Introduction

This is an introduction on using balanced armature receivers for designing earphones/in ear monitors. Consult the Sonion Academy article on Balanced Armature Technology to understand more about balanced armature receivers.

Sonion offers 5 types of solutions for earphones

• Broadband receivers for single or tweeter applications
• Woofers for multi-way applications
• Tweeters for multi-way applications
• Midrange receivers for multi-way applications
• The AcuPass™ module. Our plug and play solution

In addition to this, Sonion offers sound dampers, custom cross-over networks and customer specific fully assembled modules. But most of all: expertise!

The beauty of a balance armature (BA) receiver is its small size, making it possible to place multiple transducers in a single housing. Combining the right transducers and optimizing them to achieve the desired sound is a delicate art. A small mistake may cause inexplicable results.

In the following pages, we will share some of our knowledge on how to create great sounding earphones with balanced armature receivers. We hope that you find this information useful, and we invite you to contact Sonion for further application expertise.
Designing Earphones with Balanced Armature Receivers

Balanced Armature vs. Moving Coil Receivers in Earphones

Designing an earphone with a balanced armature differs from using a moving coil. The table below shows a short summary of the differences between these 2 types of transducers.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Balanced Armature</th>
<th>Moving Coil</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Features</strong></td>
<td>Small size</td>
<td>High efficiency</td>
</tr>
<tr>
<td></td>
<td>High output</td>
<td>Linear</td>
</tr>
<tr>
<td><strong>Suited for</strong></td>
<td>Custom &amp; universal fit</td>
<td>Universal fit</td>
</tr>
<tr>
<td></td>
<td>Occluded applications only</td>
<td>Not fully occluded</td>
</tr>
<tr>
<td></td>
<td>Single &amp; multi-way systems</td>
<td>Single &amp; (hybrid) multi-way Systems</td>
</tr>
<tr>
<td><strong>Response determined by</strong></td>
<td>Receiver</td>
<td>Receiver</td>
</tr>
<tr>
<td></td>
<td>Acoustics of nozzle &amp; ear tip</td>
<td>Acoustics of nozzle &amp; ear tip</td>
</tr>
<tr>
<td></td>
<td>Damping</td>
<td>Damping</td>
</tr>
<tr>
<td></td>
<td>Cross-over network</td>
<td>Cross-over network</td>
</tr>
<tr>
<td></td>
<td>Venting</td>
<td>Venting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Back chamber of shell</td>
</tr>
<tr>
<td><strong>Response independence</strong></td>
<td>Back chamber of shell</td>
<td></td>
</tr>
<tr>
<td><strong>Sound characteristic</strong></td>
<td>Detail</td>
<td>Soft &amp; forgiving</td>
</tr>
<tr>
<td></td>
<td>Punch</td>
<td>Strong bass</td>
</tr>
<tr>
<td></td>
<td>Presence</td>
<td></td>
</tr>
</tbody>
</table>
Designing Earphones with Balanced Armature Receivers

## Equipment

Designing an earphone requires specific tests. The table below shows the minimum that Sonion recommends.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Basic Equipment</th>
</tr>
</thead>
</table>
| **Frequency Response & THD** | Audio Analyzer or equivalent  
Audio amplifier (Rout < 1 Ohm)  
IEC711 ear simulator |
| **Receiver Testing**  | Sonion test standard  
4.5 x 1.4 mm ID + 11 x 1.9 mm ID tubing + 711  
(Representative for in ear applications)  
Often referred to as “PA-coupler” |
| **Earphone Testing**  | Conical ear-canal simulator + 711 |

### PA coupler dimensions

![PA coupler dimensions diagram]
## Receivers and Applications

The first step in designing an earphone is to select the receiver(s). Below is a summary of the receiver-families Sonion offers for earphone applications.

