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Headphone testing with 45CC

Correlating R&D and Production

GRAS Sound & Vibration
Whitepaper // By Brian Johansen

WHITEPAPER

Introduction

As higher demands are placed on the sound quality of headphones, more and more advanced solutions are being developed, and they require more sophisticated measuring equipment. Going hand in hand with the demands of higher quality goes the need to ensure that the targets set in the research and development (R&D) lab are the targets that are been accurately tested for on the production line.

To date, R&D departments have largely used head and torso simulators (HATSs) or monaural Ear and Cheek test fixtures. These products hold the standardized "711" coupler, which is without comparison the most used ear simulator in the industry—primarily because it was the only IEC standardized ear simulator that has an ear canal on which adapters for in-ear and hearing-aid testing can be easily mounted. These adapters, also called ear canal extensions, are often designed in conical metal or soft rubber, or a mixture, to emulate the properties of a realistic canal. However, since the original IEC TS 60711 (hence the name 711-coupler), the upper frequency range has been extended from 10 to 16 kHz in the present IEC 60318-4, so devices that can accurately measure in that range are considered the preferred choice in the R&D environment.

While various solutions have been put in place on production lines, there has been a lack of a uniform, standardized solution for testing on the lines that can ensure repeatable and reproducible results for the new, higher frequency, resolution and overall sound quality demands.

The need for standardized universal test fixtures

In general, the 60318-1 ear simulator (ITU-T standard simulator) is good for the evaluation of over-the-ear headphones and various headsets; however, the IEC 60318-1 coupler is not compatible with earbuds and in-the-ear communication devices, so manufacturers of those devices were motivated to test using equipment that they could "make work", such as:

- A monaural ear and cheek simulator like GRAS Type 43AG
- An IEC 60318-4 coupler with exterior ear canal GR0408 connected directly to the device under test (DUT)
- A sophisticated (but targeted towards R&D and Quality Assurance) head and torso simulator (HATS) like KEMAR
- A simplified desktop, HATS-like headphone test fixture like 45CA
- An in-house constructed custom setup

Ear and cheek simulators (Fig. 1) are primarily intended for headphone testing, and as they are available with a realistic pinna, they can be used with in-ear headphones and hearing aids. Unfortunately, this solution is monaural, which means two units are needed to simultaneously measure in-ear headphones, but provide none of the geometry of a human skull. So, testing with two ear and cheek simulators is not usable for true dual-channel measurements. An additional drawback is that it is not practical to place an artificial mouth in the case of headset testing.

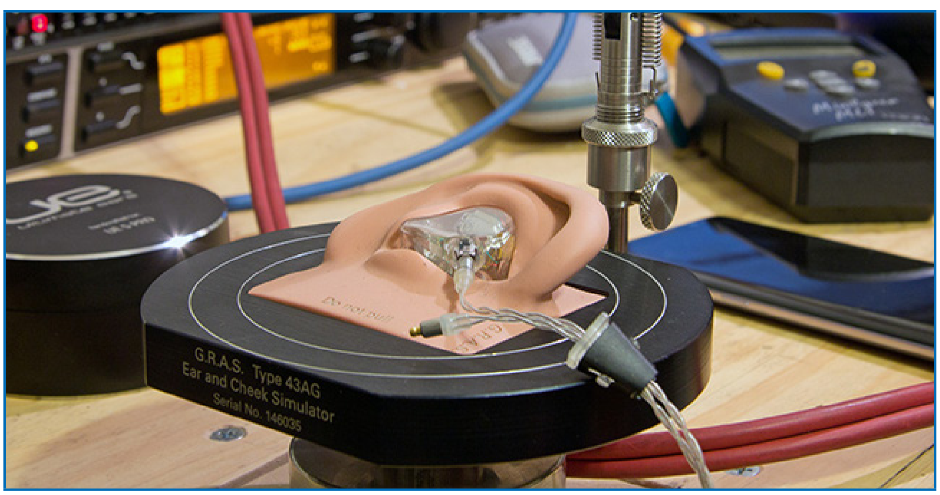

FIGURE 1.
GRAS 43AG Ear and Cheek Simulator with insert.

