Can I Hear You Now? Adjusting the Receive Audio Chain—Part 1

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Far too many contesters struggle unnecessarily to copy signals through self-inflected interference and audio impairments. And far too many of us finish the contest with temporary hearing damage that, over the years, accrues to permanent hearing loss. This article outlines improvements for received signal clarity and hearing protection at contest stations.

Dynamic Range of Receiver Audio

Modern contest-grade receivers provide excellent operation over a wide range of incoming signals. Let's begin by examining how a modern receiver transforms that range of incoming radio signals to audio, taking the Orion transceiver as an example.

In a crowded contest band, several strong interfering signals may be present nearby while the operator tries to copy a weak one. Figure 1 graphs the audio output of a receiver in this situation, with audio frequency on the X axis and signal strength (in dB above the average band noise level) on the Y axis. A dotted line shows the receiver's instantaneous internal noise level as a function of frequency. In this example, the operator correctly adjusted the receiver so that the band noise from the antenna (solid line) hovers a few dB above the receiver internal noise floor. The operator tuned an interesting weak signal (white line) to 450 Hz. Two other strong signals (gray lines), annoying multi-op stations calling CQ TEST, squat nearby at 1100 and 1550 Hz. In the figure the receiver created two artificial signals from strong signal mixing products (black lines), one of which sits underneath the interesting weak signal at 450 Hz. (I assume other artificial signals, such as IMD and reciprocal mixing noise, to be negligible and these are not included in the figure.) Fortunately for the operator, the two mixing products remain weaker than the band noise and so go unnoticed.

Dynamic range measurements help describe how a receiver performs in such situations. Sherwood Engineering measured the Orion I receiver's close-in dynamic range at 93 dB, and the Orion II at 95 dB.[1] "Close-in dynamic range" here means signals separated by 2 kHz, but falling outside the Orion's roofing filter passband used in the test. Dynamic range degrades to 85 dB in Sherwood's tests when the signals all fall within the roofing filter passband. The Orion's close-in dynamic range currently stands as the best on the market for commercial transceivers. Radio design continues to advance and we can expect even better close-in dynamic range in the future.

To put this range into perspective, the scenario of Figure 1 could describe a quiet 20m band with antenna noise near the receiver noise floor, a weak signal that doesn't move the S-meter, and those loud signals running S9+30 dB. As DXers and contesters, we wish to fully exploit the dynamic range of the receiver and easily copy that weak interesting signal.

As we will see in this article, safely exploiting the full dynamic range of the receiver requires proper adjustment of the receiver audio chain: the connection between the receiver headphone jack and the operator's inner ear.

Figure 2 illustrates a simple receive audio chain. The operator connected an ordinary headset directly to the receiver headphone jack. This configuration exemplifies a single-op one-radio or multi-op station. Even this simple case contains six factors influencing the quality of signals conveyed from the receiver to the brain. The operator must understand and control each factor to exploit fully the dynamic range of the receiver.

Receiver Audio Output

I made some simple measurements of headphone voltages using a Heil Pro II headset, an Orion radio, and an oscilloscope. The first measurements examined the receiver's apparent noise floor by disconnecting the antennas. I set the audio gain control so that, while wearing the headset, I could hear the receiver's noise floor just above the ambient noise of a quiet room. The scope measured this noise signal at about 1 μV_{P-P}.

Next, I attached an antenna and tuned in a strong broadcast carrier near the 40-meter band. This very loud audio signal measured 40mV_{P-P}, +92 dB over the just-audible hiss.

