An Earplug With Uniform 15-dB Attenuation

By MEAD KILLION, ED DEVILBISS, & JONATHAN STEWART

Currently available custom-earmold hearing protectors have one defect in common: They muffle the sound. Technically speaking, they give more attenuation at high frequencies than at low frequencies. Figure 1 shows representative performance of a well-sealed and of a poorly sealed custom-earmold type of hearing protector with solid construction, based on data from E. H. Berger.[1]

Another type of custom-earmold hearing protector includes a small vent channel, often with a stepped diameter. If the vent channel is very small (0.5-mm diameter, for example), such devices give a real-ear attenuation that is generally similar to the curve labeled "Leaky Earmold H.P." in Figure 1. If the vent channel is a little larger, an undesirable resonance peak is created, and the earplug actually provides *amplification* instead of attenuation at the resonance frequency. A 1-mm diameter vent, for example, gives a peak of about 5 dB near 250 Hz.

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Regardless of their exact construction, a reasonable generalization is that existing custom-earmold hearing protectors produce 10 dB to 20 dB of excessive high-frequency attenuation. A hearing protector with more uniform response—a high-fidelity earplug, if you will—seems needed.

A NEW EARPLUG

The curve labeled "15 dB Earplug" in Figure 1 shows the expected real-ear attenuation of the ER-15™ earplug, based on KEMAR measurements. The trick in producing this high-fidelity response is to reproduce the shape of the natural frequency response of the open ear, but at a reduced level. Figure 2 shows the response of the normal open ear, plotted as the eardrum SPL developed in a diffuse sound field, and the response of the ear with a properly constructed ER-15 earplug in place. The *difference* between these two curves represents the real-ear attenuation of the ER-15 earplug, which is a nearly uniform 15 dB as shown in the solid curve of Figure 1, based on KEMAR measurements.

The ER-15 earplug is a novel development by Elmer Carlson, who added acoustic elements into the sound channel in order to accomplish this result. Figure 3 shows a cross-section drawing of the ER-15 earplug, along with the electrical analog equivalent circuit (included for those who enjoy reading schematics). A flexible plastic diaphragm acts as a compliance, and is labeled C1 in the equivalent circuit. The sound channel (L1 in Figure 3) acts as an acoustic mass, so that a Helmholtz resonator is formed between the inertance of the sound channel and the combined compliance of the flexible diaphragm and the ear-canal volume. With the proper combination of diameter and length for the sound channel, the Helmholtz resonator will resonate at 2.7 kHz, providing the desired boost at that frequency as illustrated in the lower response curve of Figure 2.

CONSTRUCTION VARIATIONS

Figure 4 shows the medium depth ER-15 earmold with the ER-15 attenuator button snapped in place. The "canal-aid" style construction should make for a nearly invisible earplug in most ears. The right and left earmolds must be color coded.

A version designed to produce less occlusion effect (i.e., fewer "my own voice sounds hollow" complaints), shown in Figure 5, is suitable for persons with larger-diameter ear canals. The reduction of occlusion effect is a result of the deep seal of the plug.[2,3] The standard 3.5-mm diameter sound channel can be drilled with the same .142" drill used for #13 super-thick tubing. Some ear canals will be so flattened that such a hole, extending for 10 mm down the canal, will not be practical. A roughly oval hole may be used in these cases to obtain the desired acoustical results, as suggested years ago by H.S. Knowles. Figure 6 shows elon-

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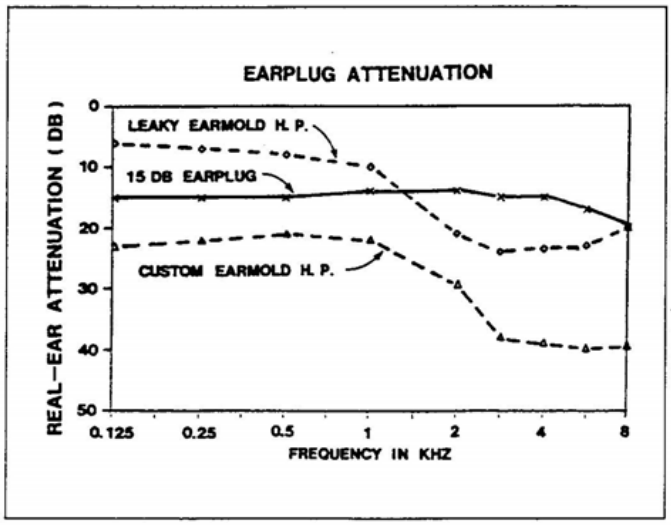

Figure 1. Performances of a well-sealed and of a poorly sealed custom-earmold-type hearing protector with solid construction.[1]

