Application Note

AN000707

AS3460 Automatic Leakage Compensation Calibration

Calibration Process for Automatic Leakage Compensation

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Content Guide

1 Introduction

The Automatic leakage Compensation algorithm (ALC) adjusts the noise cancellation filter response of a noise-cancelling earphone that is not sealed (i.e. an air gap is present between the earphone and the ear canal wall). The acoustic leakage varies with the user's ear shape and earpiece placement within the ear thereby diminishing ANC performance. The ALC algorithm improves noise cancellation performance without requiring the user to wear a sealed earpiece.

The ALC algorithm relies on two input transducers, a feedforward and a feedback microphone, as well as loudspeaker driver. The placement and design of these transducers, must follow a determined set of guidelines that are beyond the scope of this document.

This document outlines the transducer calibration process for the ALC algorithm on any earpiece using the AS3460 device, to achieve optimal performance. Further defect and ANC checks are also described.

1.1 Ordering Information

Ordering Code	Description
AS3460 FW 12-BFBT	FBGA36 [3.0x3.0x0.91mm]; 0.4mm pitch. Tape & Reel. 5000 pcs/reel
AS3460 FW 12-BFBM	FBGA36 [3.0x3.0x0.91mm]; 0.4mm pitch. Tape & Reel. 500 pcs/reel

2 Nomenclature

The following abbreviations are used throughout this document:

- *D2E* - Acoustic transfer function between the earbud unit loudspeaker driver and the internal (ear) reference microphone with frequency
- *A2E* – Acoustic transfer function between the ambient loudspeaker and the internal (ear) reference microphone with frequency
- *A2EXT* - Acoustic transfer function between the ambient loudspeaker and the external reference microphone with frequency
- *A2FF* – Acoustic transfer function between the ambient loudspeaker and the feedforward microphone with frequency
- *A2FB* – Acoustic transfer function between the ambient loudspeaker and the feedback microphone with frequency
- *D2FB* - Acoustic transfer function between the earbud unit loudspeaker driver and the feedback microphone with frequency
- FBM – Feedback Microphone
- FFM – Feedforward Microphone
- ANC – Ambient Noise Cancellation
- ALC – Adaptive Leakage Compensation
- DUT – Device Under Test

3 Equipment

The equipment required for production line calibration is outlined here. It consists of the following major components.

3.1 Hardware

- An **ams** leakage adapter: Test fixture in which the earphone under calibration is inserted. This will have space to attach an external reference microphone and includes a calibrated internal (ear canal) reference microphone.
- Ambient loudspeaker: Capable of producing at least 94 dBSPL in the test environment (80 W recommended power) and frequency response of ±3 dB between 100 Hz and 15 kHz.
- A calibrated external reference microphone to be attached to the text fixture.
- A sealed enclosure or equivalent to reduce the influence of unwanted ambient noise on the calibration process.
- A host calibration system capable of running calibration process:
  - Audio outputs connected to an ambient speaker and the music-in channel of the unit under calibration.
  - Audio inputs to monitor the internal and external reference microphones.
  - I^2C interface connected to the earphone under calibration. The physical form of the I^2C is not important; for example, an electrical connection or Bluetooth is acceptable. This I^2C interface may be used to read internal AS3460 RMS levels as well as writing internal test signal parameters in the future.

3.2 Software

- Source signals including pink noise, band passed pink noise (100 Hz – 1 kHz) and sine sweep. The output level should be set such that the SNR at both reference microphones is greater than 45 dB from 100 Hz to 1 kHz.
- An automation script to run frequency analysis on the collected data where appropriate, visualize the output and provide the calibration operator with interpretable data.

4 Transducer Sensitivity Measurements

Calibration of the transducers is required on the production line to compensate for variations in the acoustical and/or electrical properties of each earphone; this ensures a consistent ALC performance from unit to unit.

For all sensitivity measurements the ALC algorithm must be disabled completely (including music equalization). This is re-enabled when checking the ANC at the end of the process.

