Constant-Voltage Crossover Network Design*

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Consideration of the electroacoustic behavior of common loudspeaker drivers leads to the general crossover network design requirement of constant total voltage transfer. Conventional passive networks satisfy this requirement only if the cutoff slopes are limited to 6 dB per octave. Active crossover networks with steeper cutoff slopes can also be designed to meet this requirement, but these networks do not provide a rapid transition between drivers. Regardless of the network chosen, the drivers used must have useful frequency ranges which overlap by about four octaves.

INTRODUCTION Most high-quality loudspeaker systems used today are of the multiple-driver type. These systems contain two or more drivers, each designed for optimum performance over a limited portion of the system frequency range. One advantage of this approach is that the useful system frequency range may exceed that of the best single wide-range driver. Secondly, by dividing the signal spectrum among several drivers, total modulation distortion [1] of the system may be reduced.

An essential part of every multiple-driver loudspeaker system is the crossover network, also often called the dividing network. This network is responsible for dividing the signal to be reproduced into two or more separate signals on the basis of frequency; each driver receives the particular range which it is designed to reproduce.

Two important varieties of crossover network are in common use. One is the passive network which is constructed entirely of passive components and connected between a single power amplifier and a set of drivers [2], [3]. The other is the active network, or electronic crossover [4] which is connected ahead of a set of power amplifiers, one for each driver.

Traditional performance standards for crossover networks rely on simple electrical principles, without regard to the electroacoustic performance of drivers. The most common and familiar criterion is that of constant total power transfer, which is the basis of constant-resistance passive network designs [5].

A generally valid criterion for the division of the electrical signal in a multiple-driver system must take into account the driver transfer characteristics and the mechanism of recombination of the separate acoustic outputs. While the specific transfer characteristics of drivers depend on the driver design, one important feature common to all types of driver is a linear steady-state amplitude relationship between driving voltage and radiated sound pressure [6], [7]. The combined output of two drivers radiating together is found by superposition, i.e., the total sound pressure at any point is the linear sum of the two individually radiated sound pressures, phase difference being taken into account [8].

To simplify the derivation of a generally valid network performance criterion, two assumptions are made. The first is that the drivers are mounted so closely together that the path lengths to any point in the environment differ by much less than a wavelength at the crossover frequency. The second is that the amplitude and phase versus frequency characteristics of the drivers are identical (though not necessarily smooth) in the cross-

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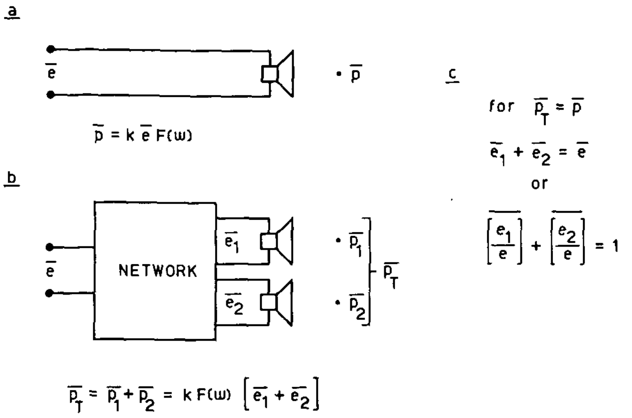


Fig. 1. Comparison of the performance of a single driver at **a** with two such drivers operated from a crossover network at **b** yields the network design requirement **c**.

over region. The practical significance of these assumptions will be discussed shortly.

CONSTANT VOLTAGE TRANSFER

The problem of crossover network design is illustrated in its simplest form in Fig. 1. In Fig. 1**a**, a single driver is connected to a voltage source; in Fig. 1**b**, two drivers identical to the first operate from the same voltage source via a crossover network. In the transfer expressions, superior bars indicate vector quantities and p is the (sinusoidal) sound pressure at a fixed distance from the driver(s), e is the (sinusoidal) driving voltage, k is a sensitivity constant, and $F(\omega)$ is the amplitude and phase characteristic of the specified drivers. Fig. 1**c** shows that the system of Fig. 1**b** will radiate the same sound pressure as the single driver of Fig. 1**a** if the crossover network satisfies the condition that the vector sum of the individual voltage transfer functions is unity.

For the general case of a crossover network having low-pass and high-pass voltage transfer functions defined by $G_L(s)$ and $G_H(s)$, respectively, the requirement is that

$$G_L(s) + G_H(s) = 1. \qquad (1)$$

It is emphasized that Eq. (1) is a vector relationship. The sum of the network voltage transfer functions must be both unity in amplitude and zero in phase for all values of frequency. This condition of unity total voltage transfer has also been derived from transient considerations in an earlier paper by Ashley [9]. In practice, the total voltage transfer may have any constant amplitude. While unity will be used for convenience in analysis, the derived performance criterion will henceforth be referred to as constant voltage transfer and the networks which meet this criterion as constant-voltage crossover networks.

