Headphone Essentials 5:

Wrapping your head around the whole flat/neutral/ Harman thing

Note: this document is part of a instructional series. If you would like to start with more foundational information on the nature of sound and related material, see *Basics of Musical Sound*, *Basics of Headphone Sound* and *The Skinny on Headphone Frequency Response Graphs* at Headphone Essentials.

This document focuses on the frequency response or tuning of over-ear and on-ear headphones. In-ears have a related but different frequency response regime. This document is a summary and synthesis of available research written by a headphone enthusiast for other headphone enthusiasts. My aim is to present the material in a readable, non-technical manner. Thus inevitably, I gloss over many complexities. This analysis and interpretation of the available research is purely my own. I provide references to easily available source material so you can form your own opinions.

The search for accuracy

If you go to the store to buy a light bulb, chances are you're looking for one that produces white light. Red, purple, blue, green, etc. make for fun and games. But for boring old practicality it's hard to beat white. White light is a mixture of all other hues except black. White light is also the colour of sunlight during the greater part of the day. Illuminating things with daylight white light maximally reveals the colours of objects from apples to zebras. This happens because our eyes and brains evolved to make it so.

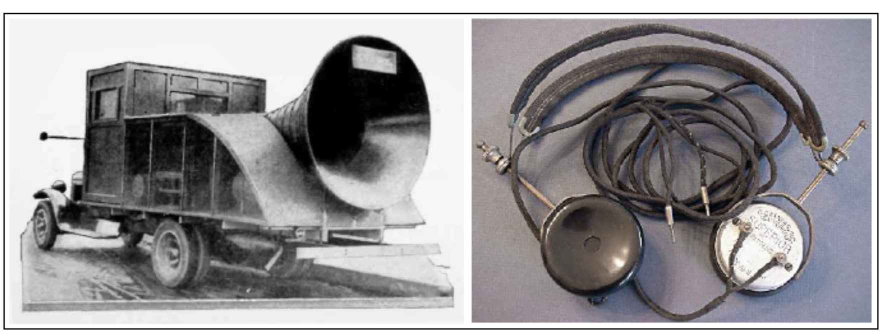

Fig. 1: left: horn loudspeaker truck, 1929, first commercial headphone, Brandes Superior Matched Tone, circa 1919-21. Photo credits: left: C. Sterling Gleason, right: John Davidson, License

Roughly the same situation exists in audio reproduction, except here we're dealing with sound instead of light (and reception instead of transmission). Testing consistently demonstrates that loudspeakers with a flat frequency response when in an echo-free environment are still the most accurate option for sound reproduction in a reverberant environment, such as a room or concert hall. Flat in this context means that the sound coming out of the speaker at all frequencies or pitches from deepest bass to shrillest treble is the same loudness as the electrical signal going in, like so:

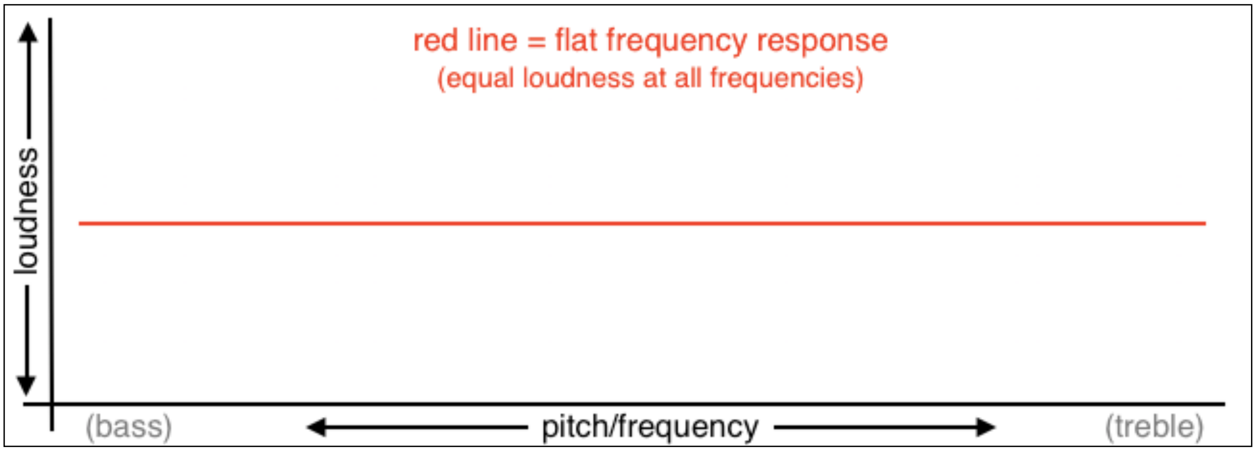

Fig. 1: flat frequency response (treble = beyond soprano)

Note: To get a better feel what this means you may want to go to the Online Tone Generator. Make sure the volume on your computer is initially set to a fairly low level, then press the space bar once to turn sound on, then move the slider fairly slowly and evenly left and right. If the sound changes in pitch but not in loudness you're hearing a flat response. If it gets louder and softer as you move the slider, that's a non-flat response. If possible, try this with more than one headphone or speaker to see how they vary (remembering to start at a low loudness level with each one). As is typical, the speaker built into my laptop doesn't produce any sound at all to the left of 100 Hz.

