Consultancy Report
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Acoustic characterisation of *Calmer* technology prototypes

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1. Introduction

ISVR Consulting was engaged by Flare Audio to perform acoustic tests on their new *Calmer* technology prototypes. These measurements aimed to characterise the acoustic response of this technology and to objectively assess its typical effect on the hearing profile of the user of this device.

It is understood that *Calmer* technology is designed to manipulate the acoustic response of the ear above 1,000 Hz, by altering the modal characteristics of the outer ear. In particular, the technology aims to reduce naturally occurring resonances associated with the geometry of the ear canal and pinna. In order to achieve this, these passive acoustic devices contain an acoustically designed geometry with two opposing openings towards the eardrums and external noise sources. The soft silicon material seals around the entrance of the ear canal and the device partially covers the concha.

The devices can also be worn under circumaural and supra-aural headphones. In this case, the technology aims to improve the headphone listening experience by controlling the acoustic characteristics of the human ear coupled to the headphone.

During the time of this measurement project, the acoustic facilities of ISVR Consulting were out of service, due to the COVID-19 lockdown period in the United Kingdom. The test procedures were designed specifically to ensure that measurements do not rely on free-field (anechoic) acoustic conditions.

The primary aim of the project therefore was to evaluate the acoustic effect of *Calmer* devices under headphones using an Acoustic Head and Torso Simulator (HATS). Frequency response functions (FRF) of 2 headphone specimens on the HATS were measured with and without the *Calmer* devices fitted. FRF results were analysed comparatively to demonstrate and quantify the acoustic effect of wearing the devices.

Similar measurements were also taken with an external sound source to characterise the acoustic effect of *Calmer* with a far field source of excitation. The acoustic effect of the room was minimised using digital signal processing.

Any alteration in the transfer characteristics of the ear that *Calmer* achieves could also influence the level of distortion perceived by the user of the technology. Distortion measurements with and without *Calmer* were assessed using headphones. Whilst the technology is not expected to control the amount of distortion generated by the headphone itself, some distortion components falling in the modal frequency range could be reduced at the ear drum, if the resonant behaviour of the system is attenuated by the technology. In order to test the total perceived distortion with and without *Calmer,* measurements were taken with a multi-tone stimulus signal.

The project aimed to quantify the effectiveness of the *Calmer* technology using frequency response and distortion measurements. This report details the measurement configuration and procedure, presents the results and provides an objective assessment of the acoustic features of this technology. The report specifically does not discuss the subjective experience of wearing the device and does not attempt to link any of these with the test results. Detailed analysis and identification of the exact physical-acoustic mechanisms of the device also fell outside the scope of this investigation.

2. Measurement set-up

All tests were performed by ISVR Consulting on the 29th and 30th April. This section of the report details the equipment, test conditions and data processing in the project.

2.1 Test environment

All tests were carried out in a furnished, ordinary room with dimensions of 3.5 m x 3.0 m x 2.2 m. The side and top boundaries are plastered walls/ceiling, the floor is covered by a thin layer of carpet. Besides a regular wooden door, the room is built with double glazing (1.6 m x 1.1 m) on one of the walls. During all tests, windows and the door were closed in order to minimise background noise levels. Furthermore, the amplitudes of test signals were selected to ensure high signal-to-noise ratios. During testing, external noise levels were observed and tests were halted if background levels were higher than normal.

2.2 Test equipment

Tests were carried out using ISVR Consulting's 'Kemar'[1] acoustic head and torso simulator (HATS). This device is a manikin with a realistic head and pinnae and incorporates ear simulators with ear canals and 'eardrum' microphones. It is representative of a median human adult and is designed to permit acoustic measurements of wearable acoustic devices. The shape of the manikin and the nature of the ear simulators ensure that the obtained recordings include the acoustic effect of the human body exposed to external sound sources or wearing headphones. For headphones the manikin also creates a realistic acoustic load on the headphone drivers. This platform is therefore ideal to investigate the changes that *Calmer* brings to this system.

The ear simulators and microphones within the manikin are tuned to imitate the transfer impedance of a typical human ear. ISVR Consulting's ear simulators conform to BS EN 60318-4:2010 [2]. The calibration of the HATS's two microphones was checked before and after the measurement session using a Brüel & Kjær (B&K) type 4220 pistonphone. The calibrations were stable. The calibrations of the ear simulators, microphones and pre-amplifiers are traceable to the manufacturer, G.R.A.S. who verified their performance in March 2020. The B&K pistonphone was calibrated at a UKAS accredited test house in March 2019.

The ear simulators accurately imitate the human ear's (standardised) acoustic transfer impedance up to the frequency of 10,000 Hz in compliance with BS EN 60318-4:2010. Results above this frequency fall outside the range of the standard and may not be an accurate human ear simulation, however comparative conclusions are made in this report up to 16,000 Hz by relating recordings with and without *Calmer* in the exact same conditions.

2.3 Frequency response measurement with headphones

The primary aim of this test was to measure and characterise how wearing *Calmer* influences the sound pressure reaching the eardrum when used under headphones. These measurements were performed by determining the impulse response between the headphone excitation signal and the corresponding microphone recordings of the ear simulator, with and without the *Calmer* prototypes 'worn' by the HATS under headphones.

Measurements without *Calmer* provide the baseline or reference impulse response of the headphones, against which any measurements with the device in place can be compared. Comparisons of the impulse responses with and without the device indicate the effect of these devices and show the changes in sound pressure levels (SPL) obtained at the eardrum. The acoustic effect of wearing these devices under headphones can be clearly determined using this method, since the only difference between corresponding test conditions is the presence of the device.

Brüel & Kjær's Dirac 5.0 (Type 7841) was used in the FRF tests to measure the impulse response of the complete electro-acoustic system from the electrical excitation signal (for the headphone) to the ear simulator microphones with and without *Calmer*. In all measurements, Dirac was set-up to produce a 10.9 second long exponential sine sweep excitation signal without any source filter, sampled at 96 kHz.

To account for any imperfections imposed by the USB measurement interface used with this software, Dirac's sound device calibration routine was performed prior to the measurements. This routine also ensured the input and output level calibrations are obtained by the Dirac and the output levels therefore were automatically adjusted by the software.

The exact calculation technique of this proprietary software is not detailed in its reference manual, but it is understood that the Dirac software estimates the impulse response by deconvolution of the ear simulator microphone signals and the corresponding loudspeaker driving signal. This technique for estimating the impulse response was established by A.Farina [3] at the 2000 AES convention in Paris.

The obtained impulse responses were processed using a 131072-point FFT analysis to obtain the corresponding frequency response functions (FRF).

2.4 Total distortion measurement with headphones

The total signal distortion present at the ear drum microphones produced by the headphones was measured with and without *the Calmer* devices using a Prism Audio dScope M1 measurement system. A synchronous multi-tone measurement technique was chosen specifically to perform distortion measurements in test conditions that can emulate the complexity of real music and other programme material, whilst allowing simultaneous distortion measurements in the whole audible range.

