Headphone Essentials 3:

Basics of Headphone Types and Tech

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Note: this document is part of a instructional series but does not depend on material covered by previous units. The series can be found at Headphone Essentials.

Headphones vs loudspeakers

Fig. 1: left: Focal Celestee over-ear closed-back headphone, right: Harbeth room loudspeaker.

We are immersed in three different types of sound production in our everyday lives: live, reproduced via loudspeakers, reproduced via headphones. The obvious difference between headphones and room loudspeakers is size. But the functional difference is that room loudspeakers are separated from the listener and transmit sound into a surrounding volume of air. Headphones are placed directly next to the listener's ears and transmit sound directly into them (this is called *direct acoustic coupling*).

Our ears and brains were designed by a mere few hundred million years of evolution for optimum processing of live sound waves reverberating in a large mass of surrounding air. Consequently, headphone designers face a very different set of hurdles than loudspeaker designers. Despite a century of on/off progress, headphone design is far from being a pinnacle of perfection.

Vocabulary snafu: the term ***loudspeaker*** is confusingly used for two different but closely related things. Loudspeaker is the word for the actual sound producing component — but also for a box containing one or more loudspeakers. I'll use the phrase room loudspeaker to refer to the later and use the word *driver* to refer to the internal component.

Over-ear, on-ear, in-ear

Fig. 2: A) **over-ear** (Sennheiser HD-600), B) **on-ear** (Monster Beats Solo HD, C) **in-ear** (Etymotic ER2SE/XR), D) AKG **ear buds**

This is the easiest aspect of the headphone universe to understand. A headphone exists to get sound into your ears. *Over-ear* headphones (Fig. 2-**A**) do so by enclosing each ear in a full-sized ear cup. *On-ear* headphones (2-**B**) rest upon the ear but don't surround it. *In-ear* headphones or earphones (2-**C**) (often called *in-ear monitors* or IEMs for historical reasons) are smaller yet and insert part way into the ear canal. *Ear buds* (2-**D**) are small enough to fit in what's called the concha bowl of the ear just in front of the ear canal.

As a broad generalization the best over-ears provide the best sound quality but are heavier and less portable. On-ears tend to compromise a bit on sound quality to achieve better portability. In-ears are generally at least slightly compromised in sound quality — but rapid progress is steadily chipping away at that — and often have comfort issues until just the right ear tip is identified. Ear buds are the easiest to manufacture at an extremely low price point but the hardest to get to produce even a decent sound.

Open backs, closed backs

Reverberation is the biggest bug-a-boo for headphone and speaker designers to overcome. The *ear cup* (large ovals in Fig. 2-**A**) of an over-ear or on-ear headphone is a little echo chamber that distorts the sound of the vibrating driver before the sound even reaches your ear. The company Sennheiser was the first to side-step much of this problem by replacing the solid back (outer surface) of the ear cups with a grill or mesh so that sound produced by the side of the drivers farther from the ears can escape instead of bouncing around. This is called *open-back* design (see Fig. 2-**A:** the interior of the ear cup can be seen through the mesh). This negates one of the main advantages of the headphone concept, namely isolation, but greatly aids in sound quality.

Another disadvantage of open-back is the difficulty in achieving enough loudness in the bass frequencies. Closed-backs (see Fig. 2-**B**), if anything, typically have a problem with too much and too boomy bass. One approach is to compromise with semi-open designs. Headphones labeled as open-back are likely to have some degree of closure (and therefore isolation). Conversely, most closed backs deliberately leak a certain amount of sound, especially in the lower frequencies so perfect seal with the head isn't necessary for a good bass response. Porous ear pad materials and tiny vents in the back of the ear cup are used to control the degree of seal/closure.

Active (wireless and noise-cancelling) vs passive

A “normal” headphone typically connects to the sound source by means of a wire or cable that terminates in a headphone jack. This is called *passive* technology, meaning the headphones do nothing but receive the electrical sound signal from the source device. One form of *active* headphone is *wireless* and uses an electronic receiver to acquire the sound signal from a transmitting source device (now often using a Bluetooth protocol).