The derivation of Eq. (1) assumes two conditions: that the drivers are mounted closely together and that they are identical. The first condition was not imposed solely to simplify the derivation; it is the only way to ensure uniform addition of the driver outputs for both direct and reflected sound throughout the listening area. If large driver spacings are employed, there is no ideal solution to the crossover design problem; hence any attempt to improve crossover network design must be accompanied by efforts to achieve the close driver spacing assumed.

In practice, some driver spacing is unavoidable, and the resulting path length difference introduces unwanted phase shift into the acoustic addition of the driver outputs. The most severe effects occur for driving signals of equal amplitude and nearly 180° phase difference, because the addition in this case is very sensitive to small additional phase shifts. Any choice in the design of crossover networks should therefore favor a solution which gives the least phase difference between outputs when the amplitudes are comparable.

The second condition appears at first to limit the usefulness of the derived performance criterion, because the drivers used in multiple-driver systems are seldom identical and often of completely different types. However, this condition is satisfactorily met by many practical driver combinations, for example, two direct radiators, each operating in its piston range.

If differences in the transfer characteristics of two drivers can be established and represented by a simple model, equalizing networks can be designed for use with one or both of the drivers to produce the required similarity of response. The network plus equalizers then constitute a correct "crossover network" for this specific set of drivers. By treating the problem of equalization separately, it is possible to design crossover networks having universal applicability. If a selected set of drivers cannot be equalized for use with a constant-voltage network, then these drivers will not produce ideal results with any network design.

CONVENTIONAL NETWORK RESPONSES

The ability of conventional crossover networks to provide constant voltage transfer is determined by examining the voltage transfer characteristics of these networks. Because the customary amplitude versus frequency response plots lack important phase information, these are supplemented here with the voltage transfer functions in polynomial form and polar plots of these functions. Low-pass functions are designated by G_L and high-pass functions by G_H. The form of these functions is simplified by adopting a normalized frequency variable $s_n = s/\omega_0$, ω_0 being the nominal crossover frequency.

Figure 2 presents the polynomial functions and plots for first-order (6 dB per octave) constant-resistance crossover networks. The same information is provided in Fig. 3 for second-order (12 dB per octave) networks and in

a $\quad G_L = \dfrac{1}{1+s_n}; \quad G_H = \dfrac{s_n}{1+s_n}; \quad s_n = \dfrac{s}{\omega_0}$

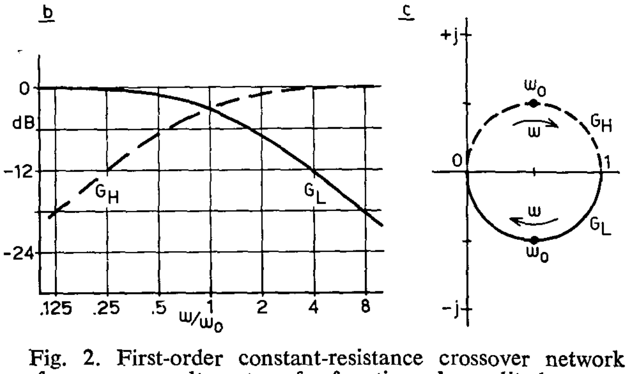


Fig. 2. First-order constant-resistance crossover network performance: **a** voltage transfer functions; **b** amplitude versus frequency response; **c** polar plots.

a $G_L = \frac{1}{1+\sqrt{2}s_n + s_n^2}$; $G_H = \frac{s_n^2}{1+\sqrt{2}s_n + s_n^2}$; $s_n = \frac{s}{\omega_o}$

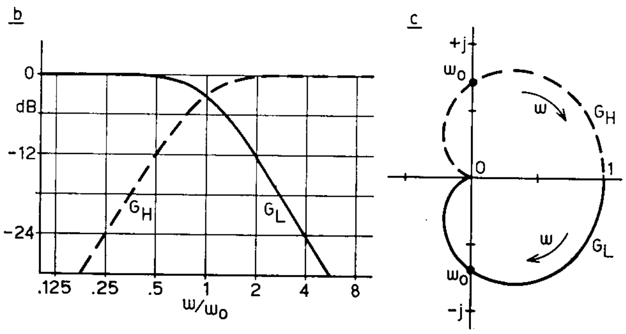


Fig. 3. Second-order constant-resistance crossover network performance: **a** voltage transfer functions; **b** amplitude versus frequency response; **c** polar plots.

a $G_L = \frac{1}{1+2s_n+2s_n^2+s_n^3}$; $G_H = \frac{s_n^3}{1+2s_n+2s_n^2+s_n^3}$; $s_n = \frac{s}{\omega_o}$