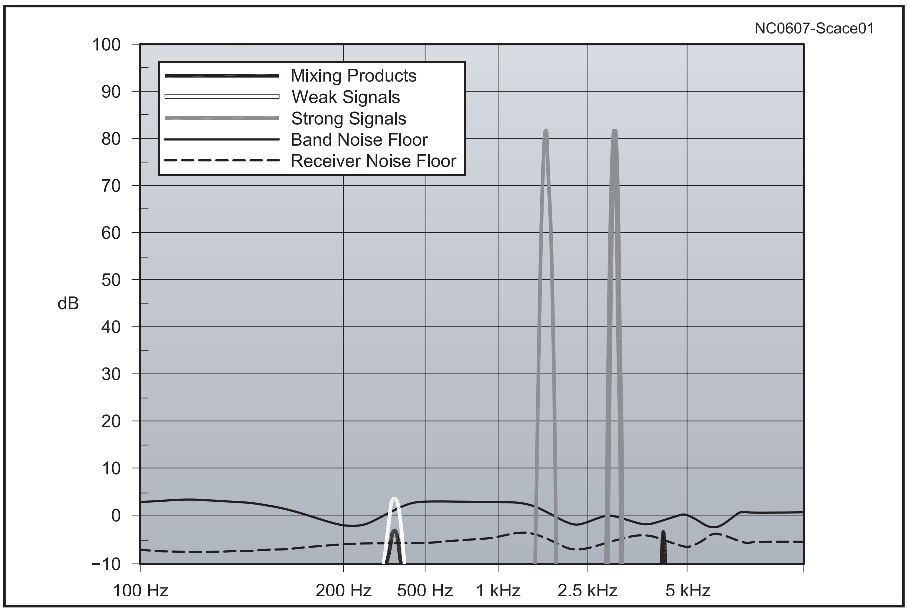

Figure 1—Receiver audio output example. Vertical scale in dB relative to average band noise.

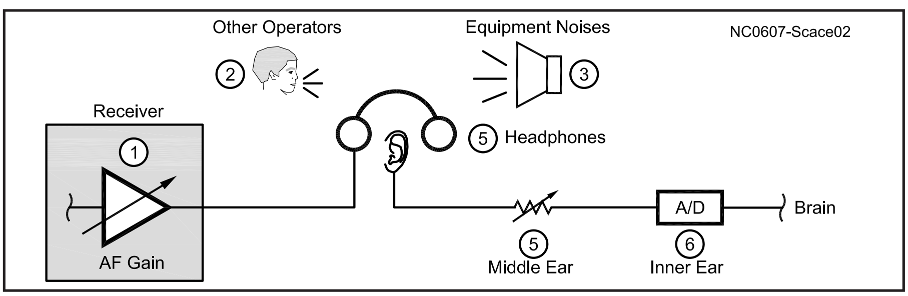

Figure 2—Simple receive audio chain.

Increasing the audio gain demonstrated the Orion could produce as much as $2V_{P-P}$ before distorting – over 120 dB above the receiver noise floor level and stunningly loud. I couldn't wear the headphones at this level.

This little exercise demonstrated that the Orion can easily deliver its 93 dB receiver dynamic range to the headset with plenty of additional headroom. Safely maintaining these large dynamic ranges between receiver and brain requires special attention to safety.

Ear

The ear exhibits the widest range of sensitivity of the five human senses. Point 6 in the Figure 2, the inner ear, functions as a biological analog-to-digital converter. This portion of the ear transforms analog sound energy (represented as pressure waves in the cochlear fluid) into nerve pulses. Like any converter, the inner ear has a minimum threshold below which it cannot detect weaker sounds. The average threshold of hearing varies by frequency. The most sensitive point ("acute threshold") lies between 3–5 kHz, a result of resonance in the outer ear canal. For measurement convenience, acute threshold as a function of frequency has been defined as "A-weighting" and each point is defined as 0 dBA for that frequency.

In Figure 3, the operator adjusted the audio gain so that band noise hovers just above the acute threshold of hearing in the frequency range beginning at 300 Hz. A little further up the audio spectrum at 1 kHz, band noise stands about 15 dBA. "dBA" represents dB above the acute threshold of hearing at the frequency of interest. This might typify ideal CW reception in a perfectly quiet environment. In absolute terms, at this setting the band noise is just louder than the sound of a mouse running across a wood floor, or a mosquito buzzing 3 feet away!

The inner ear also has maximum limits, above which pain and damage occur. Figure 3 also shows the threshold of pain. The two loud signals fit below this threshold – but, at +98 dBA, represent a danger discussed more fully below.

