Headphone Surprises

HEADPHONES ARE HUGE THESE DAYS, WITH JUST ABOUT EVERY AUDIO EVENT HAVING A DEDICATED PERSONAL AUDIO SHOW. KEITH HOWARD UNCOVERS SOME DESIGN FOIBLES

On the face of it, headphones are a doddle to review. There's no heavy lifting, no faffing with room positioning, and no fretting over spiking or cabling as there is with loudspeakers. You plonk them on your head, plug them in and listen. It's so easy that countless people do it online, most of them badly.

One of the central issues is that few who presume to review headphones bother to measure them or – arguably worse but less common – measure them cursorily and/or ineptly. Measuring headphones properly involves costly hardware and, if the measurements are to be anything more than routine, some bespoke software comes in handy too. But in saying that, I am of course open to the Mandy Rice-Davies accusation: I would say that, wouldn't I? I own the necessary test gear, and I measure headphones professionally – I get paid for it. So I'm bound to denigrate the efforts of anyone who doesn't and gives their findings away. In a conspiracy theory, alt-truth world, it's obvious.

If your own opinion inclines that way, I hope this article will cause you to reconsider and read more critically what commonly pass for headphone reviews today. It takes the form of a demonstration: a demonstration of how headphone measurement can reveal important things about headphone design and performance which you should know but simply won't read about in routine headphone reviews. You may even find them surprising, and not only because they generally pass unremarked: they also demonstrate unexpected carelessness by some headphone manufacturers (who have no possible excuse for not measuring their products properly), identify a major source of headphone tonal balance variability, and challenge an all too common myth about planar drive units.

Suck Not Blow

If you've been around the hi-fi industry for as long as I have you'll recall that in the late 1970s and early 1980s there was a brief furore in the audio press about what was widely termed 'absolute phase' but is better called signal polarity. Notionally,

Figure 1. Impulse responses obtained from (a) Beyerdynamic DT 1770 Pro, (b) Focal Elegia, (c) Focal Stellia and (d) PSB M4U 8 in passive mode. All four are polarity-inverting

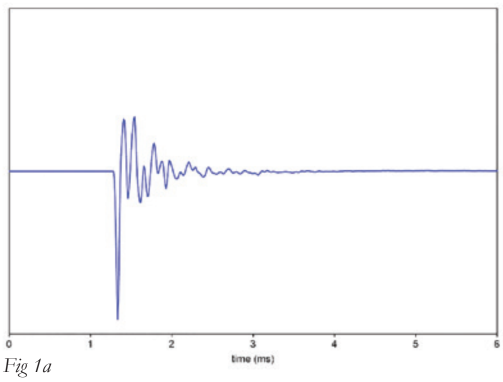

Fig 1a

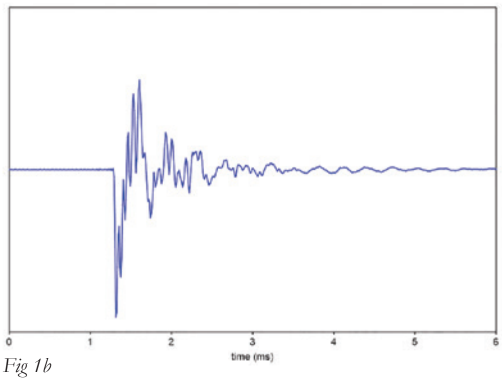

Fig 1b

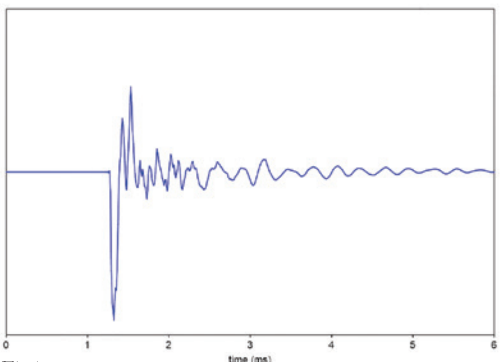

Fig 1c

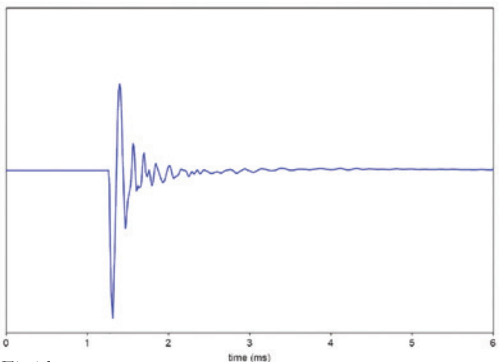

Fig 1d

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the audio chain from recording to reproduction should preserve the polarity of the signal, so that an increase in air pressure at the microphone is rendered as an increase in air pressure at the listener's ears. I say notionally because there's no guarantee that signal polarity is preserved, particularly in complex multi-tracked recordings, or even that it survives the short journey from signal source to loudspeakers in the home. It came as an unwelcome surprise to many people, for example, to find that Quad power amplifiers of the period were polarity-inverting.