HATSs, such as KEMAR (Fig. 2), have the advantage of being dual-channel ear simulators with human-like acoustic characteristics, providing simultaneous binaural testing and, depending on the manufacturer, various degrees of realistic dampening of the skull, anatomically accurate left/right transmission loss and accurately modelled ear canal geometry. In addition, most have a built-in artificial mouth according to ITU-T Rec. P. 51 for use in testing microphones in headsets/gaming headsets. However, these features come with a price, a justified price when those characteristics are needed, but the full gamut of capabilities is not always needed for all test scenarios.

FIGURE 2.
GRAS 45BC KEMAR Head & Torso with mouth simulator and on-ear headset

For testing binaural headphones or hearing protectors to various standards, various GRAS Headphone Test Fixture 45CA (Fig. 3) configurations are available: from the simplest version, with microphones only, to the more advanced with IEC 60318-1 or IEC 60318-4 couplers. 45CA is even configurable with Low-noise Ear Simulator 43BB, which, in combination with its ISO 4869-3 performance, is superior to other desktop solutions for testing noise-cancelling (ANC) hearing protectors according to IEC 60318-4. However, the option for testing headsets is limited due to the lack of a mouth-simulator option.

FIGURE 3.
GRAS 45CA Headphone/ Hearing-protector Test Fixture with headphones

Without an affordable standardized and dual-channel test solution for the IEC 60318-4 standard, some test centers resorted to building their own test fixtures. The IEC 60318-4 coupler (Fig. 4) is an occluded-ear simulator intended for the measurement of insert earphones when extended with, for example, an ear canal and pinna as described in IEC 60318-7. However, due to the lack of commercially available standard setups, repeatability and reproducibility with these setups are ongoing issues.

FIGURE 4.
GRAS RA0045-S6 Pre-polarized Ear Simulator Based on IEC 60318-4 (60711), High Sensitivity with GR0408 ear canal extension

To fill this gap as a novel solution that enables a tangible link between the uniformity of equipment used in R&D and the production line, the 45CC (Fig. 5) range has been expanded to include IEC 60318-4 couplers, anthropometric pinnae and, in essence, a modular, framework representation of the KEMAR features that can be aligned with a production line test station. Furthermore, all 45CC configurations can be configured with a GRAS-optimized high-frequency ear simulator (RA0401/RA0402)*, which is fully compliant with IEC 60318-4 but extends the frequency range to 20 kHz. The GRAS 45CC Headphone Test Fixture product family offers a standardized dual-channel system for testing headphones and headsets in a range of scenarios, from desktops in R&D to individual test stations on production lines. The modular design enables multiple configuration options: flat plates with microphones, IEC 60318-1 ear simulators, IEC 60318-4 ear simulators and human-like pinna—each with or without a mouth simulator.

FIGURE 5.
GRAS 45CC Headphone Test Fixture

Transitioning from R&D to the production line

The early GRAS 45CC configurations were initially geared towards production environments, where its ease-of-use and highly adjustable modularity are able to produce measurement results with high repeatability and reproducibility across multiple stations. However, because of the simplified, cost-effective and highly practical design, the 45CC quickly moved to desktops in R&D labs as well. The high degree of measurement reproducibility enabled R&D to define tests and measurements that can later be used in setups in the production facility for data that can be reliably compared to the specifications derived in the lab.

* *More on the high-frequency ear simulator can be found in a whitepaper by Morten Wille at GRASacoustics.com.*

Repeatability and reproducibility

Repeatability and reproducibility are two crucial factors in acquiring useful test data for production lines. If the tests are not functionally identical across multiple stations, operators or even from run to run, then those tests do not provide a significant benefit beyond the literal claim that testing has been performed.

Repeatability addresses the variation due to the measurement device. It is the variation that is observed when the same operator measures the same part many times, under the same conditions. Typically, when testing headphones, the placement of headphones is repeated 5 or even 10 times.

Reproducibility addresses the variation due to the measurement system. It is the variation that is observed when different operators measure the same part many times, using the same gage, under the same conditions in potentially different stations on the line.