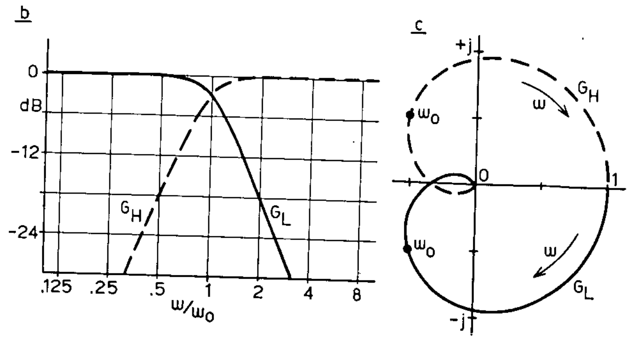


Fig. 4. Third-order constant-resistance crossover network performance: **a** voltage transfer functions; **b** amplitude versus frequency response; **c** polar plots.

Fig. 4 for third-order (18 dB per octave) networks. The constant-resistance designs result in Butterworth (maximally flat) responses for all cases.

An important feature of the pairs of polynomial functions presented is that in all cases,

$$G_L(s_n) = G_H(1/s_n). \tag{2}$$

It is this property which results in symmetry about the crossover frequency for the pairs of transfer plots and symmetry about the real axis for the pairs of polar plots.

Another important feature of the polynomial expressions is that the numerators consist of only one term. This feature is consistent in conventional active crossover network designs also. The single-term numerator is the result of choosing the simplest and most economical circuit which yields a given cutoff slope. It is also the reason for the failure of high-order conventional networks to provide constant voltage transfer, as can be shown by adding the low-pass and high-pass voltage transfer functions for each network to obtain the total response. Only the first-order conventional design results in constant voltage transfer. In the higher order designs, the shortage of numerator terms results in a nonunity total response. The second-order network has a null at crossover; the third-order network, while possessing a constant total amplitude, exhibits a complete phase reversal at crossover.

Higher order responses, which have steeper cutoff slopes, are traditionally desired because the more rapid attenuation outside the pass band eases the bandwidth requirements of the drivers. It is therefore of interest to investigate whether steep cutoff slopes can be obtained with constant voltage transfer, and to examine the extent to which the driver performance requirements may thereby be eased.

NETWORKS WITH CONSTANT VOLTAGE TRANSFER

The condition for constant voltage transfer is that the polynomial voltage transfer functions of a network sum to unity, Eq. (1). The simplest way of achieving this is to select a denominator polynomial common to both transfer functions and then to divide the terms of the denominator polynomial between the two numerators. The order of the denominator polynomial and the assignment of the terms to the numerators will determine the cutoff slopes of the two transfer functions.

If symmetrical responses having equal cutoff slopes are desired, then Eq. (2) must also be satisfied. This is achieved by selecting a denominator polynomial having symmetrical coefficients ($c_o = c_n$, $c_1 = c_{n-1}$, etc.) and dividing the terms equally between the two numerators.

The effect of these requirements on the polar plots of the transfer functions is quite interesting. It is easily shown that if Eq. (1) is satisfied, the polar plots of G_L and G_H will be identical in shape and size (the geometrical condition of congruency) and will lie in positions such that if one is rotated 180° about the point +½, 0 in the plane of the plot, it will coincide with the other. Note that this condition is satisfied in Fig. 2, where the two plots are identical semicircles, but not in Fig. 3 or Fig. 4.

As seen in the previous section, the condition imposed by Eq. (2) results in the polar plots of the transfer functions being symmetrical to each other about the real axis. Thus the polar plots of symmetrical constant-voltage functions must exhibit both congruent shapes and symmetry to each other about the real axis. These simultaneous conditions produce symmetry about the line Re = +½ for each function plot as well.

a $G_L = \frac{1}{1+\sqrt{2}s_n + s_n^2}$; $G'_H = \frac{\sqrt{2}s_n + s_n^2}{1+\sqrt{2}s_n + s_n^2}$; $s_n = \frac{s}{\omega_o}$

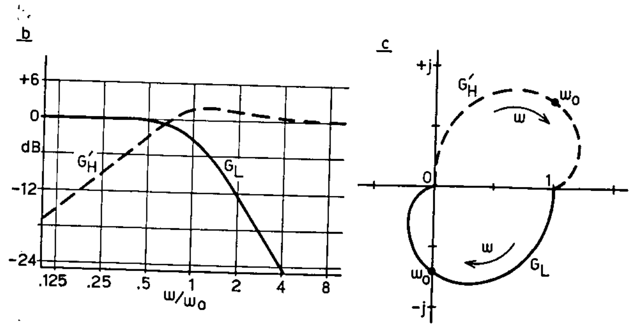


Fig. 5. Asymmetrical constant-voltage transfer functions based on conventional second-order low-pass network: **a** voltage transfer functions; **b** amplitude versus frequency responses; **c** polar plots.