I think it's fair to say that it was never definitively established to universal satisfaction that signal polarity matters. (Although the controversy continues: readers wanting to know more could do worse than start at www.stereophile.com/content/absolute-phase-fact-or-fallacy, especially the comments section). Many in the audio industry thought, and probably still think, it a fuss about nothing while others cited the nonlinearity of the ear and the asymmetry of many music signal waveforms and insisted that they could hear quite clearly when signal polarity was inverted – assuming, of course, that the signal concerned had carefully preserved polarity to begin with.

Whatever the ins and outs of this, one convention that everyone agrees on is that if you input a positive-going electrical signal to a loudspeaker or headphone it should deliver positive-going air pressure in response. In loudspeakers, actually, the situation is more complex than this suggests because certain crossover alignments require that drive units be connected with opposite polarity to prevent a cancellation notch in the frequency response at crossover. With headphones, though – the vast majority of which have a single, full-range drive unit in each capsule – no hedging is required: signal polarity can and should be preserved.

So you might be surprised by the four impulse responses depicted in Figure 1, all obtained from single-driver headphones, and not ones sourced from obscure Chinese manufacturers. In fact, running from Figure 1a to 1d, they were measured from a Beyerdynamic DT 1770 Pro, Focal Elegia, Focal Stellia and PSB M4U 8 in passive mode. If you're not familiar with impulse responses you may spot nothing amiss but the fact that the initial peak points downwards shows that these headphones are – or at least were – polarity-inverting.

Were? When I measured the DT 1770 Pro in early 2016 it was for interest rather than review and so I pointed out privately to Beyerdynamic that the headphone was wired incorrectly. I was given to understand that this would be rectified in production. I've had no opportunity to verify that it was but it may well be that current examples are now blameless in this regard. Both Focals were reviewed and so the polarity reversal – which, by the way, isn't seen in Focal's open-back models the Utopia, Elear and Clear – became public domain. I received no feedback from Focal, so whether it has fixed the issue, or intends to fix it, I know not. The M4U 8 made me smile. When I measured its predecessor, the M4U 2, I pointed out that it preserved polarity in passive mode but inverted it in active mode. Whether my observation prompted a change I don't know, but the M4U 8 is the other way around: it inverts polarity in passive mode but preserves it in active and ANC modes.

Most of the headphones I measure observe correct signal polarity – as they should, regardless of controversy as to whether polarity inversion is audible or not. How a headphone can make it into production with incorrect polarity beggars belief. But it happens – and you should be told when it does.

Radiophonic Workshop

This is an absurd idea but a valuable thought experiment. Imagine that someone suggested it would be a neat idea to link stereo loudspeakers with a thin steel band. The general reaction would be incredulity: loudspeaker designers go to considerable trouble to control structural resonances within the products, so adding an obviously resonance-prone strap would be unthinkable folly.

In circumaural (over-ear) and supra-aural (on-ear) headphones, such a strap is unavoidable: the headband is an integral part of the headphone's structure. It links the two capsules, often supports the headphone on the scalp, and provides clamping force to keep the capsules in position on the ears. But it is, of course, a potential source of unwanted vibration and resonance. So why is headband vibrational behaviour the elephant in the room? Why do headphone manufacturers talk up lack of resonance in their capsules but blithely ignore the structure which joins them? More to the point, why do reviewers do the same? I have had many headphones on review which have easily identified headband resonance issues and yet review after review of those headphones makes no mention of it.

What is especially puzzling about this is that identifying headband resonance subjectively could barely be simpler. As I've described countless times in print, if you replay pink noise over one channel only you will hear severe headband resonance as an obvious coloration of the signal. Some headphones have such prominent headband resonances – I'm thinking here of a succession of Audio-Technicas to have come my way which combine thin headband

Focal Stellia

Sennheiser HD 800

PSB M$U 8

Figure 2. Acoustic crosstalk measurements for (a) NAD HP50 and (b) Audio-Technica ATH-A2000Z showing that both suffer from headband resonances