Multi-tone testing was originally developed for rapid production line and broadcast system testing; however, the technique holds several desirable features for this test scenario. The reference manual of the measurement system used in the tests provides limited information on the exact test parameters and calculation techniques, however the system is understood to operate on the following principles:

- The test signal consists of 31 tones with frequencies close to, but not exactly corresponding to 1/3rd octave centre frequencies as defined in BS EN 61260-1:2014[5].
- The tones are identical in magnitude and their relative phases are varied randomly to ensure that signal clipping is avoided, and that the crest factor of the signal is controlled
- The frequencies of the tones are defined to avoid spectral overlaps of fundamentals and harmonics. Furthermore, all frequency components of the input signal also correspond to the exact centre frequency of an even FFT bin, allowing the use of rectangular windowing without spectral leakage.
- The system in this configuration can detect the signal in the predefined FFT bins, distortion in other even-numbered FFT bins and noise in all odd-numbered FFT bins simultaneously

Exploiting these features of the multi-tone signals, this test can maximise the production and detection of harmonic, and intermodulation distortion as well as other non-linearities, which are more difficult to evaluate with more traditional swept-sine or twin-tone tests. The complexity of the multi-tone test signal enables realistic test conditions by better approximating the dynamic characteristics and tonal content of music and other programme material on the whole audible range. Similar to real-life listening, the headphones playing the multi-tones are expected to produce significantly higher amounts of distortion products compared to those detectible in the FRF measurements. Results are presented in this report using the following quantity:

$$Total\ Distortion\ (TD): 10\log_{10}\left(\frac{sum\ of\ all\ distortion\ power^{\dagger}}{reference\ power^{*}}\right)$$

† calculated using spectral power magnitudes in even-numbered FFT bins that do not contain any components of the input signal

∗ Reference used in TD calculation is the measured signal magnitude of the tone component closest to 1,000 Hz

N.B. TD results are not directly comparable with total harmonic distortion measurements

Since these tests aimed to establish the distortion characteristics of the signals measured at the simulated eardrum rather than distortion generated by the headphones, sound levels were not adjusted to give the equivalent undisturbed field sound levels. This test relies on the assumption that the ear simulators used in this project provide a good approximation to the behaviour of the human ear, both for the main (high magnitude) signal components and the (low magnitude) distortion products. It is also assumed that the instrumentation itself does not introduce a significant amount of its own distortion that are typically not present in the human ear.

The reference power used in the distortion calculations may vary comparing cases with and without *Calmer* if the corresponding frequency responses are changed by the presence of the device at 1,000 Hz. Results were recorded with reference powers calculated by the audio analyser, however individual correction factors were used in calculations to ensure that the distortion readings are directly comparable.

Total Distortion results with and without *Calmer* were analysed comparatively. For each test case, these metrics were logged for 30 seconds in the measurement system and results in this report are calculated using linear averaging. The FFT results exported from the analyser were also utilised for further calculations.

The Prism Audio multi-tone measurement system and calculation software complies with requirements regarding multi-tone based distortion measurements set in BS EN IEC 60268-21:2018 [4].

2.5 Frequency response measurements with an external sound source

In order to characterise the acoustic effect of *Calmer* when worn without any other acoustic devices around the ear, the impulse response measurements detailed in section 2.3 were performed with a studio-grade loudspeaker as an excitation source instead of headphones. This test is designed to measure and characterise how wearing *Calmer* influences the sound pressure reaching the eardrums in a certain sound field due to external sources.

In order to ensure that such results are not affected by the acoustic response of a test venue, these measurements would need to be performed under free-field acoustic conditions. During the time of this project, it was not possible to utilise ISVR Consulting's large anechoic chamber. Measurements were carried out in the same room as used for the headphone measurements and the approximate (simulated) free-field conditions were achieved using digital signal processing.

The acoustic centre of the excitation source was placed 1.2 m away from the centre of the HATS (midway between the two ears). The direction of the HATS was aligned so both ears were the same distance from the centre of the loudspeaker.

The following steps were taken in order to minimise the influence of the room on the measurement results:

1. Each measured impulse response was analysed individually to detect the 'time-of-arrival' of the first distinct reflection from the boundaries of the room reaching the simulated eardrums. Knowing the time-of-arrival of the direct sound from the loudspeaker and that of the first reflection, a weighting window was constructed using a sinusoidal function. The length of the window function was adjusted to be shorter than twice the difference of the detected timings. The peak/centre of this

window function was aligned with the arrival of the direct sound component from the loudspeaker. The window function was applied to the impulse responses by (element-wise) multiplication, removing major room reflections from the impulse response.

2. Reference (impulse response) measurements of the excitation source were also taken with an omni-directional microphone. For these tests, the HATS was removed from the room and the reference microphone was placed 1.2 m from the loudspeaker on its acoustic axis. The signal processing detailed in point 1 were performed on these recordings as well.
3. The FRF magnitudes of the HATS and reference measurements were calculated from the corresponding impulse responses using a 131072-point FFT.
4. The loudspeaker FRFs were used to allow correction for the characteristics (any colouration) introduced by the loudspeaker itself and reducing the influence of any room effect that windowing could not remove.

Using windowing to compensate for room reflections inherently compromises the validity of results at lower frequencies. The length of the window used in this test dictates the low frequency limit. *For these results, any data below 450 Hz is invalid.*

Measurements performed without *Calmer* are also known as Head-Related Transfer Functions (HRTFs). In order to verify the effectiveness of the simulated free-field processing, HRTFs obtained in these tests were compared to results of identical measurements performed in the anechoic chamber in 2019. It was found that the real and simulated free-field HRTFs matched between 450 Hz and 10,000 Hz with the accuracy of ± 3 dB. This confirms the validity of the test set-up for this investigation.

Besides on-axis sound incidence described above, tests were also performed at 45^o and 90^o azimuth angles.

3. Measurement procedure

The aim of this test was to measure and characterise how wearing *Calmer* influences the sound pressure reaching the eardrum. These measurements were performed by determining the impulse response between the excitation source (loudspeaker or headphone) and the corresponding microphone recordings of the ear simulator. Using headphones, Total Distortion (TD) was measured with a multi-tone stimulus by analysing the corresponding ear simulator signals on the frequency domain. In all measured data pairs (with and without *Calmer*), every measurement conditions were consistent, except the presence of *Calmer* in the artificial ears.

The tests were carried out using the following Headphone test specimen:

1. BOSE Soundlink AroundEar II Wireless
2. Nubwo N16 circumaural gaming headphone

Headphone FRF results were recorded using 20 mV rms signal level. Input levels in TD tests were varied.

Loudspeaker measurements were carried out using a Genelec 8030C studio monitor. Playback level was adjusted to be 75 dB at 1,000 Hz.