a $G_L = \frac{1}{1+2s_n+2s_n^2+s_n^3}$; $G'_H = \frac{2s_n+2s_n^2+s_n^3}{1+2s_n+2s_n^2+s_n^3}$; $s_n = \frac{s}{\omega_0}$

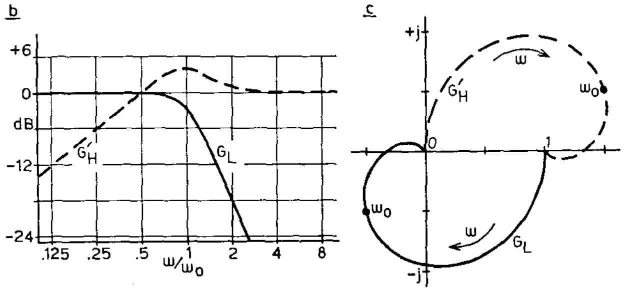


Fig. 6. Asymmetrical constant-voltage transfer functions based on conventional third-order low-pass network: **a** voltage transfer functions; **b** amplitude versus frequency responses; **c** polar plots.

Asymmetrical Networks

Taking the conventional low-pass responses of Figs. 3 and 4, the matching high-pass responses which give constant voltage transfer are easily derived, both from the polynomial functions and from the polar plots. The new function pairs are presented in Figs. 5 and 6. Note the identical shapes of the polar plots for each pair of functions. In both cases, the ultimate slope of the high-pass function is only 6 dB per octave. This is inherent in the initial choice of G_L which leaves the point $+1,0$ at an angle of $-90°$ and thus compels G'_H to leave the origin at an angle of $+90°$

Symmetrical Networks

Second Order: The simplest polynomial functions which satisfy Eq. (1) and (2) and result in second-order (12 dB per octave) responses are

$$G_L(s_n) = (1+as_n)/(1+as_n+as_n^2+s_n^3)$$
$$G_H(s_n) = (as_n^2+s_n^3)/(1+as_n+as_n^2+s_n^3).$$

For stability the coefficient a must be greater than unity. The actual choice of a determines the amount of peaking in the response and the phase difference at crossover. Choosing $a = 2+\sqrt{3}$ gives $|G(\omega_0)| = 1.0$, with 120° of phase difference between the two outputs, and approximately 2 dB of peaking in the pass band of each response. See Fig. 7 for plots of these functions.

Third Order: The simplest satisfactory polynomials are

$$G_L(s_n) = (1+as_n+bs_n^2)/(1+as_n+bs_n^2+bs_n^3+as_n^4+s_n^5)$$
$$G_H(s_n) = (bs_n^3+as_n^4+s_n^5)/(1+as_n+bs_n^2+bs_n^3+as_n^4+s_n^5).$$

For stability, a must be greater than unity, and b must be greater than $a+1$. If $|G(\omega_0)|$ is again chosen to be unity, the relationship between a and b is fixed at $a = (2-\sqrt{3})(b-1)$. A value of b can then be found which is high enough to keep the response peak below, say, 3 dB. The function $G_L(s_n)$ above has been investigated with the aid of a computer for various combinations of a and b. Response plots for $b = 21$ and $a = 5.36$ appear in Fig. 8.

General Considerations: The restriction of $|G(\omega_0)|$ to a value of unity was not arbitrary. This choice is consistent with the desire to avoid phase differences at crossover of nearly 180°, as explained earlier. At ω_0, $\mathrm{Re}(G) = +\frac{1}{2}$ for all symmetrical constant-voltage functions. Therefore, choosing $|G(\omega_0)| = 1$ gives $\angle G = \pm 60°$, or a phase difference of 120° at crossover. $|G(\omega_0)|$ cannot be decreased much below unity without producing large peaks in the pass band.

Restriction of the pass band peak is also based on rational criteria. (The shape of the polar plots shows that a peak must be present in all constant-voltage network responses except first order.) If one driver has a large excess input, constant voltage transfer requires that a large out-of-phase component be applied to the second driver. Large peaks thus produce undesirably large phase differences at the frequency of peaking. Equally important considerations are the power capability of the amplifiers and the power rating of the drivers, both of which must be increased in proportion to the amount of peaking.