Repeatability

This section covers repeated measurements of an around-the-ear headphone for left and right channels using 45CC-17, which is configured with 60318-4 high-frequency couplers and anthropometric pinnae in an R&D setup (Fig. 5) and a simplified production line-type setup with a single user using 45CC-2*. In both cases, the high repeatability is revealed by the small difference between MAX and MIN results (gray area; Fig. 7 (R&D) and Fig. 8 (production line)). Only with results above 7.5 kHz is there greater variance to be traced, which must primarily be attributed to the relatively large volume in the closed headphone.

* *The GRAS 45CC-2 configuration consists of ½" microphones flush-mounted in the ear/base plates, streamlined for use on production lines.*

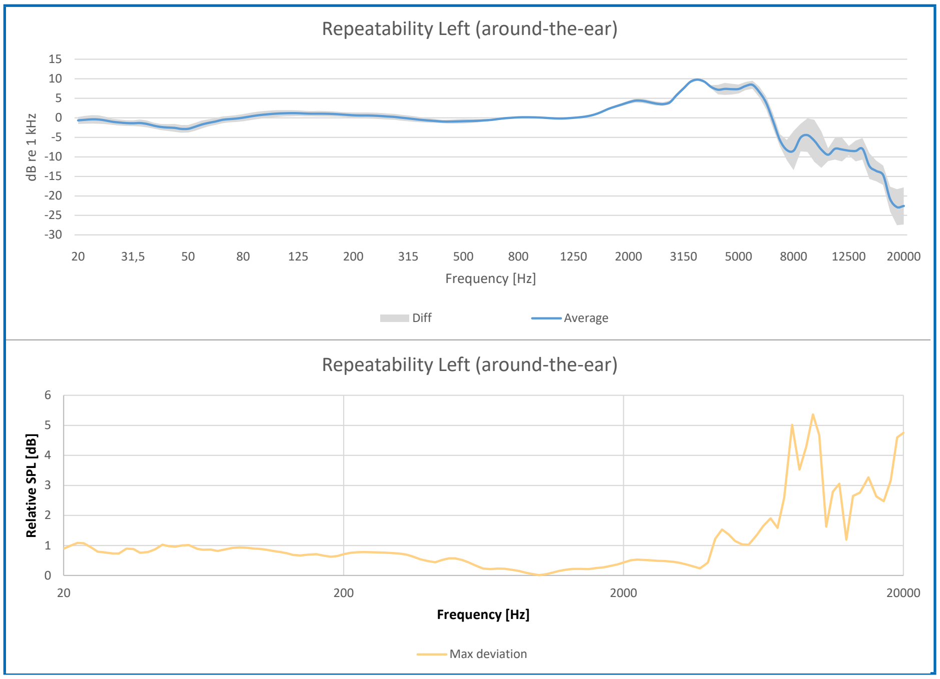

FIGURE 7.

The top graph shows the averaged results in an R&D environment using the 45CC-17 configuration with anthropometric pinnae, measuring around-ear headphones. The gray area shows the variation between the runs.

The bottom graph shows the maximum deviation (derived from the gray area in the above graph) across all of the measurements.