### Broadband

<table>
<thead>
<tr>
<th>Series</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1700</td>
<td>Adequate bandwidth, full sound, large headroom</td>
</tr>
<tr>
<td>2300</td>
<td>Widest response available, accurate sound</td>
</tr>
<tr>
<td>2600</td>
<td>Smaller size broadband with warm sound signature</td>
</tr>
<tr>
<td>2600U</td>
<td>Enhanced bass emphasis vs. standard 2600</td>
</tr>
<tr>
<td>2800</td>
<td>Powerful dual broadband with warm sound signature</td>
</tr>
<tr>
<td>3200</td>
<td>Alternative broadband for communication equipment</td>
</tr>
</tbody>
</table>

### Woofers

<table>
<thead>
<tr>
<th>Series</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1700</td>
<td>Excellent single woofer with bass emphasis vent option</td>
</tr>
<tr>
<td>2000</td>
<td>Largest size single woofer with big PA-like sound</td>
</tr>
<tr>
<td>3100</td>
<td>Smallest single true woofer with vent option for bass emphasis</td>
</tr>
<tr>
<td>3500</td>
<td>Similar to 3100 with neutral signature</td>
</tr>
<tr>
<td>3300</td>
<td>Dual woofer with vent options</td>
</tr>
<tr>
<td>3700</td>
<td>Dual woofer with accurate sound</td>
</tr>
<tr>
<td>3800</td>
<td>Most powerfull dual vented woofer available</td>
</tr>
</tbody>
</table>

### Tweeters

<table>
<thead>
<tr>
<th>Series</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>2300</td>
<td>Industry standard tweeter</td>
</tr>
<tr>
<td>2600</td>
<td>Smaller size tweeter for medium impedance applications</td>
</tr>
</tbody>
</table>

### Midrange

<table>
<thead>
<tr>
<th>Series</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1700</td>
<td>Single midrange up to 5 kHz in combination with a super-tweeter</td>
</tr>
<tr>
<td>3500</td>
<td>Single midrange up to 2 kHz</td>
</tr>
<tr>
<td>3300</td>
<td>Dual midrange up to 2 kHz</td>
</tr>
</tbody>
</table>

### Modules

<table>
<thead>
<tr>
<th>Series</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1723WT03</td>
<td>AcuPass™ technology with low-pass woofer. Combination 1700 woofer and 2300 tweeter with one spout. Optimized bandwidth, easy to use. There’s also a tuned vent variant available, which has a deeper bass response.</td>
</tr>
</tbody>
</table>
Designing Earphones with Balanced Armature Receivers

Receivers and Their Specifications

<table>
<thead>
<tr>
<th></th>
<th>1700</th>
<th>3300/3800</th>
<th>2000</th>
<th>3200</th>
<th>2300</th>
<th>2600</th>
<th>2800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (mm)</td>
<td>8.00</td>
<td>7.87</td>
<td>9.45</td>
<td>7.87</td>
<td>6.35</td>
<td>5.30</td>
<td>5.30</td>
</tr>
<tr>
<td>Width (mm)</td>
<td>5.65</td>
<td>5.60</td>
<td>7.13</td>
<td>4.09</td>
<td>4.34</td>
<td>3.10</td>
<td>3.10</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>4.12</td>
<td>4.09</td>
<td>4.10</td>
<td>2.80</td>
<td>3.02</td>
<td>2.60</td>
<td>5.30</td>
</tr>
</tbody>
</table>

General “rules of thumb”

- **Broadband receivers/tweeters**
  Bigger bandwidth but smaller headroom

- **Woofers**
  Limited bandwidth but larger headroom

- **Large size and vented receivers**
  Can produce higher SPL at low distortion

- **Large size receivers**
  Can produce full, rich sound with body and details
Sonion Sound Dampers (SSD) Acoustic Dampers

SSD dampers can be positioned in the receiver tube to dampen the acoustic output of the receiver.

