HEADPHONE 101

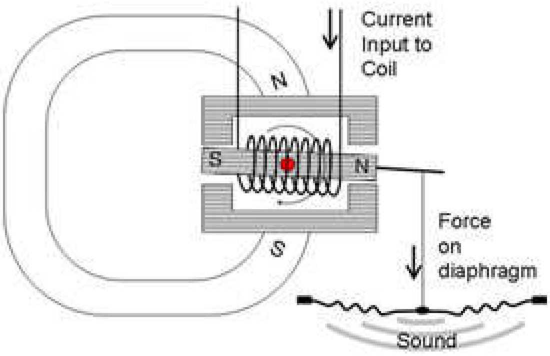
How Balanced Armature Receivers/Drivers Work

By Tyll Hertsens • Posted: Dec 15, 2014

Introduction

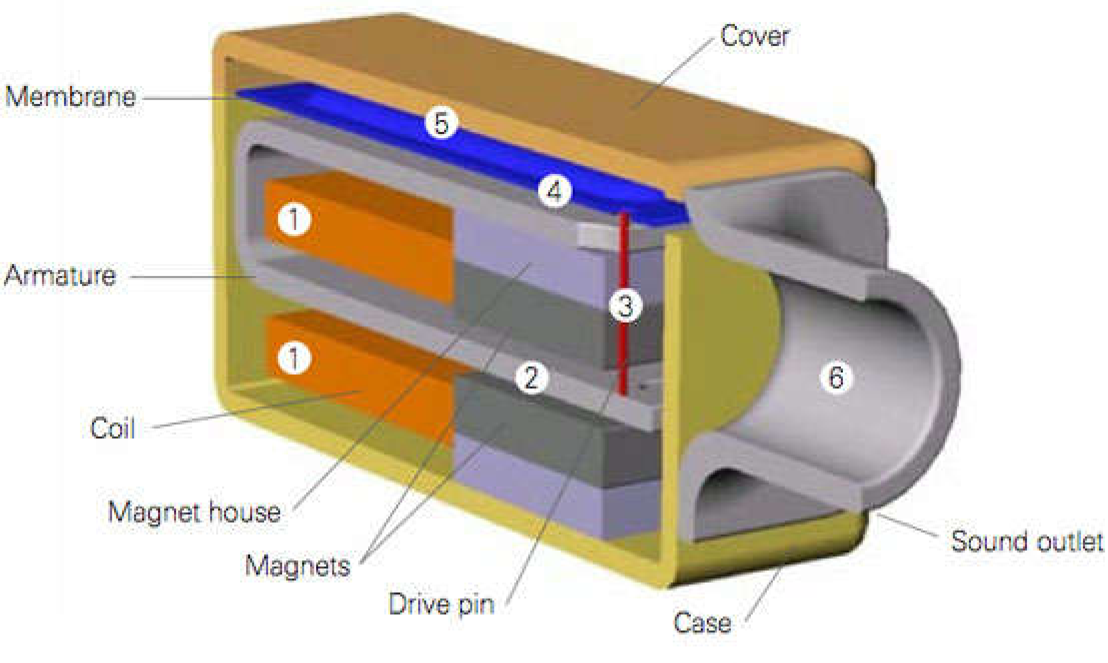
The technically correct term for this type of driver is a "balanced armature receiver." It's a bit confusing for enthusiasts as one would expect it to be a transmitter of sound, so it's commonly called a balanced armature driver by lay persons. I'll use them interchangeably in this article—just trying to be Google friendly.

I was surprised to learn that balanced armature drivers have been around since the 1920s primarily in headphones used with crystal radios. Of course, these drivers were much larger and fundamentally different than todays balanced armature devices. Diaphragms on these devices were sometimes mica.



One big advantage then (as it is now) is BA drivers are very efficient allowing them to be driven by the small signals from crystal radios or sound powered telephones used in the military. The reason why BA drivers are so efficient is because the armature (moving part of the motor, as opposed to the stator, the fixed part of the motor) is unstably balanced between two magnets and might easily, were it not for other parts of the mechanism, move too far and get stuck to the magnet. This instability also makes it very quick and easy to move with an electrical signal delivering very good efficiency. Unfortunately, it also makes BA drivers exhibit strong resonant characteristics, and damping methods must be employed to remove resonance peaks in the frequency response of BA drivers.

