High-Frequency Ear Simulator

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October 2017

GRAS Sound & Vibration

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This whitepaper discusses the properties and challenges when using the standard IEC 60318-4 (formerly IEC 60711) Ear Simulator and introduces a new High-Frequency Ear Simulator which is an improved version of the standardized IEC 60318-4 Ear Simulator. It is IEC60318-4 compliant, both mechanically and acoustically, up to 10 kHz, but improves high-frequency repeatability and distortion measurements.

The Standard Ear Simulator

The standard IEC 60318-4 (formerly IEC 60711) Ear Simulator was designed in the early 1980s and mimics the input and transfer impedance of a human ear. While the input impedance was based on measurements on human subjects, the transfer impedance was based on the assumption that the ear canal is a simple cylindrical volume with a hard termination. Obviously, the human ear canal is not a cylindrical cavity and the tympanic membrane is at an angle to the tapered ear canal. This questions the validity of the transfer impedance, particularly at high frequencies.

When the Ear Simulator was designed in the early 1980s the need for high-frequency measurements above 10 kHz was limited. Within the hearing aid industry, 8 kHz was considered adequate. Modern hearing aids and consumer electronics such as headphones require measurements at frequencies up to 20 kHz and beyond. When measuring with the ear simulator, the Device Under Test (DUT) is typically coupled by means of an ear canal extension and a rubber pinna.

Figure 1 shows the GRAS RA0045 Ear Simulator according to IEC 60318-4 with standard ear canal extension mounted.

Figure 1
The GRAS RA0045 Ear Simulator According to IEC 60318-4

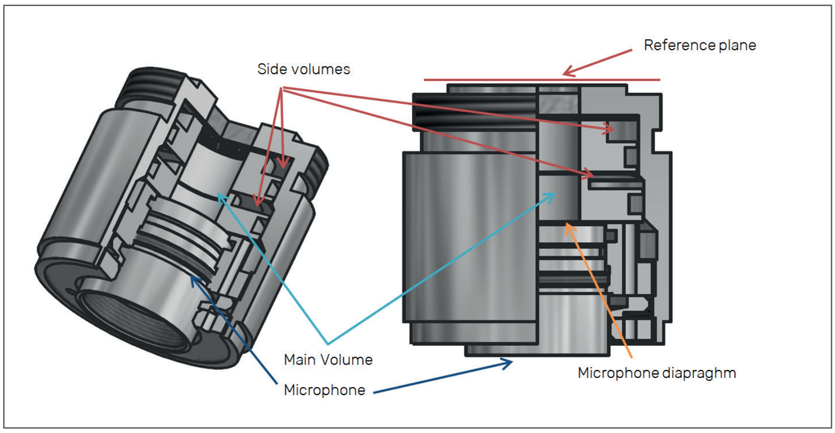

Figure 2
Cut-through of the standard Ear Simulator

Figure 2 shows a cut-through of the standard ear simulator. The ear simulator consists of a main volume, stretching from the reference plane at the entrance of the ear simulator to the diaphragm of the microphone. The diameter of the main volume is 7.5 mm and the length is approx. 12 mm. Side volumes are connected to the main volume by thin slits. The side volumes simulate the middle ear resonance in the frequency range from approximately 800-2000 Hz. The length of the main volume introduces a high Q, ½ wave resonance at 13.5 kHz. The microphone is part of the ear simulator and the system is calibrated as a complete unit. The microphone should never be removed as this can change the response of the unit.
The ear simulator is calibrated using a ¼" pressure microphone as a transmitter placed in the reference plane. This calibration gives a direct measurement of the transfer impedance of the ear simulator.

Figure 3 shows the typical transfer impedance of the standard ear simulator. The IEC specifies the tolerances from 100 Hz to 10 kHz. Also specified in the standard is the ½ wave resonance which should be at 13.5 kHz ± 1.5 kHz but does not specify a peak value for the resonance. A typical GRAS RA0045 will have the resonance at 13 kHz ± 500 Hz.