Attenuation Reflex

To reduce risk of damage, the middle ear contains two muscles that function together as an attenuator. As signal strength increases, these muscles tighten the eardrum and shift parts of the middle ear's bone structure to reduce the strength of signals reaching the cochlea.[2] This protective attenuation reflex kicks in when sound levels reach 75–90 dBA. One medical reference cites 80 dBA as a typical triggering threshold for the attenuation reflex for frequencies between 200–4000 Hz. Figure 3 includes a dotted line showing the threshold of the attenuation reflex.

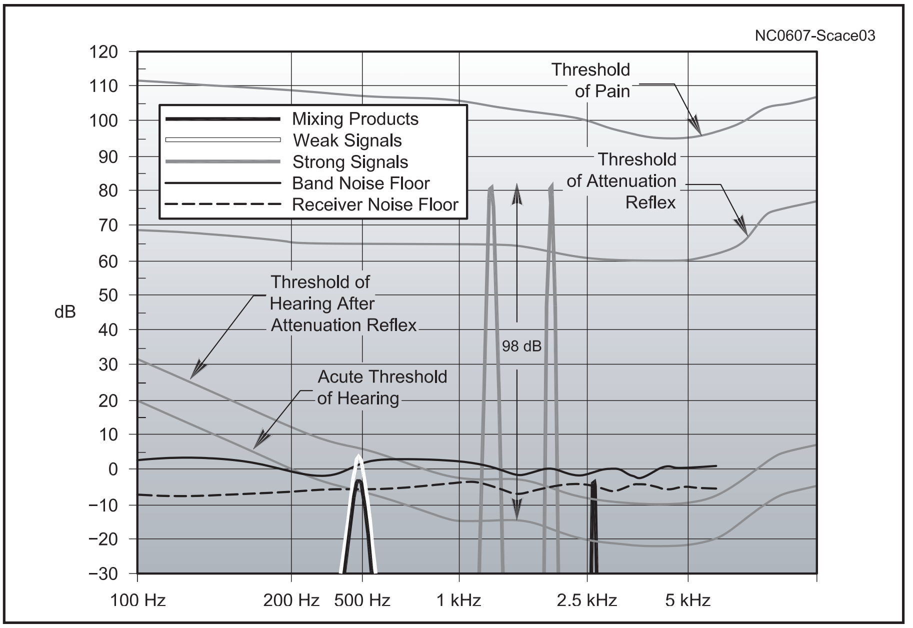

Figure 3—Positioning received signals within the dynamic range of average human hearing. Strong signals above the threshold of the attenuation reflex raise the threshold of hearing, masking the weak signal at 450Hz.

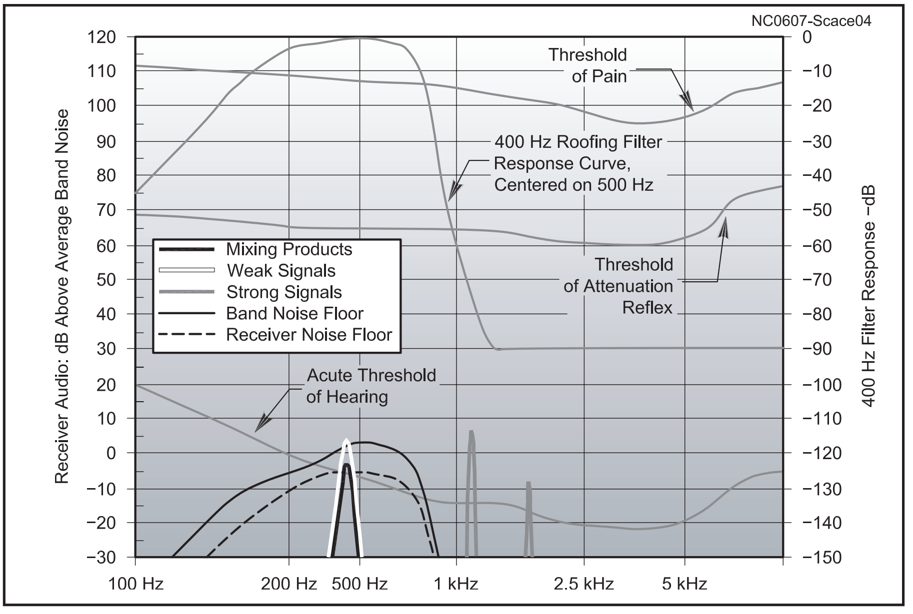

Figure 4—Using a 400Hz filter restores the threshold of hearing to the acute level, unmasking the weak signal. The filter's response curve is plotted against the vertical scale on the right.