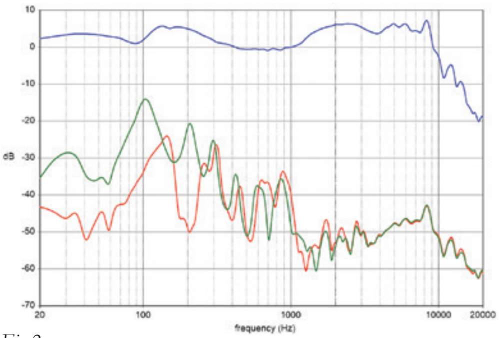

Fig 2a

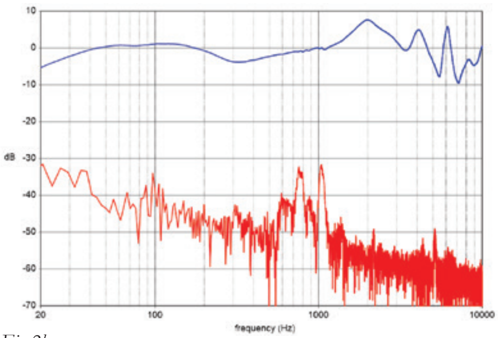

Fig 2b

loops with A-T's 3D Wing Support – that the resulting coloration sounds like an effect created for a 1950s science fiction movie or by the BBC Radiophonic Workshop for Dr Who. In less severe cases the coloration may be more subtle or undetectable but the headband will still advertise its less than inert vibrational behaviour by carrying sound across from the active to the inactive capsule. It's a straightforward test that any reviewer can perform – but nobody bothers.

Measuring headband effects

Ironically, the effect is more difficult to measure meaningfully than it is to hear, but it can be done. The method I've developed measures the acoustical crosstalk from one capsule to the other. First, the right capsule is placed on the artificial ear and its frequency response measured as normal. Leaving the headphone in place, the measurement is then repeated but with the left capsule receiving the test signal instead and the right capsule open-circuited to prevent electrical crosstalk – which occurs if the capsules share a common earth connection through a three-wire cable. For consistent results the artificial head has to be isolated from external structure-borne vibration via springs, and a large number of measurements averaged to counter low frequency variability arising, particularly with open-back designs, from room noise. I average 100 measurements, repeated three times to check that the LF response is sufficiently consistent.

Figures 2a and 2b show the results from two headphones with manifest headband resonance issues: the NAD HP50 and the Audio-Technica ATH-A2000Z. In both graphs the upper blue trace shows the right capsule frequency response with the right capsule driven, and the lower trace(s) the right capsule frequency response with the left capsule driven. In the NAD's case the latter was measured both with the headband resting on (red trace) and raised above (green trace) the artificial head; with the A-T there's just the one crosstalk trace because the headband can never be in contact with the wearer's head.

The succession of peaks in the NAD crosstalk traces are cause by headband resonances, which are easily detectable subjectively as described above. As with many headphones, they are worst at low frequencies. The Audio-Technica's narrow, thin headband behaves differently, with two high-Q resonances at 760Hz and 1040Hz. In both graphs you'll see on close inspection that wiggles in the top trace coincide with resonance peaks in the crosstalk trace, and it's usual for the headphone's impedance versus frequency trace to have tell-tale wiggles at these frequencies too.

Some headphones evince no significant headband resonance either subjectively or objectively, so it is absolutely not beyond the wit of man to control this behaviour, either by judicious damping of the headband or by contriving to decouple the capsules as in the AudioQuest NightHawk and NightOwl. But the plain fact is that many – far too many – headphone designers fail to attend to this issue. Bizarre, huh?

Flatly Misleading

You know the maxim that a lie repeated often enough becomes the 'truth'? Well, the crazy notion that drive units having thin planar diaphragms – electrostatics, isodynamics and (true) ribbons – are free of resonance because (a) they're too light to store significant energy, and (b) are driven over their entire surface, has been trotted out so many times as to have become part of hi-fi lore. But it's delusional.

Figures 3a, 3b and 3c making interesting viewing in this context, being cumulative spectral decay (CSD) 'waterfalls' measured from two planar-driver headphones – the Sonoma Model One (electrostatic) and Dekoni Blue (isodynamic, *aka* planar magnetic) – and one moving coil design, the Sennheiser HD 800 S. You don't see CSD plots for headphones very often, even in contexts where headphones are measured, perhaps because of a mistaken supposition that the ear itself (real or artificial) has resonances associated with the pinna (external ear) and ear canal which must make it difficult to tease out headphone behaviour from ear behaviour. But as the three CSD plots in Figure 3 demonstrate, this isn't true. The c3kHz length mode of the ear canal has quite low Q (*ie* is fairly well damped), while the pinna resonances occur at quite high frequencies and are not strongly excited by sound arriving on the ear's axis, as is does from most headphones. So CSD graphs are an effective means of assessing a headphone driver's resonance behaviour.

