Can I Hear You Now? Adjusting the Receive Audio Chain—Part 2

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Headphone Isolation

Well-designed headphones provide substantial passive isolation between ambient noises in the radio room and the ears. Unfortunately, many headphone manufacturers provide little or no measurements of isolation. Nonetheless, some data exists which can point the way towards better isolation.

Figure 5 shows several popular headsets with significantly different isolation characteristics. Figure 6 shows isolation as a function of frequency for typical earmuffs and earplugs discussed in the next few sections. Note that operators wearing eyeglasses experience a 3 to 8 dB reduction in isolation caused by sound leaking around the eyeglass stems. Use wire stems to minimize sound leaks. Wire stem glasses also transmit much less force from the earmuff to the tip of the stem behind the ear, reducing spot irritation during long-term wear.

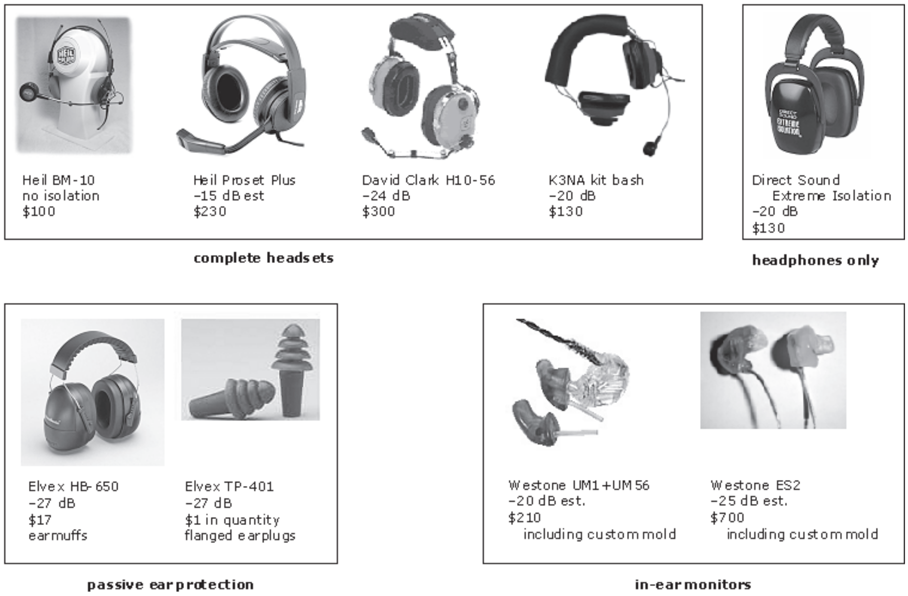

Figure 5—Examples of headsets and components that one may combine for high isolation from ambient noise. Figures in dB are mean isolation between 200–3000Hz.

The Heil BM-10 typifies headsets that simply rest on the outside of the pinnae, the external flaps of cartilage and skin we commonly call the ear. Such a design offers no isolation. Over the duration of a contest, any headset that rests on the pinnae gradually irritates these sensitive structures, to the annoyance of the operator.

Similarly, the Heil Pro Set (not shown) features small earmuffs that also rest on the pinnae. The earmuff provides limited isolation from ambient sounds, perhaps –5 to –10 dB.

Heil's Pro Set Plus is a partial step in the right direction. With the cloth cover removed, the larger earmuffs do not rest on, but fully surround, the pinnae. The earmuffs can be too shallow for many people whose pinnae stick out a bit from the head, causing the interior of the earmuff to touch or press against the pinnae. Again, no published specifications exist. Comparing this headset against other better-specified models, I estimate the isolation somewhere in the –10 to –15 dB range.

Higher isolation headsets exist in other industries and may be adapted to amateur radio use. The David Clark H10-56 headset, designed for communications in helicopters, offers a measured average –24 dB of isolation over the 200–3000 Hz audio range we use in contesting, and a peak isolation at 4 kHz of –39 dB.[6] Each ear sits inside a large hollow shell. The shell contains sound-absorbing foam and small speaker(s); the shell and foam form a passive noise reduction system. The shell depth is sufficient to keep the interior foam and all other materials off the pinnae, eliminating that source of irritation. To use aviation headsets in amateur radio service, you must replace the aeronautical standard cable plugs with suitable connectors.