The primary task during calibration is to obtain the sensitivity of the transducers; the FFM, FBM and loudspeaker driver. The sensitivity levels of each must be adjusted to match the levels of a golden reference earpiece that has been optimally tuned for ALC.

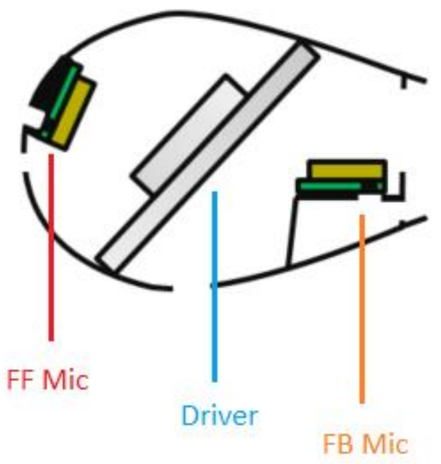
It is recommended to perform the sensitivity measurements in an acoustically isolated environment to ensure the SNR exceeds 45 dB in all measurement frequency regions. The environment must be suitably anechoic as to ensure that the acoustic paths between the ambient loudspeaker and reference microphones are predominantly direct. To achieve this, the setup must not be situated in close proximity to reflective walls and / or the walls should be absorbent.

A high leak should be set on the test fixture for two reasons. Firstly, a small variation in leakage (such as misplacement of unit on adapter) results in a smaller acoustic change than if at a low leak. Secondly, the acoustic effect of a high leak renders the difference in passive attenuation between the DUT to the golden reference is less significant. This is important when comparing DUT driver sensitivity to that of the golden reference.

4.1 Microphone Sensitivity Measurements

Regardless of the particular design of the unit, the FFM must be situated close to the exterior body of the unit whereas the FBM is located internally, close to the ear cavity. More specific guidelines on the required acoustics for ALC can be obtained from **ams**. This is shown in the figure below.

Figure 1:
Transducer Arrangement within Unit Including the Feedforward and Feedback Microphones and the Loudspeaker Driver.



The purpose of calibration is to compensate for the difference in microphone sensitivity between the DUT and the ALC golden reference between 100-1 kHz (the ANC band). It is assumed that the microphone frequency response shape is similarly flat across different units in this frequency band.

4.1.1 Technical Overview

This section outlines the relevant quantities involved in the measurement process, and how they are to be interpreted and combined.

Feedforward Microphone Sensitivity

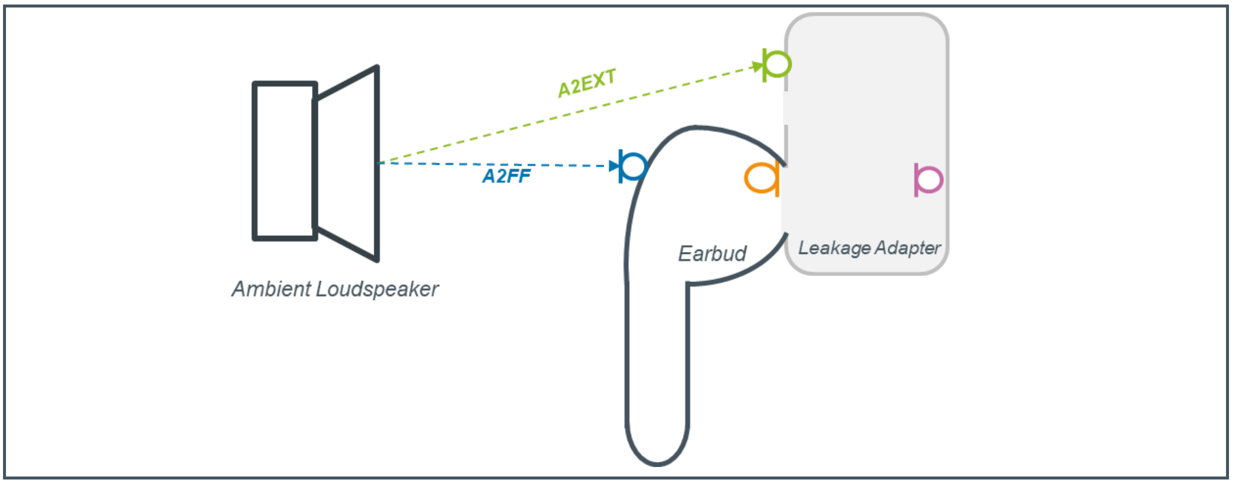
The FFM sensitivity is a single value metric which is calculated by comparing the resultant RMS level at the FFM to that of the external reference mic in response to the band passed pink noise reproduced over the ambient loudspeaker.

