TEST & MEASUREMENT FOCUS

Examining the miniDSP EARS Headphone Test Fixture

In this article, our esteemed contributor explores the capabilities of "EARS," the Earphone Audio Response System. miniDSP says its EARS brings headphone measurement capability to "the masses" with its affordable measurement rig for headphones and IEMs, which miniDSP has built using the same technology as its popular UMIK-1 calibrated measurement microphone. Alternatively, one could use EARS as a binaural microphone with USB audio streaming.

(Photo courtesy of Cynthia Wenslow)

By
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Over the years, I've done extensive testing of amplifiers, preamplifiers, signal processors, loudspeakers, microphones, and more, for which there are pretty standard and well-accepted test methods for all of these categories. Their basic performance parameters are likewise well-known. For example, amplifiers should have flat frequency response, low noise, low source impedance, low distortion, and the like, all of which are objectively and repeatably measurable across nearly any type of test equipment. Loudspeakers are a bit harder, but we know how to measure anechoic and quasi-anechoic response, on and off axis, and any good test microphone will give similar results. Moreover, the targets in all of these measurements are well defined and (basically) universal.

Challenges Associated with Headphone Testing

Here's the main problem with headphone testing: It's not transportable into the intended environment. What I mean by that is if I put a set of loudspeakers in your room and measure a gated frequency response (which removes room reflections), it will be the same as the gated frequency response of that loudspeaker in my room. Likewise, the measured in-room response will be the same for any listener in the room (at least for a given seating position!). This is not true for headphones—the frequency response on my head with my ears will not be the same as the frequency response on your head with your ears since the size, shape, and consistency of ears is not constant and the ears are a significant part of the acoustic cavity being measured. And worst of all, that difference is intrinsic, it cannot be gated out.

So how then can we characterize a headphones' frequency response? The short answer is, we can't. We can only characterize their frequency response in conjunction with a particular test fixture. This leads to two new problems—which test fixture is "correct" and what should the target response be?

One approach to the first problem is using a coupler that simulates the acoustic load of an ear (though that begs the question of which ear). Over the years, there's been several "standard" ear couplers, including National Bureau of Standards (NBS) 9A, International Electrotechnical Commission (IEC) 60318, IEC 60711, and American National Standards Institute (ANSI) S3.25-1989.

More recently, the IEC 60268-7 standard has become dominant, calling out the type of artificial ears, the couplers (which simulate the response of ear canals), and test signals. This approach does solve the issue of portability, so that two different measurers can compare their results. And it gives sort of a rough idea what the response will be with average ears, but of course, that response will not be correct for any individual user. Mike Klasco (president of Menlo Scientific, Ltd.) and João Martins (editor-in-chief of *audioXpress*) presented an excellent review of current commercial offerings last year (see Resources). It's well worth reading to see the type of equipment used in serious professional laboratories.

The second problem, that of the target response, is intimately tied up with the question of measurement method. Should a headphone be measured on a flat panel, adjusted to a flat frequency response, then the combination of the headphone and test jig as a flat response be adopted as the frequency response target? Unfortunately, the acoustic cavity formed between the flat plate and the headphone driver bears no resemblance to that of the cavity with an ear in it, so that flat response will not guarantee a natural tonal balance in use.

To try to work around this conundrum, Sean Olive's research group at Harman International developed their own target curve by taking a standard fixture (in their case, a full Head-and-Torso Simulator) and measuring the free-field response from loudspeakers known to be reasonably flat in frequency response. Matching headphone frequency responses taken with the simulator to this curve, they had trained listeners adjust an equalizer until the sound was, to their judgment, "right." As it turned out, most of their adjustment was at the bass end of the spectrum, with several extra decibels of bass boost sounding most natural to them.

There is a popular expression in audio, "Circle of Confusion," which in this case is far worse than usual—I'd call it a "Hypersphere of Confusion." We may end up with a single standard, but in my opinion, we'll never end up with something that works as universally and with the ease of interpretation as that for loudspeaker measurements.