As the three CSD waterfalls here attest, that behaviour can vary widely. I wouldn't want you to take from them the idea that, because the HD 800S clearly outperforms the two planar models, it is generally true that moving coil designs are superior in this respect. Actually, most perform much less well than the Sennheiser. But it is true that isodynamic/planar magnetic designs typically display a succession of low-level resonances like the Dekoni Blue, and sometimes – also like the Blue – more prominent modes too. Electrostatics are difficult for me to generalise about because I've only measured two: the Sonoma and Stax's Lambda Signature. The latter performed much the better, having a less cluttered CSD than the Model One, but still generated a 'grassier' result than the HD 800 S.


Sonoma Model One electrostatic headphones

Figure 3. Cumulative spectral decay waterfalls for (a) Sonoma Model One, (b) Dekoni Blue and (c) Sennheiser HD 800 S. Although the first two have planar drive units, they display more resonances than the moving coil Sennheiser

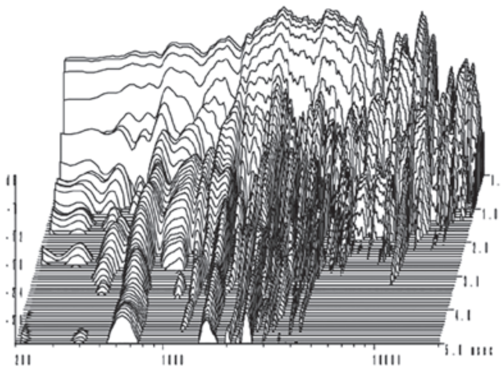
Fig 3a

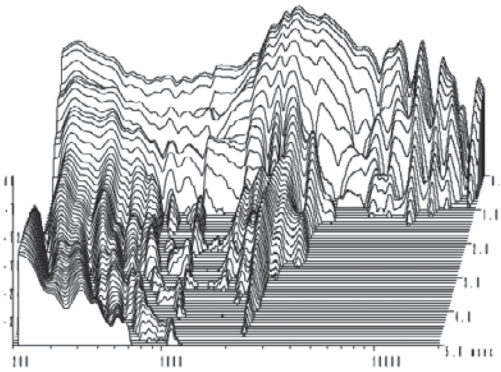
Fig 3b

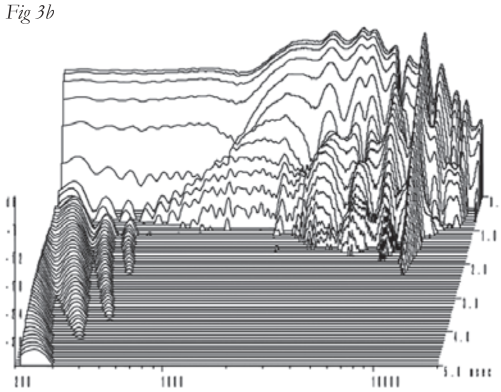
Fig 3c

The message to take away from this is that it's careless to presuppose what the resonance performance of any given headphone will be based solely on its driver type. To be sure how it performs, you have to measure it.

Bye-Bye Bass

When a headphone's frequency response is measured – which, as we've established, is rare in reviews these days – it is normal to do so in circumstances that ensure, as far as is practicable, an airtight seal of the earpads to the artificial head (with circumaural headphones) or to the artificial pinna (with supra-aural headphones). This is a perfectly reasonable, sensible way to measure headphones – but only if you concede, in the case of circumaurals, that it's an idealistic condition only likely to be achieved in normal use if the wearer is bald and doesn't wear spectacles. When earpads 'seal' against hair or around the temple bars of a pair of spectacles, airtightness is a utopian dream. What actually happens is that there is leakage, and this can play havoc with a headphone's bass output.

For years I've commented informally on this in lab reports. Headphones with sealing issues tend to evince significant variations in low frequency response even on an artificial head if, as I do, you perform not a single response measurement per capsule but rather 10 in succession, between each

Sennheiser HD800 close-up

Figure 4. How headphone frequency responses are affected by earpad sealing. The closed-back Focal Stellia (a) and open-back MrSpeakers Ether² (b) both lose a lot of bass output if the reference measurement (blue trace) is repeated with a spectacles' temple bar (red trace) or simulated hair (green trace) compromising the earpad seal. By contrast, the Quad ERA-1 (c) – like many open-back designs – is essentially unaffected