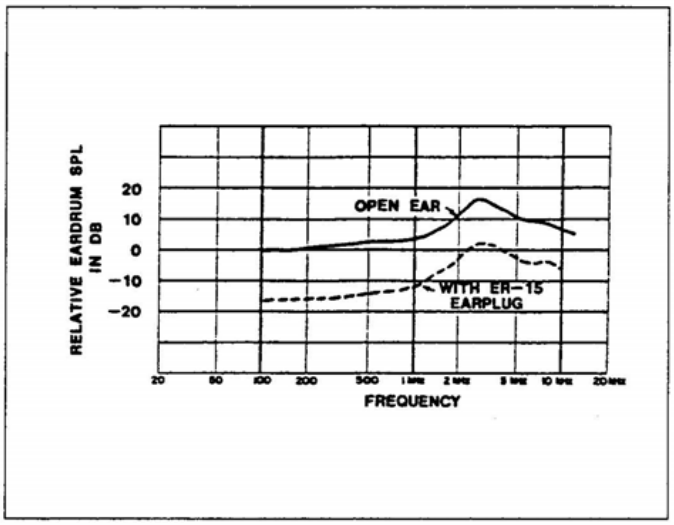

Figure 2. Expected eardrum SPL in diffuse (random incidence) sound field with ear open or occluded.

gated holes, equivalent to 3.5-mm and 4-mm diameter sound channels, with flat-side dimensions of 3 mm. In order to check the accuracy of the frequency response and/or the amount of occlusion effect on an individual ear, a 1-mm o.d. probe-tube hole can be ordered with the earmold. Figure 7 shows the preferred and alternate locations for the probe-tube channel, which should be *sealed completely* after testing is completed.

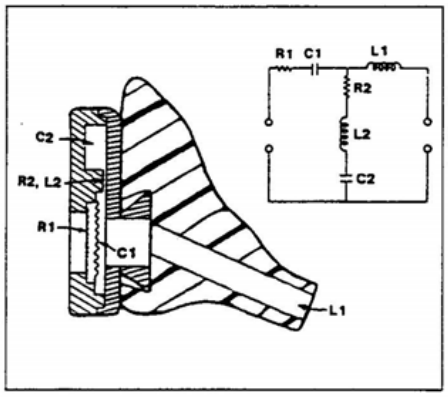

Figure 3. Construction of 15-dB earplug.

Despite the best of intentions, earmolds occasionally will be badly made. The effect of two likely errors, lack of seal and undersized sound channel, is illustrated below with specific examples. Figure 8 shows the effect of a leak or an undersized sound channel (2-mm diameter instead of 3.5-mm diameter) on the *eardrum SPL* generated in a diffuse sound field. Figure 9 shows the resulting real-ear attenuation expected for these errors.

EARMOLD MATERIAL

From an acoustic standpoint, any earmold material can be used, but we recommend soft vinyl or silicone for two reasons: (1) It eases the task of obtaining a good seal; (2) It permits a deep seal with good comfort. The disadvantage of soft (30- to 40-durometer) materials is their reduced durability compared to acrylic.

APPLICATIONS

Two potential applications for the ER-15 earmold stand out: First, for the musician who wants some protection but needs good fidelity (proper spectral balance) in order to perform properly; and second, for the factory worker who has a high-frequency hearing loss and refuses to wear conventional hearing protection because he needs to hear more clearly. Figure 10 shows the expected sound-field audiograms for a person with normal hearing, and for a typical 50-year-old man using either conventional custom-earmold hearing protectors or ER-15 custom-earmold hearing protectors. The audibility of important high-frequency speech sounds is clearly im-

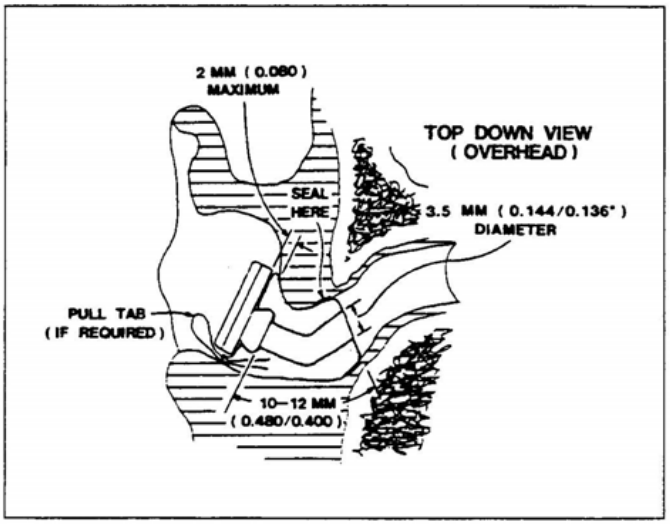

Figure 4. Medium (First Bend) Depth. (Standard ER-15 earmold for ER-15 attenuator.)