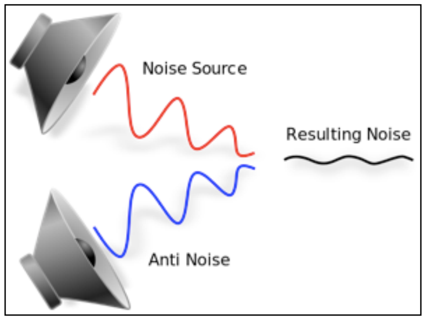

Fig. 3: active noise cancelling. (Image credit: Marekich, License)

Another form of active headphone is *noise-cancelling*, these are usually wireless as well. Noise-cancellers use tiny microphones to acquire the sound surrounding the listener, then feed that sound back *out of phase* to the listener’s ears along with the desired audio signal, such as a telephone conversation or music. Out of phase simply means there is a very slight and precisely-timed delay between two otherwise identical sounds, as shown in Fig. 3. In essence, the sound pressure pulses from one speaker fill in the gaps of the sound pressure pulses of the other speaker, leaving the listener with an overall increase in air pressure but little or nothing to hear.

Driver technologies

For a headphone to work there has to be something inside to cause the air vibrations that in turn cause the eardrum vibrations that we hear with. This vibrating thing is called a *driver* or *transducer* and converts electrical pulses into sound. There are three main types of drivers: *dynamic* which have cones like room loudspeakers, plus *planar magnetic* and *electrostatic* both of which use flat membranes instead of cones to vibrate the air. Feel free to skip the technical details that follow.

Dynamic, AKA moving-coil

Fig. 3: 3 inch dynamic speaker cone. (Photo credit: Zephyris, License)

Dynamic drivers are the same tech used in the most common type of room loudspeakers. A cone of stiff material is set vibrating by the push/pull of a *voice coil,* or variable magnet, attached to the cone which reacts to another and permanent magnet. The voice coil’s magnetic strength varies with the electrical signal from the audio source. This technology is well understood and has a workable balance of strengths and weaknesses.

Planar magnetic

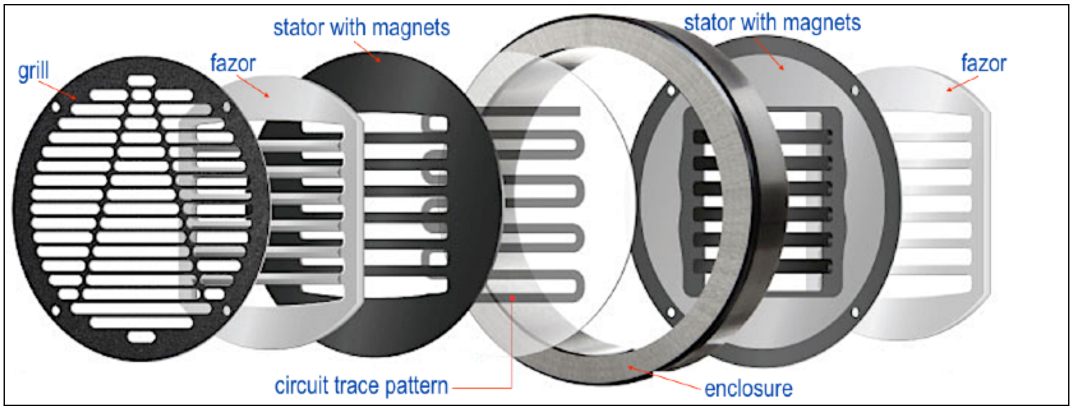

Fig. 4: Audeze diaphragm with double-sided magnets

Planar drivers have a thin, flat, light-weight membrane or diaphragm (often mylar) with an even pattern of magnetic material adhered to its surface (labeled circuit trace pattern in Fig. 4). This in turn is activated by a permanent magnet much as in a dynamic driver. Until fairly recently this technology was infrequently used in headphones but is now subject to a fairly rapid pace of research and development. Its inherent strength is that it tends to produce a fairly equal loudness from low to high frequencies. But it tends to have a problem reaching the highest frequencies. It also tends to be less efficient than dynamic drive, requiring more current flow to produce a given loudness.