There is, however, a complication. When loudspeakers are used in a room, their sound output reverberates off the room's walls and other surfaces. The result somewhat emphasizes lower frequencies over higher frequencies. This is called *room gain*. It is this modified version of flat that our ears expect when listening to recorded music. There is no one version of this — even mix and mastering studio acoustics are notoriously all over the map — but the general idea is:

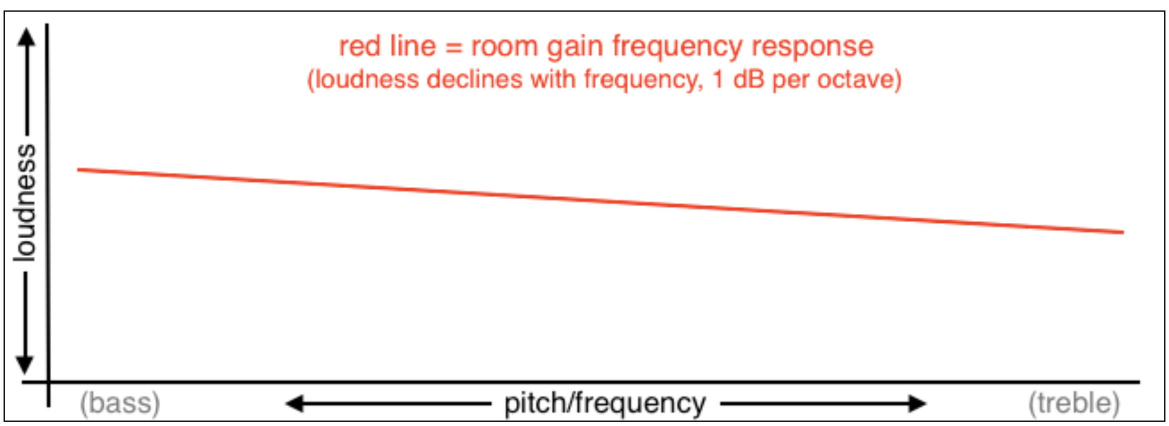

Fig. 2: room gain frequency response

The problem is that headphones ***wreak havoc*** with this simple relation between electrical signal going in and the perceived loudness of the sound coming out. We listen to loudspeakers by means of the sound pressure waves they generate in the air between the loudspeakers and our ears. Our brains were designed by millions of years of evolution to optimally interpret sound waves in a relatively large space, whether that be a room, a concert hall, a cave or the great outdoors. Plus, the particular shape of our outer ears and ear canals was designed to selectively amplify higher frequencies compared to lower/deeper frequencies. So if we measure the loudness of different frequencies at the eardrum instead of outside the ear, the results look something like this:

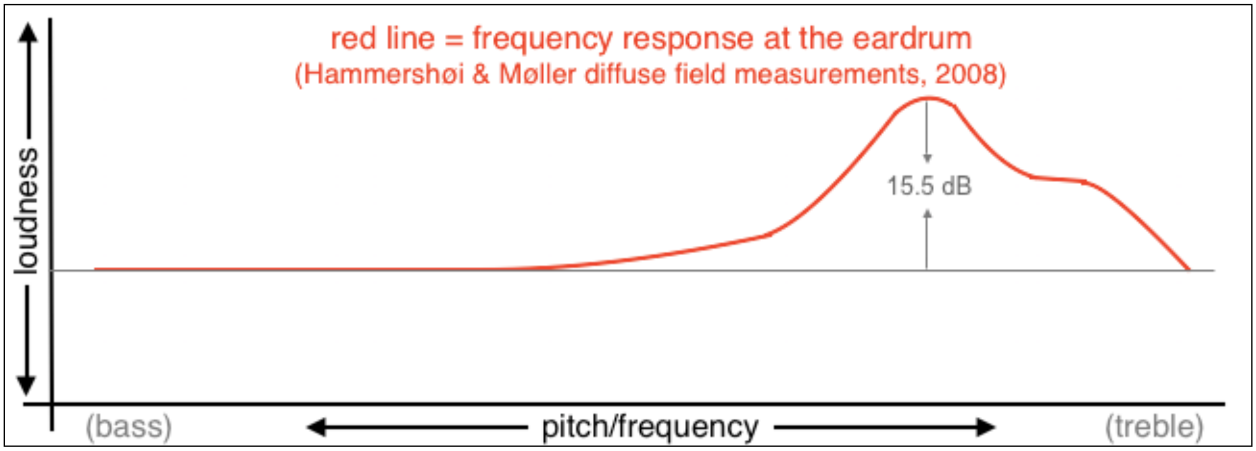

Fig. 3: eardrum frequency response (in an evenly reverberant room)