Any variability in the fitting of both the *Calmer* prototypes and/or the headphones on the HATS can significantly influence the measurement results in all tests, particularly at low and high frequencies. In order to minimise measurement errors related to the fitting of the devices and the headphones, the following actions were taken:

1. The devices were examined and worn by the experimenter to determine the properties of the typical fit the user of this device would achieve
2. Fit and seal of *Calmer* was visually examined and confirmed in the HATS's ears without the microphones in place

3. Preliminary measurements were taken with approximately 10 refits to observe variations that different fits introduce
4. Every refit of *Calmer* was visually examined to ensure proper seal and alignment in the simulated ears
5. Every fit of the headphones was adjusted to be as symmetrical as possible on the two ears, whilst ensuring that the pads fit on both ears with good seals all around. Headbands of the headphones were adjusted to help achieve these fit criteria.

Once various fit properties were observed and reasonable consistency was achieved, 3 sets of FRF and 3 sets of TD measurements using headphones were performed with a refit between every consecutive test. Using the left and right units individually, presented results are based on the average of 6 (refitted) FRF measurements and 6 (refitted) TD measurements.

In the case of measurements with external sources, on-axis, 45° and 90° azimuth (incidence of sound), measurements were performed consecutively. For each positioning of the HATS, the reference HRTF was measured once (after preliminary measurements to verify the setup), followed by 5 measurements with *Calmer* fitted in the ears. Amongst these 5 measurements, the devices were refitted each time.

A typical fit of *Calmer* is shown on Figure 1.

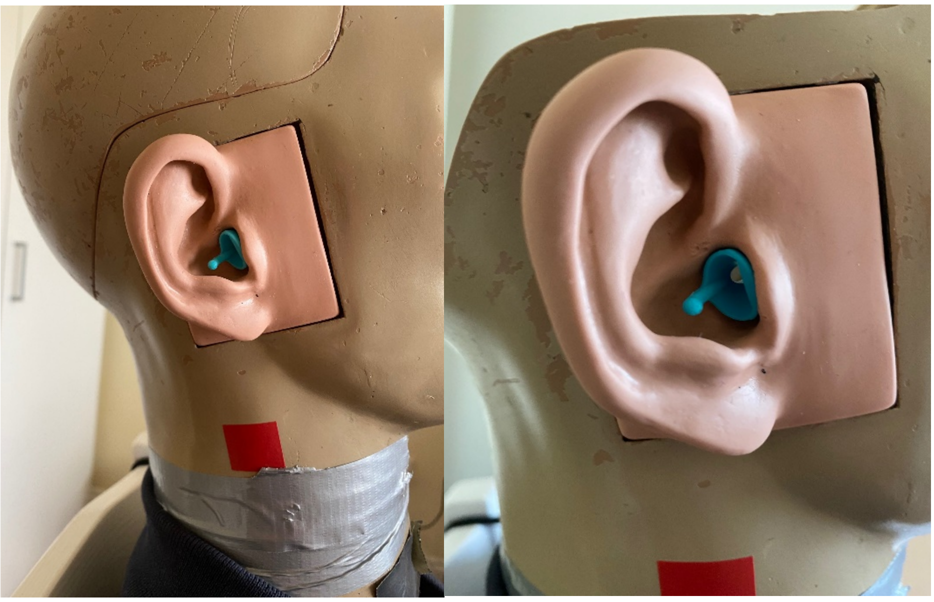

Figure 1: Typical fit of Calmer in HATS

A typical fit of the headphones are shown on Figure 2.

Figure 2: Typical fit of BOSE (left) and N16 (right) headphones on HATS

It was observed in both cases, that minor variations in fit influenced the magnitude and frequency of some high frequency resonant peaks. In order to allow averaging in these conditions, the main FRF results are presented as 1/3rd octave smoothed data. All presented averages are based on individual measurements, including averaging left and right recordings in identical conditions (except off-axis measurements). This ensures that any systematic errors introduced by minor positioning errors or other inconsistencies are minimised. The processed dataset is normalised to 0 dB at 125 Hz without the *Calmer*. The individual narrow band frequency responses with headphones are shown in the Appendix.

4. Results and data analysis

4.1 Frequency response measurements with headphones

Figure 3 presents the magnitude of the measured frequency response function of the BOSE headphones with and without *Calmer* technology applied.

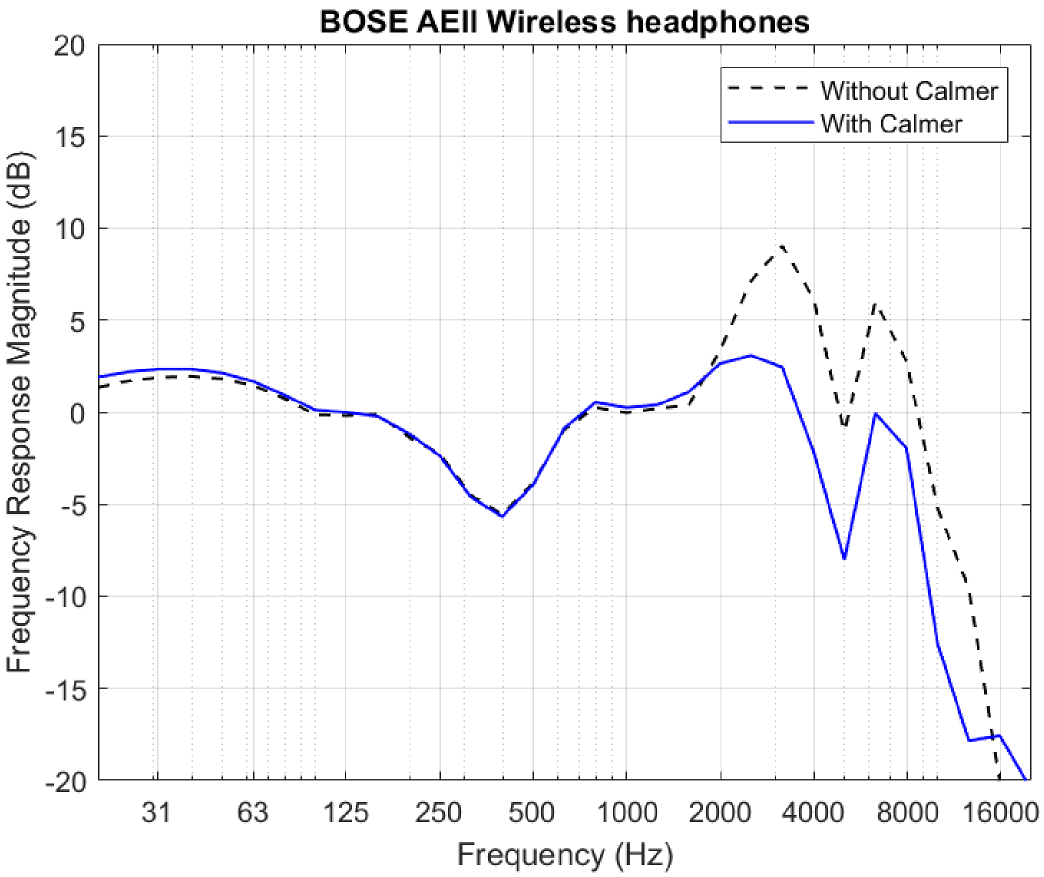

Figure 3: FRF magnitude results of the BOSE headphones, with and without Calmer

Figure 4 presents the magnitude of the measured frequency response function of the N16 headphones with and without *Calmer* technology applied.

