency power for utilization by the woofer and protection for the tweeter against damaging low-frequency power. It should be noticed, however, that in this simple system, since there is nothing in the circuit to prevent high-frequency power from getting into the woofer, that *half of the available high-frequency power is still lost in the woofer.*

It would be worthwhile to digress briefly at this point to discuss the effects of such a "high-pass network" on the listening results obtained with this two-way system. The degree of effectiveness of this type of system insofar as the high frequencies are concerned will be greatest when the main speaker is *poor* in high-frequency response. If the main speaker is truly a woofer, then despite all the high frequencies that are sent into it, it won't reproduce any high-frequency sound. Consequently, when the tweeter and its high-pass element are subsequently connected across the amplifier, highs will begin to emerge from the system only as a result of the tweeter being connected and there will be a distinct audible difference. On the other hand, there are many cases where a tweeter and a high-pass element are connected, in the fashion just described, to a main speaker which is of the "wide-range" class. This situation will arise where one has originally installed a single speaker system for good over-all reproduction and then, at some later date, decides to build "up" from it to a multi-speaker system. Since the original *single* speaker installation is generally a good wide-range unit, it will reproduce high frequencies with fair efficiency and output. If a tweeter and a simple high-pass element are now connected across this type of speaker, the high frequencies will again split between the main speaker and the tweeter. *Half of the high-frequency power will still be reasonably reproduced by the original speaker* while the other half will go to the tweeter. Thus the increased over-all audible effect of adding the tweeter to a speaker which already reproduces highs will not have quite the impact as when connected to a woofer.

Full Two-Way Network

To overcome such a condition and to provide true *network* performance that will not only properly channel the various frequencies, but will improve over-all cleanness of reproduction, we have to add a single element to the circuit of Fig. 2. Fig. 3 shows a full two-way system with both high- and low-frequency controlling elements: a capacitor in the high-frequency channel to block the low frequencies from the tweeter and a choke in the low-frequency circuit to keep the high frequencies from the woofer. The capacitor is a high-pass element and the choke is a low-pass element. The combination of the two, usually referred to as an *LC* network, provides an electrical crossover function apportioning all the low-frequency power to the *woofer* and all the high-frequency power to the *tweeter*.

The audible effects of this sort of combination will be readily apparent. In almost all cases there will be fairly clean separation between the bands of sound radiating from the tweeter and the woofer. Where the efficiency levels of the two speakers are of the same order, the output sound from the tweeter and the woofer at the *cross-over frequency* will be equal. Above the crossover point the output of the tweeter will be dependent solely upon the performance characteristics of the tweeter itself. However, as far as the woofer is concerned, its output above the crossover point does not simply fall away. See Fig. 4. It will drop off in a manner determined *first* by the output characteristic of the woofer, or main speaker itself, as discussed in the previous paragraphs. Then it will be further attenuated by the "roll-off" characteristic of the high-frequency limiting element (the choke) in the woofer circuit. The converse of this situation will hold for those frequencies below the crossover point. The woofer output will now be determined

Fig. 3. Two-way network channels lows and highs to woofer and tweeter respectively.

