Lab Notes

Improved Zobel Network

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Passive crossover filter networks for multi-way loudspeakers generally require a resistive termination for optimum performance. The driver itself generally presents a reactive load. Recall that the inductive rise with frequency above resonance of the loudspeaker electrical impedance is semi-inductive due to eddy current losses [1], see **Figure 1**.

The L2/R2 impedance model [2], [3], depicted in **Figure 2** represents the electrical impedance as seen by the amplifier output. The typical Zobel network [4], used to make the driver impedance appear closer to an ideal resistive load above resonance is a simple series resistor and capacitor shunted across the driver terminals (see **Figure 3**).

The component values are calculated as:

$$R_z \approx 1.25 R_E \quad [1]$$

$$C_z = \frac{L_E}{R^2{}_Z} \quad [2]$$

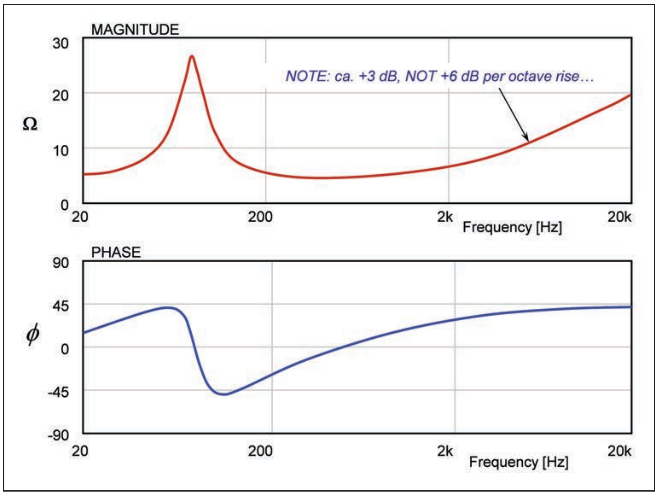

Figure 1: Typical loudspeaker electrical impedance with a semi-inductive rise above resonance

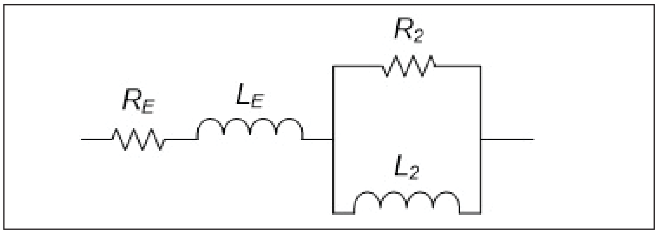

Figure 2: L2/R2 loudspeaker electrical impedance model

with:

$$P_R = \frac{V^2{}_{MAX}}{R_Z} \quad [3]$$

The resistor value is approximate and may need to be adjusted for more extreme voice coil impedances. The resistor should be power rated as shown to handle the current to the loudspeaker. The flatness of the compensated impedance magnitude above resonance is typically limited when using this simplified compensation network.

More complex and accurate compensation networks are possible [5]. An improved compensation network can be realized by using the analogous circuit "dual" of the L2/R2 model, assuming the values for the driver impedance model are known. Recall that a circuit "dual" replaces series impedances with shunt impedances and vice versa. Capacitors become inductors and inductors become capacitors. Resistors remain resistors. Applying these principles to the network of Figure 2 results in the network shown in **Figure 4**.

The component values for this improved compensation network are calculated as:

$$R_{Z1} = R_E \quad [4]$$

$$R_{Z2} = R_2 \quad [5]$$

$$C_{Z1} = \frac{L_E}{R^2{}_E} \quad [6]$$

And,

$$C_{Z2} = \frac{L_2}{R^2{}_2} \quad [7]$$

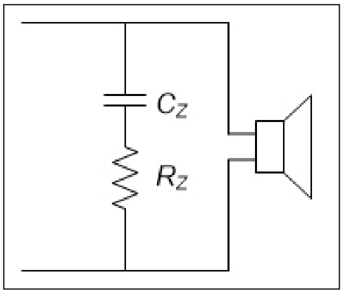

Figure 3: Typical Zobel impedance compensation network

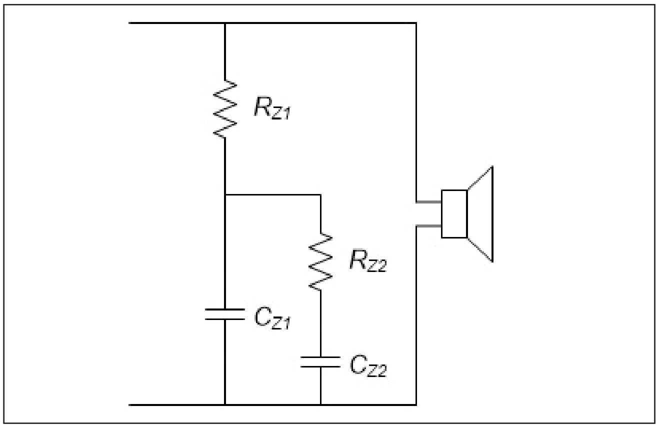

Figure 4: Improved Zobel compensation network realized as the circuit "dual" of the L2/R2 impedance model

This represents a dramatic improvement to the basic two-component Zobel network and compensates for the non-ideal semi-inductive behavior of the loudspeaker driver across the entire frequency band. The component values are easily found if the L2/R2 impedance model values are known. Again, the resistor values should be power rated to handle the current to the loudspeaker as per Equation 3. Additional circuitry is required to compensate for the motional impedance at resonance. The cost, however, is increased size, complexity, and component count. ***VC***

References

[1] J. Vanderkooy, "A Model of Loudspeaker Driver Impedance Incorporating Eddy Currents in the Pole Structure," *Journal of the Audio Engineering Society*, Volume 37, March 1989.

[2] E. E. Mott and R. C. Miner, "The Ring Armature Telephone Receiver," *Bell System Technical Journal*, Vol. 30, (1951) pp. 110-140.

[3] W. Klippel and U. Seidel, "Fast and Accurate Measurement of Linear Transducer Parameters," presented at the Audio Engineering Society, 110th Conventions, May 2001.

[4] O. J. Zobel, "Theory and Design of Uniform and Composite Electric Wave Filters," *Bell System Technical Journal*, Volume 2 (1923), pp. 1–46.

[5] W. M. Leach, "Impedance Compensation Networks for the Lossy Voice-Coil Inductance of Loudspeaker Drivers," *Journal of the Audio Engineering Society*, Volume 52, No. 4, April 2004.

About the Author

Christopher J. Struck founded CJS Labs in 2006. He holds an Electrical Engineering degree from the University of Wisconsin – Madison. He also completed the Stanford/AeA Executive Institute and the Leadership Development Program at the Center for Creative Leadership. Prior to founding CJS Labs, Struck was employed by Brüel & Kjær, Denmark where he designed and developed new measurement techniques and instrumentation, most notably the industry standard Type 4128 Head And Torso Simulator (a.k.a. HATS) and the Type 2012 Audio Analyzer. He was Principal Consultant at Charles M. Salter Associates and later, Manager of Electroacoustics at GN ReSound. He oversaw encoder/decoder licensing as Director of Engineering at Dolby Laboratories. As Vice President of Engineering at Tymphany Corp., his team developed the Linear Array Transducer as well as other innovative loudspeaker designs. Struck is the author of many technical papers, application notes and articles. He is a Fellow and former Governor of the Audio Engineering Society (AES) and a reviewer for the *Journal of the AES*. He is a Fellow and the Standards Director of the Acoustical Society of America, an ANSI/ASA Accredited Expert and the Chair of ANSI Standards Committee 3 on Bioacoustics. He is a United States expert for ISO Technical Committee 43 - Acoustics, IEC Technical Committee 100 - Audio, video and multimedia systems and equipment, and IEC Technical Committee 29 - Electroacoustics, for which he also serves as Head of the US Delegation. Struck is also a Senior Member of the Institute of Electrical and Electronic Engineers, a member of the Institute of Noise Control Engineering, and a member of the Society of Motion Picture and Television Engineers.