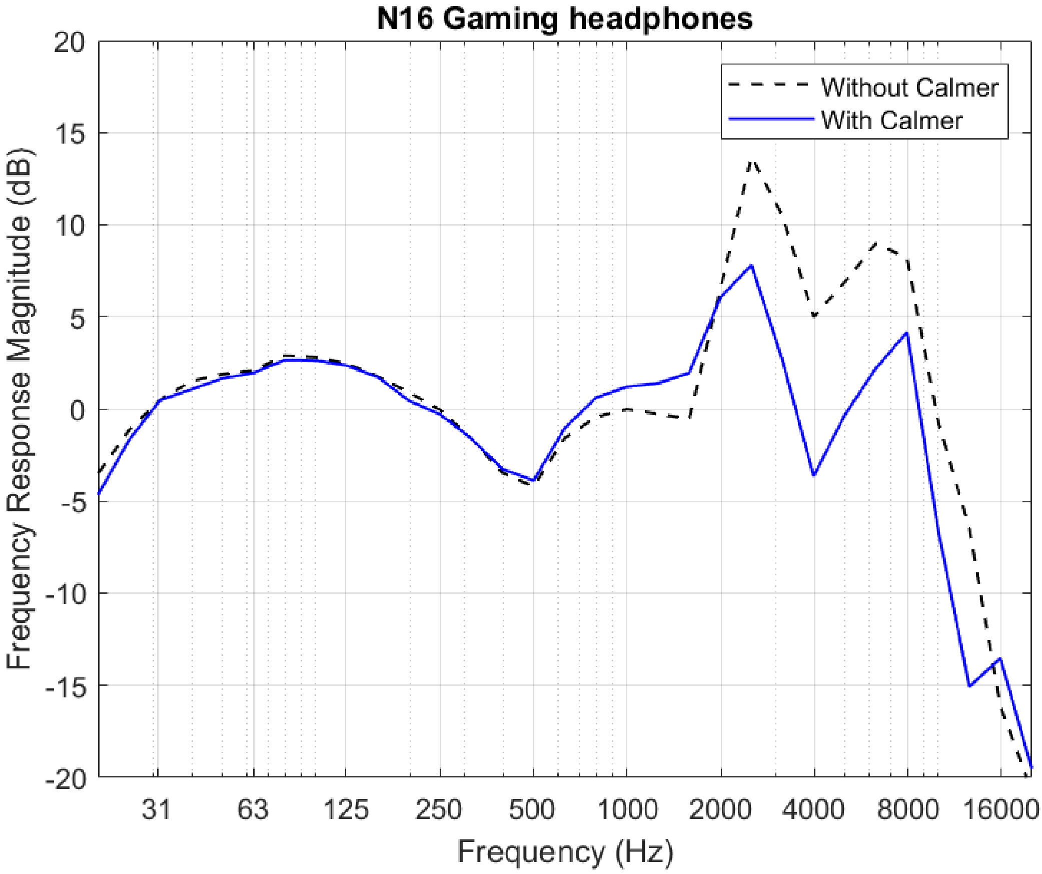

Figure 4: FRF magnitude results of the N16 headphones,
with and without Calmer

Measurements presented on Figure 3 and Figure 4 are analogous to sound pressure levels reaching the eardrum with and without *Calmer* from the headphones, assuming that all frequencies are excited equally.

Figure 5 shows the effect of wearing *Calmer* normalised to the measurement result without the devices. These results quantify *Calmer*'s influence on the sound pressure levels reaching the eardrums for these two headphones.

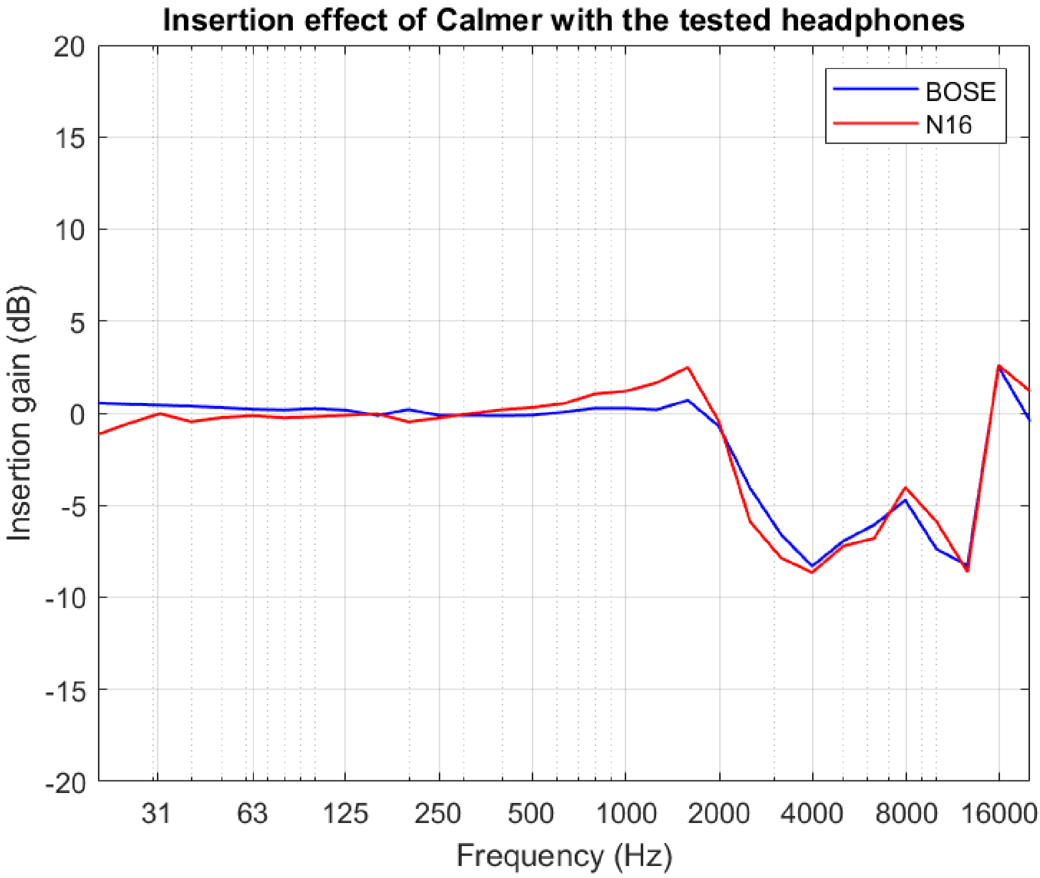

Figure 5: Insertion gain of Calmer devices with the two tested headphones

At frequencies below 1,000 Hz, *Calmer* does not significantly affect the measured response. This may be explained by the fact that at these frequencies, the wavelengths of the sound components are significantly longer than the dimensions of these devices.