The two strong signals have crossed the threshold for the attenuation reflex. The reflex reduces signal strength to the inner ear at a rate of –0.6 dB per dB. With these signals about 18 dB above the threshold of attenuation, those muscles will attenuate the operator's hearing by –12 dB. A line in the figure graphs the new threshold of hearing after the attenuation reflex kicks in. Note that the interesting weak signal has disappeared below the threshold!

The operator can restore the weak signal back above the threshold of hearing by one of the following steps:

• Increase the receiver AF gain. A +10 dB increase will bring the weak signal back above the threshold, but also brings the loud signals closer to the threshold of pain. For reasons explored later, this is a dangerous approach.

• Reduce the receiver bandwidth to weaken those strong signals. Figure 4 shows the audio spectrum, including the effects of an Inrad 400 Hz bandpass roofing filter centered at 500 Hz. (I assumed an ultimate rejection of –90 dB in the stopband.) The filter pushed the strong signals well below the threshold for the attenuation reflex. The operator now hears band noise over a small range of 350–800 Hz, and again hears the weak signal.

Similarly, a notch filter wide enough to weaken both offending signals by at least –15 dB could push those signals below the attenuation reflex threshold.

When optimizing the receive audio chain, the operator should:

- Place the band noise very close to the acute threshold of hearing; and,
- Avoid triggering the attenuation reflex by keeping the strongest signals within 80 dB above the threshold of hearing.

When transmitting, reduce the CW sidetone and voice monitor signals to the lowest practical level and well below the attenuation reflex threshold. In a 48-hour contest, you will make over 10,000 transmissions, totaling one-third to one-half your operating time. You don't need a loud sidetone to send CW accurately or to know when the memory keyer approaches the end of its message. Give your ears some hours of rest!

Hearing Damage

While examining these charts, one might fairly ask why we cannot exploit the 25 dB of headroom between the attenuation reflex threshold and the threshold of pain. So what if the attenuation reflex reduces signals by ten or twenty dB? Just turn up the receiver gain to compensate! And, unfortunately, this is exactly what most of us do. At the end of a 48-hour contest, the operator removes his headphones to find the rest of the world sounds a bit muffled. Maybe he even has a bit of ringing or white noise in the ears. Damage to the cochlea has occurred, and some of that damage is irreversible. This damage occurs from both long- and short-term events during the contest.

Whenever sounds above the threshold for the attenuation reflex are present, a risk exists for temporary or permanent hearing loss. The USA National Institute for Occupational Safety and Health established these limits for safe exposure to noise in the workplace:

80 dBA: 25.4 hours.[3]
85 dBA: 8 hours.
90 dBA: 2.5 hours.
100 dBA: 15 minutes.
110 dBA: 90 seconds.

Contesters interested in preserving their hearing for a lengthy contesting career should observe these limits. That means keeping receiver gain at the lowest practical settings. If you typically operate with the band noise 30 dB above the acute threshold of hearing on a quiet band, and tune across an S9+20 signal, you're hitting that 100-dBA level and chewing up safe exposure time rapidly.

Over the course of a single contest, lengthy exposure to sounds above 80 dBA degrade the cochlea's threshold of hearing, reducing further the ear's dynamic range. If, over the course of the contest, you accumulate eight hours exposure to 100 dBA, for example, you will lose about 40 dB of dynamic range from threshold shift. Twelve to 48 hours after the end of the contest most of this shift disappears, but a small amount remains as a permanent loss in hearing. Over time, repeated exposure accumulates these permanent loses.