Note that this is what our ears do to a flat-line signal. What we actually ***experience*** after our brains process this signal is ***subjectively right back to a flat line*** again. In other words, our brains make use of the ear's boost of e higher frequencies to detect faint sounds. Our brains bring those faint sounds to our attention but ***not*** the loudness boost it used to recognize them.

Unlike loudspeakers, headphones beam the sound waves directly into our ears. This by-passes much of our ears' natural high frequency amplification (and additionally eliminates many of the cues our brains interpret for directionality). So a headphone that produced sound like Fig. 1 or Fig. 2 would sound drastically weaker in the high frequencies because the Fig. 3 boost our brain expects to receive from our ears is missing.

The upshot is that headphones have to be deliberately designed to artificially boost high frequencies to compensate for the problem they create by being coupled directly to the ear. So the frequency response of a pair of headphones should look more like Fig. 3 than Fig. 1. But not quite. At least for recorded music listening we also need to factor in a loudspeaker room gain element such as shown in Fig. 2. When we merge Fig. 2 and Fig. 3 we get:

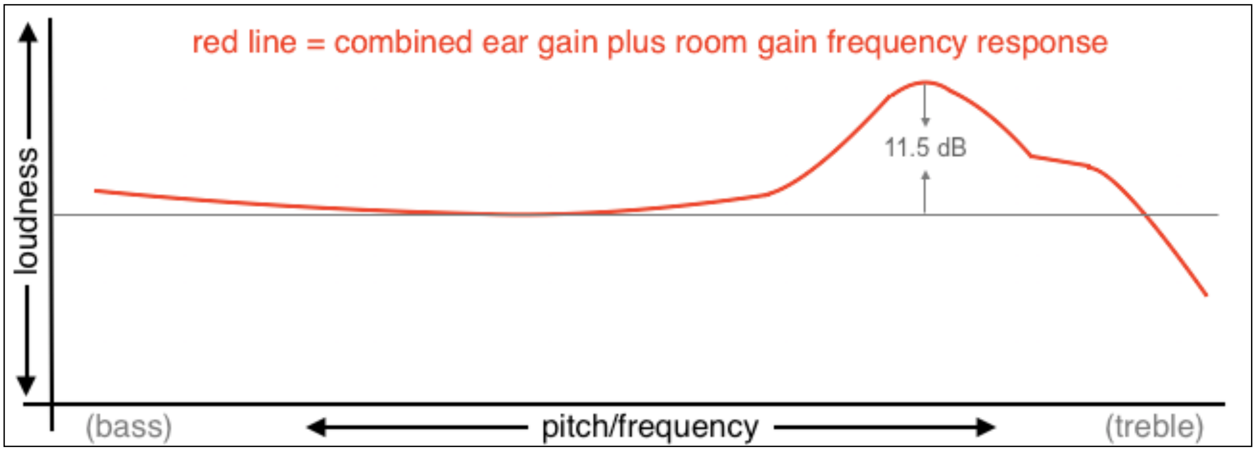

Fig. 4: eardrum + room gain (-1 dB per octave). (See also Warren TenBrook: InnerFidelity.com.)

Fig. 4 may not look all that different from Fig. 3. But the peak of Fig. 4 is crucially 4 decibels lower than that of Fig. 3. A headphone that transmits sound as shown in Fig. 3 would sound uncomfortably piercing in the high frequencies at otherwise comfortable loudness levels.