The miniDSP Test Jig

With that bit of pessimism stated, let's consider how individual users and hobbyists might perform headphone measurements on their own. Professional test fixtures compliant with existing standards (e.g., the Audio Precision AECM206 that was recently reviewed in *audioXpress*) are necessary for serious headphone research, but even the lowest-cost stereo models cost more than $10,000, which is a bit much for a small lab or a hobbyist.

Enter miniDSP, best known for its line of low-cost high-performance crossovers, equalizers, streamers, and signal processors. miniDSP's starting point was recognizing that, irrespective of the sophistication, all headphone test fixtures boil down to one or more miniature microphones embedded in a mechanical interface—most commonly, pinna replicas. The company's product offering, the EARS Headphone Measurement Jig (see **Photo 1**), is intended to fill the needs of headphone enthusiasts who want to perform their own measurements without taking out a second mortgage. I should note that, although its website and all the documentation calls this unit "EARS," the silk-screened name on the jig is "HEARS." For the purpose of clarity, I'll use the former name in this review.

miniDSP offers the following suggested uses for this device:

1. Check that your headphones are operating correctly (e.g., the balance of left/right frequency response).
2. Take measurements that you can use as a basis for equalizing your headphones.
3. Observe the effect on frequency response of different ear-pads and ear-tips.
4. Measure the effect of modifications to the headphones.
5. Compare your headphone measurements with other EARS users.

Based on its popular UMIK-1 room measurement microphone technology, the EARS basically consists of a pair of molded ears, two electret microphone

Photo 1: The miniDSP EARS headphone jig is a basic and inexpensive alternative to laboratory-grade measurement systems. (Photo courtesy of Cynthia Wenslow)

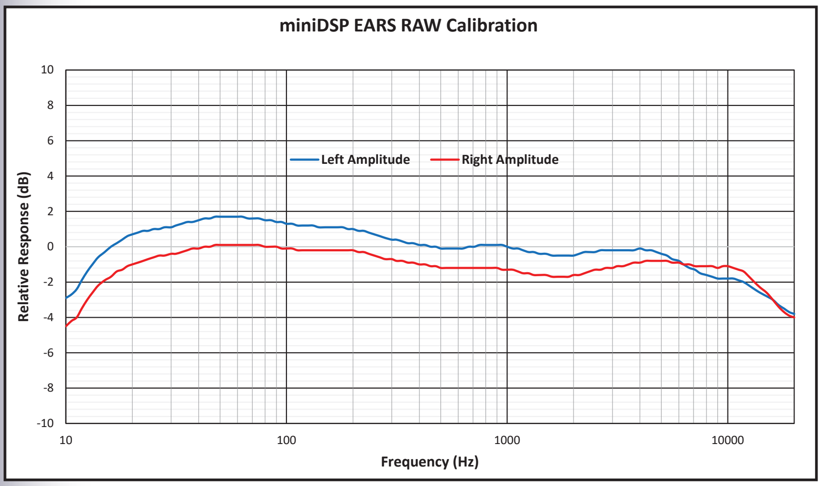

Figure 1: The RAW EQ files provided with the miniDSP EARS compensate for the frequency response of the embedded electret microphone capsules.

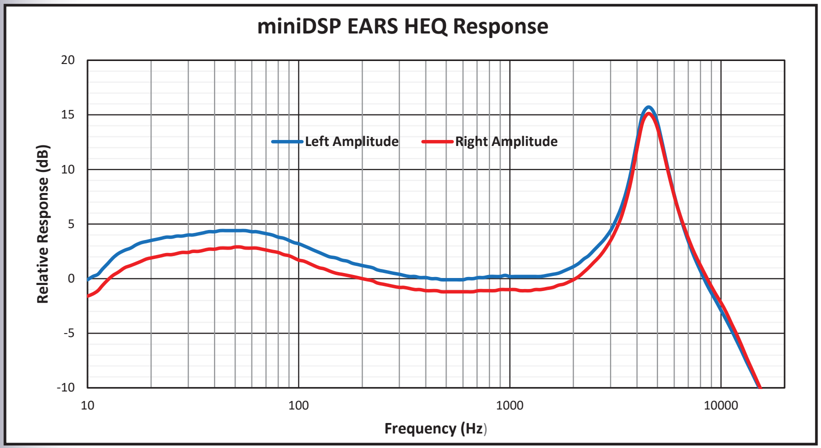

Figure 2: The HEQ equalization curves account for the acoustic effects of the simulated pinnae and ear canal, and are a starting point for users to equalize to a flat frequency response.