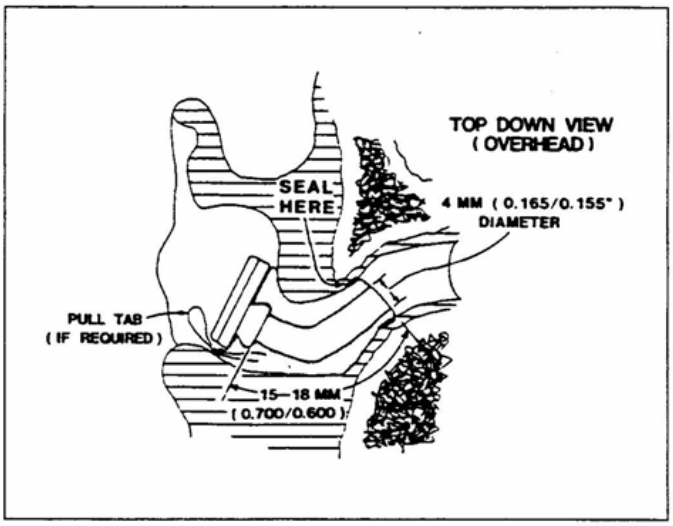

Figure 5. Long (Second Bend) Depth. (Low-occlusion-effect version of ER-15 earmold for larger ear canals.)

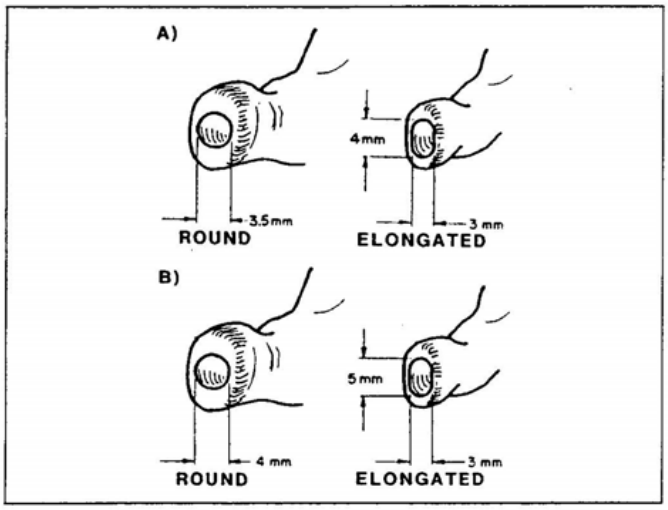

Figure 6. Sound channels for round and flattened ear canals: (A) 3.5-mm equivalent diameter; (B) 4-mm equivalent diameter.

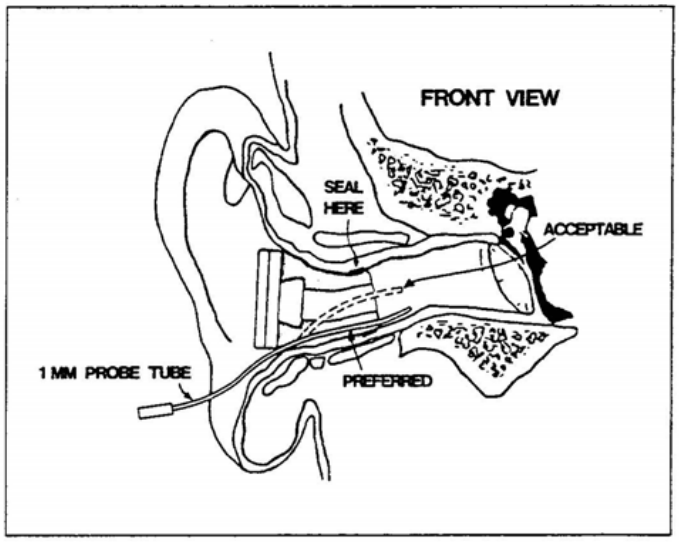

Figure 7. Preferred and alternate probe-tube channel locations.

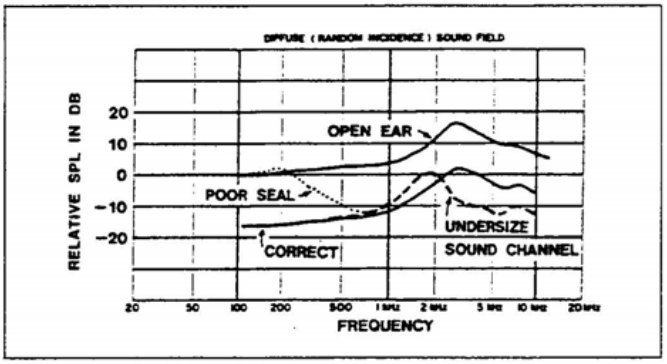

Figure 8. Expected eardrum SPL with ear open and with three constructions of ER-15 earmold.