Apparently, the headphone company Sennheiser conducted similar research. Their venerable HD 600 model fairly closely follows the Fig. 4 curve, except for some fall-off in the deep bass that is difficult to overcome with a standard speaker-cone type driver and some recession between 1 and 2 ½ kHz:

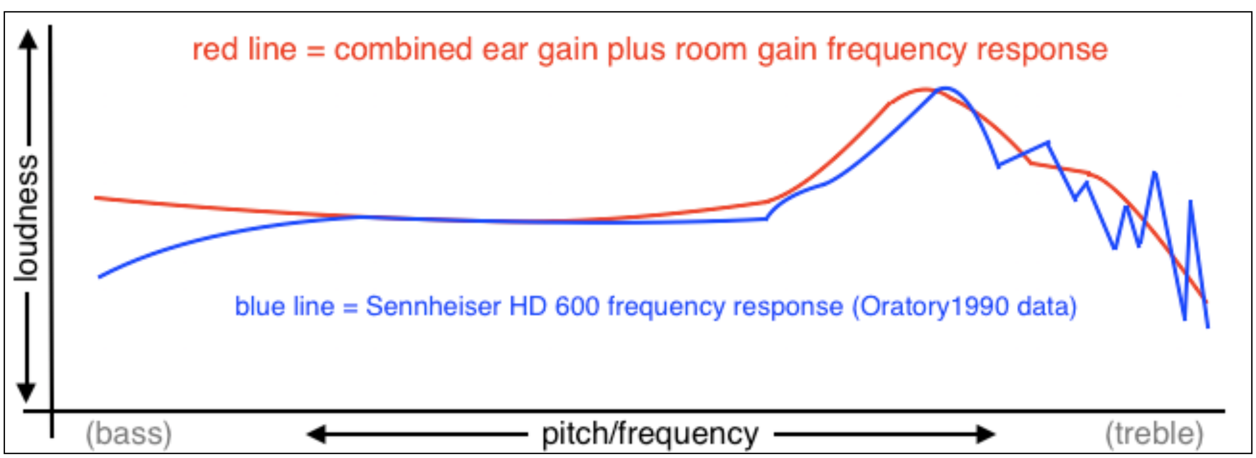

Fig. 4b: Sennheiser HD 600 compared to eardrum plus room gain
(source: based on Oratory1990: reddit.cpm)

In its product manual Sennheiser simply refers to the HD 600 as being tuned to a diffuse field response, the technical term for Fig. 3. We see from Fig. 4b that in fact Sennheiser used a diffuse field response modified to correct for room gain. A true, unmodified, diffuse field response would resemble Fig. 3 and would have a much more prominent ear amplification peak.

So Fig. 4 shows us a rough equivalent of daylight white light for headphones. Fig. 4 gets us in the right ball park of a practical tuning, or frequency response, one that would more-or-less accurately reproduce the loudness aspect of recorded sound. However, there are still some further factors to consider. (Are we having fun yet?)

One factor is that people who listen at high loudness levels are more likely to prefer an even more reduced ear amplification peak and higher frequencies as being less piercing. This also depends on the type of music involved, since some instruments — for example, electric guitars, synth, and violins — tend to have a lot of high frequencies in their sounds.

Photo credit: morphological study, License

Another factor that impinges on Fig. 4 is the great variety of shapes and sizes people's ears come in (https://link.springer.com/article/10.1186/s41935-019-0111-0). And this is true for the high frequency shaping ear canal as well as the more obvious outer ear. Again, for loudspeaker listening this isn't an issue. Our brains know how to compensate for our own ear anatomy.

But for headphone listening it very definitely is an issue. Fig. 4 may be close to accurate for a person with a hypothetical average human outer ear and ear canal, listening at some standard loudness. It's unlikely to be completely accurate for you. And the differences modify the shape of the ear amplification hump in Figures 3 and 4. (Technically, this is called the *head-related transfer function* or HRTF.) The differences also wreak havoc on the high frequency cues our brains use to localize the source of a given sound.

The upshot of all this is that, if you happen to want or need to hear an accurate frequency response from a pair of headphones, even Fig. 4 will only take you part way. There simply is ***no single frequency response graph*** that will be accurate for even the majority of individuals. Fig. 4 was:

1. based on Fig. 2, which ***approximates*** one of many possible room gain slopes
2. based on Fig. 3, which ***assumes*** equal reverberation from all directions (diffuse field), ***assumes*** an average ear anatomy, plus diffuse field measurement results differ
3. based on a ***reasonable*** loudness level
4. based on a theoretically ***average*** human ear anatomy.

But peel yet another layer off the onion and yet another question emerges — does any of this matter? I noted above that your brain is designed to automatically compensate for the amplification resulting from the particular shape of your ears under normal circumstances. It is also designed to compensate for the often wildly varying acoustics of one room versus another and for any enclosed space versus the outdoors. Given a chance, your brain will also compensate for a certain amount of departure of a given headphone from the frequency response that would be accurate for your ear shape and listening loudness. Your brain creates a model of how your headphone departs from accurate at each frequency. It then uses that model to correct for those inaccuracies.