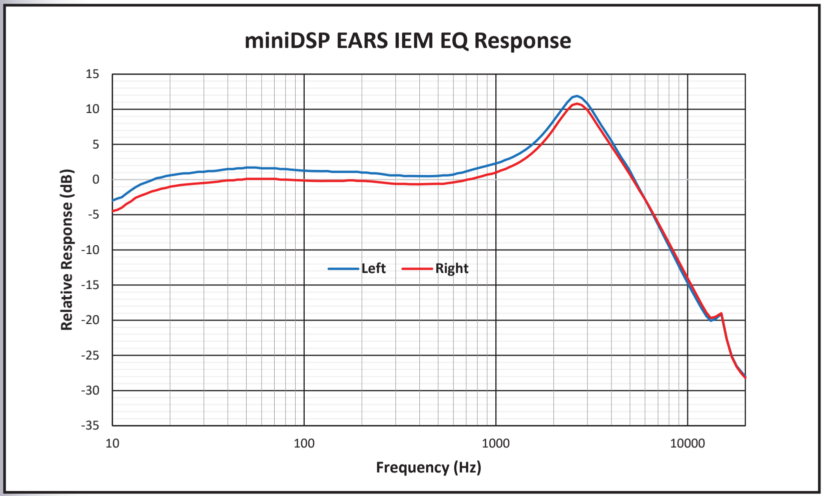

Figure 3: miniDSP also provides IEM equalization curves for users of in-ear headphones where the HRTF contribution of the pinnae are minimized.

capsules, and a USB interface, all mounted on a stamped metal stand with a curved upper piece to allow the headband of the headphones under test to be adjusted for an optimal fit. The vertical distance between the top of the jig and the ears is adjustable to accommodate a range of headphone sizes—the distance between the ears is fixed at about 14 cm (5.5″).

Unlike more expensive fixtures that use elaborate and expensive couplers, there's no attempt to simulate the acoustic effects of the ear entrance or canals—the passageway between the molded ears and the microphones is a simple cylindrical hole.

Because of the stamped sheet metal construction, the unit is relatively lightweight, with none of the acoustic isolation that metal mass brings to expensive fixtures. What that means is that you can't test the acoustic isolation of over-ear headphones, nor the effects of active noise cancellation circuitry.

This horizontal distance is small and not adjustable. Smaller than my head, smaller than my wife's head. Small enough that getting a lot of headphones to sit properly on the jig is an issue (with concomitant variability in bass response measurement because of reduced tension from the headphones' headbands). Hoping that I could modify this by putting spacers between the molded rubber ears and the metal stand, I removed the ears and found that the microphone capsules were glued to the metal and couldn't be easily repositioned on a new spacer. Adding the spacers would greatly change the acoustic properties because of the extra ear canal length. Several people on the Internet have suggested using rubber bands to hold the headphones more tightly against the ears, but the variability of that fix is unacceptable. I'd call this a basic design flaw, but it's one that's easy to fix, and I hope that miniDSP does that for the next version of this jig.

The interface electronics are connected to the user's computer via a standard USB printer cable. No special driver is needed, and the USB connection also provides power to the EARS. A set of DIP switches allows the gain of the microphone preamps to be adjusted to accommodate a wide dynamic range of test signals. The factory default setting is 18 dB, which allows a maximum SPL of about 120 to 125 dB SPL for a 0 dB FS output, but gain can be reset in 6 dB increments between 0 and 36 dB. Sample rate and bit depth should be fixed at 48 kHz and 24 bits for the jig to properly function.