Using the BOSE headphones with *Calmer*, no change in sound pressure levels were observed up to 2,000 Hz. In case of the N16 headphones, *Calmer* had a minor boosting effect on frequencies between 500 Hz and 2,000 Hz. The peak of 2.5 dB of this boosted region was observed at 1,600 Hz.

Considering the measured results of the two headphones without *Calmer*, both headphones show elevated responses in the 2,000 Hz to 8,000 Hz range. In this frequency region the various dimensions of the headphones and outer ear become comparable with the wavelengths of the sound waves. Therefore, various wave reflections from the headphones' body, parts of pinnae and the eardrum lead to modal/resonating acoustic characteristics in this frequency region.

Resonant mechanisms of the open/unaided ear are well established. Shaw and Teranishi[6] (1968) investigated the various components of head-related acoustic transfer functions. Amongst various mechanisms related to the presence of head and shoulders, for a free-field sound incidence of 45^{o} azimuth, they identified resonances of approximately 11 dB at 2,700 Hz and 8 dB at 5,800 Hz. Their research linked these resonances to the geometry of the ear canal and concha respectively. When using headphones and depending on the listeners exact ear geometry, the magnitude and frequency of these resonances may change, however they will be present, influencing the sound pressure reaching the eardrum. Results in this frequency region may also be influenced by the frequency response characteristics of the headphone drivers themselves.

According to test results on Figure 3 and Figure 4, *Calmer* attenuated these naturally occurring acoustic phenomena and it was observed that this technology significantly modified most of these effects. The responses of both headphones showed their highest peak around 3,000 Hz (most likely due to simulated ear canal resonances). *Calmer* attenuated these features, reducing levels by approximately 6.6 dB and 7.8 dB around 3,000 Hz respectively with the BOSE and N16 headphones.

The responses of both headphones showed further resonances in the 4,000 Hz to 8,000 Hz range. These are most likely linked to the geometry of the simulated concha and other parts of the outer ear. *Calmer* achieved 6.4 dB and 6.7 dB of average attenuation in this range with the BOSE and N16 headphones respectively.

Results in Figure 3 and 4 show that responses recorded with *Calmer* were lower than those without this technology above 8,000 Hz. It is important to note that the response of the ear simulators in the HATS are not defined above 10,000 Hz in BS EN 60318-

4:2010, however comparative analyses of the 10,000 Hz, 12,500 Hz 16,000 Hz one-third octave bands were performed, accepting that the two of these fell outside the usual range. In these bands *Calmer* achieved an average attenuation of 4.4 dB (BOSE) and 3.9 dB (N16) compared to the corresponding cases without the devices.

4.2 Total Distortion measurements with headphones

Distortion measurements were performed using a multi-tone test method, as described in section 2.4 of this report. Preliminary tests were carried out to assess the characteristics of the distortion generated by the headphones and recorded by this test method. The following observations were made with both headphones:

- Both headphones generated a significant number of distinct distortion products.
- FFT plots were analysed to identify 2nd to 7th harmonic distortion products of the tones. This check identified a significant number of distortion products that are not harmonically related to the input tones (confirming the effectiveness of the test over swept sine measurements).
- Even bins, where distortion components were expected, were in most cases higher than readings in neighbouring odd frequency bins. This indicates that most of the detected distortion components were sufficiently above the noise floor of the measurement.
- Highest distortion components were observed below 300 Hz, increasing towards lower frequencies.
- Examining tendencies in distortion magnitude, on average, higher readings were observed between 2,000 Hz and 8,000 Hz, compared to those between 300 Hz and 2,000 Hz.

The audio analyser used in the tests calculated total distortion during the tests as detailed in section 2.4. Results for both headphones were recorded at 3 different input rms levels. In order to allow direct comparison of the distortion readings, correction factors were used based on individually recorded levels at 1,000 Hz for each measurement pair. In order to reflect the frequency dependent sensitivity of the human hearing, total distortion and total signal power results were recorded with an A-weighting filter applied to the inputs of the audio analyser.

Table 1 shows the average reduction in Total Distortion that *Calmer* achieved. Individual distortion readings (with appropriate corrections applied) are shown in Table A2 in the Appendix.

Table 1: A-weighted average reduction in Total Distortion (TD) by *Calmer*

BOSE AEII Wireless

Input (mV rms)	Overall A-weighted SPL at eardrums without *Calmer* [dBA]	Total reduction in TD by *Calmer* A-weighted (ΔTD) [dBA]	Total reduction in signal power by *Calmer* A-weighted (ΔSIG) [dBA]	Total reduction in distortion by *Calmer* A-weighted ref'd to reduction in signal power (ΔTD/ΔSIG) [dBA]
10	93.7	5.2	3.4	1.8
20	99.6	5.1	3.3	1.8
100	113.7	5.9	3.3	2.5
average	***N/A***	**5.4**	**3.3**	**2.1**

N16 Gaming Headphone

Input (mV rms)	Overall A-weighted SPL at eardrums without *Calmer* [dBA]	Total reduction in TD by *Calmer* A-weighted (ΔTD) [dBA]	Total reduction in signal power by *Calmer* A-weighted (ΔSIG) [dBA]	Total reduction in distortion by *Calmer* A-weighted ref'd to reduction in signal power (ΔTD/ΔSIG) [dBA]
10	94.5	5.9	4.2	1.8
20	100.5	5.9	3.9	2.0
100	114.5	6.2	3.9	2.3
average	***N/A***	**6.0**	**4.0**	**2.0**

Based on data corrected to common reference in dB calculation

In all the tested cases, *Calmer* reduced the overall magnitude of the distortion components reaching the eardrum. The highest reduction in total distortion of 6.2 dB was observed with the N16 headphone at 100 mV rms input level.

The A-weighted total distortion results show an average reduction of 5.4 dB and 6.0 dB with the BOSE and N16 headphones respectively. Reductions in corresponding signal powers of 3.3 dB and 4.0 dB were recorded. In both cases, the reduction in distortion power was greater than the reduction in signal power.

