1. Two Stage RIAA Phono Preamplifier (Continued)

TABLE 2. Equivalent input noise and signal-to-noise ratio for RIAA preamplifier circuit of *Figure 3*. Noise levels are referred to gain at 1 kHz.

NOISE WEIGHTING	CCIR/ARM	"A"	FLAT
Noise voltage	0.26 μV	0.23 μV	0.37 μV
S/N referred to			
5 mV input at 1 kHz	86 dB	87 dB	82 dB

2. Active Crossover Network for Loudspeakers

A typical multi-driver loudspeaker system will contain two or more transducers that are intended to handle different parts of the audio frequency spectrum. Passive filters are usually used to split the output of a power amplifier into signals that are within the usable frequency range of the individual drivers. Since passive crossover networks must drive loudspeaker elements whose impedances are quite low, the capacitors and inductors in the crossovers must be large in value, meaning that they will very likely be expensive and physically large. If the capacitors are electrolytic types or if the inductors do not have air cores, they can also be significant sources of distortion. Futhermore, many desirable filter characteristics are either impossible to realize with passive circuitry, or require so much attenuation to achieve passively that system efficiency is severely reduced.

An alternative approach is to use low-level filters to divide the frequency spectrum, and to follow each of these with a separate power amplifier for each driver or group of drivers. A two-way (or "bi-amped") system of this type is shown in *Figure 6*. This basic concept can be expanded to any number of frequency bands. For accurate sound reproduction, the sum of the filter outputs should be equal to the crossover input (if the transducers are "ideal"). While this seems to be an obvious requirement, it is very difficult to find a commercial active dividing network that meets it. Consider an active crossover consisting of a pair of 2nd-order Butterworth filters, (one is a low-pass; the other is a high-pass). The transfer functions of the filters are of the form:

$$\frac{V_L(s)}{V_{IN}(s)} = \frac{1}{s^2 + \sqrt{2s} + 1}$$

$$\frac{V_H(s)}{V_{IN}(s)} = \frac{s^2}{s^2 + \sqrt{2s} + 1}$$

and their sum is:

$$\frac{V_L(s)}{V_{IN}(s)} + \frac{V_H(s)}{V_{IN}(s)} = \frac{1 + s^2}{s^2 + \sqrt{2s} + 1}$$

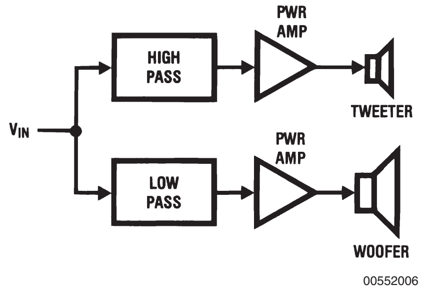


FIGURE 6. Block diagram of a two-way loudspeaker system using a low level crossover network ahead of the power amplifiers.

The output will therefore never exactly equal the input signal (except in the trivial case of a DC input). *Figure 7* shows the response of this crossover to a square wave input, and the amplitude and phase response of the crossover to sinusoidal steady state inputs can be seen in *Figure 8*. Higher-order filters will yield similarly dissatisfying results when this approach is used.

A significant improvement can be made by the use of a constant voltage crossover like the one shown in *Figure 9*. The term "constant voltage" means that the outputs of the high-pass and low-pass sections add up to produce an exact replica of the input signal. The rolloff rate is 12 dB/octave. The input impedance is equal to R/2, or 12 kΩ in the circuit of *Figure 9*. The LM833 is especially well-suited for active filter applications because of its high gain-bandwidth product. The transfer functions of this crossover network are of the form

$$\frac{V_L(s)}{V_{IN}(s)} = \frac{a_1 s + 1}{a_3 s^3 + a_2 s^2 + a_1 s + 1}$$

and

$$\frac{V_H(s)}{V_{IN}(s)} = \frac{a_3 s^3 + a_2 s^2}{a_3 s^3 + a_2 s^2 + a_1 s + 1}$$

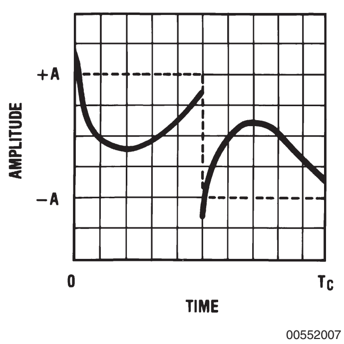
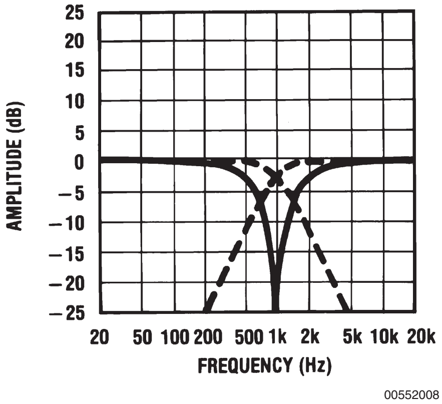
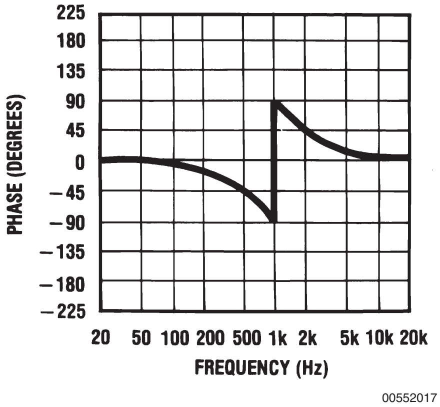


FIGURE 7. Response of second-order Butterworth crossover network (high-pass and low-pass outputs summed) to a square wave input (dashed line) at the crossover frequency. Period is $T_C = 1/f_C$.