Balanced armature receivers in today's IEMs and hearing aids are quite a bit different than in headphones of old. Conceptually, the biggest difference is that current BA drivers don't have the "see-saw" pivoting armature like that shown in the diagram above. Todays drivers use an armature that acts mechanically like a diving board. Let's take a look inside a typical BA receiver used in today's IEMs and hearing aids.



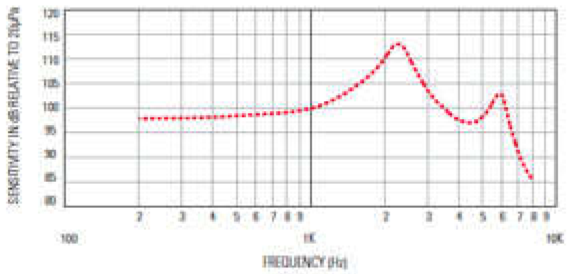
Generalized illustration of a balanced armature receiver.
Credit: Sonion

the innards of the receiver with better detail.

The incoming audio signal goes through a coil (1) that wraps around the armature (2). The electrical signal induces magnetic flux in the armature, which in turn causes the end of the armature to be drawn towards one of the poles of the permanent magnets. As the electrical signal goes up and down, so does the armature. (The top part of the "U" shaped armature is fixed in position, and only the bottom part moves up and down—sort of like a diving board.) A drive pin (3) at the end of the armature transfers the movement to the diaphragm (4). As the diaphragm moves up and down it changes the volume of air enclosed above the diaphragm (5) and produces sound that escapes out the front nozzle (6).

Typical BE Receiver Response

The graph to the right shows a typical BA receiver response as measured from the output nozzle directly into a 2cc measurement coupler. Generally speaking, the first peak is due to the combined resonance of the armature, armature dampers, and rear volume. The second peak is due to the combined resonance of the diaphragm and membrane, membrane tuning holes, front volume, nozzle filter, any tube between the nozzle and measurement microphone, and in-tube damping filters.

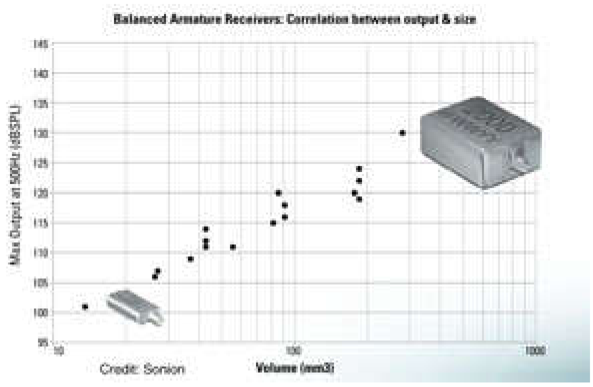


Design Variables

One look at the range of products from Knowles and Sonion and you'll understand that these devices come in many shapes, sizes, and internal configurations. Efficiency, bandwidth, tonal character, and durability are all effected by numerous design variables of the various products. Here are some of the important variables used to control the performance of a balanced armature receiver.