(Planar drivers can additionally be divided into *orthodynamic*, meaning the magnetic material on the diaphragm is laid down in a serpentine pattern, and *isodynamic*, meaning the magnetic material on the diaphragm is laid down in a spiral pattern.)

Electrostatic

Fig. 5: Stax SR-L700 headphone with SRM-D10 portable amplifier

Electrostatic headphones are often called ear speakers. Like a planar, an electrostatic driver has a thin, flat membrane or diaphragm that causes air vibration. However this membrane is sandwiched between two plates that generate a static electrical field that induces the vibrations in the electrically charged diaphragm. This technology is prized for its low levels of sound distortion. But it’s major weakness is in how loudly it can sound — less an issue for headphones than room loudspeakers. Another issue is that electrostatic headphones require a separate specialized amplifier to generate the unusually high voltages it requires to operate.

Plus, there are several other driver technologies that are infrequently encountered. One that is causing some excitement as I write this is the HEDD Audio HEDDphone using an *air motion transformer* (AMT) driver, sort of a pleated planar diaphragm on steroids.

Limitations of today's headphone technology

We might think that with a century of continuous development loudspeakers and headphones would be pretty much perfected devices by now, but that's far from the case. To consider just one aspect by today's standards the measurement shown below in Fig. 6 are very good. We don't need to understand what aspect of headphone performance the graph in Fig. 6 is presenting (frequency response). The orange line shows the headphone's response; the green line shows one possible target that the measured response should ideally agree with:

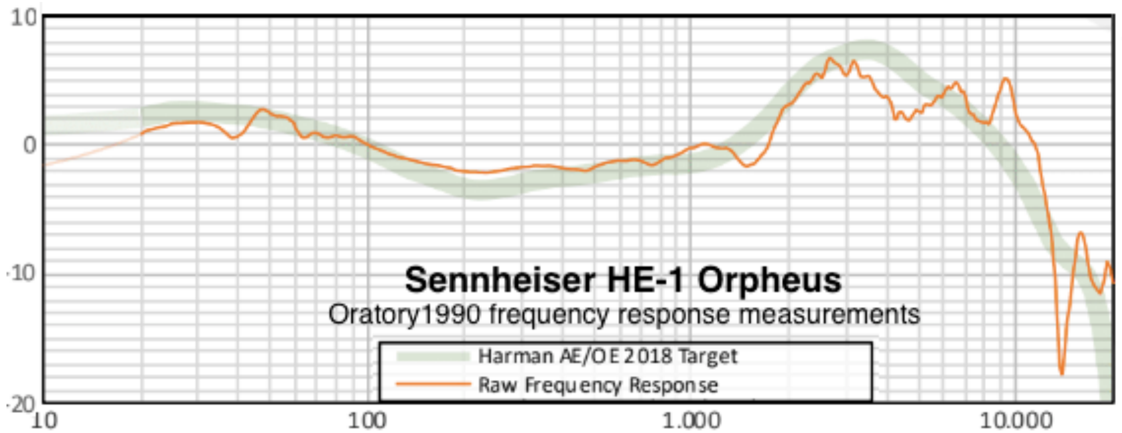

Fig. 6: measurements of a $59,000 headphone

It's not the orange line's (impressively small) departure from the green line that matters in this case. The *jaggedness* of the orange line measurement plot shows that it cannot *precisely* agree with any sensible target response. And again this is an excellent showing by today's state of the art. Few headphones the sell at anything like affordable prices come anywhere close to Fig. 6's accuracy and smoothness.