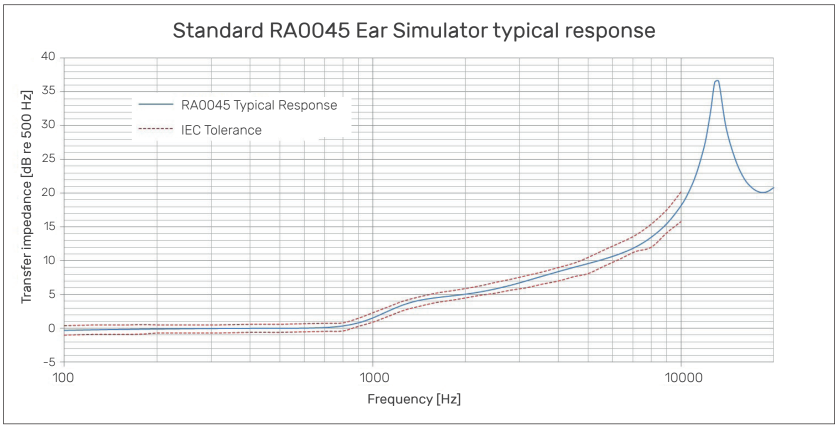

Figure 3
Typical response of the standard ear simulator

Measurements with the standard ear simulator

When measuring with the ear simulator the placement of the Device Under Test (DUT) is critical because the exact frequency location of the resonance peak is governed by the distance from the driver of the DUT to the microphone. This means that adding an ear canal in front of the ear simulator will change the frequency response of the simulator. Figure 4 shows measurements of the change in ½ wave resonance when adding ear canals to the Ear Simulator. The ear canals consist of steel cylinders with a diameter of 7.5 mm and varying lengths from 2-13 mm. Adding an ear canal will in practical terms increase the length of the main volume.

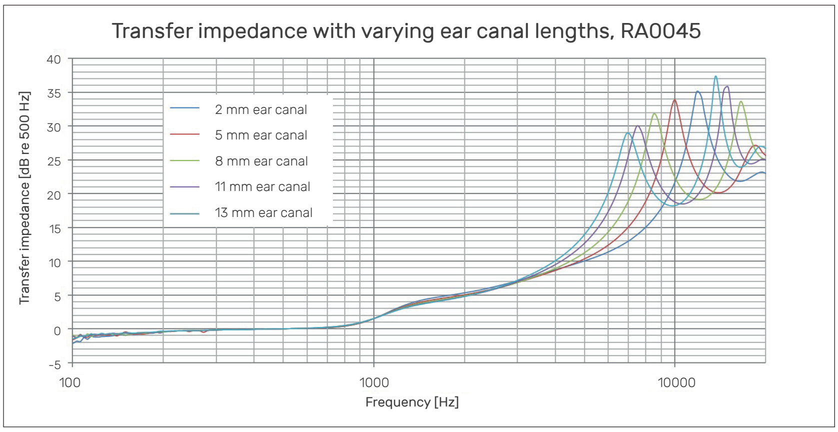

Figure 4
Change in response due to varying ear canal lengths in the standard Ear Simulator

As the measurements show, the peak of the resonance moves down in frequency as the length of the ear canal and thus the main volume is increased. Also, the peak value of the resonance has a downward slope due to the introduction of a small acoustic resistance in the ear simulator when the distance to the microphone changes. Translated into practical measurements this means that while measuring at the reference plane the user can be confident that the resonance is at 13.5 kHz however, this will change when the DUT (e.g. in-ear headphone or hearing aid receiver) is placed at a somewhat random distance to the reference plane in an ear canal extension. The exact distance from the reference plane moves the resonance to a new location in the frequency spectrum and this can introduce large differences between measurements due to the high-Q of the resonance.

Measuring THD and other distortion products

THD is calculated as the ratio between a fundamental frequency and the resulting harmonics introduced by distortion. The harmonics will receive an undesired gain when the multiple of the fundamental equals the resonance frequency of the Ear Simulator. Figure 5 shows an example of a THD measurement in the standard Ear Simulator. The fundamental frequency of 3300 Hz results in harmonics at 6600 Hz, 9900 Hz, and 13.2 kHz. The fourth harmonic at 13.2 kHz coincides with the resonance and the resulting gain will give a faulty reading of the distortion at 3300 Hz.

The same problem can be seen on other distortion measures such as Rub n'Buzz or Intermodulation Distortion.

The V4 harmonic coincides with the ½ wave resonance and the actual measurement of the harmonic is much higher than the true level of the harmonics.