Internal Volume

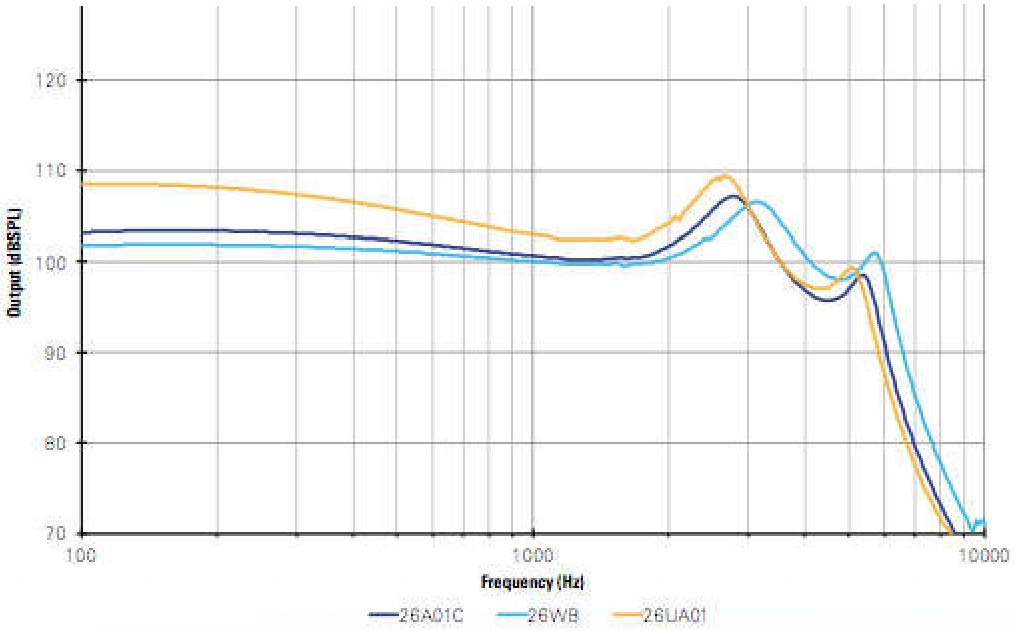
The size and internal volume of a BA drive have a strong effect on the maximum output level. The larger the BA receiver, the larger the diaphragm is and therefor it can displace more air making it potentially louder than smaller designs.



Also, as the internal volume gets smaller, it becomes an acoustically stiffer impedance at the rear of the diaphragm and therefor reduces the amount of diaphragm excursion. Some BA receivers have small vents in the housing behind the diaphragm to effectively make the internal volume larger to deliver higher volumes.

Armature Variables

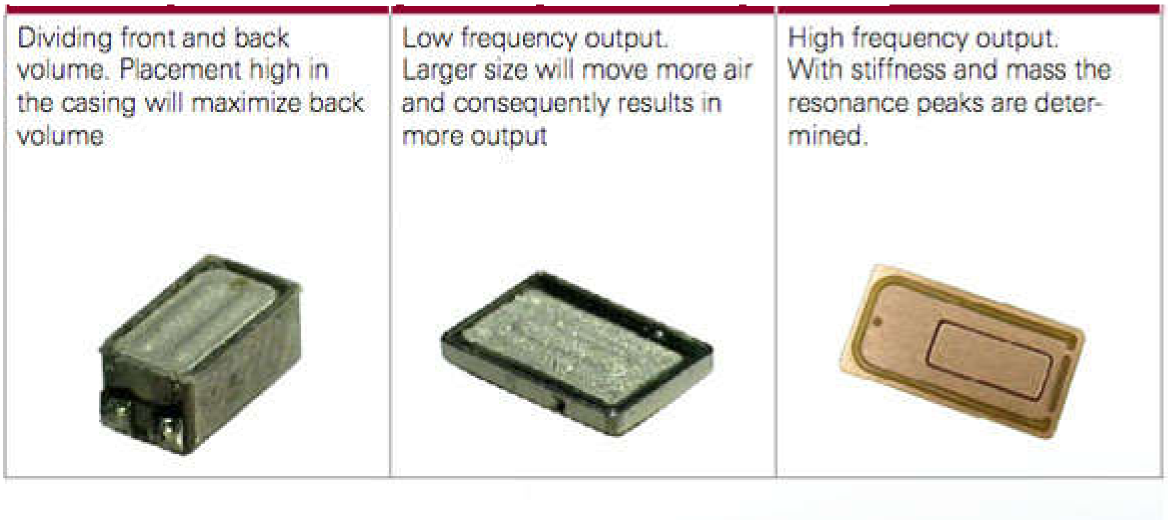
Central to the performance of a BA receiver is the armature itself, which largely determines the mass and stiffness of the acoustic system and therefore the resulting efficiency and resonant characteristics of the driver system. Generally speaking, to optimize for low frequency efficiency you match the armature stiffness to that of the back volume and membrane. To maximize low frequency output you increase the mass of the armature to permit greater magnetic flux carrying ability. And to optimize for widest band width you reduce mass and increase stiffness.



Credit: Sonion from this .pdf.