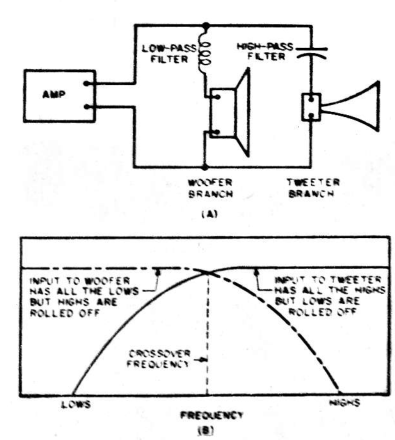
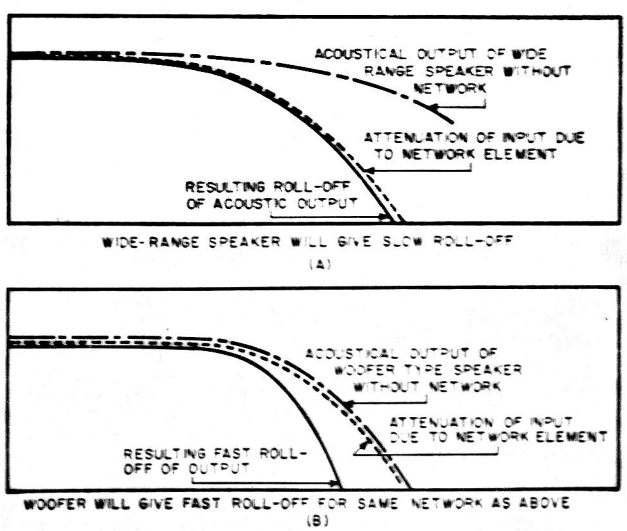
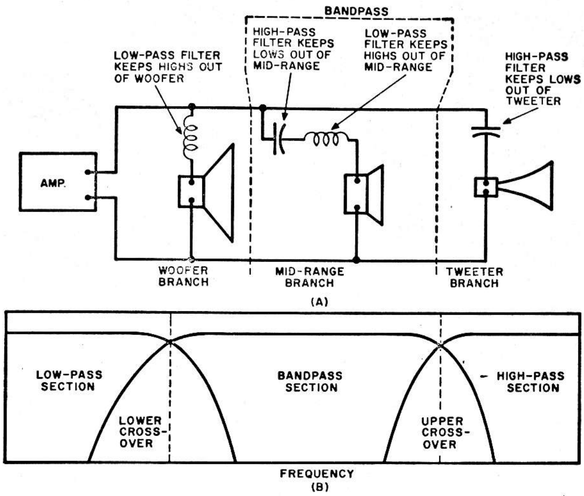
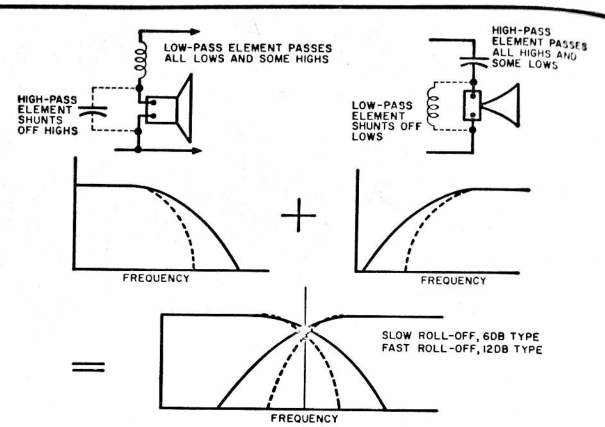


Fig. 4. The over-all system performance will be a function of both the performance of the loudspeaker and the network characteristic. Note the operation of the system with a wide-range speaker (shown at A) and with a woofer (shown at B).







↑ **Fig. 6. Slow roll-off network may be changed to fast roll-off by shunting the speakers with frequency bypassing elements.**

← **Fig. 5. Mid-range section is made by limiting lows with high-pass element, then limiting highs by means of low-pass element.**

entirely by the woofer performance characteristic while the tweeter performance will be controlled first by the output characteristic of the tweeter and then additionally modified by how the high-pass frequency element in its circuit rolls off the low frequencies. As shown in Fig. 4, *the end result of the speaker network combination is a function neither of the network nor the speakers, but is controlled by both the electrical characteristics of the network and the acoustic output of the speakers.*

Intermodulation Distortion

How does a two-way network of this *LC* type provide improved audio performance beyond the simple unit of Fig. 1 without the network? First, complete audio power utilization from the amplifier is now feasible. If there are a full 10 watts of low frequencies available from the amplifier, they will all go to the woofer and be reproduced there without half of them being wasted in the tweeter. Alternately, when there are a full 10 watts of high frequencies available from the amplifier, they will all go to the tweeter and be reproduced without half of them being wasted in the woofer. Then, of course, there will be full protection for the tweeter against damaging low frequencies.

However, most important from a performance standpoint is the fact that the full two-way crossover network system will provide considerable improvement (reduction) of the intermodulation distortion of the system. With the elimination of the highs from the woofer and their being channeled instead to the tweeter, these high frequencies are no longer bounced around by the large excursions of the woofer diaphragm which would be the case if both highs and lows were to come from the main speaker. By thus providing a separate tweeter diaphragm entirely independent of the more violent excursions of the large woofer diaphragm, considerable reduction in intermodulation distortion is possible, resulting in over-all cleaner sound.

Spatial and Level Response

When frequency division of this sort is practiced it is possible to overcome another defect of single-speaker operation, namely high-frequency beaming. In any large speaker, such as a typical 12″ or, especially, a 15″ unit the high frequencies tend to concentrate in a rather sharp beam in front of the speaker and high-frequency response over a wide listening angle is thus deteriorated. When, however, the highs are not reproduced by the large cone but are instead reproduced by a separate branch, then wide-angle dispersion of the high frequencies may be obtained, either through the use of dispersing type horn tweeters or a bent array of cone-type tweeters. Level control of the treble frequencies may also be easily accomplished now that they have a channel of their own. Such controls are referred to as "brilliance" controls. They raise or lower the entire *plateau* of the tweeter band, thus maintaining the full-frequency range of the tweeter despite the over-all output level of the unit.

Summary of Two-Way System

In summary, a two-way system with full two-way network provides complete utilization of audio power, reduction of intermodulation distortion, improvement in high-frequency spatial response, treble-balancing control, and complete protection of the tweeter against low-frequency damage or burn-out.

