Zobel Network Design

(From the book *Introduction to Electroacoustics and Audio Amplifier Design, Second Edition, Revised Printing*, by W. Marshall Leach, Jr., published by Kendall/Hunt, © 2001.)

The voice-coil impedance of a loudspeaker driver is not purely resistive. This can have a major perturbation on the performance of crossover networks. At high frequencies, the voice-coil impedance becomes inductive. For odd-order crossover networks, this inductance can be utilized as part of the crossover network. Because the inductance is lossy, some experimentation may be necessary. For even-order networks, the inductance can be canceled by using a simple RC matching network as discussed below.

The impedance rise near the resonance frequency of closed-box midrange and tweeter drivers can have a major perturbation on the performance of the high-pass crossover networks. The effect is to cause a peak to appear in the pressure output of the driver at or near its resonance frequency. It can be very difficult to pull down this peak without causing a depression in the frequency response over a much wider band. To minimize the problem, the lower crossover frequency for the midrange and the tweeter should be greater than the fundamental resonance frequency of the drivers. The matching network described below can be used to cancel the impedance rise, but the element values may not be practical.

A matching network, sometimes called a Zobel network, between the crossover network and the voice-coil terminals of a driver can be used to cause the effective load on the crossover network to be resistive. Fig. 1 shows the network connected to the voice-coil equivalent circuit for a closed-box driver. The high-frequency part of the network consists of R_1, C_1, R_2, and C_2. This network can be designed to correct for the lossy voice-coil inductance in an equal ripple sense between two specified frequencies in the band where the impedance is dominated by $Z_e(\omega)$. At the fundamental resonance frequency of the driver, L_1 and C_3 resonate and put R_3 in parallel with the voice coil. This cancels the rise in impedance at the fundamental resonance frequency f_C.

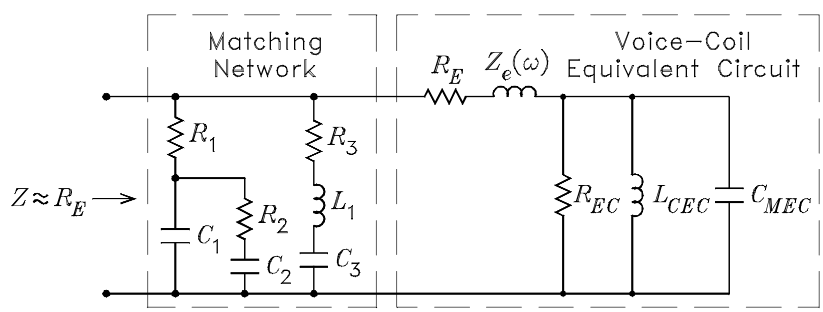

Figure 1: Voice-coil equivalent circuit with matching networks.

Let the lossy voice-coil inductance have the impedance $Z_e(\omega) = L_e(j\omega)^n$, where L_e and n are defined in the paper "Loudspeaker Voice-Coil Inductance Losses: Circuit Models, Parameter Estimation, and Effect on Frequency Response." Let the network consisting of R_1, C_1, R_2, and C_2 correct for the lossy voice-coil inductance over the frequency band from f_1 to f_2. The frequency f_1 might be chosen to be the frequency above the fundamental resonance frequency f_C where the voice-coil impedance exhibits a minimum before the high-frequency rise caused by the voice-coil inductance. The frequency f_2 might be chosen to be 20 kHz. In order for the input impedance to the network plus the driver to be approximately equal to R_E at all frequencies, the matching network elements are given by

$$R_1 = R_E \qquad C_1 = \frac{L_e}{(2\pi)^{(1-n)} R_E^2 \left[f_1^n f_2^{(2+n)}\right]^{\frac{(1-n)}{2(1+n)}}} \tag{1}$$

$$C_2 = \frac{L_e}{(2\pi)^{(1-n)} R_E^2 \left[f_1^{(2+n)} f_2^n\right]^{\frac{(1-n)}{2(1+n)}}} - C_1 \qquad R_2 = \frac{1}{2\pi f_1^{\frac{1}{(1+n)}} f_2^{\frac{n}{(1+n)}} C_2} \tag{2}$$

$$R_3 = R_E\left(1 + \frac{Q_{EC}}{Q_{MC}}\right) \qquad L_1 = \frac{R_E Q_{EC}}{2\pi f_C} \qquad C_3 = \frac{1}{2\pi f_C R_E Q_{EC}} \tag{3}$$

where R_E is the voice-coil resistance, f_C is the closed-box resonance frequency, Q_{EC} is the electrical quality factor, and Q_{MC} is the mechanical quality factor.

The above equations are derived under the assumption that C_1 and C_2 are open circuits in the low-frequency range where R_3, C_3, and L_1 are active and that L_1 is an open circuit in the high-frequency range where R_1, C_1, R_2, and C_2 are active. For a lossless inductor, n has the value $n = 1$. In this case, $C_1 = L_e/R_E^2$, and both R_2 and C_2 are open circuits.

Example 1 *A closed-box midrange driver has the parameters* $R_E = 7.5\ \Omega$, $L_e = 0.00689$, $n = 0.7$, $f_C = 250$ *Hz,* $Q_{EC} = 1.1$, *and* $Q_{MC} = 4$. *For the high-frequency network, assume* $f_1 = 733$ *Hz and* $f_2 = 20$ *kHz. Calculate the element values for the matching network which will make the driver impedance look like a* $7.5\ \Omega$ *resistor to the crossover network.*

Solution: From Eqs. (1) - (3), we have $R_1 = 7.5\ \Omega$, $C_1 = 4.44\ \mu$F, $R_2 = 15.8\ \Omega$, $C_2 = 3.52\ \mu$F, $R_3 = 9.56\ \Omega$, $L_1 = 5.25$ mH, and $C_3 = 77.2\ \mu$F. The figure below shows the calculated voice-coil impedance over the frequency range from 20 Hz to 20 kHz without the Zobel network (red curve) and with the Zobel network (blue curve). The frequency f_1 corresponds to the frequency at which the red curve exhibits a minimum in its midband region.

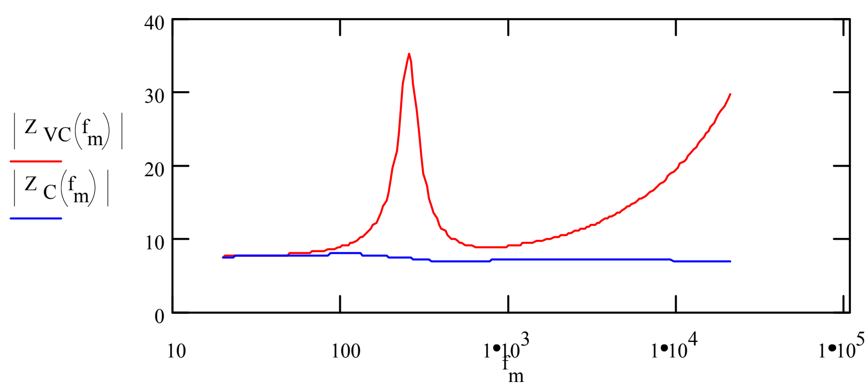

Figure 2: Calculated voice-coil impedance with and without the Zobel network.