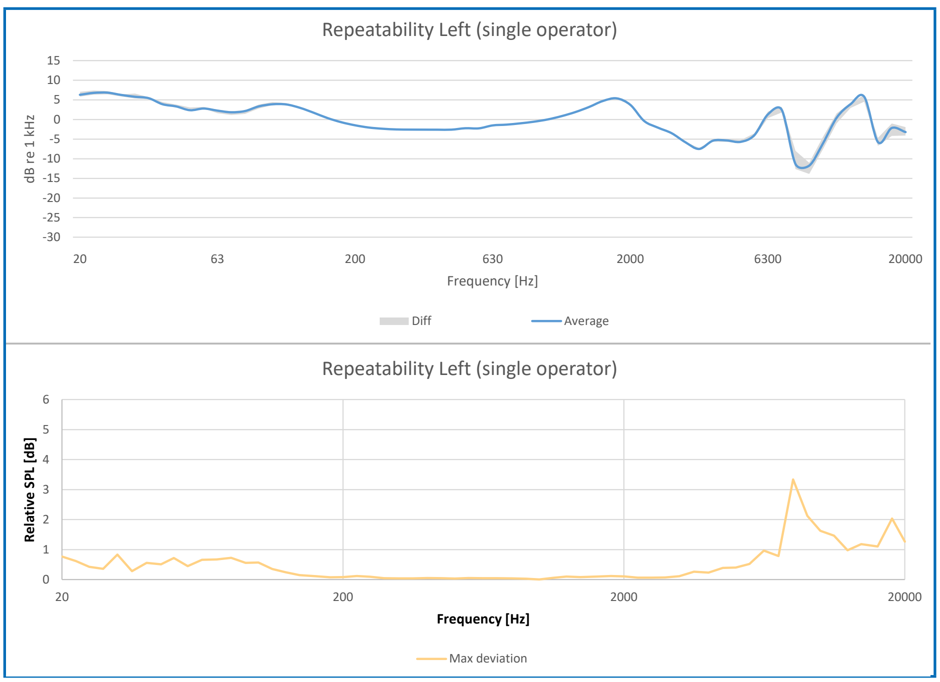

FIGURE 8.

The top graph shows the averaged results in a production line environment using the 45CC-2 configuration with ear/base plates and flush-mounted microphone. The gray area shows the variation between the runs.

The bottom graph shows the maximum deviation (derived from the gray area in the above graph) across all of the measurements.

Note that the repeatability of the single-user scenario is improved over the more complex R&D setup, in large part due to the increased simplicity of the setup that reduces margins of potential placement error (Fig. 8).

Because 45CC-14 through -17 have ear canals, we can also measure and determine the repeatability of in-ear headphones (Fig. 9). Here again there is a variance in the results (gray), but due to the decreased total volume, there is better repetition for high-frequency measurements where the results largely coincide throughout the audible range.

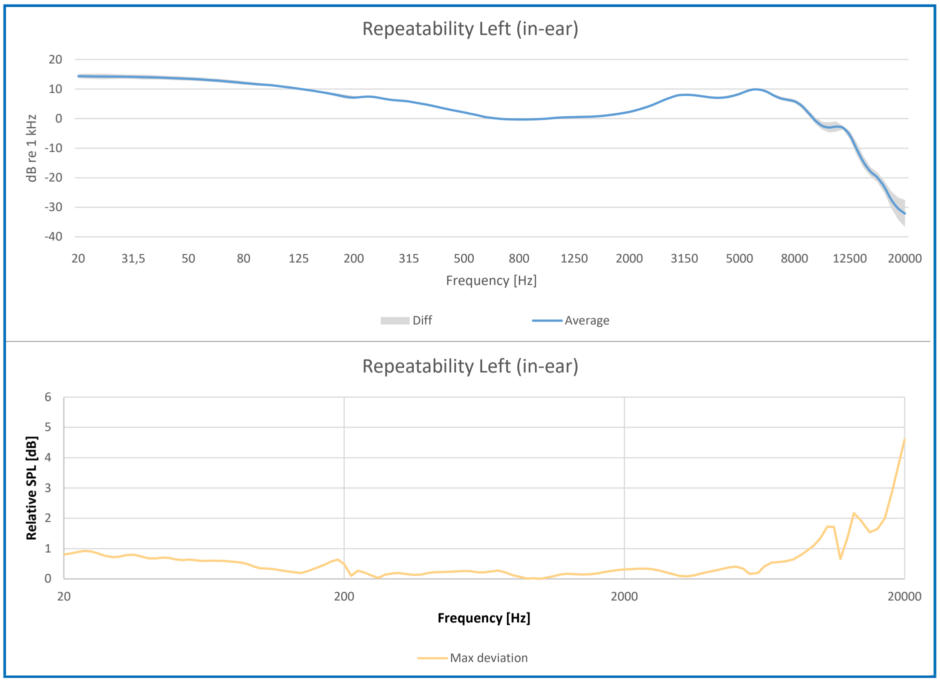

FIGURE 9.

