Crossover Networks

Part II

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The coil former may be made out of the nearest size of PVC conduit pipe, or a wooden cylinder. The sides of the former are made from two pieces of plywood held tightly against the edge by a nut and bolt through the centre as shown in Fig. 11. The coil may be hand or machine wound on this. Preferably, the coil should be layer wound. If not, care should be taken to ensure that all space is filled up. After winding, a diluted epoxy adhesive (like araldite) may be applied to the coil to help it maintain its shape and the former can be slipped off, after loosening the sides. Insulation tape is tied round the coil to prevent the outer ends from opening up. Before winding, the number of turns required can be calculated using the formula given below:

$$n^2 = \frac{L \times 10^9}{24.5a}$$

where n is the number of turns, L is the inductance required in Henry, and a is the length of winding in cm equal to radius of the former.

It may be noted that the winding section is square and is equal to half the diameter of the former, a, i.e. the length of the former is equal to the thickness of the winding and is equal approximately to a. Following the above directions, fairly accurate coils can be wound. If desired, the inductance of the coils may be checked by setting up a simple AC bridge such as the Owens bridge. The circuit for this is shown in Fig. 12. Here, L is the inductance which is to be checked. The balance of the bridge is independent of frequency. The sensing device should most suitably be a CRO. In the absence of this, an AC millivoltmeter, a sensitive AVO meter or even a loudspeaker can serve the purpose. Here, VR is a wirewound potentiometer. Capacitors C1 and C2 are fixed and of any values between 0.1 μF and 0.47 μF normally serve the purpose. R1 and R2 are fixed resistances, where R2 should satisfy the following equation:

$$R2 = (C1/C2)\,R1 \qquad ....5$$

The balance point of the bridge is obtained by carefully adjusting VR till the voltage across the arms A and B is minimum. The inductance is then given by:

$$L = R1.\ VR.\ C1\ (\text{in mH}) \qquad ....6$$

The balance point appears as a sharp dip, and not a gradual decrease. If this eludes you, then first check all connections, and then the fixed value components. Substitute an approximate estimated value for the inductance, and work backwards to get suitable component values for the fixed value components, using equations 5 and 6.

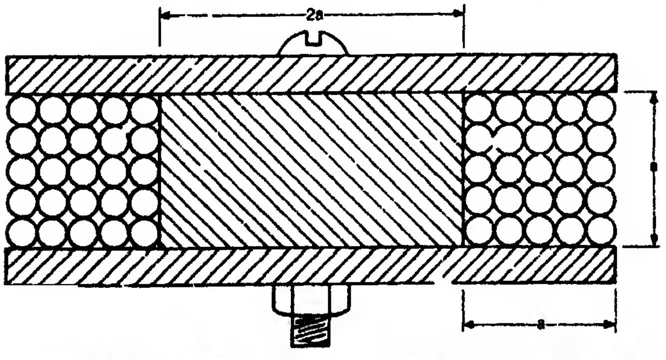


Fig. 11: Schematic showing the construction of a typical former for an air-cored coil.

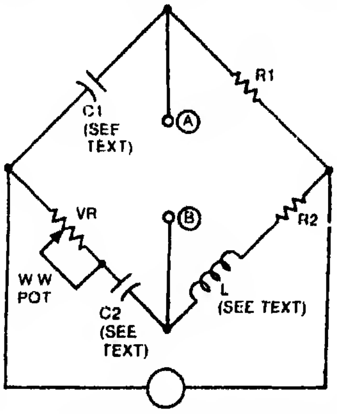


Fig. 12: Typical setup to check the inductance of coil by using the Owen bridge network.

Phasing of loudspeakers

The introduction of any reactive element usually causes a phase shift of the output, with respect to the input. The same can therefore be expected in any crossover circuit. The relative phase of the constituent loudspeakers ultimately affects the frequency response of the speaker system. The polarity of any loudspeaker is usually indicated by the manufacturer by means of a red dot, or some other marking on the appropriate terminal. This can be checked very easily The positive terminal is the one to which the application of a positive voltage causes the cone to move forwards (or outwards). The reverse, obviously causes it to move backwards. Care must be taken, however, to ensure that the voltage is just sufficient to move the cone, not blow it across the room.

A first order network, with a slope rate of 6 dB/octave, has desirable characteristics. It is simple to construct and has constant voltage and power transfer as well as a zero phase shift in the output across the entire band. From all angles therefore, the first order network is apparently the most preferable.

The relatively slow rate of attenuation, however, poses a problem. When a first order network is proposed, the component loudspeakers must overlap in their frequency ranges over a four-octave range. That is, the woofer under consideration should have a usable frequency response extending up to two octaves above the crossover frequency, and the tweeter should have a frequency response extending to two octaves below the crossover frequency.