Identification and verification of the exact distortion reduction mechanism of *Calmer* fell outside the scope of the project. However, based on the narrow-band FFT data used in these calculations the following observations were made:

- Apart from distortion detected below 300 Hz, the frequency of the highest distortion peaks without *Calmer* corresponded to the frequency of the resonant peaks observed in Figure 3 and 4.
- Highest reductions in distortion components were found in the 2,000 Hz to 8,000 Hz range
- Analysis of distortion components in the 2,000 Hz to 8,000 Hz range, that fell close to the corresponding signal tones showed comparable reduction to results observed at the nearby tones
- Distortion components were present in a large number of even FFT bins across the whole measured frequency range. A relatively small number of even FFT bins were observed with levels comparable to odd frequency bins (containing noise only)

Using these observations, it is speculated that the primary acoustic mechanism behind these results, is *Calmer*'s capability to attenuate the naturally occurring resonances in the ear (as observed in the FRF results). In other words, *Calmer* reduces amplification of distortion components at these resonant frequencies.

Although the amount of distortion generated by the headphones without the acoustic effect of the head and ears is not determined in this test, one can expect that the observed resonances of the ear canal and pinna would boost the magnitude of distortion received at the ear drums in the modal frequency range. This test demonstrated that a relatively small number of signal components played by the headphones will excite a significantly larger number of distortion components. It showed that *Calmer*'s effect of resonance mitigation will affect both signal and distortion components. However, these tests demonstrated that due to the significantly larger amount of distortion components the overall reduction in distortion is greater than the overall reduction in signal components.

This test assumes that most real playback signals would behave similarly to the test signal used, in terms of excitation and corresponding broadband distortion generation mechanisms. However, the actual reduction in distortion relative to the signal components experienced by the user will depend on the headphones used, the fit of the devices and properties of the music or programme material reproduced.

It is important to note that this analysis is not exhaustive and is based purely on the data collected in this project.

4.3 Frequency response measurements with external source

Figure 6 shows the magnitude of measured FRFs of *Calmer* technology applied to the HATS with an external source place at 0° azimuth. Results without these devices are also shown for comparison.

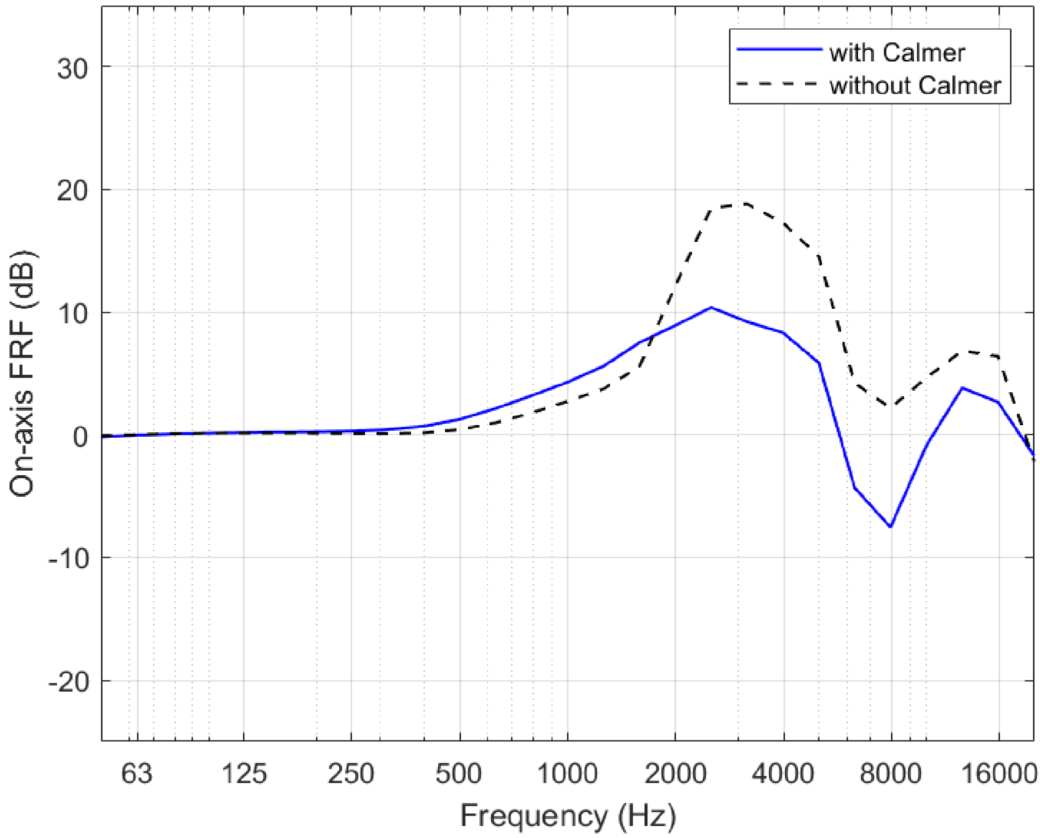

Figure 6: On-axis frequency response magnitude of Calmer measured using HATS

Figure 7 and Figure 8 show the magnitude of measured FRFs of *Calmer* technology applied to the HATS with and external source place at 45° and 90° azimuth respectively. The corresponding results without these devices are also shown for comparison.

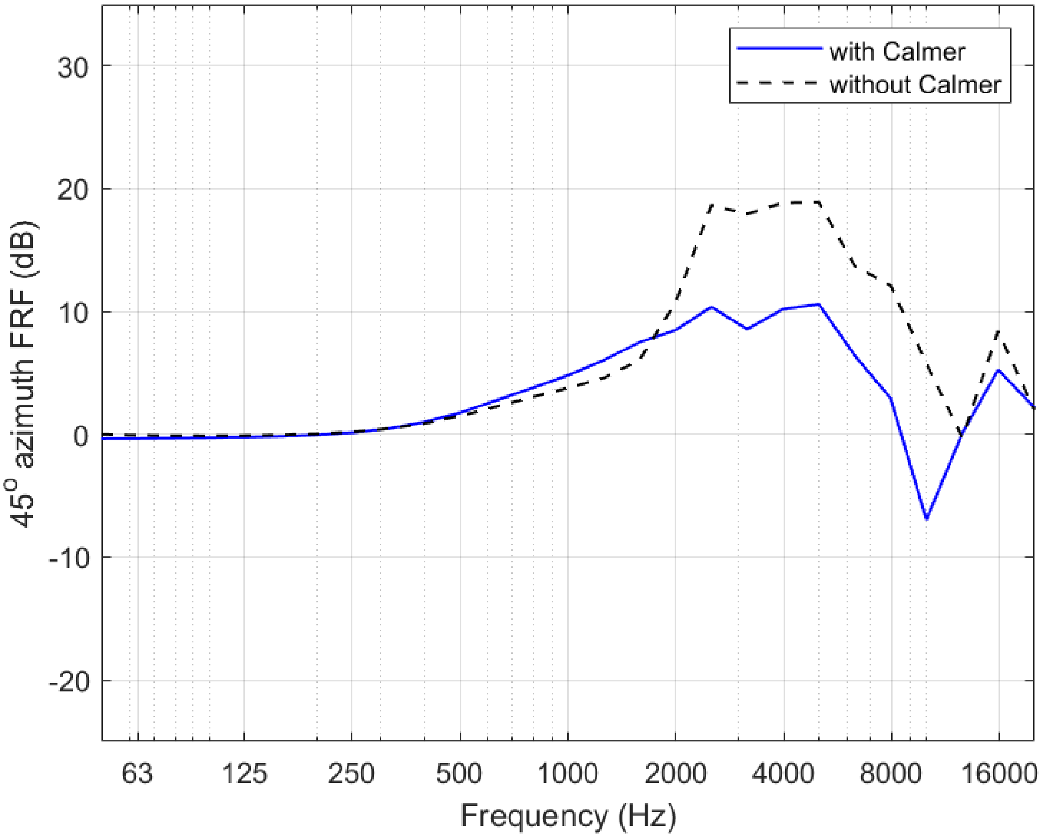

Figure 7: 45° azimuth sound incidence frequency response magnitude of Calmer measured using HATS