2. Active Crossover Network for Loudspeakers (Continued)



(a)



(b)

FIGURE 8. Magnitude (a) and phase (b) response of a second-order, 1 kHz Butterworth crossover network with the high-pass and low-pass outputs summed. The individual high-pass and low-pass outputs are superimposed (dashed lines).

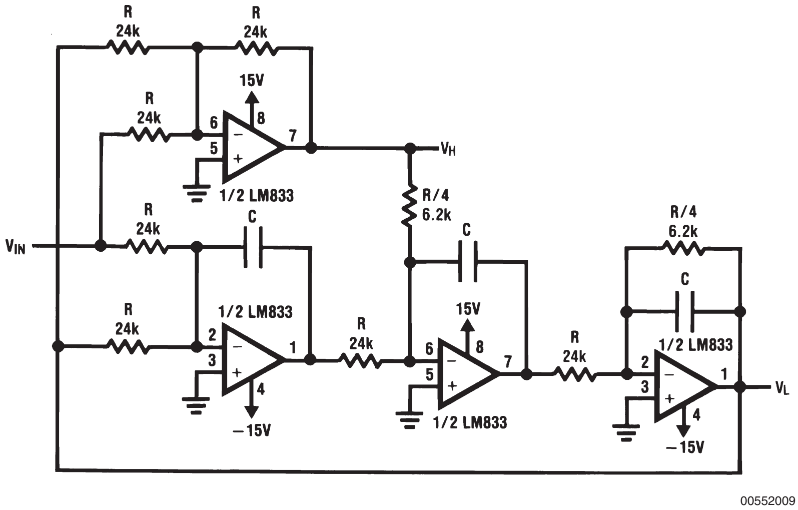


FIGURE 9. Constant-voltage crossover network with 12 dB/octave slopes. The crossover frequency is equal to $\frac{1}{2\pi RC}$.

The low-pass and high-pass constant voltage crossover outputs are plotted in *Figure 10*. The square-wave response (not shown) of the summed outputs is simply an inverted square-wave, and the phase shift (also not shown) is essentially 0˚ to beyond 20 kHz.

2. Active Crossover Network for Loudspeakers (Continued)

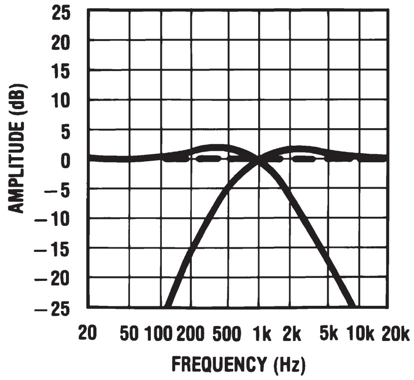


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FIGURE 10. Low-pass and high-pass responses of constant-voltage crossover network in *Figure 9* with crossover frequency of 1 kHz. For the circuit of *Figure 9*, a_1=4, a_2=4, and a_3=1. Note that the summed response (dashed lines) is perfectly flat.

It is important to remember that even a constant voltage crossover transfer function does not guarantee an ideal overall system response, because the transfer functions of the transducers will also affect the overall response. This can be minimized to some extent by using drivers that are "flat" at least two octaves beyond the crossover frequency.

3. Infrasonic and Ultrasonic Filters

In order to ensure "perfectly flat" amplitude response from 20 Hz to 20 kHz, many audio circuits are designed to have bandwidths extending far beyond the audio frequency range. There are many high-fidelity systems, however, that can be audibly improved by reducing the gain at frequencies above and below the limits of audibility.

The phonograph arm/cartridge/disc combination is the most significant source of unwanted low-frequency information. Disc warps on 33⅓ rpm records can cause large-amplitude signals at harmonics of 0.556 Hz. Other large low-frequency signals can be created at the resonance frequency determined by the compliance of the pickup cartridge and the effective mass of the cartridge/arm combination. The magnitude of undesireable low-frequency signals can be especially large if the cartridge/arm resonance occurs at a warp frequency. Infrasonic signals can sometimes overload amplifiers, and even in the absence of amplifier overload can cause large woofer excursions, resulting in audible distortion and even woofer damage.

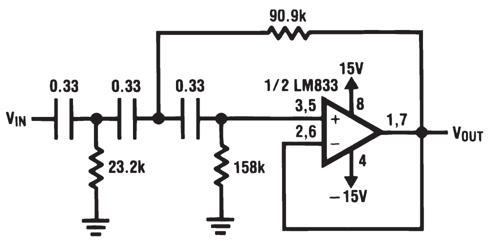

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FIGURE 11. Filter for rejection of undersireable infrasonic signals. Filter characteristic is third-order Butterworth with –3 dB frequency at 15 Hz. Resistor and capacitor values shown are for 1% tolerance components. 5% tolerance units can be substituted in less critical applications.

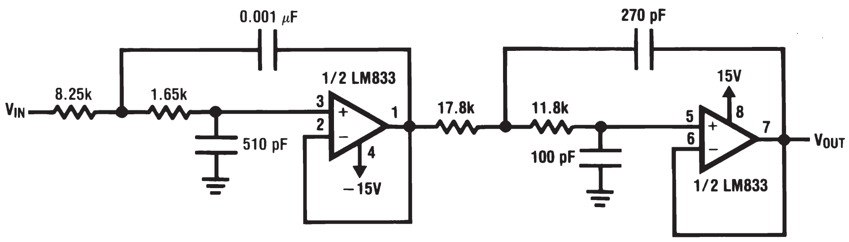

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FIGURE 12. Ultrasonic rejection filter with fourth-order Bessel low-pass characteristic. The filter gain is down 3 dB at about 40 kHz. As with the infrasonic filter, 1% tolerance components should be used for accurate response.