Which brings us to a potential snag: calibration to obtain SPL. Because it's a USB device, the EARS jig will give a response curve referenced to full scale—but what's full scale in actual SPL? miniDSP

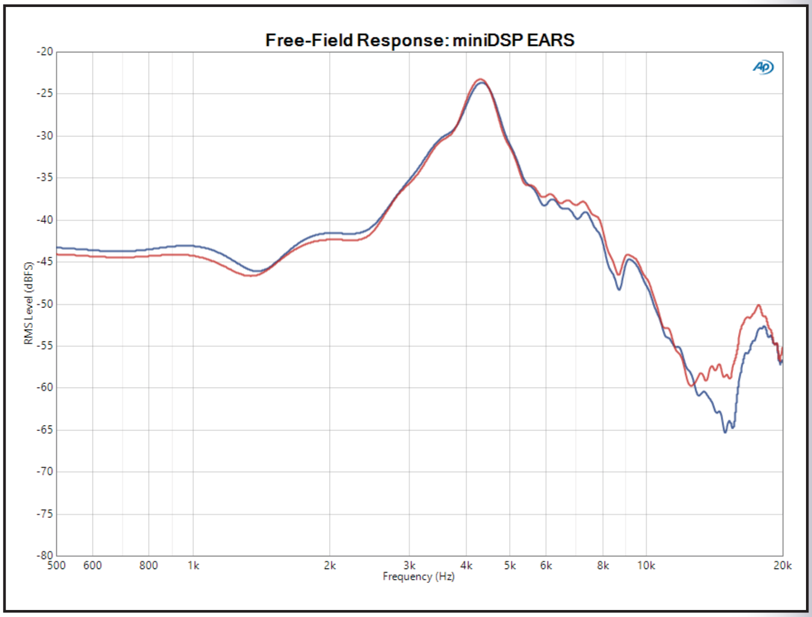

Figure 4: The free-field response of the EARS test jig was taken using a 1 meter distance from the source and gating out reflections.

provides a calibration procedure that works with Room Equalization Wizard (REW) software and (in theory) gives actual decibel sound pressure level (dB SPL). With any other measurement software (e.g., ARTA, Virtins MI, and RightMark), you're on your own. You can at least get into the ballpark by noting that at the default 18 dB gain setting, 0 dBFS equates to about 123 dBSPL.

And to be fair, REW is an excellent software package, free to use, and with a large user base for support. Nonetheless, you should be aware of this limitation.

The EARS jig is serialized—entering the serial number on the support page at miniDSP's website will get you access to a set of calibration equalization (EQ) files in text format. There are separate RAW files for left and right, which compensate for the non-flat response of the electret mic capsules, but not the fixture itself. miniDSP also provides files called HEQ, which provide frequency response compensation and for over-ear headphones, and IDF, which provide the same function but for in-ear monitors (IEMs). With the HEQ and IEM equalizations, the intent is to make the target frequency response curves for headphone equalization be flat, but you can certainly experiment with modifying the provided EQ files to suit your taste—and (this time, literally) your ears.

Figure 1 shows a graph of the RAW EQ files provided for my particular EARS jig. **Figure 2** shows a graph of the HEQ files. There's a couple of decibels difference between the channels and the upper midrange and treble don't track well, but that's the price one pays for using inexpensive mic capsules. However, this is the point of providing these curves—those differences can be removed by implementing the RAW EQ files.

You can see the effect of the jig on the acoustic cavity between headphones and jig due to the pinna and the simple hole used for the ear canal in the HEQ curves shown in Figure 2—the latter forms an almost undamped Helmholtz resonator, which causes the large peak at about 4.5 kHz. This peak dominates any waterfall plots and spectrograms, so the jig really should only be used for frequency response and not for spotting non-minimum phase phenomena. It's also evident that the channel matching issue is accounted for in these curves. The relatively steep drop in the treble is characteristic of this ear geometry as well.