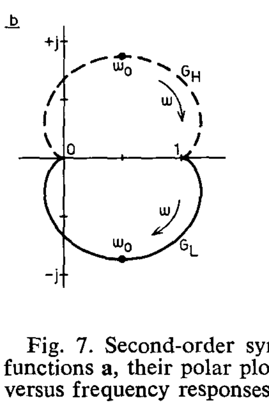
Features of Constant-Voltage Networks

Inspection of the voltage transfer characteristics of the various constant-voltage networks discussed reveals an interesting fact: in every case, asymmetrical or symmetrical, there is a broad overlap region on the frequency

a $G_L = \frac{1+as_n}{1+as_n+as_n^2+s_n^3}$

$G_H = \frac{as_n^2+s_n^3}{1+as_n+as_n^2+s_n^3}$

$a = 2+\sqrt{3}$



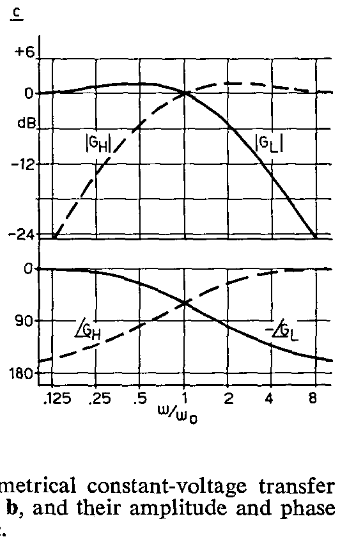
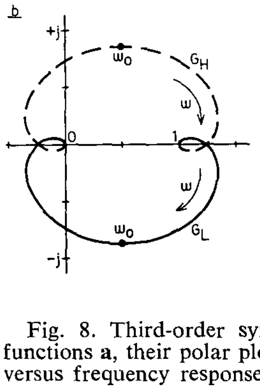


Fig. 7. Second-order symmetrical constant-voltage transfer functions **a**, their polar plots **b**, and their amplitude and phase versus frequency responses **c**.

a $G_L = \frac{1+as_n+bs_n^2}{1+as_n+bs_n^2+bs_n^3+as_n^4+s_n^5}$

$G_H = \frac{bs_n^3+as_n^4+s_n^5}{1+as_n+bs_n^2+bs_n^3+as_n^4+s_n^5}$

$a = 5.35898$, $b = 21$



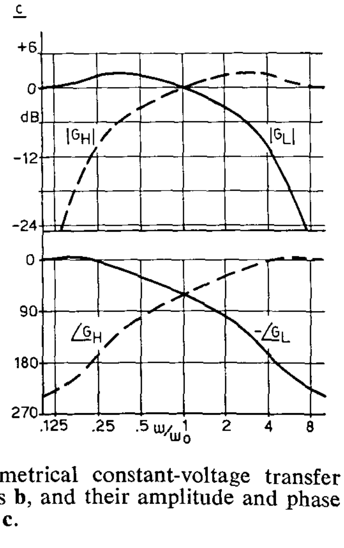


Fig. 8. Third-order symmetrical constant-voltage transfer functions **a**, their polar plots **b**, and their amplitude and phase versus frequency responses **c**.

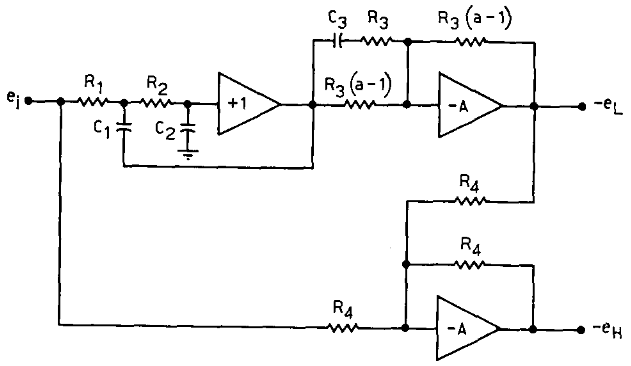


Fig. 9. Active realization of second-order symmetrical constant-voltage crossover network.

scale which is about four octaves wide between the −12 dB points of the related function pairs. This general rule holds for all the responses investigated; it can be overcome only by permitting undesirably large peaks or phase differences. Thus a steep ultimate cutoff slope does not help materially to reduce the overlap region where both drivers must operate satisfactorily and have closely similar characteristics.

For the general case of symmetrical networks, each driver must be designed to operate for two octaves beyond the nominal crossover frequency—at both ends of its range for a midrange driver. Over the four-octave overlap range, the driver characteristics must be closely similar or must be made so by the use of equalizers.

If it is necessary to cut off one driver rapidly due to an uncontrollable response irregularity, this can be done using an asymmetrical network. But the other driver must then have a well-behaved response for three octaves or more beyond the nominal crossover frequency.