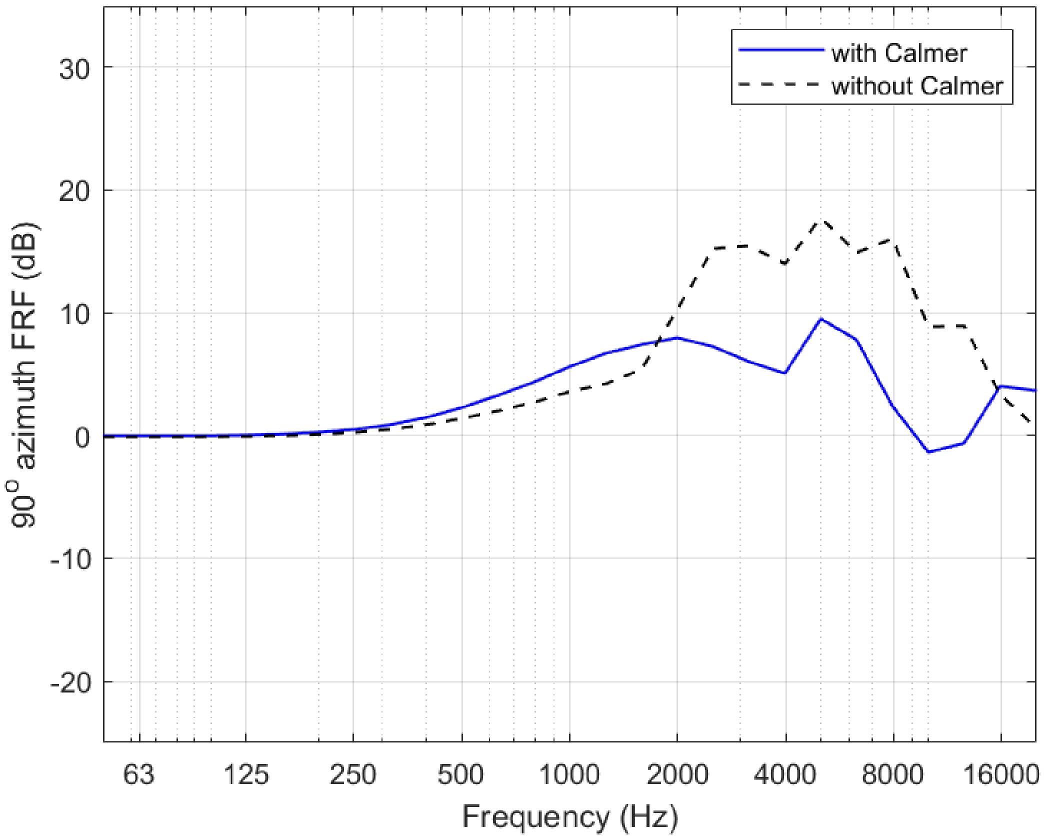

Figure 8: 90º azimuth sound incidence frequency response magnitude of Calmer measured using HATS

These measurements are analogous to sound pressure levels reaching the eardrum with and without *Calmer* from a point excitation source with a flat frequency response placed in front of the listener (at 0°, 45° and 90° positions), in free-field conditions, assuming that all frequencies are excited equally.

Figure 9 shows frequency response functions with *Calmer* normalised to the corresponding FRFs without the devices. These results quantify *Calmer*'s influence on the sound pressure levels (SPL) reaching the eardrums with external sound sources.

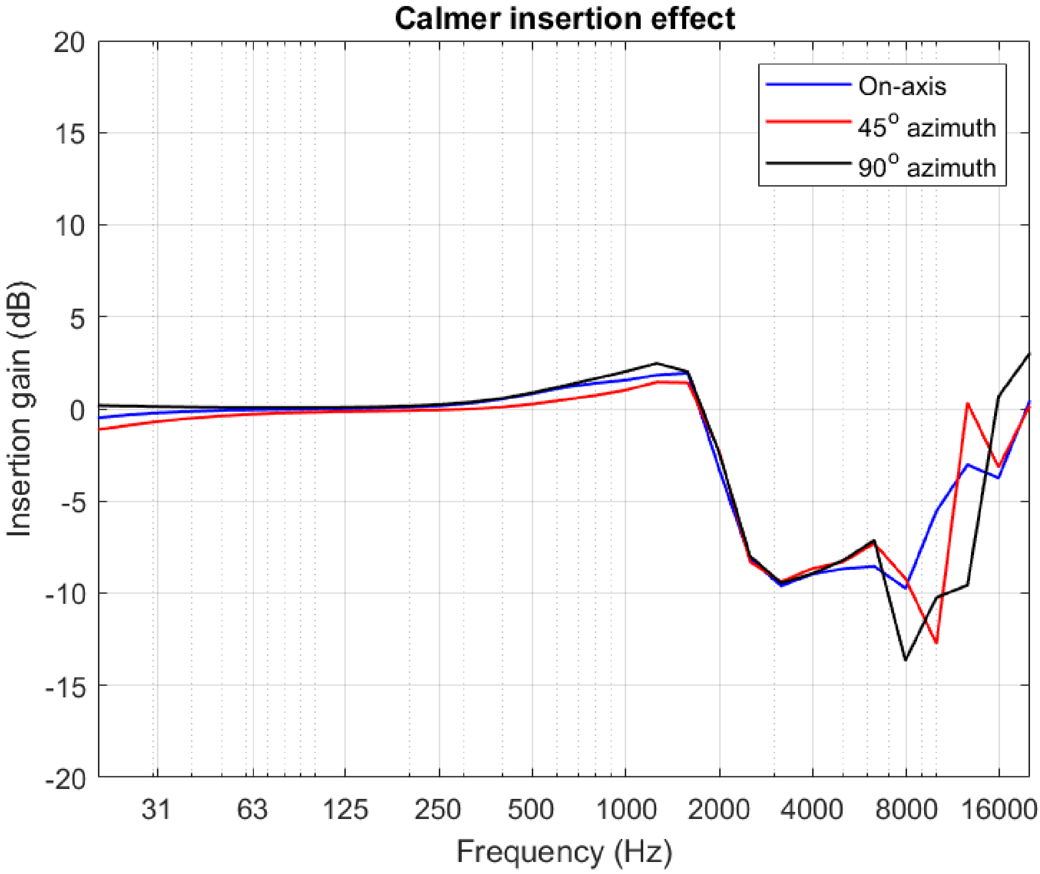

Figure 9: Insertion gain of Calmer measured with an external source

Insertion gain results of *Calmer* with external sources of excitation presented in Figure 9 show similar features to the results observed with headphones (near-field sources of excitation) presented in Figure 5 of this report.