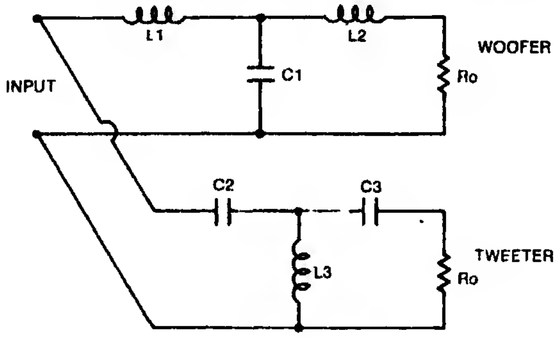
This is a condition which is satisfied by very few units. A consequence of this constraint is an audible harshness of the sound, particularly in the region of the crossover. A first order network would therefore not be recommended for a two-way system. This condition can be fulfilled in case a three-way system is envisaged. That is, it is possible to have a woofer and a midrange which could overlap in a frequency band over the four-octave range. Similarly, we can have a midrange and a tweeter overlapping over a four-octave range. A suitable first order system network can therefore be designed for a three-way system, taking these factors into consideration.

A second order network with a slope rate of 12 dB/octave provides increased attenuation, and thereby decreases the region of overlap in frequency response required between two drivers. The second order network, however suffers from one very serious drawback. At the crossover frequency, the outputs from the respective arms are 180° out of phase with respect to one another. This leads to a 'null' in the output in this region and is audible as a 'hole' or a 'void' in the response of the system.

The most common solution adopted is to simply reverse the polarity in one of the loudspeakers in the system. This is actually a compromise because the 'hole' gets replaced by a 'hump' as a result of the extraordinary phase characteristic which is produced. This method is preferred because the ears are more sensitive to changes in level rather than phase shifts. Also, a 'hump' is always preferred to a 'hole' in the response of the system. In spite of the above deficiency, the second order network remains the most popular network in commercial use.

The third order alternative

L.M. Henne has successfully demonstrated that a third order network with an attenuation rate of 18 dB/octave has a constant voltage as well as power transfer, with a gradual change in phase across the entire band. This gradual phase change is, of course, inaudible. The third order network is therefore a 'no compromise' solution which provides a rapid roll-off rate as well as desirable phase characteristics. The third order network is strongly recommended for use in a two-way system where a good degree of overlap in frequency response in the constituent drivers is not available for a first order network to be used, and when the decrease in sound quality caused by the hump or hole in the second order network is to be avoided. Computer-generated values for the third order networks with 8-ohm drivers for various crossover frequencies are given in Table I. The design equations and the general two-way circuit arrangement is given in Fig. 13.



Design Equations

Low Pass Section

$$L1 = \frac{3R_o}{4\pi f_c}$$

$$L2 = \frac{R_o}{4\pi f_c}$$

$$C1 = \frac{2}{3\pi f_c R_o}$$

High Pass Section

$$C2 = \frac{1}{3\pi f_c R_o}$$

$$C3 = \frac{1}{\pi f_c R_o}$$

$$L3 = \frac{3R_o}{8\pi f_c}$$

Fig. 13: The third order Butterworth filters as an 18 dB/octave constant-resistance frequency dividing network.

TABLE I
Element values for third order Butterworth filters with 8-ohm drivers

fc (Hz)	L1 (mH)	L2 (mH)	C1 (µF)	C2 (µF)	C3 (µF)	L3 (mH)
100.00	19.10	6 37	265 26	132.63	397.89	9.55
125.89	15.17	5.06	210.70	105.35	316.05	7.59
158.49	12.05	4.02	167 37	83.68	251.05	6.03
199.53	9.57	3.19	132.94	66.47	199.42	4.79
251.19	7.60	2.53	105.60	52.80	158.40	3.80
316.23	6.04	2.01	83.88	41 94	125.82	3.02
398.11	4.80	1.60	66.63	33.31	99.94	2.40
501.19	3.81	1.27	52.93	24.46	79.39	1.91
630.96	3.03	1.01	42.04	21.02	63.06	1.51
794.33	2.40	.80	33.39	16.70	50.09	1.20
1000.00	1.91	.64	26.53	13.26	39.79	.95
1258.93	1.52	.51	21.07	10.54	31.61	.76
1584.89	1.21	.40	16.74	8.37	25.10	.60
1995.26	.96	.32	13.29	6.65	19.94	.48
2511.89	.76	.25	10.56	5.28	15.84	.38
3162.28	.60	.20	8.39	4 19	12.58	.30
3981.07	.48	.16	6.66	3.33	9.99	.24
5011.87	.38	.30	5.29	2.65	7.94	19
6309.57	.30	.10	4.20	2.10	6.31	.15
7943.28	.24	.08	3.34	1.67	5.01	.12
10000.00	.19	.06	2.65	1.33	3.98	.10

The quasi-second order network

The third order filter discussed above is both expensive and complicated. Very few readers would, I am sure venture into its construction! The most elegant crossover arrangement—the quasi-second order network—however, is extremely simple and meets almost all requirements. The quasi-second order network is due to A.L. Kaminsky, and is basically the series first order network and is designed according to a modified Butterworth filter characteristic with a response which is unusual, but very desirable.