In the illustration above the dark blue line is the standard Sonion 26A01C BA receiver. The light blue line uses the 2600 wideband armature that is thicker to increase stiffness, but also narrower to decrease mass. The orange line shows increased bass achieved with a high mass armature to increase flux carrying capability. (Armature not shown.)

Diaphragm Variables
Like the armature, the diaphragm itself has both stiffness and resonant characteristics that can be adjusted in similar ways. BA receiver diaphragms are usually small metal plates or diving board shapes. A thin membrane fills the space between the diaphragm and surrounding surface to act as a suspension and to acoustically separate the front and back volumes.



Credit: Sonion from this .pdf.

Generally, placing the diaphragm as high as possible in the BA housing will increase the rear volume permitting the driver to have higher output levels. Larger diaphragm surface areas gives louder output, but increased mass will limit high-frequency output. Resonant peaks are unavoidable with BA receivers, but membrane stiffness and diaphragm mass can be adjusted to modify the position, relative amplitude, and Q of resonant peaks.

Armature Damping
BA receivers can be quite sensitive to mechanical shock. If you drop a BA IEM on a hard surface the momentary shock can force the fragile armature to go past it's elastic limits and deform in one direction resulting in a significant increase in distortion and loss of volume level.

To prevent this, manufacturers will often put little bumpers within the permanent magnet structure that will limit travel of the armature. Unfortunately, it may also limit maximum output volume levels.

A recent development by Knowles uses Ferrofluid between the permanent magnets and armature to damp and limit armature excursions. In the illustration below you can see the two drops of Ferrofluid between the armature and magnets. These drops are held in place by the magnetic field itself. Damping and shock resistance properties can be modified by adjusting the amount of fluid injected.

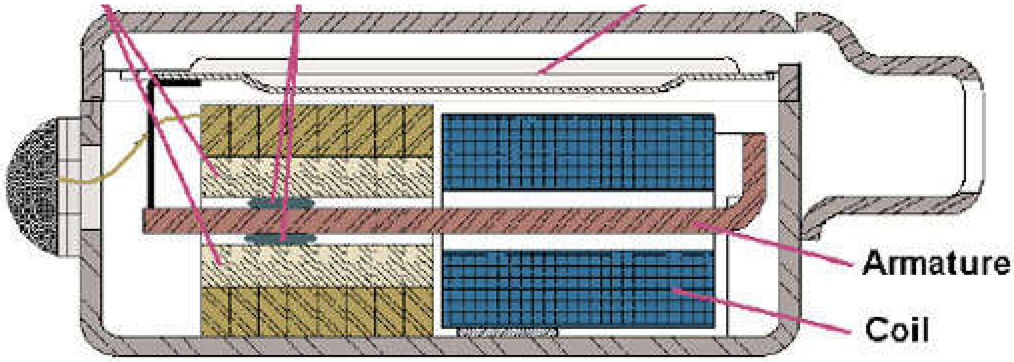


Figure 1: Cross-section of the Knowles FED receiver (i.e., ferrofluid-damped ED receiver)