There seem to be limits to this, particularly at higher frequencies, on how much inaccuracy your brain can correct for. And switching from one model headphone to a different model at least temporarily defeats this ability. But given a chance your brain will learn to compensate for the inaccuracies of a reasonably accurate headphone. Audio enthusiasts call this familiar phenomenon *brain burn-in*.

Given all the above, something like Fig. 4 can be used as a reference point when shopping for a headphone when the goal is accurate recorded music listening. Your brain will overcome some departure from Fig. 4 in some areas. Too much departure from Fig. 4 may well result in a persistent frequency response annoyance, such as boominess, muddiness, sibilance or shrillness.

The search for the fun factor

Fig. 4 would be a good target for headphone designers to shoot for if the goal were to please the perhaps five percent of potential customers who want accuracy and who listen at moderate loudnesses. Presumably, the other 95 percent are looking for something more like this:

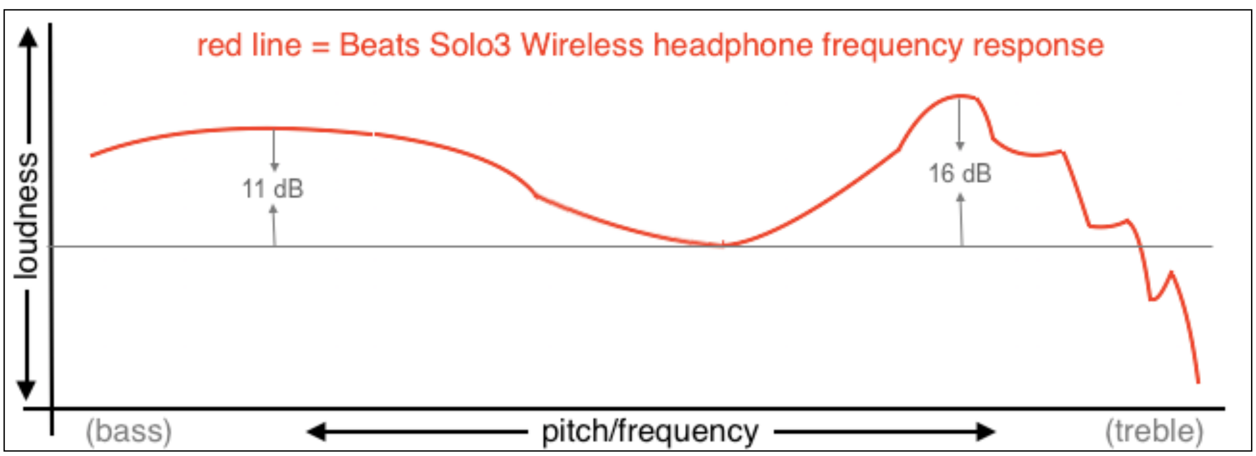

Fig. 5: example consumer preference curve .(Source: rtings.com)

And many headphones actually measure more or less like Fig. 5. This is what consumer demand dictates. Immediate grab. Instant party time. The problem is that it fails miserably when listening to something like a jazz performance or a love ballad, where voice and instrument quality actually matters:

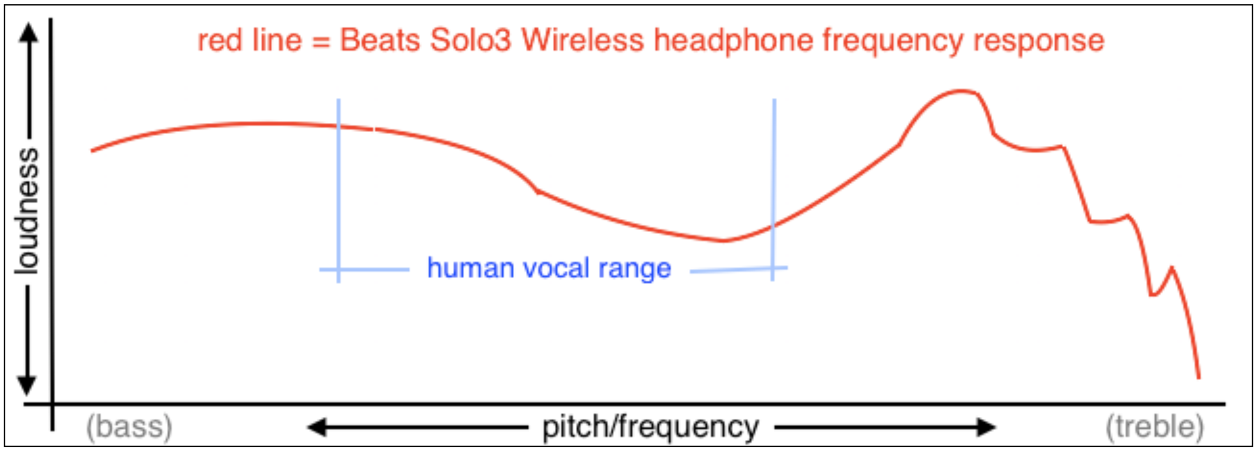

Fig. 5b: vocal range

Compare the portion of the red line in Fig. 5b between the two blue lines with the same portion of Fig. 4, which is very nearly flat. It's generally still possible to recognize a singer's voice even when distorted as extremely as shown in Fig. 5b. It's also possible to recognize yourself stretched and pinched in a fun house mirror. Whether that's what you want to look like is another matter. (Of course, I exaggerate. It's really more of a muffled sound, like listening to someone through a wall of mattresses.)

Sean Olive, Todd Welty and colleagues at Harman International (not pictured above) set themselves the challenge of finding a single frequency response curve for headphones that would be most enjoyable to the greatest percentage of people … but. importantly. remain enjoyable while listening to a wide variety of music. Their result looks something like this:

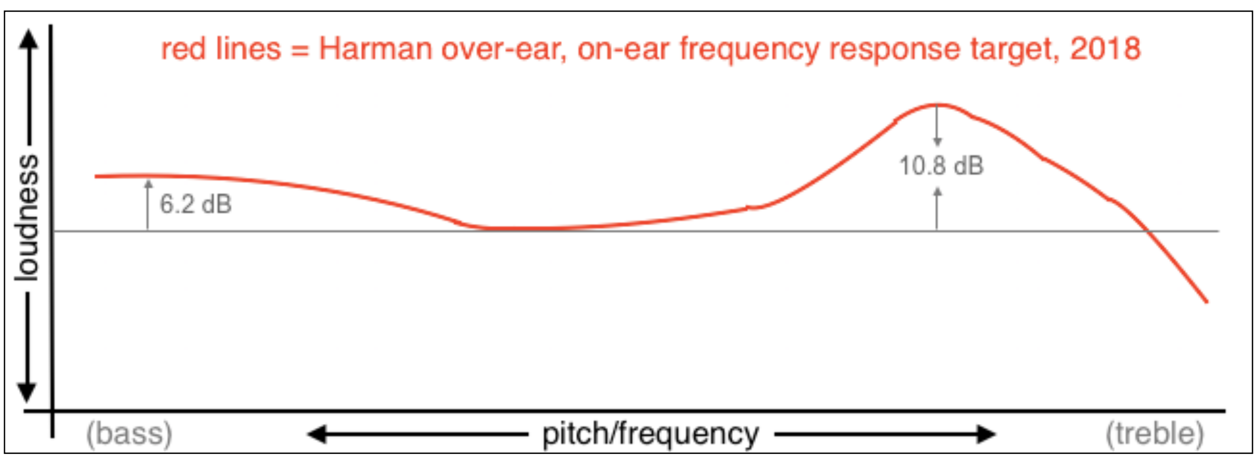

Fig. 6: Harman target. Source: InnerFidelity.com.

As a nod to consumer preference there is definitely a bass elevation. But it gently comes to an end where the bass range does — before the mid/vocal range. Also, the ear amplification peak is slightly lower than in Fig. 4 to accommodate loud listening levels. This curve was achieved by having about 250 people of different ages, sex, nationality and auditory training freely modify the bass and treble response of a headphone while listening to a variety of music samples.

However, it's not that everyone came up with the same curve. Instead there was a range of variance something like this:

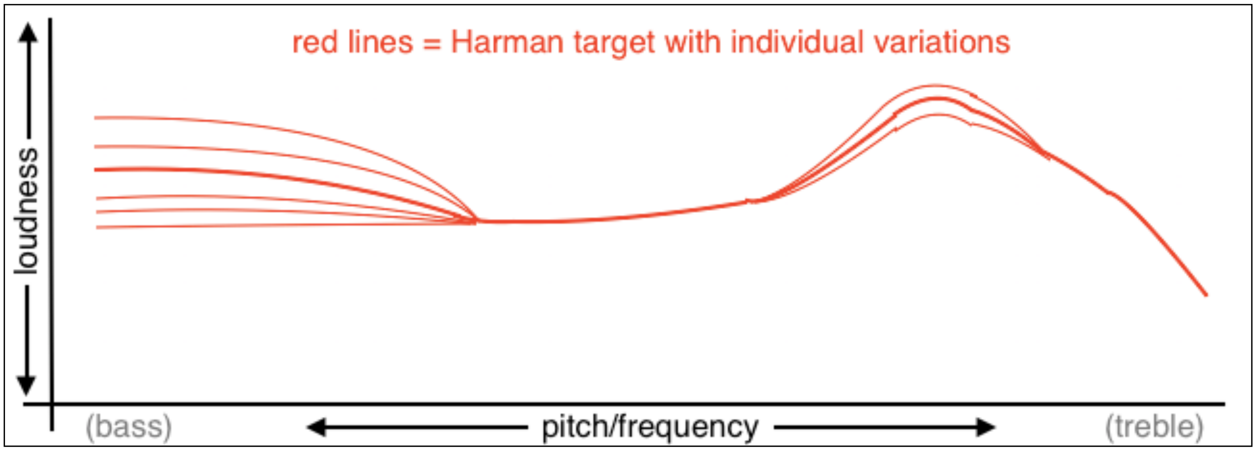

Fig. 6b: Harman target plus some individual variations. Source Oratory1990, Sean Olive.

(Yes, at least one individual actually preferred a slight bass reduction.) If the neutrality curve of Fig. 4 is a daylight white light bulb, the Harman target curve in Fig. 6 is a warm white light bulb. In other words, a compromise between strict practicality and the dictates of the human auditory pleasure response.

Some take-aways

In the world of 2-channel loudspeakers, listening to an accurate loudspeaker is easily described by its flat-line frequency response when room effects are removed. But those very room effects are the great challenge for 2-channel. Given the variation that exists, they can only be approximated as some sort of down-sloping line.

In contrast, in the world of over-ear and on-ear headphones, room effects are virtually eliminated. The challenge is re-creating a natural ear amplification. The combination of this re-created average ear amplification curve plus a room gain downslope is at least a ball park approximation of the frequency response of an accurate loudspeaker system in a hypothetical ideal room. That said, there can be no one truly correct/accurate headphone tuning, due to room gain and ear shape issues. Even so, brain adaptation can and often does compensate for these issues.

In any case, accuracy does not drive headphone sales. A headphone with market appeal typically has a highly boosted bass response that extends well into the mid-range frequencies, distorting vocal and instrumental sounds. The Harman frequency response curve is a carefully researched compromise between strict accuracy and consumer preference. But by its very nature it is a compromise that will be good for about ⅔ of potential consumers.

Addendum: Obscure technical material

For those with a more technical bent, here is the Fig. 4 eardrum + 1 dB/octave room gain graph plotted to the common logarithmic scales and labelled:

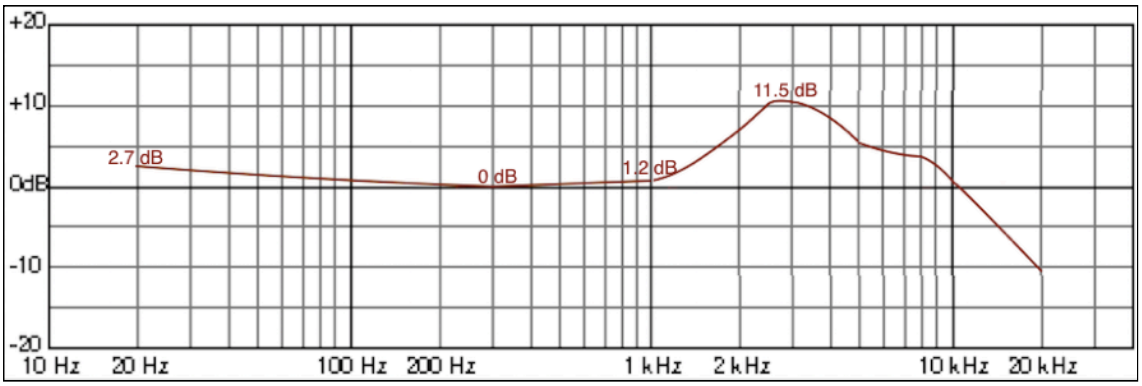

Fig. A1: H&M DF + 1 dB/octave room gain

An earlier study by the acoustics technology firm Brüel & Kjær showed some roll-off in the bass. When combined with the diffuse field curve we get:

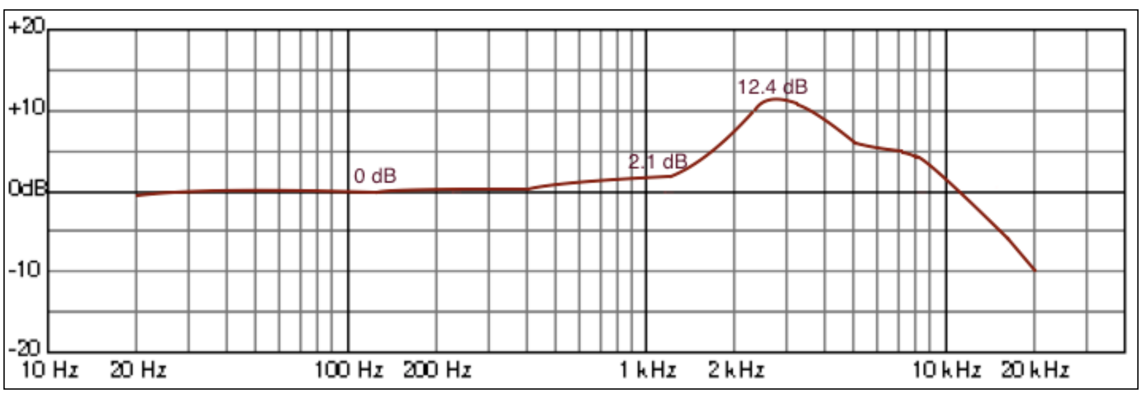

Fig. A2: H&M DF + B&K room gain

Again, there is no one correct curve and Fig. A2 may well be closer to what Sennheiser was targeting with the HD 600.

Finally, here is my rendition of the 2018 Harman target curve to the same scale for comparison:

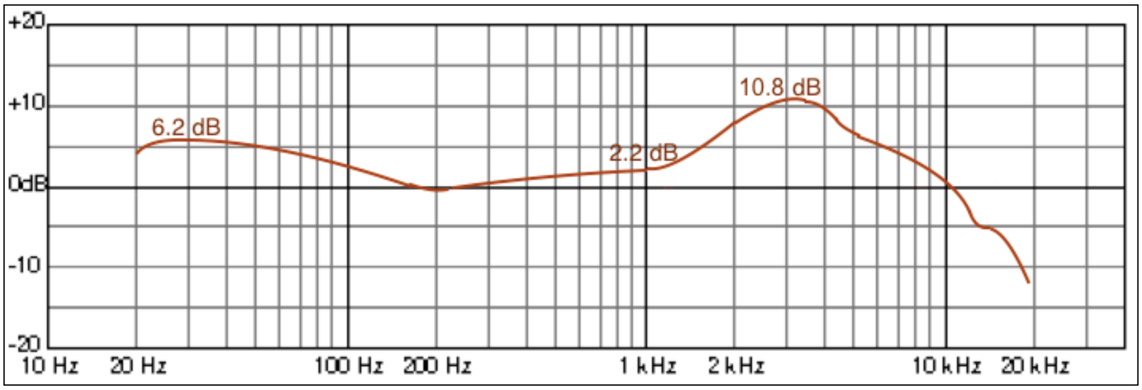

Fig. A3: Harman target, 2018

The ⅓-octave decibel numbers I used for plotting these graphs may be found on my website at https://daystarvisions.com/Music/31-band_HP_EQ_values.csv. The Hammershøi & Møller and the Brüel & Kjær numbers are estimates based on visual inspection of the published graphs and have no greater authority than that.

Some source material and further reading:

5. D. Hammershøi and H. Møller, "Determination of Noise Emission from Sound Sources Close to the Ears", *Acta Acustica*, Vol.94 No.1 (January 2008)
6. Brüel & Kjær, "Relevant loudspeaker tests in studios in Hi-Fi dealers' demo rooms in the home etc." (1974), https://www.bksv.com/media/doc/17-197.pdf
7. Wikipedia, "Head-related transfer function", https://en.wikipedia.org/wiki/Head-related_transfer_function
8. Tyll Herstens, "Headphone Measurements Explained - Frequency Response Part One", https://www.innerfidelity.com/content/headphone-measurements-explained-frequency-response-part-one
9. Warren TenBrook, "Warren TenBrook's Summary of Head Measurements at Harman", https://www.innerfidelity.com/content/warren-tenbrooks-summary-head-measurements-harman
10. Warren TenBrook, "An Acoustic Basis for the Harman Listener Target Curve", https://www.innerfidelity.com/content/acoustic-basis-harman-listener-target-curve
11. Oratory1990, "Differences between the Harman Curve and Diffuse Field", https://www.reddit.com/r/headphones/comments/78x77b/initial_impressions_of_2016_audeze_lcd2f_with/doyj84e/
12. Oratory1990, list of EQ presets [and measurements], https://www.reddit.com/r/oratory1990/wiki/index/list_of_presets
13. Sean Olive, Do Listeners Agree on What Makes a Headphone Sound Good?, https://www.youtube.com/watch?v=f1EVZVDaeLw
14. Olive and Welti, AES 139 Presentation 2015 Olive and Welti Preferred Bass and Treble Levels, https://www.youtube.com/watch?time_continue=2&v=ySQV5OR71e4&feature=emb_logo