Equation 1:

$$sens_{FF} = \frac{A2FF_{rms}}{A2EXT_{rms}}$$

Note: The numerator is obtained via the RMS feature on the AS3460 firmware (runtime registers **CAL_RMS_MONITOR01/23**). The recording duration must be long enough to ensure that subsequent RMS readings do not exceed 0.2 dB error and AS3460 RMS value reaches a stable result. The resultant sensitivity measurement must be entered as the FFM calibration gain. Such a measurement set up is shown in the figure below.

Figure 2:
Acoustic Paths Required for FFM Sensitivity Measurement.



Feedback Microphone Sensitivity

The measurement of FBM sensitivity is very similar to that of the FFM sensitivity measurement. In order to determine this signal, the effects of passive attenuation due to the location of the microphone inside the unit cannot be discounted. For this reason, a reference microphone inside the leakage adapter / test fixture is required. The common effects of passive attenuation present on both the internal reference microphone and the FBM are discarded.

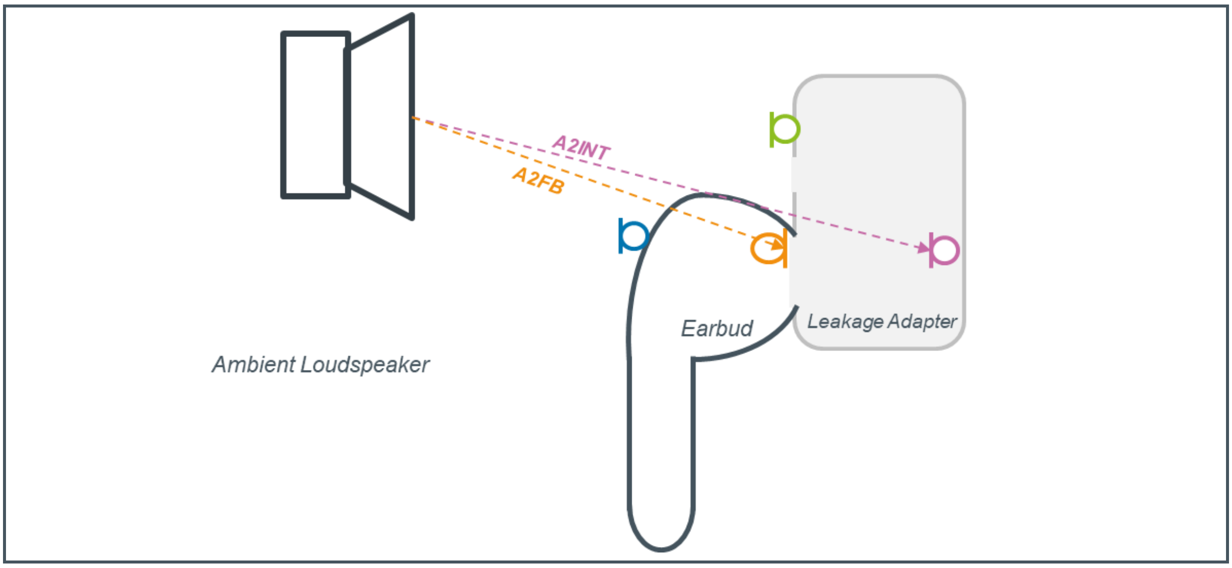
The FBM sensitivity is a single value metric which is calculated by comparing the resultant RMS level at the FBM to that of the internal reference mic in response to the band passed pink noise reproduced over the ambient loudspeaker.