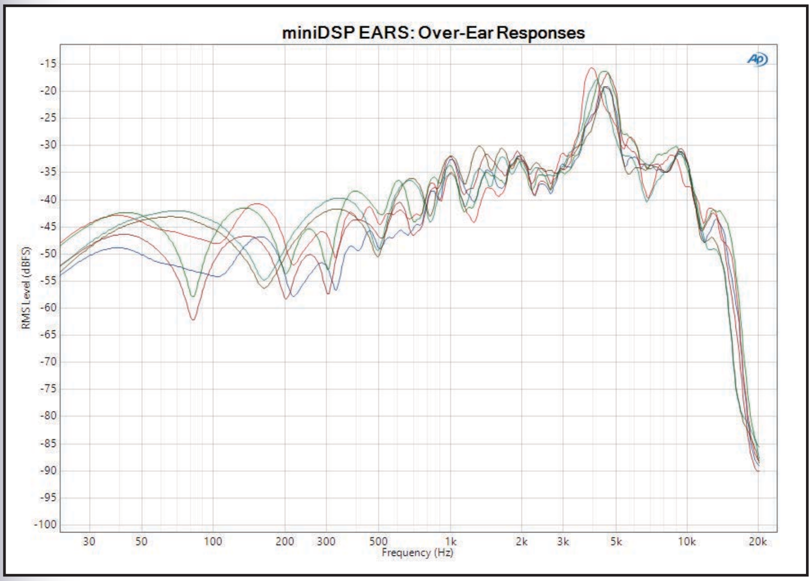

Figure 5: The variation in frequency response caused by removing and replacing the headsets between repeated measurements demonstrates the need to average over multiple repetitions.

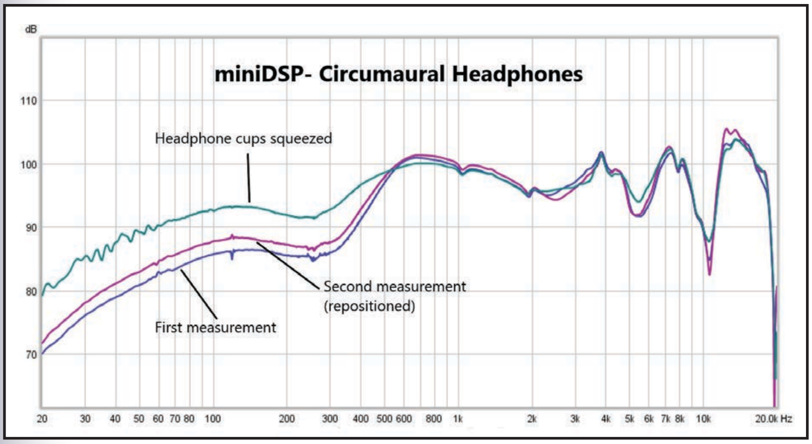

Figure 6: The measured bass response is greatly affected by headphone positioning and tension. Blue curve = first measurement. Magenta curve = measurement after repositioning the headphones. Green curve = measurement with pressure applied to the headphone cups.

The IEM EQ curves are shown in **Figure 3**. The lack of pinna/ear-cup cavity interaction removes a lot of the frequency response ripple. The peak from the simulated ear canal is still present, but lowered in frequency to about 2.5 kHz because of the IEM stopping up the end of the canal. There's also the same relatively steep treble roll-off seen in the HEQ curves. Of course, different insertion depths or tip geometries will change these features greatly, which adds another layer of measurement uncertainty.

Measurements and Use

As usual, my measurement setup consists of an Audio Precision APx525 with an APx1701 acoustic interface. The reference microphone was a PCB Piezotronics 376A33 phantom power 1/2" condenser mic. For REW measurements, the headphones were driven by a Scarlett 2i2 interface.

First, I measured the free-field response by positioning the EARS one meter from a mini-monitor, running log chirps, and gating the impulse response to remove echoes. The results were normalized to the mini-monitor's response measured by the reference mic at the same position. The measured response for the EARS jig is shown in **Figure 4**. We would expect some differences from the HEQ calibration curves because of the geometry of the EARS jig, but the major feature of the 4.5 kHz canal resonance is still evident. You can also see the same steep treble roll-off that appears in the HEQ and IEM EQ curves and that the bass response is relatively even.

Next, I checked the measurement repeatability with headphones placed and removed between each repeated measurement. This is shown in **Figure 5**, and emphasizes the need for multiple runs and power averaging when using this (or any other) headphone test jig to determine a frequency response. I would recommend at least six averaged measurements.