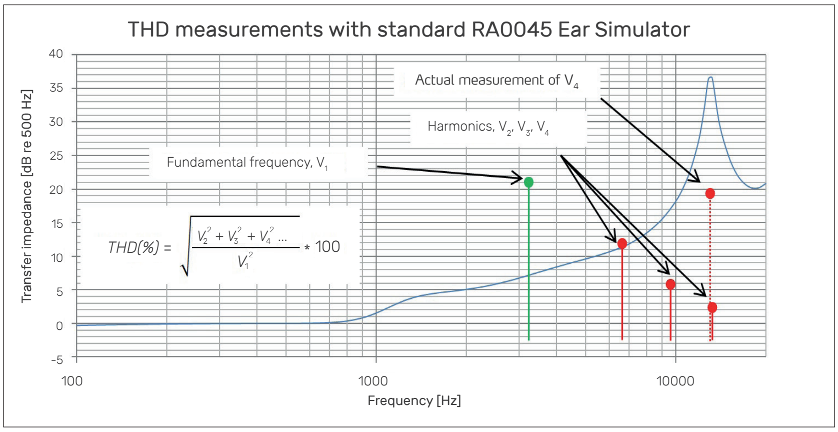

Figure 5
Example of THD measurement in the standard Ear Simulator. The V4 harmonic coincides with the ½ wave resonance and the actual measurement of the harmonic is much higher than the true level of the harmonic.

The new GRAS High-Frequency Ear Simulator

Figure 6 shows our new High-Frequency Ear Simulator. To mitigate the drawbacks presented by the resonance in the standard ear simulator, GRAS has developed two new variants of the IEC 60318-4 Ear Simulator, the RA0401 Externally Polarized High-Frequency Ear Simulator and a prepolarized equivalent, the RA0402.

Figure 6
The new High-Frequency Ear Simulator

Figure 7 shows the typical response of the High-Frequency Ear Simulator compared to the standard ear simulator. By adding highly accurate acoustic damping to the ear simulator, the resonance is damped by about 14 dB while still adhering to the strict tolerances below 10 kHz imposed by the IEC 60318-4 standard. The damped resonance enables the introduction of production tolerances in the frequency range from 10-20 kHz. The IEC standard calls for a tolerance of ±2.2 dB at 10 kHz. The accuracy of the High-Frequency Ear Simulator has extended the ±2.2 dB tolerance up to 20 kHz. This ensures that the difference between simulators will be much smaller with the High-Frequency Ear Simulator compared to the standard ear simulator.

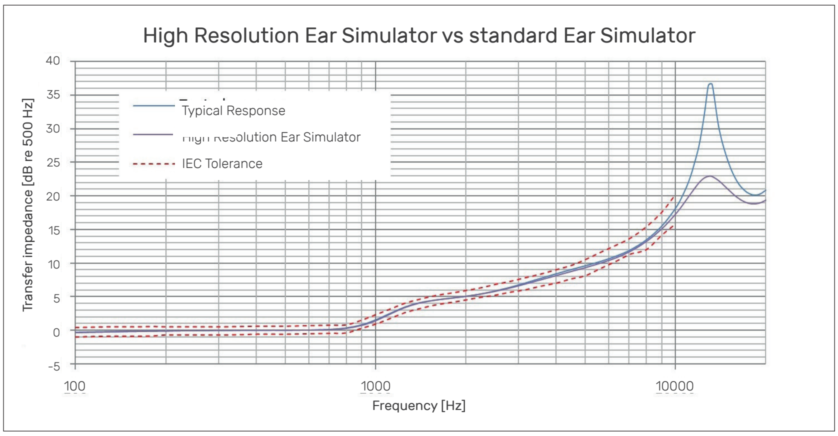

Figure 7
Typical response of the new High-Frequency Ear Simulator compared to the standard ear simulator

If two standard ear simulators have the resonance at the extremes of the IEC tolerance (12 and 15 kHz) the differences in the response above 10 kHz would be profound.

Figure 8 shows the typical response overlaid with the tolerances for the High-Frequency Ear Simulator.