<table>
<thead>
<tr>
<th>Types</th>
<th>Color</th>
<th>Nominal Acoustic Resistance [Ω]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSD 01</td>
<td>White</td>
<td>680</td>
</tr>
<tr>
<td>SSD 02</td>
<td>Green</td>
<td>1500</td>
</tr>
<tr>
<td>SSD 03</td>
<td>Red</td>
<td>2200</td>
</tr>
<tr>
<td>SSD 04</td>
<td>Grey</td>
<td>320</td>
</tr>
<tr>
<td>SSD 05</td>
<td>Brown</td>
<td>1000</td>
</tr>
<tr>
<td>SSD 06</td>
<td>Orange</td>
<td>3300</td>
</tr>
<tr>
<td>SSD 07</td>
<td>Yellow</td>
<td>4700</td>
</tr>
</tbody>
</table>

Features
- ABS housing
- The color of the housing identifies the acoustic resistance
- Rounded corners assure easy mounting in tube
- Mounting/removal tool available

Effects of the SSD acoustic dampers on the output of a receiver

General notes on use of acoustic dampers
- 320, 680, 1000 and 1500 ohms are used to reduce acoustic peaks
- 3300 and 4700 ohms are used as acoustic low pass on woofers
- The efficiency of the damper depends on its placement
Designing Earphones with Balanced Armature Receivers

Target Response Discussion

Now that we know you have the tools needed for earphone design, you should move forward with a target sonic signature. Define the impedance (depends on the application of the earphones), max SPL level, accepted IMD and THD levels and the target response you’d like to have.

What does a “flat” response look like?

It’s important to have a unique sound signature and it’s not as easy as it seems. Earphones modify the acoustics of the human ear and the earphone design needs to compensate for this change.

![Acoustical gain components external ear according to Shaw (1794)](image)

There is not one widely accepted “correct” target response curve. Here are some examples.

<table>
<thead>
<tr>
<th>Specification</th>
<th>50 Hz</th>
<th>Insertion peak (3Khz)</th>
<th>Perception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical flat</td>
<td>-2 to 0 dB</td>
<td>12 - 15 dB</td>
<td>Harsh and lean</td>
</tr>
<tr>
<td>Natural flat</td>
<td>0 to +3 dB</td>
<td>6 - 8 dB</td>
<td>Flat, like room speaker</td>
</tr>
<tr>
<td>Emphasized bass</td>
<td>+6 to +9 dB</td>
<td>6 - 8 dB</td>
<td>Often preferred</td>
</tr>
</tbody>
</table>

Practical implementation

Please consider the following when defining the target curve:

- The 711 coupler is not accurate above 8 kHz
- Curves change with SPL
- Source Impedance changes the frequency response
- Canal length greatly affects what the listener hears
Designing Earphones with Balanced Armature Receivers

**Crossover and Filtering**

**Crossovers and Dampers**

Below are some basic tools to get the desired target response.

### Electrical crossover network considerations

About the same rules apply as for loudspeakers:

- Electrical crossover networks work well but the components can be physically large
- Capacitors roll off the LF’s (high pass)
- Resistors in series with woofers pull out the LF bump
- A balanced armature receiver is highly inductive: using an inductor as a low pass filter is not very effective
- 6 and 12 dB per octave crossovers are common
- SMD capacitors are preferable

### Acoustic filtering

- Use SSD's with low to medium resistance to smooth the frequency response
- Higher resistance dampers can be used to create an acoustic low pass filter on woofers
- Position of damper has influence on it's efficiency

**Close to receiver:**

- Less efficient

**At end of tube:**

- Most efficient but sensitive for clogging
  
  - The preferred position is at 50% to 75% distance from receiver
Response Shaping

Nozzle design and tubing. Don’t rule out the affect of the nozzle and the tubing!

Effect of nozzle design

General rules

- Distribution of acoustic peaks (2nd and up) depend on length of the nozzle
- Adjust length to prevent deep dip in response
- A length between 6 to 20 mm is common

Small diameter tubes reduce high frequency output
- Avoid diameters below 1.5 mm
- Diameters between 1.5 are 2.0 mm are common

Some horn shapes may reinforce higher frequencies
- Stepped diameter from 1.5 mm at receiver to 2.5 mm at the front

Eartips are part of the acoustic design
- Foam eartips provide good seal
- Single flange tips are comfortable but at the cost of seal and passive noise reduction
- Tips with larger aperture may reinforce the HF performance

Deep fit custom shells require a different approach than universal fit eartips positioned at the ear canal entrance.