A less expensive approach is Direct Sound's Extreme Isolation headphones for drummers, but one must add a boom mic.

By the way, some operators find the ear gets hot or sweaty in the dead air trapped inside the earmuff. George Baltz, N3GB, produced an excellent solution. A few seconds with an alcohol swab or baby-wipe gives the pinnae a refreshing and cleansing break.

Kit Bashing a Better Headset

Frustrated by existing headsets that irritated my pinnae and lacked adequate isolation, I began a process of kit-bashing: modifying some headsets in combination with parts from others.

Figure 5 (top, center right) shows an early prototype. An inexpensive set of earmuff protectors, purchased from the local hardware store, form the basis of this project.

I disassembled a Heil BM-10, yielding two small speakers and the boom mic assembly. After pulling out the foam from the ear protector shells, I drilled a small hole for the speaker cable. On the left shell, a second hole and bolt form the boom mic mount. The speakers sit behind the foam. A dab of silicone sealed the holes. The earmuff headband didn't have any padding. An easy solution employs dense foam pipe insulation, available in 6 foot lengths in the plumbing section of the hardware store for a few dollars. A short piece wraps around the headband and seals to itself, forming a comfortable pad for the top of the skull.

This project created a communications headset with the high isolation of industrial earmuffs for a new cost of about $130. The homebrew headset represented a significant improvement. In a library-like quiet radio room, the headset reduced ambient room noise to about 10 dBA. If I set the receiver gain so that the band noise stood a few dB above the attenuated room noise, I now had 70 dB of dynamic range before triggering the attenuation reflex. I could copy weak signals in the pileups significantly better because I was making better use of the receiver's dynamic range.

SSB contests at multi-ops, however,

remained a problem. Even with –35 dB of isolation, an adjacent operator's normal speaking voice runs around 25 dBA. That left 55 dB of dynamic range to work with, meaning signals above S9+10 dB on a quiet band still triggered the attenuation reflex.

Combining Muffs and Plugs

Using earplugs together with earmuffs could achieve better isolation from ambient noise, as shown in Figure 6. Several types of earplugs exist with different isolation characteristics:

Polyurethane (PU) earplugs: These compressible foam cylinders come in a variety of densities with differing isolation levels. The user rolls up the cylinder between his fingers and inserts it deep into the ear canal. The cylinder gradually expands to seal the canal, attenuating outside sounds. A denser foam plug inserted deeper into the canal provides greater attenuation. The inexpensive disposable PU earplug available in drug stores, when properly inserted, could average more than –20 dB isolation.

Thermoplastic elastomer (TPE) reusable plugs: At $1 a pair, the Elves TP-401 model typifies this style. The best plugs provide about –27 dB isolation, and some models have a flatter response curve; i.e., the isolation varies less with frequency. The flat curve versions sometimes are called "musicians' earplugs".

By wearing earplugs together with my high-isolation earmuff-style headset, I could achieve greater isolation from the ambient noise.

One might think that –20 dB earplugs together with –35 dB earmuffs provide –55 dB of passive isolation from the outside world. Measurements show this is not quite the case. Ambient sounds carry through the bones of the skull directly to the middle and inner ear. Figure 6 graphs the bone conduction limit as well as a typical curve for a combination of earmuffs and earplugs.

I found three drawbacks to the combination of drugstore PU earplugs and earmuffs/headset:

• After 24–30 hours, my ear canals tired of the pressure from PU earplugs and felt irritated. I would have to remove them for the remainder of the contest, losing their isolation benefits.

• The frequency response curve for PU earplugs is not very flat. The increased attenuation at higher frequencies detracted from the intelligibility of SSB signals. For receivers with an equalization control (such as the Orion), a boost of higher frequencies in the receiver can compensate.

• To compensate for the signal loss in the earplug, the headset volume must increase. This 20 dB increase in headset volume was OK for many signals, but the loudest signals would drive my headset speakers (recycled from that disassembled Heil BM-10) into distortion. The need to reduce volume to avoid distortion partially defeats the benefits of added isolation.