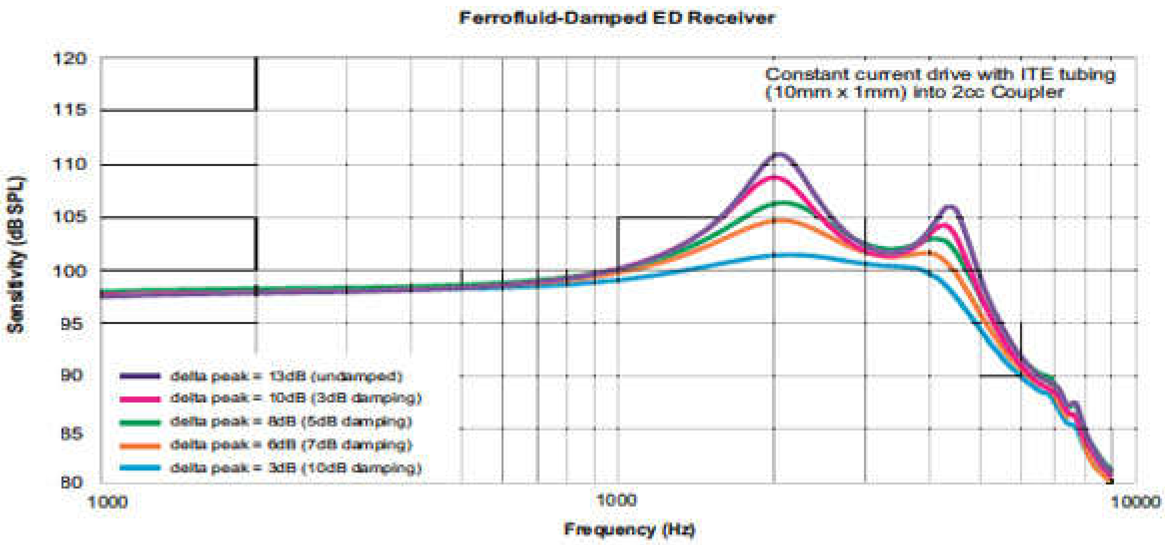
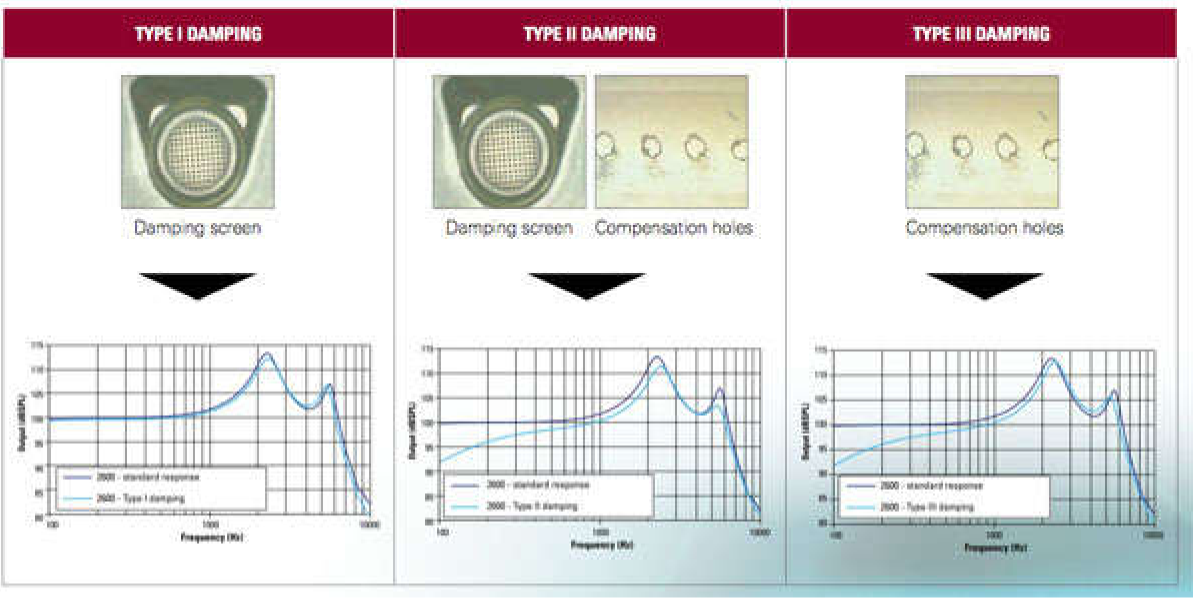


Figure 3: Frequency response curves under constant current drive conditions for fluid-damped FED receivers and a response curve for an undamped ED receiver. Labels in legend are the delta peak values.

Credit: Knowles from this .pdf on Ferrofluid damping.

The graph above shows changes in frequency response with ever greater amounts of Ferrofluid injected between magnets and armature. This method also damps resonant peaks without effecting overall sensitivity. Another advantage of this method is that it tends to damp all resonances, both driver resonances and those occurring in the tubing. One problem with putting a filter in the outlet of the BEA receiver is that it can get clogged with ear wax over time. Using Ferrofluid allows designs without clog-prone in-line filters.

BA Receiver Fine Tuning



Just before a BA receiver is completely assembled, one last chance for fine tuning exists to make variants of that particular model. An acoustic filter can be placed within the nozzle, which generally reduces the the amplitude of the first peak. Very small holes can be punched into the diaphragm suspension membrane (with a laser), which reduces the second peak and bass response. Or a combination of both may be employed.