REALIZATION OF CONSTANT-VOLTAGE NETWORKS

Active Networks

Given polynomial expressions for a desired response, such as those of the previous section, network circuits may be developed using the techniques of circuit synthesis [10], [11]. For example, the second-order symmetrical response of Fig. 7 requires a low-pass function $G_L(s_n) = (1+as_n)/(1+as_n+as_n^2+s_n^3)$. This function may be factored to

$$G_L(s_n) = (1+as_n)/(1+s_n)\,[1+(a-1)s_n+s_n^2].$$

Thus one way of synthesizing the network function is to cascade a shelf network with another network giving a damped pole-pair, as shown in the upper part of Fig. 9.

The complementary high-pass function may similarly be generated by a cascaded shelf network and second-order high-pass filter. However, if the low-pass response can be produced with unity gain at low frequencies, the high-pass response can then be obtained simply by means of a difference amplifier connected between the input and output of the low-pass circuit [12]. This is possible because of the constant-voltage property, Eq. (1). If the low-pass response is realized with a net phase inversion as in Fig. 9, a summing amplifier may be used to recover the high-pass response as shown in the lower part of the figure [9, p. 243].

The synthesis techniques described are applicable to all functions discussed earlier. All polynomials can be broken down into first-order and second-order polynomial factors, and the response functions can then be synthesized in cascade using the methods of [10] and [11].

First-order active networks are trivial. The simplest synthesis uses two complementary passive *RC* networks, with buffer amplifiers if necessary to eliminate loading errors.

Terminated Passive Networks

It was shown earlier that only the first-order variety of conventional passive networks exhibits constant voltage transfer. Higher order constant-voltage responses cannot be obtained with driver-terminated passive networks due to the nature of the required transfer function zeros.

Suitable first-order passive networks are presented in Fig. 10. Effective operation of such networks depends upon correct resistive termination, which is often assumed to be provided by loudspeaker drivers. This assumption is in fact usually false, and may lead to highly undesirable system responses (see next section).

Where resistive termination can be ensured, the series network of Fig. 10**b** is inherently advantageous because tolerances in component values, both in the crossover network and in the termination, will have no effect on the total network voltage response. Because the drivers are connected in series across the amplifier output, the sum of the voice-coil voltages must always be equal to the driving voltage.

NETWORK TERMINATION AND DRIVER EQUALIZATION

Figure 11**a** is a plot of the magnitude of the voice-coil impedance versus frequency for a typical moving-coil driver. The peak at 55 Hz is produced by the mechanical resonance of the moving system, the rising characteristic above 2 kHz by the self-inductance of the voice coil. This driver resembles a constant resistance only over the limited frequency range of 150–1000 Hz.

Termination of a constant-resistance crossover network with nonresistive drivers has two effects on system operation: first, the impedance presented to the amplifier is not resistive and may upset the stability or response of the amplifier; second, the voltage response of the network may be altered.

Regarding the impedance presented to the amplifier, the most common problem is reduced loading of the crossover network by the driver (due to the fundamental reso-

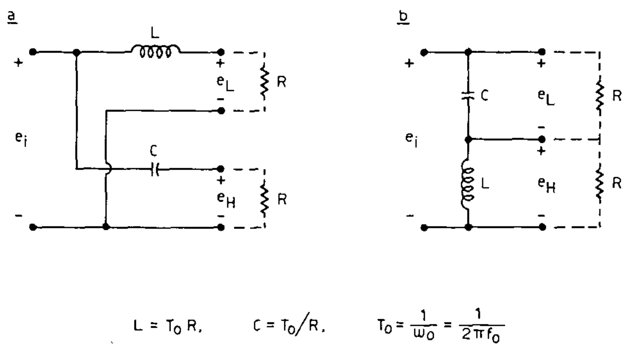


Fig. 10. First-order passive terminated crossover networks: **a** parallel network; **b** series network.

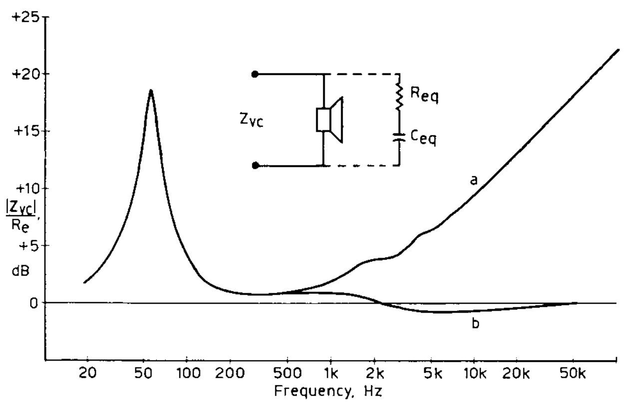


Fig. 11. Modulus of voice-coil impedance versus frequency for: **a** a typical moving-coil driver; **b** the same driver with voice-coil inductance equalizer.

nance of a tweeter or the large voice-coil inductance of a woofer) at a frequency where series resonance occurs in the crossover network. Series resonance can occur in the series first-order network and all higher order passive networks. The result is an unusually low network input impedance at resonance, which may cause overload and distortion in the amplifier or a troublesome ringing in the system transient response [13], [14].