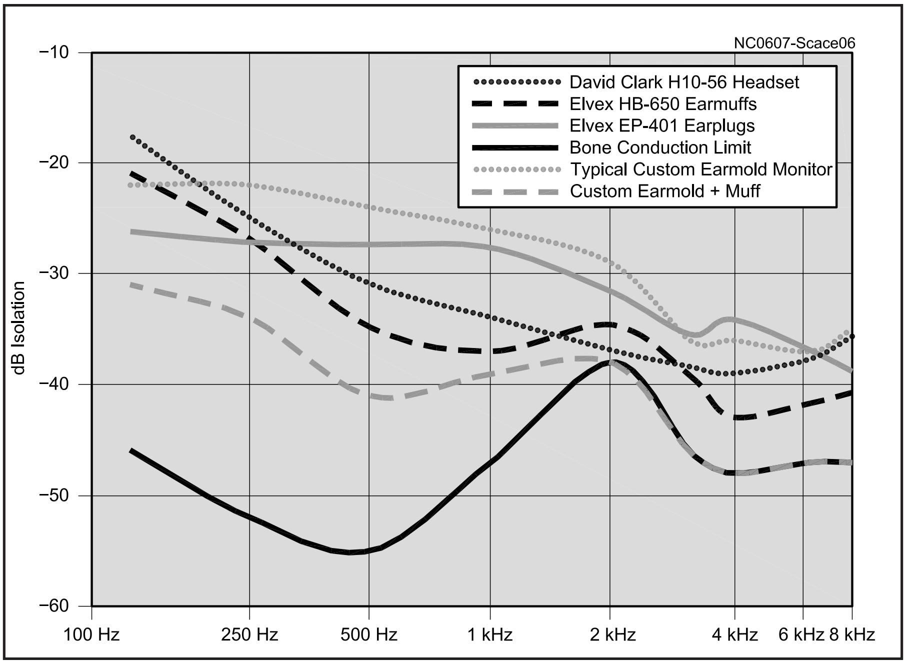

Figure 6—Isolation response vs. frequency for high-isolation earmuffs and earplugs. The bottom curve shows the limit to isolation from bone conduction paths in the skull. A combination of earplug/mold and earmuff provides greatest isolation.[7]

After a few years' experience with this solution, I began to explore two avenues for improvement. Custom earplugs, manufactured by Westone and others from a variety of hard or semi-soft materials, offer more isolation and fit precisely into purchaser's own ear canal shape. For about $40, a doctor or nurse at a hearing health center makes a pair of molds from purchaser's ear canals. The center or purchaser mails the molds to the manufacturer, who then creates the plug. A typical pair of plugs costs $75. Custom earplugs are more comfortable for long-term wear, especially the newer heat-sensitive models with elastomer that softens slightly from body heat.

However, adding further isolation in the ear canal demands more volume from the headset speakers, with a greater chance of distortion or speaker damage. A different approach avoids this problem.

In-Ear Monitors

In-ear monitors such as those shown in Figure 5 (bottom right) contain very tiny, low-power, high fidelity speakers that sit in the ear canal as part of the earplug. By using in-ear monitors together with inexpensive earmuffs (that have no speakers), the operator achieves maximum isolation from ambient noises in the radio room with high fidelity, full dynamic range sound from the receiver.

In-ear monitors typically contain one or two drivers (speakers). The two-driver models, although more expensive, provide flatter response below 100 Hz, useful for low-band CW operators who tend to favor CW notes at 250 Hz or even lower.

In-ear monitors fall into two broad families (see Figure 5 lower right):

• Detachable units, shown on the left in Figure 5: The monitor, a separate unit, fits into a specialized earplug. The plug contains one or two tunnels to carry the sound from the monitor speakers into the ear canal. Both "universal" earplugs (similar to the PU foam cylinder or flanged TPE insert) and customized molded earplugs (with better isolation and comfort but at extra cost) are available.

• Integrated units, shown on the right: Here the manufacturer casts the drivers into customized earplugs. Isolation levels increase by 5 dB compared to the detachable units with custom earplugs.

Because musicians make extensive use of in-ear monitors, the earplug design provides a flatter frequency response than a standard industrial or drug store plug. Musicians may plug their in-ear monitor into a belt-mounted wireless unit, so cord lengths are short – around four feet. One may require an extension cable to reach the radio headphone jack at a contest station, as well as a 1/8 to 1/4inch stereo plug adapter.