This inaccuracy could likely be all but eliminated by incorporating a form of active electronics called digital signal processing (DSP) into the headphone itself. But in the case of an expensive headphone such an unorthodox approach would presently be considered as unsatisfactory as attaching a Stradivarius to an amplifier in a concert recital. In part this is due to pure conventionality. But it also reflects that integrating digital electronics with traditional passive headphone design is fraught with technical challenges. Still, progress is rapid and a game-changer product is probably on someone's test bench even as I write this.

Yet another problem headphone designers face is the vast difference between individual's outer ear and ear canal sizes and shapes. This becomes especially significant at high frequencies. Our brains automatically compensate for our own ear acoustics, but people still have very different degrees of treble sensitivity. The right-hand portion of the wide, pale green curve in Fig. 5 is the optimal loudness level at each frequency for the large majority of people. The closer the design engineers can get to matching a headphone's loudness output to the right half of the green curve the more customers will complain neither of too much or too little treble. (The rise on the left is an average of personal bass levels preferences.)

Keep this in mind when you read or watch a headphone review. What the reviewer is hearing is very likely significantly different from what you would hear. Suppose you were beside him or her taking turns listening to the same recording by swapping the same headphone. You would literally be hearing different things. One person's high-pitched shrillness is another person's refreshing sense of clarity.

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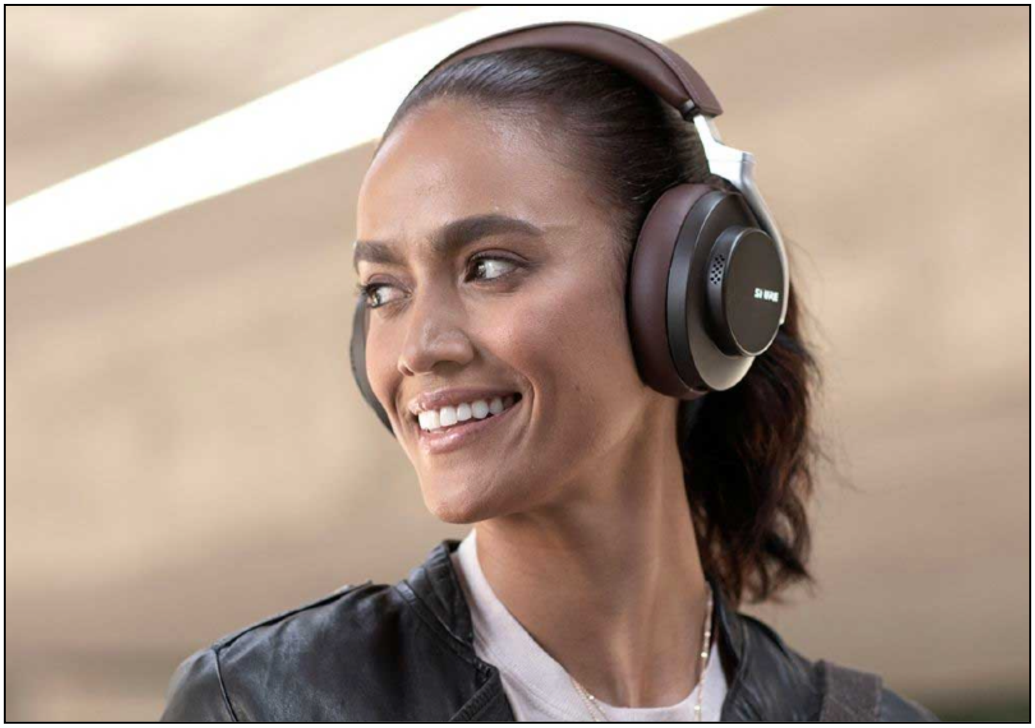

And that's it! You're now hep to the basic headphone design concepts. Be sure to proceed on to the next exciting instalment of this must-read Headphone Essentials series: *HE-4 The Skinny on Frequency Response Graphs* (http://daystarvisions.com/Music/index.html).