The top graph shows the averaged results in an R&D environment using the 45CC-17 configuration with anthropometric pinnae for measuring in-ear and insert headphones. The gray area shows the variation between the runs.

The bottom graph shows the maximum deviation (derived from the gray area in the above graph) across all of the measurements.

Results

The repeatability for both around-the-ear and in-ear headphones is satisfying. It is also of great benefit that the data from the simplified setup in the production line setting for a single user shows even higher repeatability. As always, care needs to be taken when actually placing the DUT, and it is recommended that the final measurement should be based on an average of a minimum of five consecutive measurements to ensure a valid and confident result.

Reproducibility

NOTE: For securing headphone test reproducibility, the operator should be presented with as few degrees of freedom as possible. For example, the unique ear-pad positioning guides of the 45CC assist the operator in placing the DUT uniformly between measurements. This is a big advantage compared to other systems.

Reproducibility is especially important for productions where the operators, due to changing tasks or working hours, for example, share equipment with colleagues.

Figure 10 shows the results of a set of DALI IO-6 Headphones measured on the same 45CC-2 (Fig. 11) by three different operators.

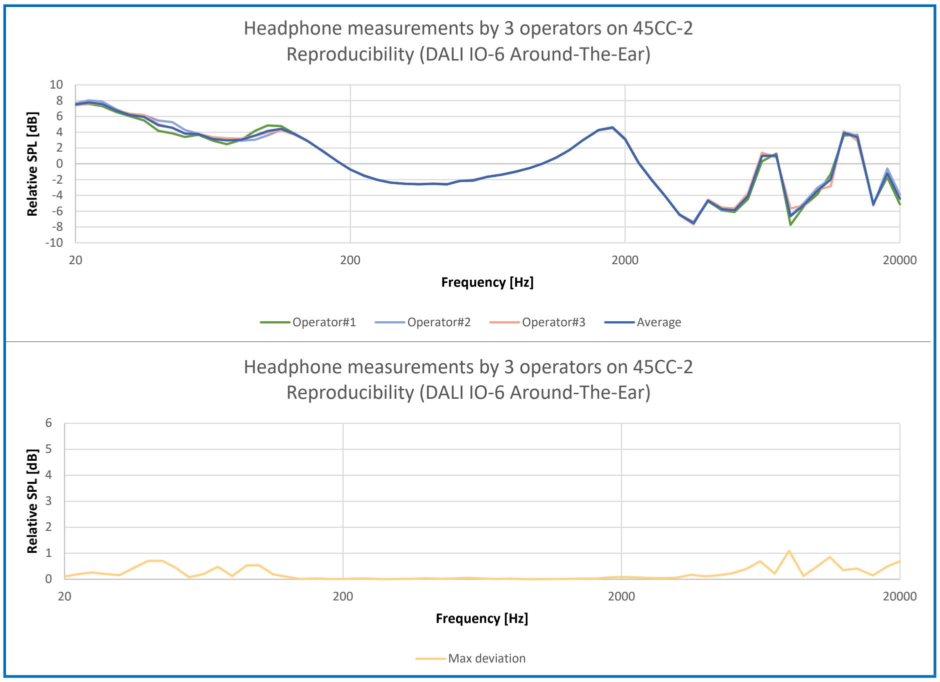

FIGURE 10.

The top graph shows the results of three operators, each with 10 averaged measurements, and DALI IO-6 headphones on a 45CC-2 configuration.

The bottom graph shows the maximum deviation across all of the measurements.

FIGURE 11.

DALI IO-6 headphones on a 45CC-2 configuration.

Each operator received a two-minute introduction on how to mount a specific set of headphones onto the 45CC fixture and acquire measurements using an Audio Precision APx517B analyzer. Each operator derived their results by averaging 10 measurements.

Results
There is a small difference among operators, within 1.2 dB, which is seen as highly acceptable for this type of application.