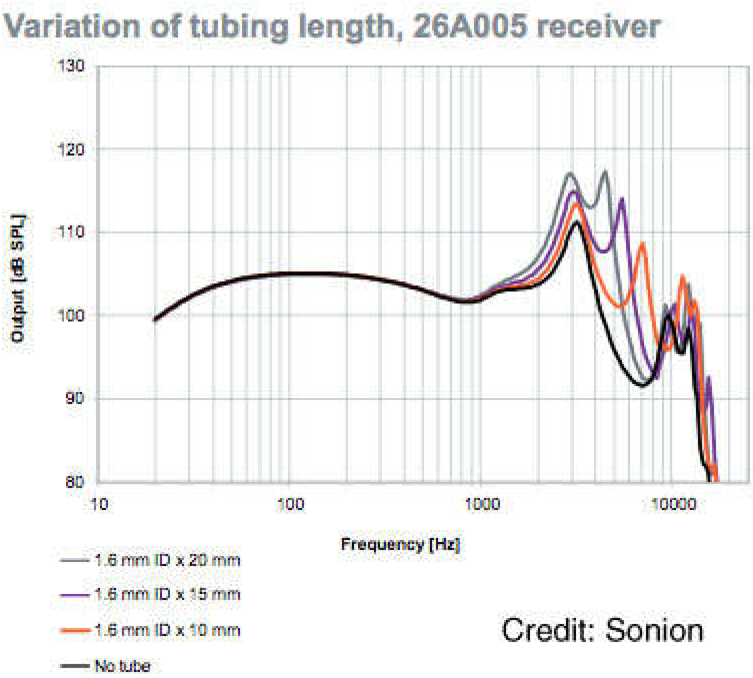
External Tuning Methods

As if this subject isn't difficult enough, it gets worse when we consider actually using these devices in an IEM. The tubing that goes from the receiver nozzle to the exit port on the ear tip will have effects on the frequency response delivered. Overall length and diameter of the tube will change the sonic profile, as will a variety of acoustic tuning filters and their position within the tube.

Multiple drivers and cross-over networks can also be used to sculpt frequency response in ways not available to a single driver. Let's take a look.

Tubing Length

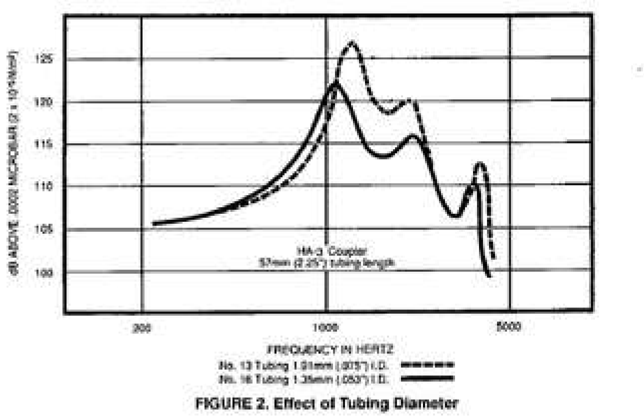
The graph at right show the response of a Sonion 26A005 BA receiver with various tube lengths. Remembering that the first peak in response is the BA internal resonances, and the second peak is the tube length resonance, you can see that the tube resonance gets lower in frequency as the tube lengthens. Generally speaking, designers will want the second peak to fall nicely between the primary resonance at 2kHz and ear canal resonances that occur at 10kHz and above (depending on insertion depth). 10mm is a common length.