Effect of nozzle design

Variation of tubing length, 26A005 receiver

- Tube resonance fills response at upper frequencies
- Very short (no) tubing does not work
- Optimum usually at ~10 mm

Effect of nozzle diameter

Variation of tubing diameter, 26A005 receiver

- Small diameter functions as low pass
- Range 1.5 to 2.0 mm is common
Designing Earphones with Balanced Armature Receivers

**Work Methods and Tips**

Sound signature and quality

We suggest the following working method:

1. Start by selecting the receivers
2. Design the electrical crossover network
   (One shortcut is to use active crossovers at this point)
3. Design the acoustic crossover
4. Go back through the process until the acoustic goals have been met
   - Transient response (ring overshoot damping / vented versus un-vented)
   - 2 pairs of earphones can have the same frequency response but still sound very different

**Max SPL (headroom)**

- More headroom is almost always perceived as being better
  (true even with novice users at reasonable listening levels)

**Crossover points and slope (electrical and acoustic)**

- High order crossovers will not fit
  (large values of capacitors (C) & inductors (L) will not fit)
- Low order filters and small values of L and C equate to less freedom in crossover design
- Phase and delay issues resulting from the crossover can make the earphone sound muddy

**THD and IMD**

- Lower distortion levels are always better
- Good crossover designs help the overall sound quality
  (i.e. keep the kick drum out of the vocals)

**Balanced armature receivers are not “leak tolerant”**

- Make sure the earphone seals tightly to the ear to ensure good low frequency/bass performance
- Deep fit earphones are less comfortable for the average person, but they do offer improved bandwidth. It’s up to you to find the perfect balance
Concepts

Examples with several receivers, dampers and combinations

All these variables gives you the choice between numerous response types and sound signatures.

Remember, the perceived bass quality and quantity depends on the receiver you choose and the resulting response curve. A receiver with more volume has a more pronounced sound than a small broadband receiver, despite the fact that frequency responses might look the same.

We encourage you to fine tune your design to optimize your acoustic sound signature, just like Sonion does in our development department.
## Design Examples

<table>
<thead>
<tr>
<th>Parameters and components</th>
<th>Example with a single driver</th>
<th>Triple 2-way example</th>
<th>Example with a dual driver (using 1723TW AcuPass™ module)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound signature</td>
<td>Accurate with some LF emphasis</td>
<td>Smiley, bass emphasis</td>
<td>Smiley</td>
</tr>
<tr>
<td>Segment</td>
<td>Universal fit (consumer audio)</td>
<td>Custom, Universal fit (consumer &amp; Pro audio)</td>
<td>Custom, Universal fit (consumer &amp; pro audio)</td>
</tr>
<tr>
<td>Full range</td>
<td>2356</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Midrange</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woofer</td>
<td></td>
<td>33AJ007i/9 tuned vent (parallel)</td>
<td>1700</td>
</tr>
<tr>
<td>Tweeter</td>
<td></td>
<td>2389 half coil</td>
<td>2300</td>
</tr>
<tr>
<td>Crossover for tweeter</td>
<td></td>
<td>4.7 uF ceramic cap</td>
<td>2.2 uF ceramic cap</td>
</tr>
<tr>
<td>Crossover for woofer</td>
<td></td>
<td>AcuPass™</td>
<td></td>
</tr>
<tr>
<td>Damper</td>
<td>SSD 02 (1500 Ohms)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Damper for tweeter</td>
<td>SSD 01 (680 Ohms)</td>
<td>SSD 05 (1000 Ohms)</td>
<td></td>
</tr>
<tr>
<td>Damper for woofer</td>
<td>SSD 07 (4700 Ohms)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tubing in mm</td>
<td>7 x 1.5 ID + 2.5 x 2.1 ID + 3 x 2.5 ID</td>
<td>12 x 2 mm ID, both</td>
<td>Horn l = 13 mm: 1.5 mm ID x 7.5 2.1 mm ID x 2.5 3.0 mm ID x 3</td>
</tr>
</tbody>
</table>

### Response

- **Damped response**
- **Undamped response**

### Circuit

- 2300 will work nice for deep fit eartips
- Dual tube design for custom shell
- 1723WT03/9 module
  - Design details: See AN_1723_AcuPass
Please contact Sonion or one of our distributors for detailed application expertise.

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