The network voltage response is altered whenever the load impedance departs from the design value near crossover or in the stop band of each driver. (In the pass band, the voltage transfer is always close to unity and is not sensitive to load variations.)

Both difficulties may often be overcome by the use of simple impedance equalizers placed across the driver voice-coil terminals and adjusted to present the crossover network with a nearly constant resistive load.

Equalization of the voice-coil inductance, for example, is obtained with a series *RC* network. If the voice-coil inductance and dc resistance are L_e and R_e, respectively, then the required equalizer components are $R_{eq} = R_e$ and $C_{eq} = L_e/R_e^2$. The network load impedance is then equal to R_e. Figure 11**b** shows the equalization achieved on the driver of Fig. 11**a** using such a network. Losses in L_e make the equalization slightly inexact, but the impedance variations are less than 1 dB.

Electrodynamic drivers designed for low-frequency use usually have larger values of voice-coil inductance than drivers designed for high-frequency use. Unless the crossover frequency can be kept below the frequency at which the woofer voice-coil impedance begins to rise, equalization of the driver impedances to maintain correct network voltage response may not result in correct system acoustic response at crossover. This is because driver cone motion is the result of force developed from current flow in the voice coil; different values of voice-coil inductance thus produce amplitude and phase differences in the voltage-to-cone-motion characteristics of the drivers.

One satisfactory solution to this problem is to redesign the passive network to include the woofer voice-coil inductance, as suggested [5, p. 108]. A parallel network must be used, and the design value of crossover inductance is reduced by the amount of the voice-coil inductance. This solution, which requires no impedance equalizer, is limited to cases where the voice-coil inductance is less than the required crossover inductance; also, it cannot be used with drivers which have special cone treatment to offset the response effects of the voice-coil inductance.

In an active crossover system, the above condition is treated as a general response equalization problem. The lag caused by the larger voice-coil inductance is equalized by a complementary lead network in the amplifier. Ordinary driver response irregularities, if not too severe, may also be corrected by equalizers installed in the amplifiers [15].

A special equalization problem occurs when a direct-radiator driver is combined with a horn-loaded or electrostatic driver. The problem is that the direct-radiator diaphragm motion is mass controlled, while that of the other types is resistance controlled. The result is a constant phase difference of 90° between the two driver transfer characteristics [16]. This constant phase difference cannot be exactly equalized, although approximate networks may be designed to reduce the system amplitude errors in the overlap region.

MULTIPLE CROSSOVERS

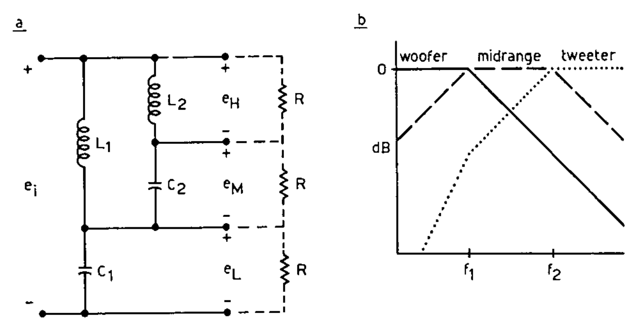
Multiple crossover networks exhibiting overall constant voltage transfer may be developed from the single-crossover principles developed earlier. The design criterion for an *n*-way crossover network having voltage transfer functions $G_1, G_2, \cdots, G_n$ is that the vector sum of *all* transfer functions is unity, i.e.,

$$G_1+G_2+\cdots+G_n = 1. \quad (3)$$

Equation (3) can be satisfied by simple cascading of networks (active or passive) which satisfy Eq. (1).

For passive first-order constant-resistance networks the method is to replace the resistive load at one or each output of a first network with another network having its own resistive loads. Figure 12 shows a three-way passive network using two cascaded single-crossover networks of the series type. The configuration shown gives minimum losses (one inductor only) in series with the woofer. Both networks affect the output of the second, giving a band-pass response to the midrange driver and an extra reduction of low-frequency drive to the tweeter. This "extra reduction" is a natural result of the constant voltage transfer property of the network. Four-way passive crossover networks are easily developed by extension of the above technique.

Figure 13 illustrates one of the many possible ways of developing a four-way active crossover network by cas-



$L_1 = T_1 R,\ C_1 = T_1/R,\ L_2 = T_2 R,\ C_2 = T_2/R;\ T_1 = \frac{1}{\omega_1} = \frac{1}{2\pi f_1},\ T_2 = \frac{1}{\omega_2} = \frac{1}{2\pi f_2}$

Fig. 12. Three-way series passive network with constant voltage transfer: **a** network circuit; **b** asymptotes of network voltage responses.