The protective attenuation reflex also has limits to its effectiveness:

- Maximum attenuation runs as much –20 dB for children and teenagers (which partially explains why they tolerate louder music). As we age, the attenuation reflex degrades gradually toward –10 dB, providing less protection.
- The attenuation reflex does not act instantaneously. When new signals just over the threshold appear, 150 milliseconds elapse before attenuation develops. If a very loud sound suddenly begins, the reflex still requires 25–35ms to activate. Gunshots, a dropped wrench on concrete or a big signal suddenly firing up on frequency will slam into the inner ear at full power.[4]

I hope you have been convinced about the importance of keeping audio signals largely within the 80 dB range between the acute threshold of hearing and the threshold of the attenuation reflex.

Ambient Noise

One of the biggest challenges in maintaining audio signals within the safe range comes from our radio room. Points 2 and 3 of Figure 2 identify two typical troublemakers: other operators and equipment noise.

Normal speech runs about 60 dBA. An excited SSB operator sitting next to you can yell at 90 dBA, already triggering the attenuation reflex! If you were not convinced by last month's discussion of the transmit audio chain to speak quietly into the microphone, these numbers should get your attention.

Equipment cooling fans tend to be as much as 20 dB louder at lower frequencies (300 Hz and below) compared to mid-range frequencies around 5 kHz. A single quiet muffin fan, mounted in a cabinet and moving a modest amount of air, averages 25–35 dBA in the frequency range most commonly used for copying CW. Equipment noise in your shack likely stands substantially above that number, depending on the type of equipment, location, and orientation. In comparison, the ambient noise level in a library runs around 40 dBA. Let's pick a 40 dBA figure as illustrative for this discussion, recognizing that it represents very quiet radio room.

Absent any controls on ambient noise, the operator will set the receiver gain until the band noise becomes audible over the ambient noise levels in the room. At a station with a library-like ambient noise environment, the operator may set the receiver gain so that the band noise level runs about 45 dBA to listen on a speaker or headphones with no isolation from room noise. This gives him about 35 dB of audio range to play with before signals start triggering the attenuation reflex. That's not very much! If the band noise sits around S1 on the meter, any signals over S8 trigger the attenuation reflex, perhaps covering up weaker signals of interest. More importantly, loud signals consume the available budget of safe listening time before temporary or permanent hearing damage occurs… and, as an experienced contester, think of how much of the time you listen to signals at S8 and above.

You can do the arithmetic for SSB contest at a multi-op station: the situation is grim. No wonder we finish the contest with muffled hearing and tinnitus (ringing in the ear).

We can do a lot to improve matters. Our goal: to reduce ambient noises down to 0 dBA.

Reducing Ambient Noise

The first step focuses on the radio room. As pointed out in a sister article in the preceding issue of *NCJ*[5], a noisy radio room clutters up your SSB transmitted signal, reducing intelligibility. And now we see a noisy radio room reduces your audio dynamic range on reception.

Relocate or re-orient equipment that generates noise. An amplifier with a noisy blower might benefit from dense foam blocks underneath to reduce sound transmission to the shelf. Wayne Hillenbrand, N2FB, relocated his amplifier cooling fans behind a partition, using a duct to bring air to the amplifier chassis. If the operating position sits in the cellar near a noisy furnace, consider a dividing partition containing fiberglass insulation batts or other sound-absorbing material.

In a multi-op environment, separate the operators as much as possible. On-duty operators should adjust their equipment so they can speak quietly into the microphone, and should use voice memory keyers as much as possible. Off-duty operators should take their conversations into a different room.

To be continued…

Notes

[1]See **www.sherweng.com/table.html**

[2]Stevens, S. S., & Warshofsky, Fred, eds. *Sound and Hearing*, Time-Life Books, NY, 1965.

[3]Time weighted average. See **www.cdc.gov/niosh/98-126a.html** and **www.aearo.com/pdf/hearingcons/earlog11.pdf** for more details.

[4]Just before speaking, the attenuation reflex automatically kicks in to protect the cochlea from one's own voice. One can exploit this fact to protect oneself when anticipating a loud noise (start of a power tool, canon fire, etc): simply start humming a few seconds in advance! The act of humming triggers the attenuation reflex, preparing the ear for the following loud noise.

[5]Scace, Eric K3NA, "Can You Hear Me Now? Adjusting the Transmit Audio Chain", *National Contest Journal*, 2006 May/June, p. 23 ff; ARRL, Newington CT.

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