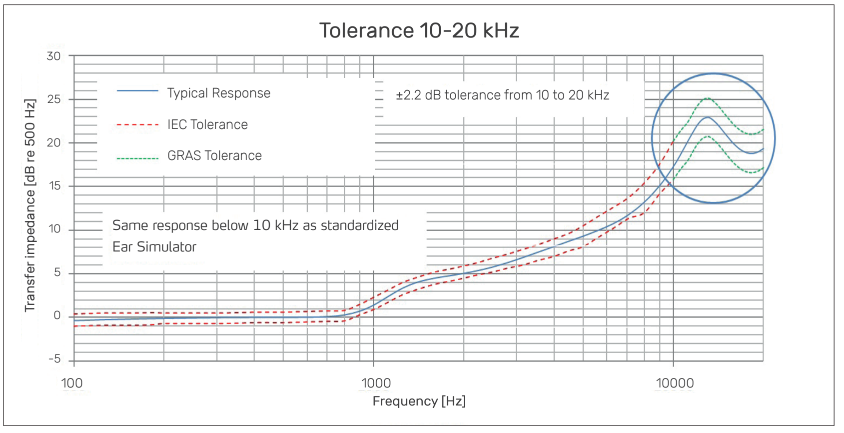

Figure 8
The damped resonance enables the introduction of production tolerances from 10 to 20 kHz

As shown in the section on the standard ear simulator, the location of the ½ wave resonance will change when the DUT is not placed in the reference plane. This is also true with the High-Frequency Ear Simulator, however, the damping will remain the same and the peak of the resonance does not change with the length of the ear canal. This is shown in Figure 9. Compared to the identical measurement with the standard Ear Simulator, shown in Figure 4, the High-Frequency Ear Simulator shows a stable response throughout the range of ear canals without the downwards slope of the resonance peaks. The damped nature of the resonance also limits the differences introduced by the change in the placement of the DUT.

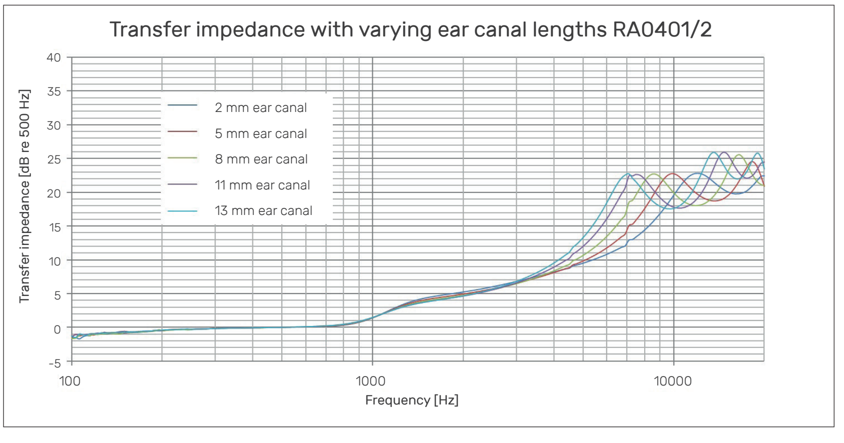

Figure 9
Change in response due to varying ear canal lengths in the High-Frequency Ear Simulator

Specifications

Table 1 summarizes the specifications for the new High-Frequency Ear Simulator. Note that the form factor is the same for the new Ear Simulator and thus can be used with all legacy products like the KEMAR, 43AG. The High-Frequency Ear Simulator comes in two variants, the externally polarized RA0401 and the pre-polarized RA0402.

100 Hz-10 kHz	Transfer Impedance According to IEC 60318-4
10-20 kHz	Damped Resonance, with Peak @ 13.5 kHz, +/- 2.2 dB Test Tolerance
Volume @500 Hz Microphone	1260 mm^3, According to IEC 60318-4 ½" pressure microphone, either externally or pre-polarized
Resonance	Peak at 13.5 kHz
Sensitivity	12.5 mV/Pa
Form factor	Same as RA0045

Table 1
Specifications for the High-Frequency Ear Simulator

Benefits when using the High-Frequency Ear Simulator

Several benefits can be observed when using the High-Frequency Ear Simulator. This section will highlight two such cases.

Measurement with in-ear headphone

When measuring the frequency response of in-ear headphones the product is typically coupled to the ear simulator by a steel ear canal extension or ear canal combined with a rubber pinna on a head and torso simulator like the KEMAR or 43AG Ear & Cheek Simulator. The following examples are measurements of an in-ear headphone in a steel ear canal placed on the Ear Simulator as seen in Figure 10. The headphone is mounted in the ear canal with the rubber padding in place.