Equation 2:

$$sens_{FB} = \frac{A2FB_{rms}}{A2E_{rms}}$$

Note: The numerator is obtained via the RMS feature on the AS3460 firmware (runtime registers **CAL_RMS_MONITOR01/23**). The recording duration must be long enough to ensure that subsequent RMS readings do not exceed 0.2 dB error and AS3460 RMS value reaches stable result. The resultant sensitivity measurement must be entered as the FBM calibration gain. Such a measurement set up is shown in the figure below.

Figure 3:
Simplified Acoustic Paths Required for FBM Sensitivity Measurement



4.2 Loudspeaker Driver Sensitivity

The response of the loudspeaker driver to a reference input signal across a frequency range determines its sensitivity at the different frequencies. This may vary from unit to unit and from the golden reference; for this reason, it must be calibrated.

4.2.1 Technical Overview

For the purpose of calibration, the driver sensitivity is the acoustic response between the driver input and the internal reference microphone. As the driver sensitivity is dependent upon acoustic loading at low frequencies, the leakage (and therefore passive attenuation) must be similar between the unit under calibration and the golden reference. Following this, the passive attenuation must be measured and compared to that of the golden reference. This quantity is found using

Equation 3:

$$passive\ atten(f) = \frac{A2E(f)}{A2EXT(f)}$$

Where, the respective responses are obtained using a sine sweep. If the passive attenuation difference exceeds that of the golden reference by 0.2 dB over the frequency band of interest (20Hz – 1 kHz), the driver sensitivity will not be comparable and calibration is impossible.

Once the passive attenuation has been validated, the driver sensitivity may be found by performing a sweep between the music in and the internal reference mic as follows:

Equation 4:

$$sens_{driver}(f) = D2E(f)$$

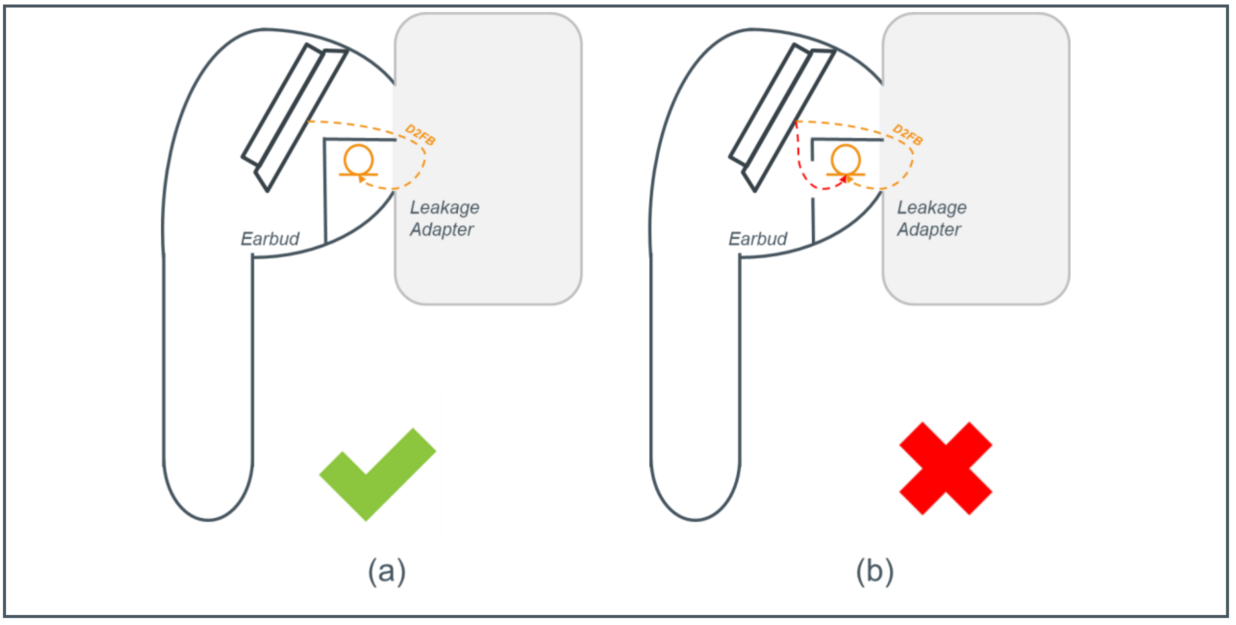
The test signal should be a sine sweep in the music channel and it must be ensured that no non-linear or spectral shaping components are present in the signal path, including the Bluetooth path.