The reproducibility for around-the-ear headphones is generally lower in the upper frequency range when testing with pinnae due to the earpads forming a cavity together with the pinna, which leads to change in frequency responses if the position of the headphone is shifted by even few millimetres. This test using flat plates, shows only a minor deviation between testers. Therefore, flat plates are recommended to maximize reproducibility when shifting between multiple operators.

Moving from R&D to production: GRAS Headphone Test Fixture with IEC 60318-4 compliance

Headphone design is typically done with an ear simulator according to IEC 60318-4 (with pinnae) in a development department. However, when handing over test specifications for production, there is often a desire to reduce the complexity of the test system and eliminate potential points of failure where possible. This can be accomplished by introducing a simplified test station, where ear simulators have been replaced with measuring microphones. This will not give a correct absolute result, but deviation can be accounted for and is seen as an acceptable solution.

Because a different setup is used by R&D and production, new test limits must be specified to enable a transition from absolute to relative measurements. The ideal curve is derived by developers by using IEC60318-4 ear simulators (with pinna) to adjust and achieve the target curve (Fig 12).

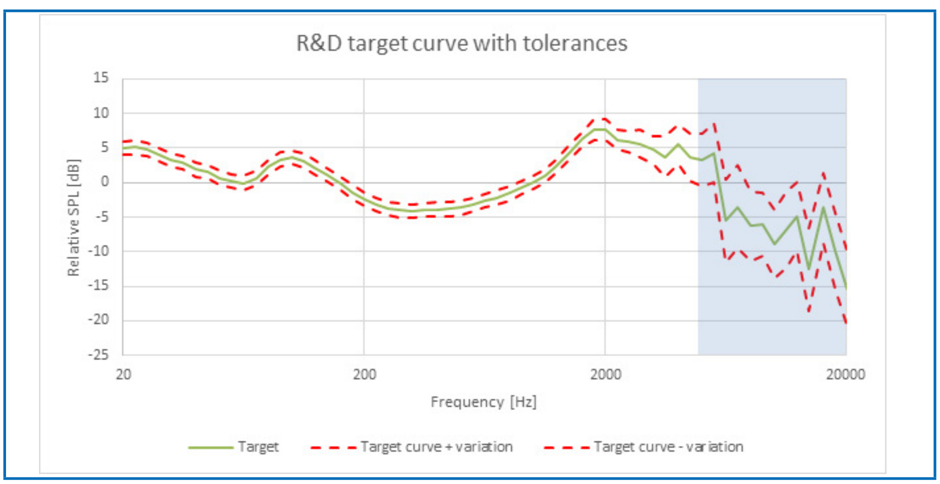

FIGURE 12.
Ideal curve including expected variation. Variation derived from reproducibility test with 45CC-17 comprising the 711 Ear Simulators. Note the increased variation above approx. 5 kHz (blue box), primarily due to ear pad placement between tests.

The above target curve cannot be used directly to form test limits. For this you need one or more reference units known to comply with R&D specifications. However, this assumes that there is no significant difference in components (such as electronics from suppliers that each have their own tolerances) and factors that significantly change the acoustic impedance response in the system being tested. Mechanical deviations in the individual components must be minimal in order for testing to provide valid results. You could say it is the “cost” of throttling the complexity of its measurement chain.

After mounting measuring microphones on the 45CC, new measurements must be taken to estimate how new test limits should be set (Fig. 13).

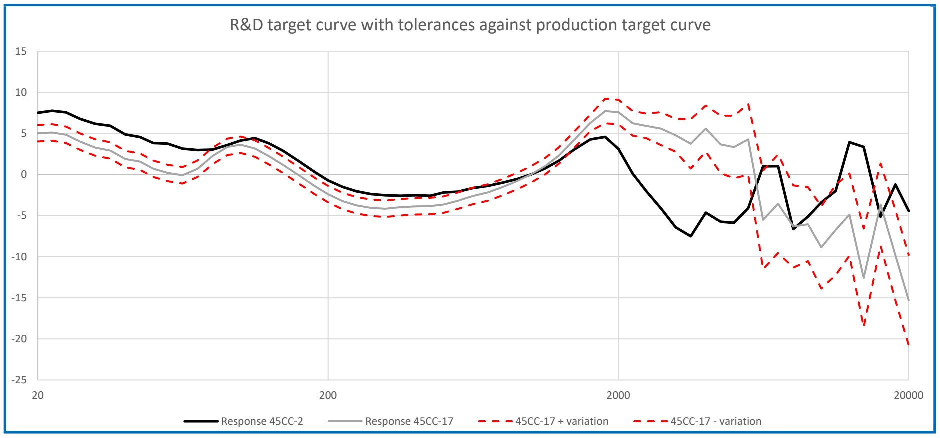

FIGURE 13.