Figure 10
In-ear headphone placed in the ear simulator via steel ear canal extension

The measurements compare the frequency response and THD as measured in the standard ear simulator and the High-Frequency Ear Simulator. Figure 11 shows a comparison between the frequency response in the standard as well as the High-Frequency Ear Simulator. In the standard ar simulator the resonance of the headphone driver and the resonance of the ear simulator almost coincide making it difficult to interpret the result. In the High-Frequency Ear Simulator the ear simulator resonance is damped and the resulting frequency response is much clearer.

Also, due to the distance from the driver to the microphone, the ear simulator resonance is at 10.5 kHz and the driver resonance is at 12 kHz. It would be an easy mistake to swap the two when measuring with the standard Ear Simulator.

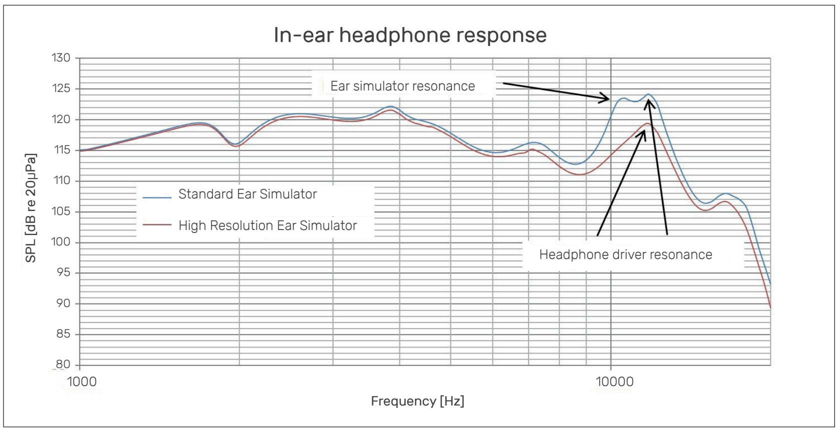

Figure 11
Comparative measurements of an in-ear headphone in the standard ear simulator and the High-Frequency Ear Simulator

Figure 12 shows the THD measurement with the same in-ear headphone. When examining the result for the THD it is clear that the standard ear simulator overestimates the distortion at 3.3 kHz and 5 kHz due to the gain imposed by the resonance whereas the THD peak at 900 Hz is clearly the same in both cases and thus not related to the resonance but in fact, a real peak in the distortion of the driver. The differences in the peaks are 6.5 dB at 3.3 kHz and 4.5 dB at 6 kHz.

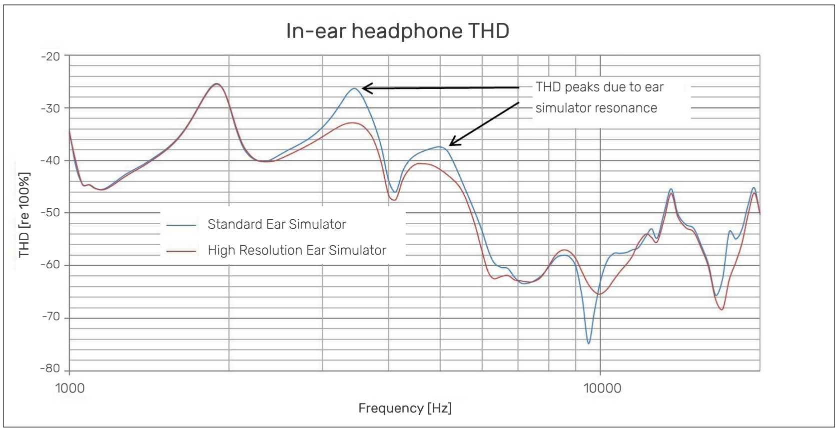

Figure 12
THD measurements in the standard ear simulator and the High-Frequency Ear Simulator

Conclusion

The challenges posed by the high-Q resonance in the standard IEC 60318-4 Ear Simulator are mitigated by the new High-Frequency Ear Simulator. Not only does it provide more stable and easier to interpret results it also improves distortion measurements for wearable products like In-Ear headphones and hearing aids. The new High-Frequency Ear Simulator is backwards compatible acoustically up to 10 kHz and mechanically compatible with the standard IEC 60318-4 Ear Simulator.

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