VOICE COIL

THE PERIODICAL FOR THE LOUDSPEAKER INDUSTRY

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What About Headphones?, Pt. 1

By Steve Mowry

Increasingly, companies are looking to Asian suppliers to take on development of transducers, including headphone transducers. Unfortunately, the Asian suppliers have focused on getting the manufacturing right, but typically lack technical capability and the willingness to invest in engineering tools and to train engineers to utilize these tools. There are few, if any, moving coil headphone transducer patents in effect at this time. This could also indicate that little or no R&D on headphone transducers is ongoing.

An Internet search for technical information on the topic of headphones shows there is not much available. Furthermore, there are no canned software headphone modeling tools such as LspCAD, FINEBox, and LEAP for loudspeaker simulation and design. This indicates a lack of demand for this type of engineering simulation tool. Surely, the software development capability exists.

WHO'S WORKING

When I try to identify "headphone" engineers, I am at a loss. I do know of one gentleman at BOSE Corp. Roman Sapiejewski has several US patents on headphone systems to his credit, and there is the author of the chapter of the text that I used for reference, C. A. Poldy, AKG Acoustics, but that's it. Larger and well-established companies such as Sennheiser, Beyerdynamic, Denon, and Koss have their Goodwill market resources, but what percentage of sales revenue is actually going to fund headphone transducer R&D? From my standpoint, this number seems to be small, at best.

I was shocked when I examined the transducers from a major headphone developer. They were clearly not proprietary, looking very similar to transducers pictured in *Loudspeaker and Headphone Handbook* 2nd Edition (1994) on page 540, figure 12.82. A $349 headphone with $0.75 transducers with pleated "Glad Wrap®" diaphragms from a company with one of, if not the, largest R&D budgets and most capable R&D staffs in the industry only goes to further support my concerns. I also examined Beyerdynamic transducers and found them to be proprietary, but again nothing really special. They had a glass-fiber-reinforced polymer diaphragm with no pleats.

When I began my dynamic headphone transducer R&D, I first observed that with a typical price of $0.40 to $0.80 per unit from the manufacturer within China there is typically not enough margin to initiate headphone transducer R&D and/or new product development. However, the manufacturability and quality control issues that accompany headphone transducers are some of the most challenging within the audio industry. Thus, the typical headphone transducers are "me-too" commodity products. Actually, the state of technology within this segment of the industry reminds me of the loudspeaker—what headphone people refer to as the "big" speakers—industry about five years ago.

I remember a question a friend asked at the 2002 Hong Kong Electronics Fair. "Why do all the loudspeaker transducers look the same?" My answer was that the manufacturers tend to copy each other. Is the headphone industry lagging behind the loudspeaker in innovation and R&D at this time? I believe this to be true in most instances. It looks as though there is work to do.

Before I start, I need to state that this topic is just about as challenging as any I have encountered in my engineering career to date. The objective of the following discussion is to introduce information on the basic characteristics of several types of headphone ear-cups and enclosures, while also discussing the application of each type. Circumaural headphones are defined as having ear-cups that form a seal against the sides of the head because the headphone cup surrounds the outer ear pinnae. Supra-aural headphones are similar but utilize smaller ear-cups with soft compliant cushions that attempt to seal to the outer ear rather than the head. Sealed headphones are preferred in noisy environments such as an airplane cockpit.

PRESSURE COUPLING

At low and lower midrange frequencies, f, where the wavelength, λ, of the sound pressure is large compared to the dimensions of the ear-cup, the amplitude and phase of the sound pressure are distributed uniformly within the volume of the circumaural ear-cup coupler,

where $\lambda = \frac{344}{f}$ (m) (1)

This sound pressure is in phase with the volume displacement of the transducer diaphragm, and the amplitudes are proportional and follow the adiabatic compression law.

$pV^{1.4}$ = constant (2)

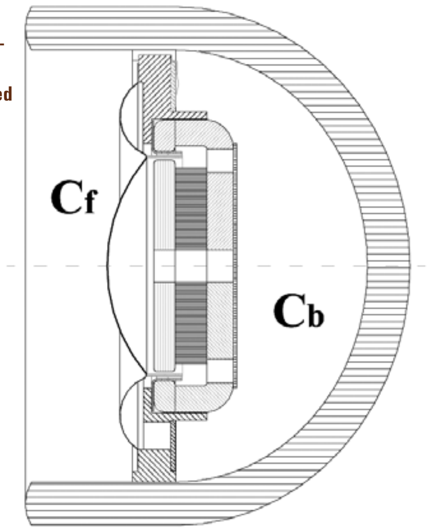
where p is the total pressure, including atmospheric pressure, V is the volume of a fixed quantity of air, and $\frac{dp}{dV}$ is the rate of change of pressure with respect to change in volume. Then the sound pressure per unit volume is given by equation 3 and is constant for a given volume. If the pressure changes, then so must the volume.

$$\frac{dp}{dV} = \frac{1.4 \times \text{constant}}{V^{2.4}} \qquad (3)$$

Note that the sound pressure within the volume is independent of frequency in this case. This is very different from loudspeakers, in which the sound pressure is proportional to the volume velocity. This behavior in loudspeakers requires larger displacement as frequency is decreased. Whereas with circumaural headphones, the sound pressure within the coupler is proportional to the volume displacement that is independent of frequency!