I then tried to measure some circumaural headphones that I've been using a lot recently. The frequency response acquired by REW is shown in the bottom (blue) curve in **Figure 6**. The response here has a shelf below 500 Hz, which suggests a very lightweight bass. This does not accord at all with my subjective perception, which is that of a deep and well-defined low-frequency end. Suspecting that this could be caused by a sealing issue, I repositioned the headphones and re-ran the frequency response, resulting in the second (magenta) curve, which was slightly better, but not much. Remembering the small width of the fixture, and hence, the low compression of the ear-pads to form a seal, I then tried re-running with extra compression. I hated the idea of rubber bands, so after hitting the "measure" button in REW, I quickly reached over and manually squeezed the cups more tightly against the jig using my hands. This produced considerably improvement in the bass response (the green curve), but still indicating inadequate bass. And I think I know the reason.

Photo 2 shows a close-up of the mechanical interface between the EARS and the headphone pads. The screws miniDSP uses to assemble its pinnae onto the stand are round head and not flush with the surface. So there's an inevitable leakage path for headphones (like these) that have relatively large diameter pads. It's an easy design flaw to correct, and replacing those screws with the same size screws having countersunk heads is an easy modification for EARS users to make without having to countersink the pinnae moldings; the rubber used is soft enough to deform under the screw head pressure to give a much flatter surface.

Figure 7 shows distortion vs. frequency for the circumaural headphones measured above. It's difficult to attribute the high bass distortion to the headphones alone given the seal issues previously noted. But the distortion in the mid-band was quite low (other than a peak at the 4.5 kHz resonance, almost certainly an artifact), so this jig should be able to give a user some insight into headphone distortion performance.

Photo 2: The screws used to fasten the rubber pinnae to the test fixture can compromise the seal of circumaural headphones. These should be changed to countersunk screws. (Photo courtesy of Cynthia Wenslow)

About the Author

Stuart Yaniger has been designing and building audio equipment for over half a century, and currently works as a technical director for a consumer products company. His professional research interests have spanned theoretical physics, electronics, chemistry, spectroscopy, aerospace, biology, and sensory science. One day, he will figure out what he would like to be when he grows up.

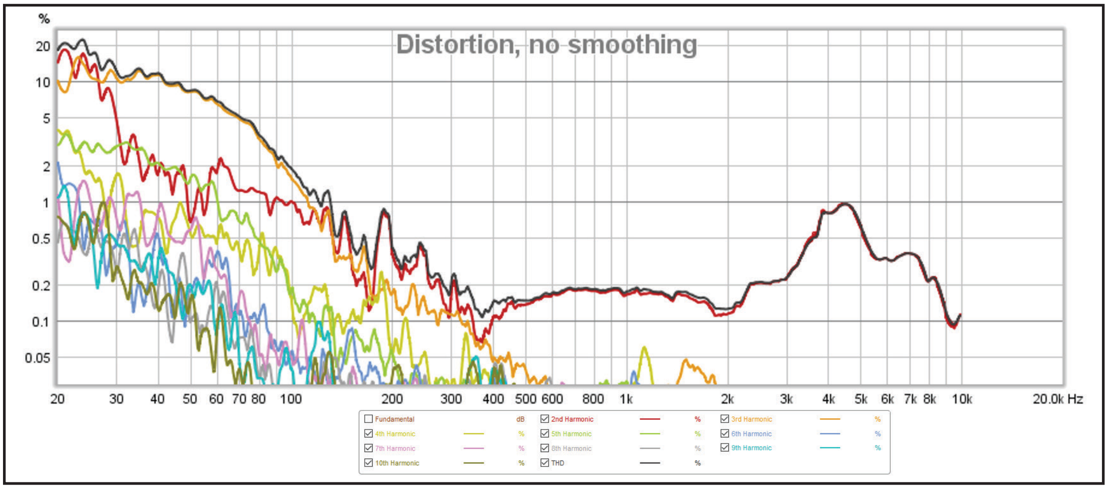

Figure 7: The distortion vs. frequency curves for the circumaural headphones used in testing indicate that the EARS's distortion floor is reasonably low, at least at mid frequencies.