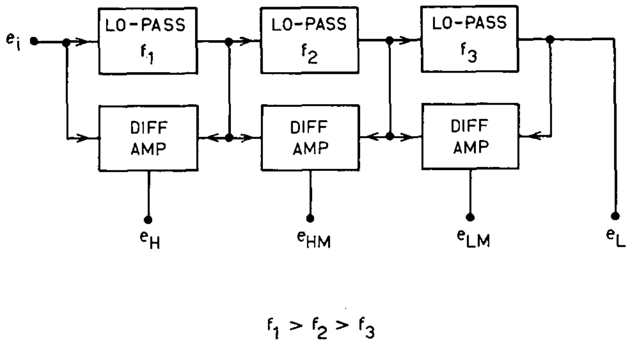


Fig. 13. Block diagram of four-way active crossover network with constant voltage transfer.

cading. This particular approach uses only three low-pass filters. Constant voltage transfer is assured by the difference amplifier recovery technique; hence the filters may be of any selected design so long as the derived high-pass responses are suitable for the drivers used.

TESTING CROSSOVER NETWORKS

Any completed crossover network design may be tested for constant voltage transfer by fairly simple means. Such tests may serve either to evaluate the performance of an existing network or to aid in the adjustment of one newly designed.

Active networks and passive parallel networks normally possess a terminal common to all outputs. It is then a simple matter to connect the various outputs to a summing network or summing amplifier. A sensitive test is to apply a square-wave input and to observe the total network output with an oscilloscope. The frequency of the square wave is adjusted to the vicinity of each crossover in turn. This test quickly reveals any departure from constant voltage transfer.

Constant voltage transfer can also be checked with sine waves. An oscilloscope having horizontal input and similar vertical and horizontal amplifiers can be used to display output versus input and thus provide simultaneous amplitude and phase indication.

The load presented to the amplifier by passive networks can also be checked simply. The method is to drive the network, with its driver loads, from a high-resistance source and to observe the voltage at the network input terminals [13, p. 26]. The high-resistance source may be either a generator with high output impedance or a normal loudspeaker amplifier having a resistor added in series with its output. Sine-wave drive can be used to obtain an impedance versus frequency plot, while square-wave drive with oscilloscope output indication will very sensitively reveal any impedance irregularities.

PHYSICAL INSTALLATION OF DRIVERS

As stated earlier, it is highly desirable that the drivers be mounted closely together so that the path lengths from each driver to listeners or to reflecting surfaces are equal over the greatest possible area. The ideal condition is approached only in a few coaxial designs which provide nearly coplanar location of the voice coils. This solution is not available to three- and four-way systems using separate drivers; for these systems, some compromise mounting method must be used.

In direct-radiator systems, it is almost invariably necessary to mount all drivers on the same baffle, which results in the radiating surfaces being more or less coplanar. The driver spacings then determine the path length differences in various directions. Because tolerable path length differences are related to the signal wavelength, the driver spacing is more important for the higher crossover frequencies.

If the drivers are mounted in a vertical line with the higher frequency units in the upper positions, the sound addition will be reasonably uniform in the horizontal plane at the level of the upper drivers. This is the area that is normally occupied by listeners.

CONCLUSION

The design of crossover networks is inextricably linked with the driver mounting problem.

For ideal mounting conditions, constant-voltage crossover networks provide an exact solution. The most interesting feature of these networks is the consistently wide overlap region. Response in the overlap region must be carefully considered when selecting and mounting drivers for a multiple-driver loudspeaker system.

For systems having unavoidably large driver spacings, there is no perfect crossover design. Intuition suggests, however, particularly when room reverberation is considered, that in this case constant power transfer (constant-resistance) networks would provide the best results on average.

The most desirable crossover network for general use would seem to be the simple first-order network. This network provides both constant voltage transfer and constant power transfer, the least phase difference of any network design, as well as economy and simplicity of construction.

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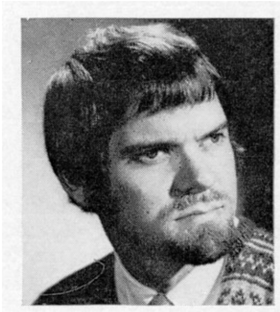

Richard H. Small was born in San Diego, California in 1935. He received a BS from California Institute of Technology in 1956, and an MSEE from Massachusetts Institute of Technology in 1958. Following this, for six years (1958 to 1964) he was engaged in electronic circuit design for high-resolution mass spectrometers and other analytical instruments at the Research Center of Consolidated Electrodynamics Corporation, a subsidiary of Bell & Howell Company.

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