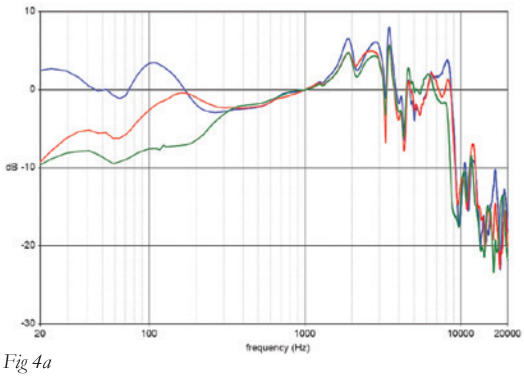

Fig 4a

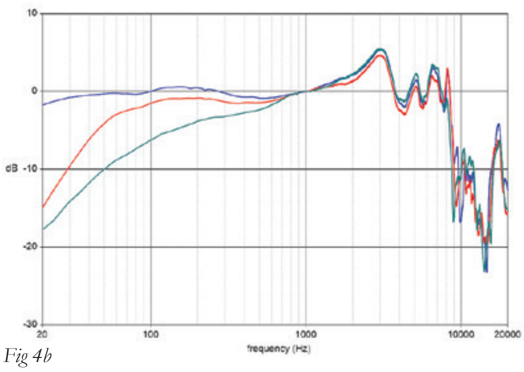

Fig 4b

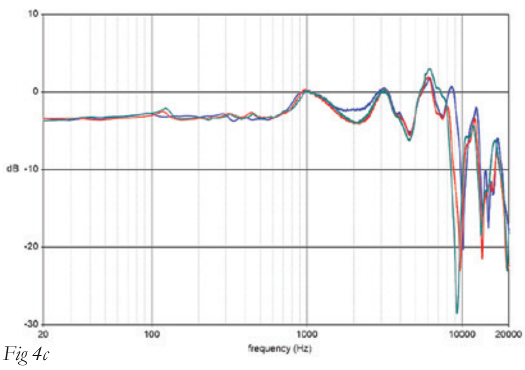

Fig 4c

of which the headphone is removed and re-seated. As part of my measurement post-processing the mean and standard deviation of the 10 responses is calculated, the latter making it easy to see where the largest variations occur. Differences at high frequencies are expected, caused by small changes in positioning of the headphone capsule on the artificial ear – which is precisely what the procedure is intended to capture. Significant differences at low frequencies are not and indicate a sealing problem.

Recently I've expanded my measurement regime to investigate this issue more closely. Now I perform three sets of 10 frequency response measurements per capsule: the first as described above, the second with a thick spectacles temple bar bolted in place over and behind the artificial pinna, and the third with a shaped pad of 6mm-thick hemp mat attached to the artificial head, simulating hair. (Hemp has a range of fibre thicknesses similar to human hair.)

What this extra testing has revealed is just how severely some headphones react to compromised earpad sealing, and how tolerant of it others are. Closed-back headphones are generally the sensitive ones, open-back headphones the relaxed ones. But there are exceptions, as revealed in the uncorrected frequency responses of Figures 4a, 4b and 4c, which were obtained from the Focal Stellia (closed-back), MrSpeakers Ether² (open-back) and Quad ERA-1 (open-back) respectively. In each graph the blue trace shows the mean response measured conventionally, the red trace the mean response with the temple bar, and the green trace the mean response with the 'hair'.

Clearly the Stellia (4a) is quite badly affected by compromised earpad sealing, losing 10.6dB of bass output at 23Hz because of the temple bar and 11.6dB because of the 'hair'. Surprisingly, the open-back Ether² (4b) fares even worse, losing 11.5dB and 15.4dB respectively – and note how high in frequency the losses begin. The ERA-1 (4c), in marked contrast, is barely affected by either challenge to its sealing. The same is true of other open-back designs I've measured recently like the HIFIMAN Sundara, Arya and Susvara, but not the KLH Ultimate One which, like the Ether², does not take kindly to less than perfect sealing.

Given that headphone tonal balance is already a controversial issue and headphones generate widely differing responses on different real ears, this is a further variable we could very well do without. Almost certainly it explains, in part at least, why different listeners' reactions to the tonal balance of certain headphones can be so diverse.

Guilty or not guilty?

So, to return to my opening theme: have I talked up the importance of measuring headphones (with a dash of creativity) out of self-interest, or because the results really do matter to headphone buyers? I hope you're persuaded of the latter.

Measurements will likely never tell us exactly how a headphone sounds. As with everything to do with human hearing, there are too many factors and too many subtleties involved for measurement to achieve that feat. But headphone measurements, correctly performed and carefully contrived, are an important adjunct to subjective assessment. If anyone chooses to tell you otherwise, I suggest that they're the ones with a hidden agenda.