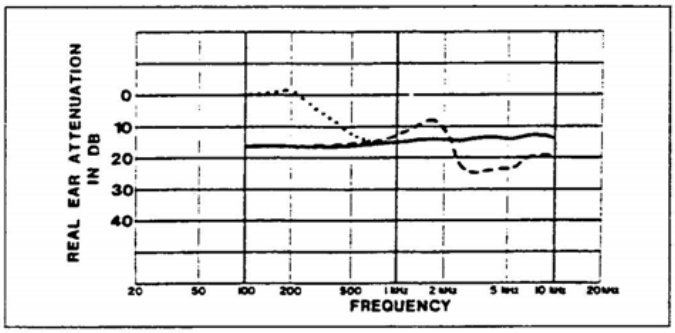

Figure 9. Calculated ER-15 performance vs. earmold construction: (—) correct (3.5 mm) sound channel, well-sealed; (. . .) poor seal, equivalent to 0.028" vent hole; (- - -) undersized sound channel (2-mm dia.).

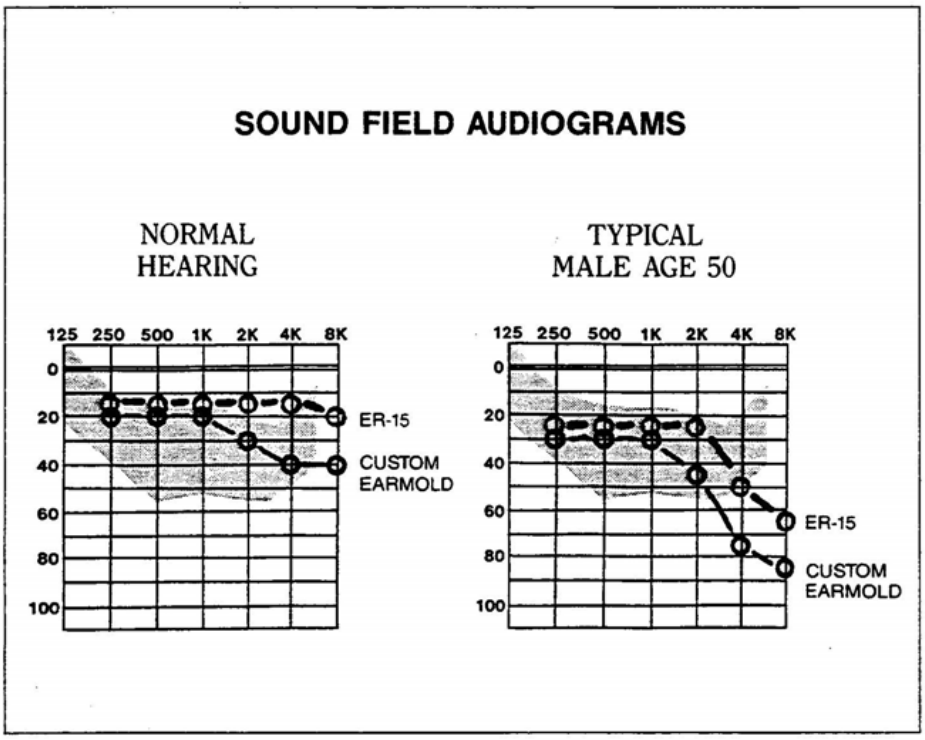

Figure 10. Expected sound-field audiograms, using conventional or ER-15 hearing protectors, for a normal-hearing person (left) and for a typical 50-year-old man (right).

proved with a flat attenuator. Note: this is a low-attenuation earplug with an estimated noise reduction rating (NRR) of 5 dB to 8 dB,* and is not meant for prolonged use in high levels of industrial noise or with gunfire.

Another potential application is for the person whose hearing probably is not really at risk, but who would prefer to hear without discomfort at amplified-music concerts. The authors also find that these attenuators make travel by both automobile and airplane more enjoyable. Production quantities will be available in the third quarter of 1988.

* The NRR estimates the A-weighted noise exposure from a C-weighted sound level meter reading under worst-case (- 2 sigma) conditions. The calculation of NRR is laborious and not simply related to the actual attenuation of an earplug at any frequency.

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3. Berger EH, Kerivan JE: Influence of physiological noise and the occlusion effect on the measurement of real ear attenuation at threshold. *J Acous Soc Am* 1983; 74:81-94.