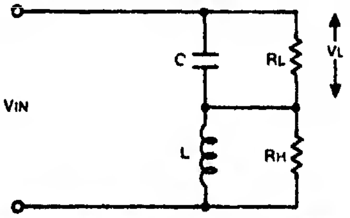


Fig. 14: A simple quasi-second order crossover network.

The circuit of the quasi-second order network is shown in Fig. 14. The computer-generated element values of this network with 8-ohm terminations are listed in Table II.

TABLE II
Computer-generated element values for quasi-second order network

Fc (Hz)	L (mH)	C (μF)
100.00	6.37	397.89
125.89	5.06	316.05
158.49	4.02	251.05
199.53	3.19	199.42
251.19	2.53	158.40
316.23	2.01	125.82
398.11	1.60	99.94
501.19	1.27	79.39
630.96	1.01	63.06
794.33	.80	50.09
1000.00	.64	39.79
1258.93	.51	31.61
1584.89	.40	25.10
1995.26	.32	19.94
2511.89	.25	15.84
3162.28	.20	12.58
3981.07	.16	9.99
5011.87	.13	7.94
6309.57	.10	6.31
7943.28	.08	5.01
10000.00	.06	3.98

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The low frequency channel cuts off at 12dB/octave at the crossover frequency and at 6 dB/octave above twice the crossover frequency. Likewise, the high frequency channel also cuts off at 12 dB/octave at the crossover frequency and then at 6 dB/octave—an octave below the crossover frequency. Hence the name quasi-second order for this class of filters. The quasi-second order filter has all the advantages of the first order networks, with constant voltage and power transfer and minimum phase difference in the outputs. In addition to being simple and having half the components of a conventional second order filter, the quasi-second order filter is not affected by minor component tolerances, as an error in the crossover point effects both the HF and LF sections in a complementary manner.

The two-way crossover as described can easily be extended to three-way or even four-way networks by cascading two or more networks, taking the HF output as the input for the second network. The three-way arrangement is shown in Fig. 15. If f1 and f2 are the two crossover frequencies for the three-way system, then L1 and C1 are found by using f1, and L2 and C2 are found by using f2 in Table II.

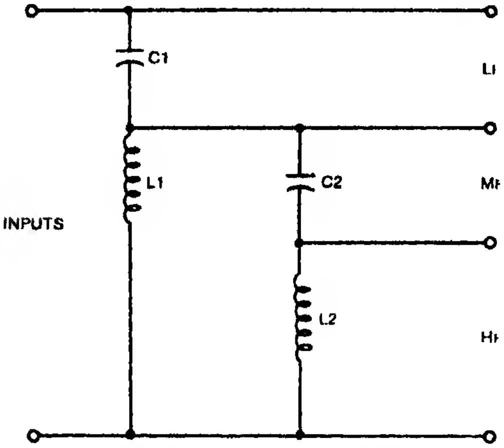

Fig. 15: A three-way crossover series network.

The design of a crossover network cannot be considered independently of the drivers of the system. The component loudspeakers should be compatible with each other, with similar sensitivities and frequency responses overlapping over a two to four octave range.

No particular crossover design can be generalised for use with all loudspeaker systems since the characteristics of the individual loudspeakers determine the crossover frequency and the attenuation rates required.

So, for any system, the simplest crossover design performing the desired function appropriately, may be considered as the ideal one. The first order crossover network has zero phase shift in the output and constant power and voltage transfer. But its slow attenuation rate makes it necessary for the loudspeakers in use to overlap in the frequency range over four octaves.

The second order network has an attenuation rate of 12 dB/octave and is commercially the most popular. The phase shift introduced by this network, however, adversely affects the frequency response of the system.

The third order network has a steep attenuation rate (18 dB/octave) and thereby permits the use of loudspeakers having minimal overlap in the frequency ranges. It also has acceptable phase characteristics and is best in performance though being more complicated.

The quasi-second network is by far the best in terms of simplicity and in providing a fast roll-off and zero phase shift, while maintaining constant voltage characteristics. ☐