The driver sensitivity should be compared to that of the golden reference unit at three non-harmonically related frequencies between 20 Hz and 1 kHz (50, 370, 820 Hz for example). The difference between these three values should be averaged to find the best fitting calibration gain. This value must be entered as the output calibration gain.

5 Driver to Feedback Microphone Cavity Damage Check

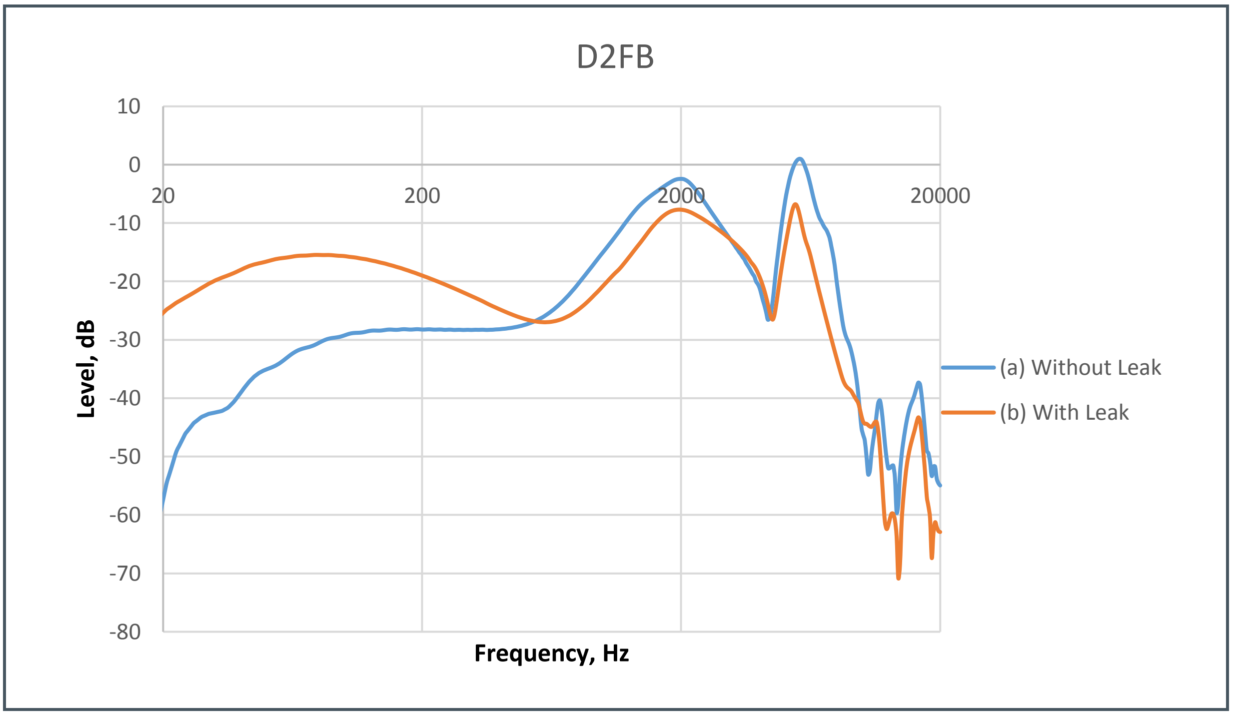
The seal around the FBM cavity should be checked to confirm that there are no unwanted acoustic leakages between the driver and the FBM cavities. This defect can be seen when inspecting the D2FB transfer function (see figure below).