In-ear monitors have much greater sensitivity than traditional amateur radio headsets. When I first connected one to an Orion receiver, I heard a broadband hiss that remained unchanged with audio gain setting, and even the lowest gain setting delivered far too much audio. I added about 40 dB attenuation by constructing two back-to-back T-pads in each of the left and right channel; see Figure 7. Exact resistor values are not essential, but use very similar resistances for the left and right channels to maintain balance between the left and right audio level. I used two 10 Ω resistors in parallel for the 5 Ω legs. The 100 Ω resistor value is not critical. Source and termination impedance for these pads are 27 Ω, which matched the Orion headphone jack and the in-ear monitor. If you need different impedance or attenuation, the Internet offers convenient T-pad calculators.[7]

I now use these in-ear monitors with a high-isolation, deep shell industrial earmuff.[8] The combination delivers the maximum achievable isolation from ambient sounds in the radio room. A Heil boom mic (scrounged from that old BM-10 and retrofitted with an HC-5 mic element) bolts onto the left earmuff. The effect of inserting the plugs and donning the muffs is striking: the outside world drops away and the sound of one's own breathing largely defines the noise floor.

With receiver gain set low so the band noise becomes just perceptible, the full dynamic range of hearing becomes safely available for radio reception. With no or very minimal receiver AGC action, the clarity of signals is stunning. Loud signals are loud, but weak signals remain unobscured. The effect resembles a walk in a mature forest: tall trees (big signals) surround you, but mushrooms and flowers (weaker signals) are easily spotted. Tuning across a signal with bad key clicks or splatter feels like wading through a patch of thorny bushes! But best of all, when the contest ends, the ears feel neither exhausted nor deafened by temporary threshold shift.

Initially I felt some reluctance to risk the significant amount of money needed for good in-ear monitors with customized earplugs. No other contester I knew used this approach. I eventually took the plunge, in the name of research (?!) for this article but, more importantly, to protect my hearing. My ears are the only part of my station that cannot be repaired or replaced. The results were outstanding… and the in-ear monitors work great with my iPod!

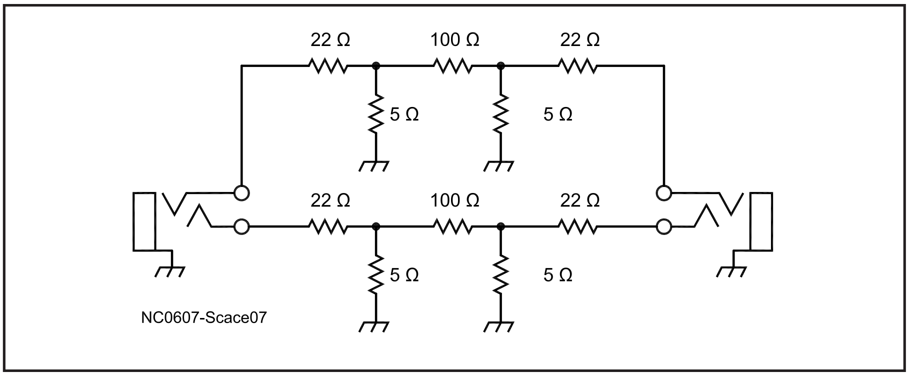

Figure 7—Attenuators for in-ear monitors.

Noise-Reduction and Wireless Headphones

As prices declined, some operators have tried so-called "noise-canceling" headphones. One should consider these factors:

• Despite the marketing name, noise cancellation reduces broadband noise by just –10 to –15 dB and only at lower frequencies.

• Noise cancellation does nothing to reduce ambient interference that does not resemble broadband noise; e.g., the adjacent SSB operators at a multi-op station.

• Some noise canceling headphones add a small background hiss, adding to the workload of the operator trying to concentrate on real signals.

• Noise cancellation models based on digital technology add an asynchronous co-decoding to the audio path. A later section explains the disadvantages of these co-decodings.

• Many models do not use fully encompassing earmuffs. The headphones rest on the pinnae, adding irritation over a long contest.

Wireless headphones, used by some operators to eliminate the headphone cord, share many of the drawbacks of noise-reduction headphones. These systems have significantly smaller dynamic range (some below 80 dB). As a result the wireless headset user simply throws away signal quality.

SO2R Audio Switching

SO2R headphone audio switching may also introduce impairments into the receive audio chain.