This graph incorporates the operators' results from Figure 10 into the ideal-curve graph shown in Figure 12.

Now we have transferred the target curve from R&D (with ear simulators) to the production environment (ear simulators replaced by microphones) by measuring a typical response with the 45CC-2 microphone configuration. The final step is to introduce upper and lower allowed limits for the frequency response.

We have the uncertainty of reproducibility (measurement among operators) and the variation between repeatability. These two tolerances will be added to the production target curve, and then we can define the acceptable frequency band test limits (Fig. 14).

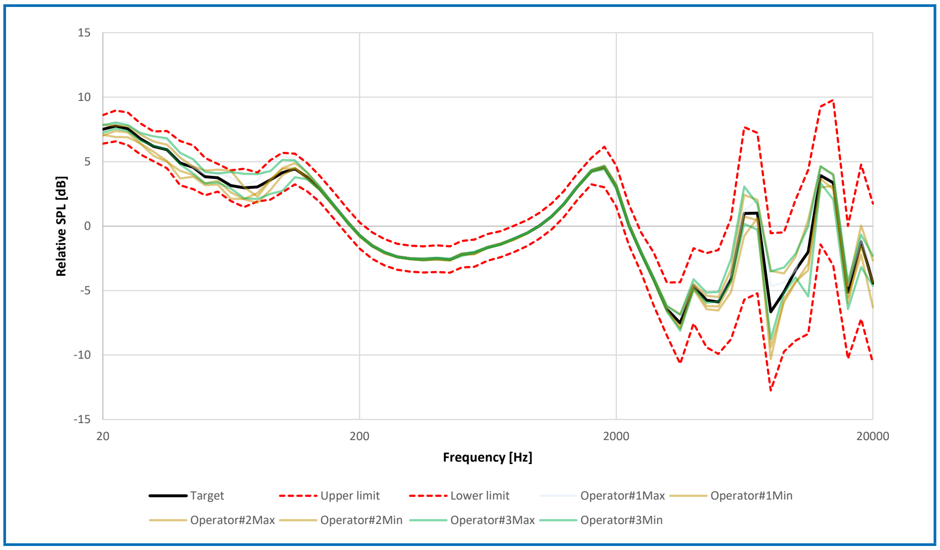

FIGURE 14.

Final Production target curve with acceptance limits.

For verifying whether the generated tolerances limits seem reasonable, we can illustrate max/min values of the operator measurement results.

NOTE: The illustrated limits above are being tested with the same measurements as those with which the limits were established. To verify the robustness of the limits, new and fresh measurements shall be performed in order to fine-tune limits, if necessary.

Conclusion

The need in the industry when testing headphones, headsets and hearing aids is to ensure that every test performed at each station on a production line provides data that is valid compared to the targets set in the R&D labs. It was with that in mind that GRAS 45CC Headphone Test Fixture was developed. This document presents the evaluation of how well 45CC ensures repeatable and reproducible measurements.

Reproducibility (measurements across operators) is demonstrated to be very high thanks to, among other things, the unique ear-pad positioning guides. Thus, it is easy to position headphones uniformly, despite changing operator.

Repeatability is also comparatively high, but as expected, somewhat lower when using IEC 60318-7 pinna. In upper midrange frequencies, this is primarily due to the geometric influence of the ear canal, and at high frequencies (> 5 kHz) it is primarily related to ear pad design versus the design of the pinna. The deviation is expected as it is the same phenomenon experienced with HATS measurements and is a pure reflection of the geometry and experience of a real-world headphone user.