Figure 4:
D2FB Acoustic Transfer Function (a) without and (b) with Acoustic Leak between Driver and FBM Cavities



An example D2FB comparison between a unit with and without such a leak is shown in Figure 5.

Figure 5:
Comparison Between D2FB with and without Driver to FBM Cavity Coupling



It can be seen that the low frequency amplitude is boosted when a leak between the driver and FBM cavity is present. By comparing the driver response (D2E) and the driver response via the FBM, this boost in low frequency response may be reliably recognized. If these two responses match, it is likely there is no leak; if not, a leak is likely. The response comparison is as follows:

Equation 5:

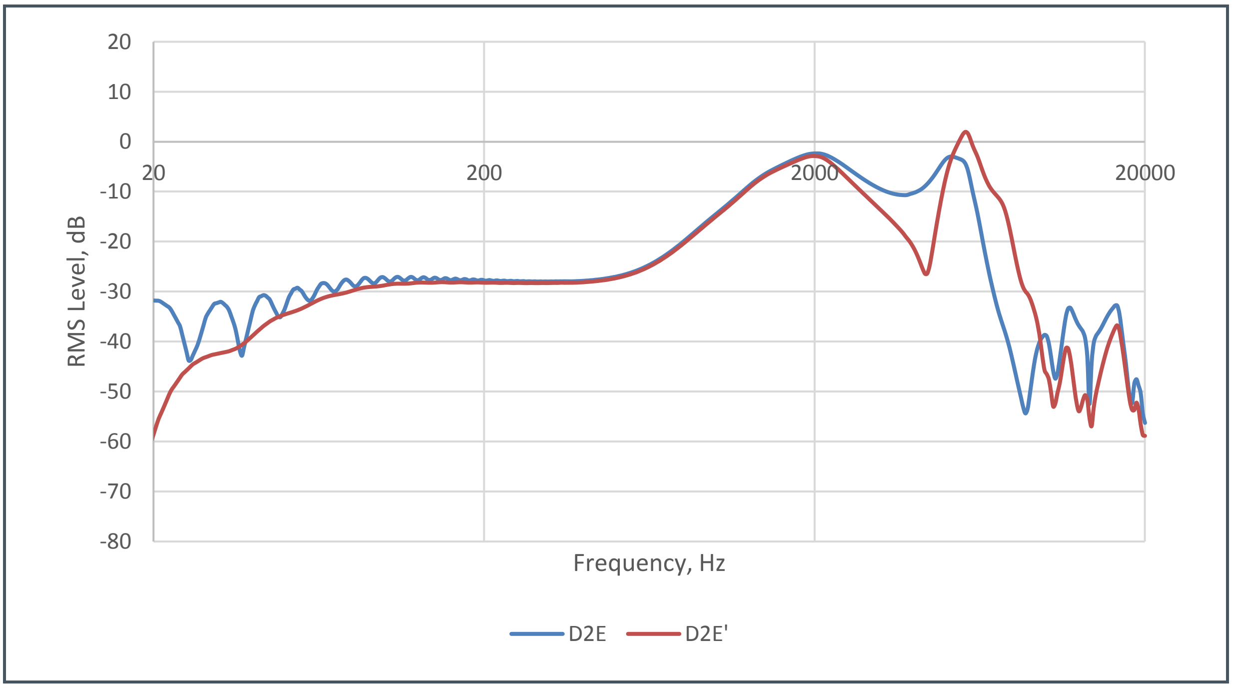
$$D2E' \equiv D2E$$

Where

$$D2E' = D2FB * sens_{FB}^{-1}$$

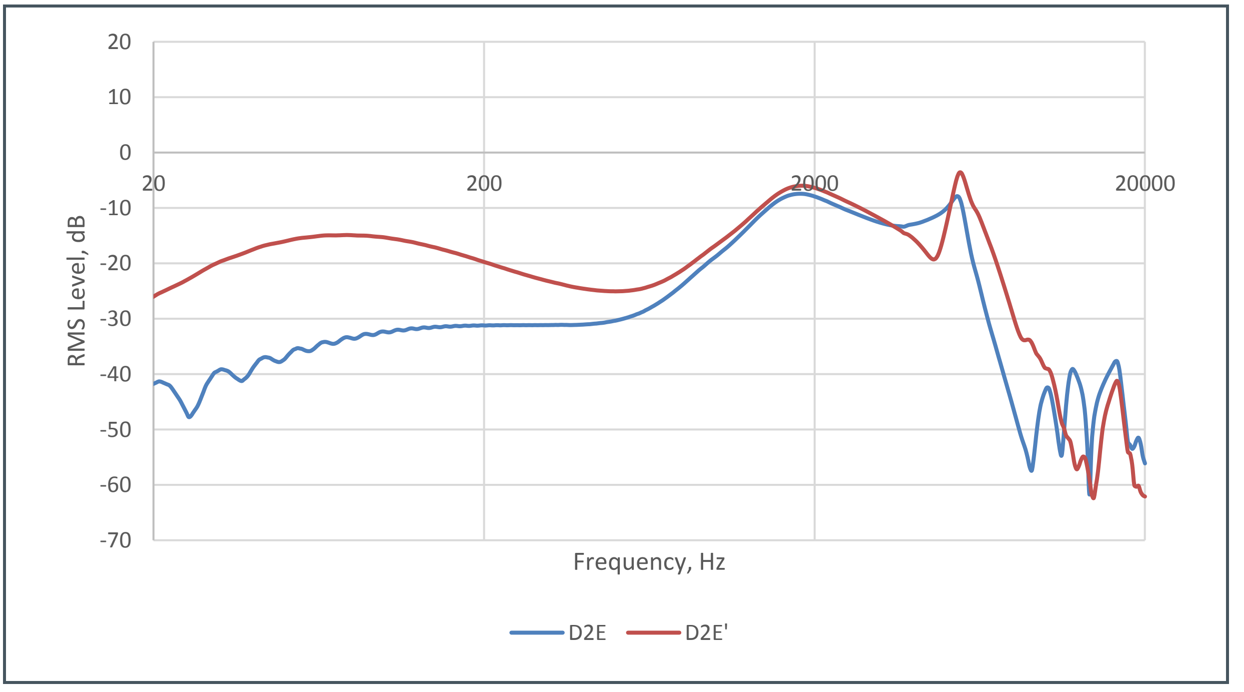
Where all quantities are in the frequency domain. It is noted that $sens_{FB}^{-1}$ is the reciprocal of the FBM sensitivity found in in the previous step. It can be seen that if there is boosting in D2FB the two equations will not match at low frequencies and it is likely that there is a leak between the FBM and driver cavity. The figure below illustrates the difference between D2E and D2E via FBM when there is no leak.

Figure 6:
D2E Comparison with No Leak between Driver and FBM Cavities



It can be seen that the two responses match when there is no leak between the FBM and the driver cavity. The figure below shows a similar case when there is a leak between the FBM and the driver cavity.

Figure 7:
D2E Comparison with Leak between Driver and FBM Cavities



It can be seen that the two spectra are not comparable – at low frequencies there is an amplitude offset.

During the calibration procedure this comparison must be undertaken at three frequencies below the driver cut-off (around 100 Hz in Figure 7), i.e.

Equation 6:

$$D2E_i' \equiv D2E_i$$

Where *i* indicates each discrete frequency; mains frequency should be avoided. If the difference is greater than 1 dB at all three frequencies, it is likely that there is a defect on the unit and should be either discarded or the seal between the driver and FBM re-manufactured.