Tube Diameter

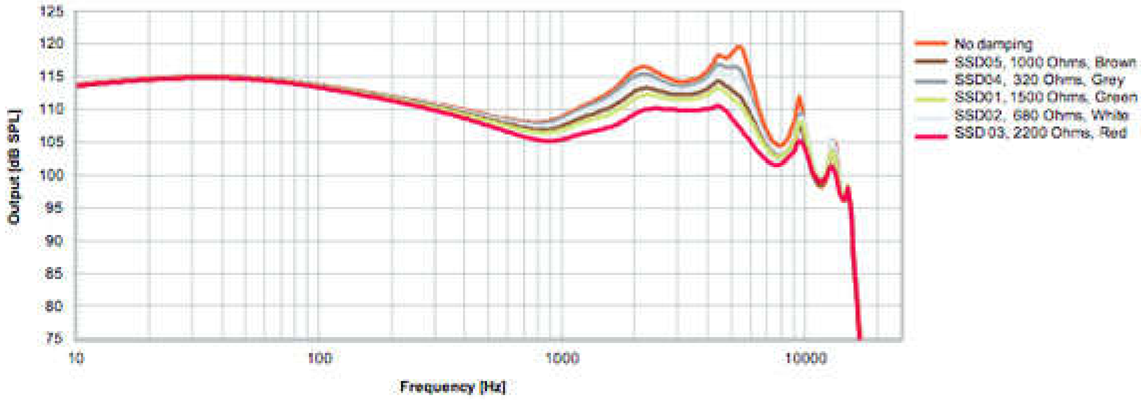
Unlike tubing length that shifts resonant peaks, tubing diameter tends to act as a narrow the response curve in the low-and mid-treble region as tube diameter increases.

In the graph to the left you can see the response in that region becoming more peaky as tubing diameter increases from 1.35mm to 1.91mm.



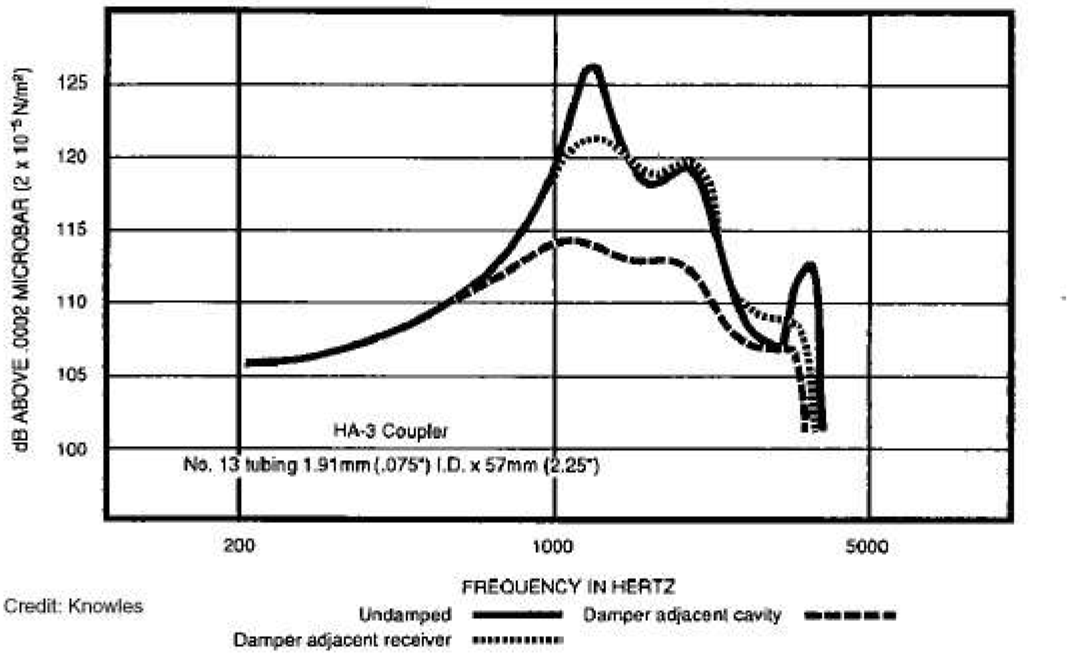
In-tube Sound Damping Filters

Similar in effect to decreasing tube diameter, damping filters restrict airflow within the tube and generally reduce response in the 1kHz to 8kHz region. In the graph below, you may just be able to make out that these filters, because they act as resistive elements, are calibrates in Ohms!



Credit: Sonion from this web page.

In-tube filters also have differing effects depending upon how far along the tube they rest.