In another typical user scenario, I investigated some gaming headphones I had on hand that never sounded quite right to me. **Figure 8** shows the frequency response using the RAW equalization, and the performance issue stands out starkly. One channel has a severe bass droop and the matching in the 1 to 2 kHz octave is off by several decibels. As a check, reversing the headphones caused the inter-channel anomalies to reverse as well, confirming that the headphones were the source of the problem.

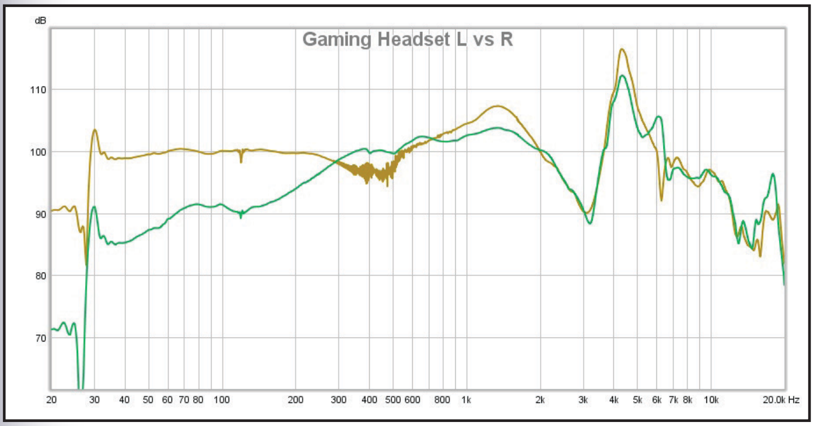

Figure 8: Using the EARS to test some gaming headphones that sounded bad immediately showed the problems.

Resources

M. Klasco and J. Martins, "Earphone and Headphone Test Instrumentation: A Comprehensive Roundup," *audioXpress*, April 2018.

M. Klasco, "Testing Headphones and Earphones: The GRAS Low Noise Ear Simulator," *audioXpress*, March 2016.

S. Olive and T. Welti, "Factors That Influence Listeners' Preferred Bass and Treble Balance in Headphones," Audio Engineering Society (AES) Convention Paper 9382, New York, 2015, www.aes.org/e-lib/browse.cfm?elib=17940.

R. Tipton, "A DIY HRTF Binaural Microphone Head," *audioXpress*, April 2018.

S. Yaniger, "Fresh From The Bench: The Audio Precision AECM206 Headphone Test Fixture," *audioXpress*, April 2018, www.audioxpress.com/article/fresh-from-the-bench-audio-precision-aecm206-headphone-test-fixture.

Wrap-Up

A product like this ought to be approached with the right attitude. It's not a $15,000 laboratory fixture—there's a lot of interesting measurements that just can't be done (e.g., acoustic isolation, noise cancelling, waterfall response, spectrograms, etc.). The EARS frequency response does not correspond to current standards, though admittedly all standards suffer from the quid est veritas problem, since all of them will be guaranteed to be inaccurate for any actual individual user. If an ambitious user wants to seriously examine head-related transfer function (HRTF) issues and develop more customized EQ curves, a better option might be Ron Tipton's DIY HRTF binaural microphone head (see Resources).

For less sophisticated, but still useful calibrated measurements, the miniDSP EARS user is tied to one piece of software (albeit, a very good one). The mechanics and packaging, particularly the width between left and right pinnae, cause unnecessary variability and uncertainty. But $200 is almost impulse purchase money, and with a large installed user base, the EARS response could arguably be said to have the same validity, and perhaps even better portability, as the IEC or Harman curves. And of course, the user can modify the EQ files in any manner desired. The driverless installation and operation is a major user convenience. With a couple of minor design changes, miniDSP could make this even better without increasing the cost.

The bottom line is that the miniDSP EARS is not a research tool, but is meant to be an inexpensive source of fun and interest for headphone enthusiasts, giving them insight into the performance of their headphones and efficacy of modifications and EQ curves that alter frequency response and perhaps distortion. And that fun is delivered in spades.