6 ANC Check

A basic ANC validation at the end of the calibration procedure is suggested. In this section the ALC algorithm is running.

The test should be run as follows:

- Measurement of ambient to ear mic under the same conditions as the FFM sensitivity measurement with ANC off.
- Repeat the measurement starting with adaption turned off and then turned on for the duration of the measurement.

This determines the time taken for adaption to stabilize at the chosen leakage, as well as giving a metric for the resultant ANC.

For greater accuracy, a further ANC adaption measurement could be performed at a low leak, by adjusting the leakage adapter appropriately, to verify consistency of the ANC performance and adaption times. The ANC result should be smoothed and compared to that of the golden reference ANC performance.

7 Data Processing and Evaluation

As previously outlined, the feedforward and feedback microphone sensitivities are scalar values whilst the driver sensitivity is taken at several frequencies. As such, frequency information must be extracted from the measured time-domain signals to provide data for analysis.

The automated script for analysis should have the capability:

- Import the time series of reference microphone signals
- Perform frequency transformations for passive attenuation and driver sensitivity calculations
- Calculate RMS values for microphone and cavity check calculations
- Calculate sensitivity levels for the driver
- Draw a graphical plot for each of the sensitivities of the calibration earpiece, as well as the ALC golden reference

Allow the user to adjust the gain levels in the AS3460 to compensate for the sensitivity difference of each transducer to match those of the ALC golden reference unit or calculate the optimum gain automatically.

8 Step by Step Calibration Process

1. Determine Passive Attenuation
    - Ensure the leakage adapter is set to a high leak
    - Measure acoustic response between ambient loudspeaker and both reference mics using sine sweep
    - Calculate passive attenuation with automated script
    - If the passive attenuation doesn't match that of the golden reference DO NOT proceed to the sensitivity measurements before making the necessary adjustment. The likely fault is that the headphone is not inserted correctly into the leakage adapter. Remove the headphone and re-insert it into the leakage adaption then restart the test.
2. Calibrate the FFM and FBM
    - Ensure the leakage adapter is set to a high leak
    - Whilst playing band passed pink noise in via ambient source:
        - Record the time series of both reference microphones over specified time window
        - Record RMS value indicated on the FFM and FBM within the RMS block of the AS3460 firmware (ensure result converges)
    - Calculate RMS value at the reference mics
    - Calculate FFM and FBM sensitivity with the automated script
    - Compare to golden reference result and record difference (this is the calibration value).
3. Check for leaks between the driver cavity and FBM
    - Whilst playing each of the three sine tones into the music in:
        - Record RMS levels of internal mic and FBM via AS3460 RMS block
        - Repeat for all 3 frequencies
    - Calculate D2E and D2E'
    - Compare values at each frequency – if they deviate more than the specified amount the unit must be visually inspected and calibration must be repeated.
4. Calibrate the Driver
    - Measure the acoustic response using a sine sweep between the driver (music in) and internal reference mic.
    - Calculate driver sensitivity with the automated script
    - Adjust driver calibration gain to match the ALC golden reference unit using the average of the 3 frequencies.
5. ANC Check
    - Ensure ALC and ANC is still disabled
    - Play broadband pink noise via the ambient speaker
    - Record RMS value of Internal Reference Mic
    - Turn on ANC and ALC
    - Undertake the same measurement once adaption has converged
    - Measure ANC performance, adaption time et al. with automated script.

9 Summary / Results

This document has outlined the ALC transducer calibration procedure with the use of a modified **ams** leakage adapter. Furthermore, a method for verifying ANC performance and gain convergence has been outlined as well as a method for recognizing possible physical defect on the unit.

10 Revision Information

Changes from previous version to current revision v1-00	Page
Initial version	

- Page and figure numbers for the previous version may differ from page and figure numbers in the current revision.
- Correction of typographical errors is not explicitly mentioned.

11 Legal Information

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