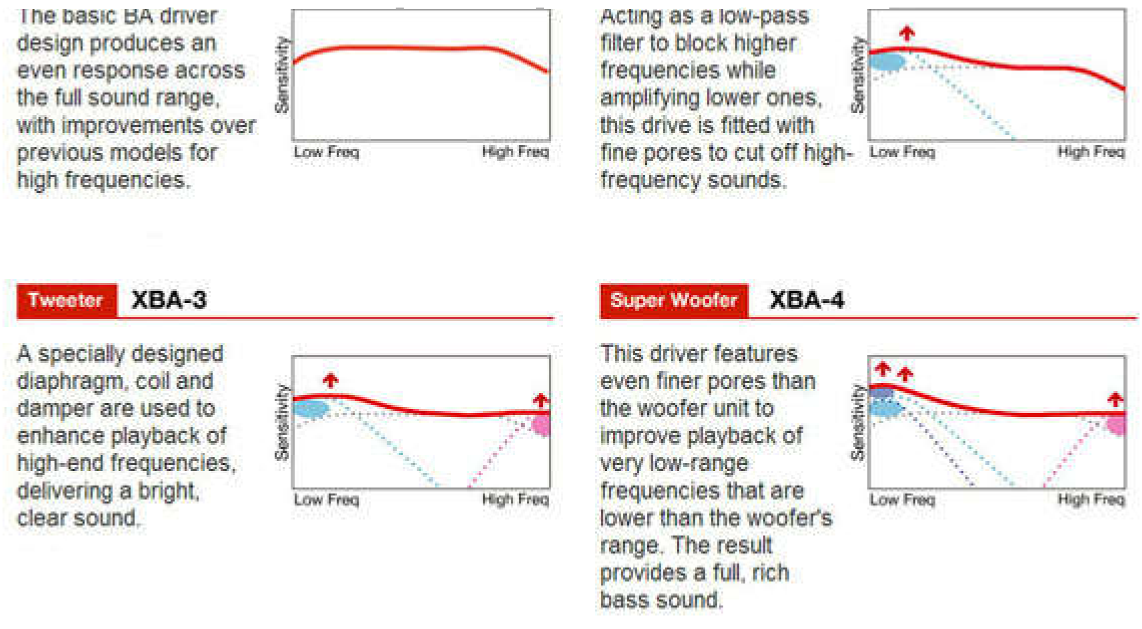


Credit: Knowles from this downloadable .pdf.

When located near the receiver, the small volume of air in the tube is fairly stiff allowing the receiver's output to effectively push air through the filter. When the filter is farther away from the receiver, the elasticity of the air makes it harder to push signal through the filter resulting in a more damped output.

Tuning with Multiple Drivers

Using multiple drivers with cross-over networks allows IEM designers to create further modifications to the EQ curve not possible by the methods mentioned above with a single driver. Low-frequency drivers can be introduced to elevate bass levels and deliver low notes with less distortion. High frequency BA receivers can be added to extend high-frequency response. (Wide-band BA receivers have problems getting extension above 10kHz.)



Credit: Sony

The above graphs show a simplified view of how Sony tuned their XBA series IEMs as they added more and more drivers.

Summary
Balanced armature receivers are not particularly acoustically flat devices and suffer from significant resonant behaviors. But because of there very small size and high efficiency they are attractive transducers for in-ear monitor and hearing-aid manufacturers.

Numerous methods for acoustical damping and control of frequency response are, fortunately, available to BA receiver manufacturers and IEM designers both within the device and externally. In addition, multiple drivers with cross-overs further allow IEM makers to sculpt the sound from IEMs.

Please be careful with your BA IEMs as dropping them onto hard surfaces can permanently degrade performance.

I'd like to thank Knowles and Sonion for producing excellent applications notes and technical bulletins, virtually all the information in this article can be found in more in-depth form on their websites. It's truly a pleasure when manufacturers take the time to clearly explain their products. Links to all the papers used in this article in Resources below.

Resources
What is Balanced Armature receiver Technology? Sonion
Designing Earphones with Balanced Armature Receivers. Sonion
Poster Describing a BA receiver. Sonion
Effects of Acoustical Termination Upon Receiver Response. Knowles
Ferrofluid Damped ED Receivers. Knowles
The effect of acoustic damping plugs on receiver response. Knowles