I will present illustrations of several headphone ear-cup topologies along with simplified electromechanical circuit analogs and normalized characteristic frequency response plots. Within this exercise is the question—can one transducer design be used effectively for all illustrated topologies, couplers, and enclosures? Look at these topologies.

FIGURE 1: Sectional illustration of a supra/circumaural-sealed back headphone.



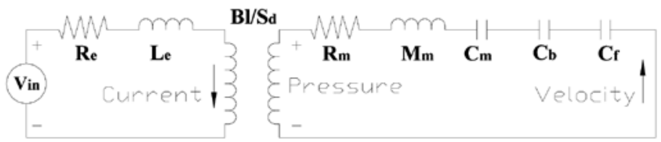


FIGURE 2: Electromechanical model of a supra/circumaural-sealed back headphone.

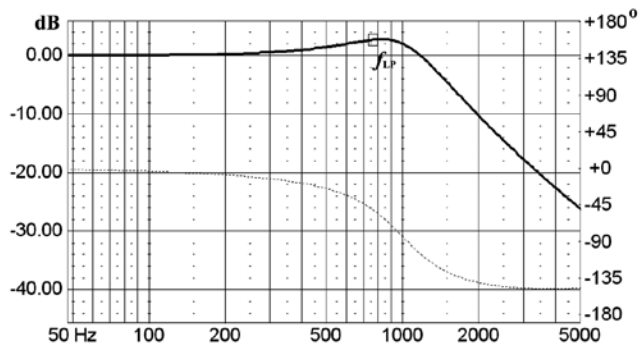
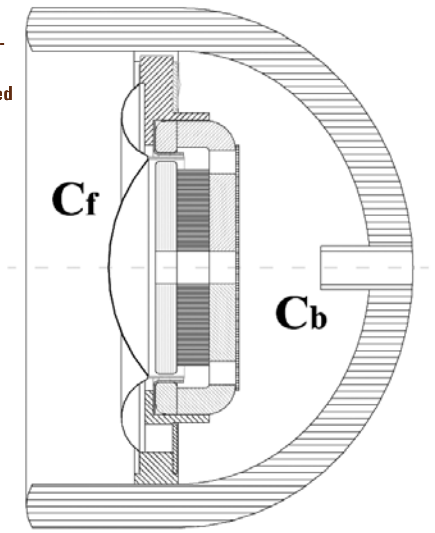


FIGURE 3: Normalized characteristic frequency response of a supra/circumaural-sealed back headphone.

FIGURE 4: Sectional illustration of a supra/circumaural-ported rear to outside headphone.



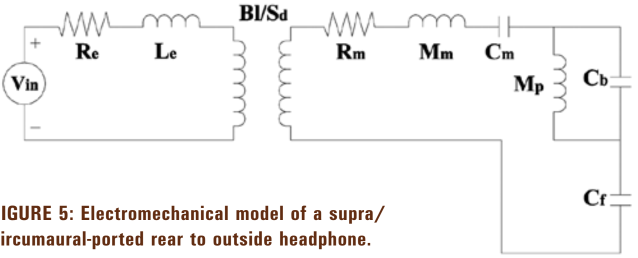


FIGURE 5: Electromechanical model of a supra/circumaural-ported rear to outside headphone.

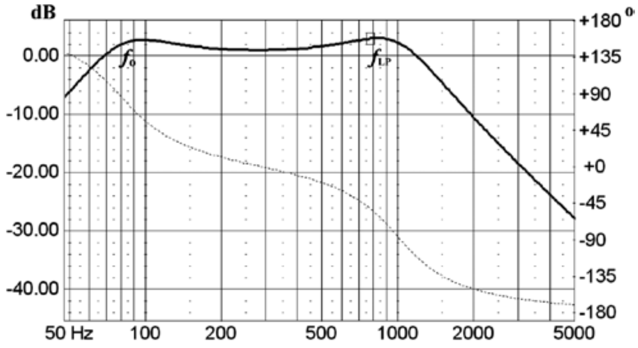


FIGURE 6: Normalized characteristic frequency response of a supra/circumaural-ported rear to outside headphone.

MODELS AND SIMULATIONS

The topologies illustrated in ***Figs. 1*** and ***4*** are suitable for Active Noise Cancellation, ANC headphone, and communications applications. The model in ***Fig. 2*** implements a second-order low-pass characteristic response with the frequency of interest defined by equation 4. The normalized characteristic response is illustrated in ***Fig. 3***.

$$f_{LP} = \frac{1}{2\pi\sqrt{Mm\left(\frac{1}{\frac{1}{Cm}+\frac{1}{Cb}+\frac{1}{Cf}}\right)}}\,Hz \qquad (4)$$

Every example of the moving coil transducer is also subject to the first-order low-pass effect of self-inductance. The additional frequency of interest is shown in equation 5.

$$f_L = \frac{Re}{2\pi Le}(Hz) \qquad (5)$$

Typically, this frequency is quite high, although inductance should be minimized within the transducer design implementation for reasonable high frequency sensitivity.