Three-Way System

The principles of the two-way network may be readily extended to the popular three-way system. Such a system comprises a woofer, a mid-range unit, and a tweeter—speakers which reproduce, correspondingly, the low frequencies, the middle frequencies, and the treble frequencies. The same general attributes that were found for the two-way network system are now applicable to the three-way system but with more definition of detail. Obviously, with three-band operation, the separation of the high frequencies from the lows is more efficiently accomplished and more readily audible. Where in the two-way system, for instance, a crossover of 2000 cps may have been chosen, in the three-way system an upper crossover of 5000 cps may be utilized. Those frequencies from 5000 cps down to perhaps 350 cps would be carried by the mid-range unit, while below that all the low frequencies would come from the woofer. With this sort of separation, there is no question at all as to which band is carried by the woofer and which by the tweeter. Audibly, the difference between the woofer cutting off at 350 cps and the tweeter starting at 5000 cps is as clear-cut as night and day. The mid-range unit, bridging these two extremes, has a characteristic personality all its own, again very distinct from the other two branches.

Balance in Three-Way System

Psychological use is made of the mid-range tonal quality by referring to it as "presence." There are many who feel that reducing the level of the mid-range unit makes the performer recede somewhat in the background, while raising the mid-range level brings him forward—or increases his "presence." This controlling feature of mid-range "presence," along with the treble "brilliance" control, obviously makes the three-way system more versatile than the two-way set up.

Since there is greater separation of the frequency bands in the three-way system than in the two-way system, we should expect further reduction of intermodulation distortion.

Mid-Frequency Controls

The filtering elements for a three-way network are actually a combination of the principles used in the design of two-way networks. The frequency controlling elements are, in the mid-range case, a capacitor to limit the low-

(*Continued on page* 146)

Hi-Fi Crossover Networks

(*Continued from page 46*)

frequency input to the speaker unit, in series with a choke to subsequently limit the high-frequency input to the same unit, as shown in Fig. 5. In this instance, the mid-range section is a *bandpass* type of filter, whereas the low-frequency section is a *low* pass and the high-frequency section is a *high* pass.

6 db and 12 db Networks

The electrical structures shown in Figs. 3 and 5 for the two-way and the three-way networks respectively are representative of the popular "6 db-per-octave attenuation" type. They are the simplest types to construct and provide an "easy" type of roll-off, that is, a gradual falling off of the frequencies. Where it is desired to provide sharper electrical attenuation of the signals going into the speakers, then a 12 db system may be designed by doubling up the filter elements—not two capacitors where one exists, but instead pairing off an inductance with an already existing capacitor, and a capacitor with an existing inductance. (The initial value of these *pairs* will not be the same for the 12 db as for the 6 db network. This will be discussed in detail in Part 2.) As an illustration of the conversion of a 6 db to a 12 db network, let us again consider the case of the two-way system of Fig. 3 which is a 6 db-per-octave network, the slow type, and examine the tweeter section. The capacitor passes high frequencies to the tweeter, as determined by the normally decreasing impedance of the capacitor as the frequency is increased. There is no sharp "yes and no" line of demarcation where the capacitor passes and where it does not pass power on to the tweeter. The manner in which this power is transferred to the tweeter is a *gradual one* determined by the value of the capacitor in series with the tweeter. Some low frequencies below the crossover point will inevitably be transferred to the tweeter.

We can, however, *bypass* these low frequencies from the tweeter by shunting it with a choke, a *low-pass* element which has low impedance at low frequencies. Thus, if we have a tweeter in series with a capacitor, we may put *a choke across* the tweeter for faster roll-off of the low frequencies from the tweeter terminals, as shown in Fig. 6. As the frequency goes up, however, so will the impedance of the choke and the high frequencies that get passed on to the tweeter through the capacitor will not be bypassed from the tweeter by the choke.

In a similar manner, if a capacitor were to be put across the woofer terminals, it would bypass any high frequencies that might get through the choke to the woofer terminals and the high-frequency roll-off at the woofer would thus be faster than that provided by the choke itself. At the low frequencies the capacitor shunted across the woofer terminal would be relatively ineffective. It is thus possible to design a "fast" 12 db-per-octave network from a "slow" 6 db-per-octave network by simply adding, across each loudspeaker unit, a reactance element opposite in nature to that normally found in that particular branch of the circuit as a 6 db-per-octave network (but altered in value). Fig. 7 shows 12 db-per-octave counterparts of the simpler 6 db-per-octave networks.

We have intentionally avoided reference to numerical values for these reactive elements because it was desirable to first establish a general speaking acquaintance with the principles behind these common network systems. We have indicated why they were necessary; we have briefly discussed how they function; and the general nature of the differences among the various types. We are now ready to assign values to the components used in the various filter elements—a subject which we will cover in full in Part 2. (*To be concluded*)

Fig. 7. A 6 db network is transformed to a 12 db network by adding into each filter circuit an opposite type of filter element. Values will be altered—see text.