IEM Design

Designing a good sounding IEM can be quite a difficult without the right knowledge. Several factors are important for a good result, let's review some.

The Fitting

Bass from balanced armature drivers rely on the "pneumatic effect" of the coupled systems "ear canal-earphone". Poor sealing will act as a high pass filter, the more leakage the more the loss of low frequencies. Having a flat frequency response down to 20 Hz will not help if there is leakage.

A Correct Frequency Response

The ear canal has a natural resonance at 2.7-3 KHz due to its length, so it is very sensitive in this region. When an earphone is inserted into the ear canal, it will lose its natural resonance, so an earphone needs to be compensated in the frequency response for this loss, otherwise it will sound "muddy, dead" without any mids.

Extended High Frequency Resolution

The ear is also quite sensitive in the 8-10 KHz region, so it is important to consider the earphone's frequency response in that area, too much of these frequencies and the earphone will sound harsh, too brilliant and sibilant, not enough of these frequencies and the earphone will sound dark and lacking in harmonics and details.

Choice of the Right Drivers

Choosing the right drivers is not easy, the market offers so many different options that it is quite easy to miss the target. Impedance of the drivers is one aspect to consider, especially nowadays. Electronics become every day smaller and smaller to reduce power consumption and the modern music player or headphones amplifier that are powered from batteries often have an output impedance that is far from being low (a very good amplifier should have an output impedance from 0.1 to 0.5 Ohm). Connecting a very low impedance earphone to these devices will cause them to change the frequency response of the earphone because the power amplifier will not be able to deliver the right amount of current to the earphone, especially at low frequency where the content of the energy is very high and the amplifier should respond instantly to the signal (music). If the amplifier is unable to deliver the right amount of current at low frequencies the effect will be a "loss" or "slow" bottom end, without the right transient response. The same effect could be present at high frequencies, a very low impedance high driver will "stress" the amplifier, resulting in a harsh sound, even if the measured frequency response seems to be correct. On the opposite side, a very high impedance driver will sound very low, without power, because the amplifier will not be able to deliver enough power. In a multi driver IEM, every driver needs to be chosen for a specific range of frequencies in order to optimize the result, the total frequency response. A driver also needs to be matched with the other, to optimize frequencies overlapping at the crossover point, THD and impedance.

A good driver for lows should have a flat frequency response down to 20 Hz, because even if the perception of the low region from 20Hz up to 150 Hz is mainly physical, the human ear can hear down to 20 Hz so this information needs to be present (with a very extended low driver the earphone will sound more “real”, almost physical, and the bass will sound more fun).

A driver for the “mids” should have a low THD (the ear is very sensitive to distortion especially in the mid frequency region) and should be chosen and then optimized for the desired target (forward mids, backward mids, warm mids, analytical mids etc.).

A driver for the “highs” should have primarily an extended frequency response and low THD and as the mid driver should be chosen and optimized for the desired target.

Tubes and Dampers

For a balanced armature driver use a PVC tube to deliver the sound to the ear drum. A tube connected to a balanced armature driver will act as an acoustic tube with one end closed that resonate at ¼ of wavelength and multiples (3/4, 5/4, 7/4 etc.). This is because the driver has a relative low acoustic impedance compared to the ear drum, so the tube is seen with one end closed (the one connected to the driver) and one open (the one towards the ear drum) and then resonate at ¼ wavelength for which inside the tube will generate resonance peaks as a function of its length. This tube can be “tuned” in length and diameter to obtain the desired sound signature. A shorter tube will move the peaks up and a longer tube will move the peaks down, so this together with changing the diameter can be “used” to tune the system in the mid and high frequencies range. Obviously this peaks (and valley) are “irregularity” in the frequency response, so we need to dampen them with acoustics dampers.
Acoustics dampers have the ability to smooth the peaks introducing an acoustic resistance to the displacement of the air molecules, this resistance is available from 330 Ohm up to 4700 Ohm. Right values need to be chosen to dampen the peaks without affecting too much of the frequency response, furthermore the damper needs to be placed in the right position in order to work best. Usually the end of the tube. The one towards the ear drum should be avoided because the ear wax will eventually clog the damper.

Crossover and Electronic Components

To make the most of an IEM, one should design multi-way systems. A single driver will not be easily able to reproduce the entire human ear sound spectrum so it will be better to split the spectrum into two, three or more bands using dedicated drivers for every small band.
To make this, one should use a crossover. A crossover can be a simple first order low pass-high pass (a capacitor and a resistor) or two, third or quad order. Inductive low pass will not really be effective because the balanced armature drivers are already highly inductive.
Crossover points need to be carefully chosen to minimize the THD and the phase relationship between the drivers. To get good results, it is important to use capacitors and resistors with low tolerance and for the capacitors with low ESR that is the “Equivalent Series Resistance”, the resistance that a capacitor will “shows” in AC and that will affect the design, changing the calculated crossover point and at the end, the desired frequency response.

Acoustic Phase

A good frequency response needs to be accompanied by a good acoustic phase response. When two or more drivers are combined together we need to look carefully to the phase relationship between them. Sometimes two drivers have a good phase at the crossover point, but really bad interferences somewhere else and this interference will cause some audible artifact in the frequency response (often there will be some deep “valley” due to the destructive phase relationship).

A good acoustic phase will make an IEM sound very coherent (all the different instruments will sound together, the sound will be very compact) and with a wide soundstage.

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