The model in ***Fig. 5*** implements fourth-order band-pass response characteristics with two frequencies of interest for this case. One frequency is defined by equation 4, the other is shown in equation 6. The normalized characteristic response is illustrated in ***Fig. 6***.

$$f_{HP} = \frac{1}{2\pi\sqrt{MpCb}}(Hz) \qquad (6)$$

The model in ***Fig. 8*** also implements fourth-order band-pass response characteristics; however, the upper cutoff is at a much higher frequency. The two frequencies of interest are shown in equations 7 and 8. The normalized characteristic response is illustrated in ***Fig. 9***.

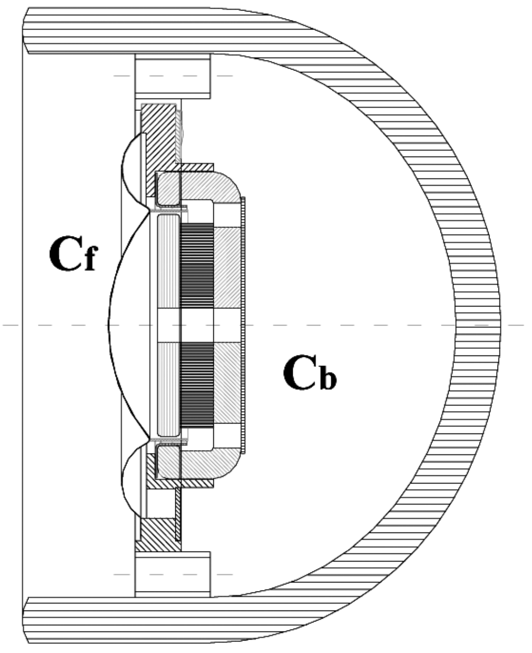


FIGURE 7: Sectional illustration of a supra/circumaural-ported rear to front headphone.

$$f_o = \frac{1}{2\pi\sqrt{MmCm}}(Hz)$$

$$f_{LP} = \frac{1}{2\pi\sqrt{Mp\left(\frac{1}{\frac{1}{Cb}+\frac{1}{Cr}}\right)}}\,Hz \qquad (7), (8)$$

Because the mass load of the port can be made much less than the transducer moving diaphragm assembly, a low-pass filter is implemented at the tuning frequency. In effect this significantly lifts the high frequency response (***Fig. 9***). The topology class in ***Fig. 7*** can also be implemented with passive diaphragms, passive radiators. They add losses and thus damping to the system. AKG utilizes this topology in several of their headphones. ***VC***

—We'll continue our look at headphone transducers in next month's issue of *Voice Coil*.

Steve Mowry, president of SM Audio Engineering, has a BS, Business Administration, from Bryant College, and a BS and MS, Electrical Engineering, from URI with highest distinction. Steve has worked in R&D at BOSE, TC Sounds, EASTTECH, and P.Audio. Steve is currently an independent consultant/lecturer in project management/transducer and system design. His website is www.s-m-audio.com.

REFERENCE

John Borwick, *Loudspeaker and Headphone Handbook*, Focal Press, 2nd Ed. 1994, pages 466-543.

IEC 60268-7: 1996 Headphones and Earphones International Standard.

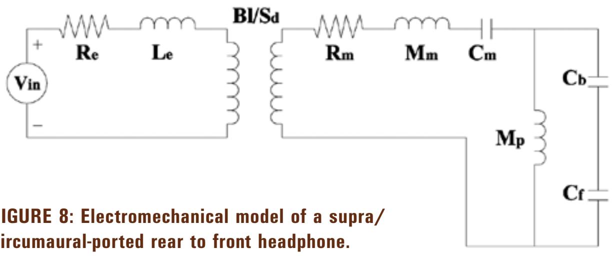


FIGURE 8: Electromechanical model of a supra/circumaural-ported rear to front headphone.

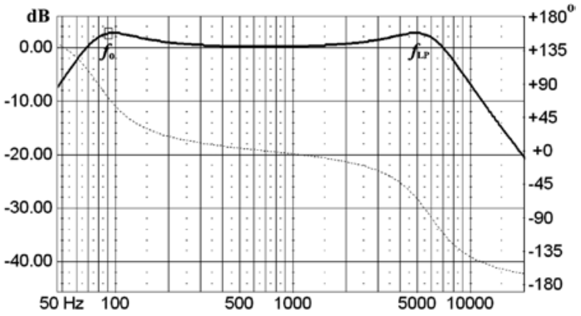


FIGURE 9: Normalized characteristic frequency response of a supra/circumaural-ported rear to front headphone.