Computer-controlled analog switching systems such as *WriteLog's* MK1100 multi-keyer may introduce ground loops between the switching system, the computer, and the radios. Ground loops add weak noise or tones to the operator audio. If your receiver sounds clean with the headphones plugged directly into the headphone jack, but you hear additional noises when listening through the SO2R switchbox, then ground loops are the likely culprit. An article in the May/June 2006 issue (pp 23-27) discussed galvanic isolation techniques to eliminate similar problems in the transmit audio chain; these techniques apply equally to the receive audio chain.

Analog switching systems with manual switching may also introduce ground loop signals into the audio. The switchbox ties together the signal grounds of both radios. Again, galvanic isolation will remove the impairments from the audio delivered to the headphones.

N1MM logging software introduced SO2R headphone audio switching using a computer soundcard. Users of this digital system must:

• Employ galvanic isolation;

• Set the radio's audio output level and the computer soundcard's line input volume control to appropriate settings for the soundcard's A/D converters.

• Set the soundcard's line output volume control appropriately for the operator headphones.

The May/June article discussed all the techniques needed to measure signal voltages, measure A/D encoder range use, and configure and set soundcard levels.

An additional small impairment comes from the added conversion from analog to digital and back again. Recall that modern receivers digitize the analog RF signal (usually at an IF stage) for some signal processing, and then convert the result back to analog (usually at audio frequencies). In an ideal implementation, only one such "co-decoding" would occur before delivering the audio to the operator's ears. Each additional asynchronous co-decoding, such as that done by the soundcard, adds small errors to the resultant audio.[9] These errors accumulate as more asynchronous co-decodings occur in the audio path; e.g., receiver, followed by soundcard switching, followed by an external DSP audio processor, followed by a wireless headset or digital noise-reducing headset. Reduced signal quality results.

When using *N1MM*-style SO2R soundcard audio switching, configure the soundcard without any kind of data compression, and use a high sampling rate (e.g., 44.1ksamples/s) and high sample bit size (e.g., 32 bits).

A test at **www.phys.unsw.edu.au/~jw/hearing.html** will give you an idea of the collective sensitivity of your ears plus headphones and soundcard at frequencies between 30 Hz and 16 kHz. If the test results are not flat between 200 Hz and at least 3 kHz, a problem needs attention.

Summary

You can protect your hearing while improving your ability to hear weak signals amongst the strong during the contest by combining these techniques:

• Minimize the ambient noise in the radio room; strive for a library-like atmosphere.

• For multi-op stations, adjust transmitters so that operators can speak quietly. Use voice memory keyers as much as possible. Keep conversations between off-duty operators outside the radio room.

• Use a high-isolation headset with deep-shell earmuffs that fully surround the ear. The earmuffs should not touch the pinnae at any point. If you wear glasses, use flexible wire stems to reduce pressure at the stem tip behind the ear and to minimize ambient noise leakage around the earmuff.

• To improve isolation further, use earplugs or in-ear monitors in combination with high-isolation earmuffs.

• Do not use wireless headphones.

• Noise-reduction headphones may add impairments to the receiver audio, and do not isolate the operator from many types of ambient sounds.

• SO2R operators may need galvanic isolation between the radio headphone jacks and the SO2R audio switching system.

• SO2R operators using the *N1MM* second soundcard solution for audio switching must set soundcard configuration, encoding, and levels correctly to accommodate the full dynamic range of the headphone audio.

• Using the receiver's RF gain and front-end attenuator controls, set the antenna noise just above the receiver noise floor.

• Using the AF gain control, set the antenna noise just above your threshold of hearing.

• Use the receiver's notch and bandpass filters to weaken adjacent QRM below the threshold of the attenuation reflex.

• In a quiet radio room, using high isolation earmuffs and plugs, and setting the controls as described above, you will need no or very minimal AGC action in the receiver.

• Set the transmitter's CW sidetone and SSB/RTTY monitor levels to the lowest practical volume.

Notes

[6]**www.davidclark.com**

[7]**www.rfcafe.com/references/calculators/attenuator_calc.htm**

[8]Elvex Ultra-Sonic HB-650, available for $17 from **www.elvex.com**.

[9]An "asynchronous" co-decoding means the encoding algorithms for the adjacent D/A and A/D converters are not identical, or the sampling rates and timing are not identical, or both.

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