At frequencies below 1,000 Hz, *Calmer* does not significantly affect the measured response. Frequencies between 500 Hz and 1,600 Hz are slightly boosted with the devices. The highest amplification of 2.5 dB was observed at 1,250 Hz when the loudspeaker was placed 90º off-axis relative to the HATS.

Resonant mechanisms of the human ear were briefly discussed in section 4.1 of this report. HRTFs measured without the devices in Figures 6, 7 and 8 show the frequency response of a typical, unaided human ear in the sound field established in this experiment. It can be observed that the 3,000 Hz region is significantly enhanced by the presence of the human body and ear as well as that lower ranges show an increasing trend towards 1,000 Hz. This observation is understood to be the combined effect of numerous acoustic factors, of which the most significant are the natural resonances occurring in the simulated ear canal, diffraction around the head, and reflections from the pinnae and shoulders of the HATS, though shoulder reflections are minimised by placing a tee-shirt on the HATS, as is recommended.

These results revealed that fitting *Calmer* to the HATS influenced these naturally occurring acoustic phenomena. In the 2,000 Hz to 8,000 Hz range, the devices reduced sound pressure levels measured at the eardrums. Comparative analysis of results with and without *Calmer* were also performed in the 10,000 Hz, 12,500 Hz and 16,000 Hz third octave bands. These high frequency bands also showed a reduction in sound pressure levels compared to the corresponding HRTFs. Table 2 shows average reductions observed at high frequencies.

Table 2: average reduction in SPL achieved by *Calmer*

External source position	SPL reduction with *Calmer*, 2,000 Hz to 8,000 Hz [dB]	SPL reduction with *Calmer* 10,000 Hz to 16,000 Hz [dB]
0^0 azimuth	8.0	4.1
45^0 azimuth	7.6	5.2
90^0 azimuth	8.2	6.4

Results shown in Table 2 indicate comparable average attenuation figures at the 3 tested source locations up to 8,000 Hz. It can be concluded that up to this frequency, the acoustic effect of *Calmer* is reasonably uniform for ipsilateral sources in front of the listener. At higher frequencies however, *Calmer* behaves more directionally with moderately higher attenuation at wider source angles.

Results presented in Figure 5 and Figure 9, along with the calculated average attenuation data at high frequencies confirm the effectiveness of *Calmer* technology with respect to Flare Audio's design objective:

1. The devices do not influence the magnitude responses measured below 1,000 Hz (below the resonant region of the outer ear) significantly.
2. The devices attenuate sound pressure levels reaching the ear drum above 1,000 Hz. Peak SPLs due to natural resonant mechanisms observed in HRTFs in this frequency region are significantly reduced.
3. The devices showed a comparable effect with near-field sources (headphones) and far-field sources (external sounds and noises). Flare's design target is met in both cases. However, it was observed that the attenuation achieved with loudspeaker sources were moderately higher compared to those measured with headphones.
4. With external sources, the devices did not significantly alter the directivity of hearing (in the measured span of source locations)

5. Conclusions

Acoustic tests were performed on Flare Audio’s new *Calmer* technology prototypes. Measurements were carried out using an acoustic head and torso simulator using two different headphones and an external sound source. The acoustic effect of *Calmer* fitted in the open ear and placed under the headphones was evaluated.

Frequency response measurements of the headphones and external source with and without the technology prototypes revealed:

- No significant alterations in response were observed below 1,000 Hz when the *Calmer* was fitted on the HATS
- *Calmer* reduces the magnitude of natural resonances observed in the HRTFs (with external source) and in the headphone-to-eardrum acoustic system between 2,000 Hz and 8,000 Hz.
- Between 2,000 Hz and 8,000 Hz *Calmer* achieved average attenuations of 7.9 dB and 5.9 dB with an external source and with headphones respectively
- Between 10,000 Hz and 16,000 Hz, the *Calmer* also decreased sound levels in the ear with both source arrangements
- Results showed minor variations with the 2 different headphones used, however results were comparable
- With external sources, the devices did not significantly alter the directivity of hearing (in the measured span of source locations)
- The devices showed comparable effect with near-field sources (headphones) and far-field sources (external sounds and noises).

Total distortion measurements of the headphones with and without *Calmer* showed:

- Multi-tone stimulus tests showed an average reduction of 5.7 dB(A) in total distortion power when *Calmer* was fitted under the headphones compared to baseline recordings without the technology prototypes
- A-weighted measurements showed that the reduction in total distortion power was greater than the reduction observed in the total A-weighted signal power of the multi-tone stimulus
- It is speculated that the primary reduction mechanism behind these results is *Calmer*'s capability to attenuate the naturally occurring resonances in the ear (as observed in the FRF results)

The actual auditory experience and the effectiveness of wearing Calmer may vary depending on the external sound field, type of headphone, fit and properties of the programme material played.

6. Appendix

6.1 Equipment list

Table A1: Details of measurement equipment used

Equipment	Manufacturer	Type	Serial number	Measurement
HATS	G.R.A.S	KEMAR	1043	FRF, TD
Left ear coupler	G.R.A.S	RA0045	100378	FRF, TD
Left ear coupler microphone	G.R.A.S	40AG	88384	FRF, TD
Left ear microphone preamplifier	G.R.A.S	26AC	86190	FRF, TD
Right ear coupler	G.R.A.S	RA0045	100376	FRF, TD
Right ear coupler microphone	G.R.A.S	40AG	88469	FRF, TD
Right ear microphone preamplifier	G.R.A.S	26AC	86191	FRF, TD
Left pinna simulator	G.R.A.S	KB0066	96746	FRF, TD
Right pinna simulator	G.R.A.S	KB0065	96722	FRF, TD
HATS microphone power supply	Brüel & Kjær	Nexus Type 2690	2572658	FRF, TD
Loudspeaker	Genelec	8030C	8030CP61122275	FRF
Reference microphone	Brüel & Kjær	4189	2539752	FRF
Measurement frontend for B&K software	Creative	X-Fi HD Sound card	N/A	FRF
Pistonphone (Ear Coupler calibrator)	Brüel & Kjær	4220	966195	FRF, TD
Audio Analyser	Prism Audio	dScope M1	20040	TD
Headphone Amplifier	FIIO	A3	N/A	FRF, TD

6.2 Narrow band frequency response data

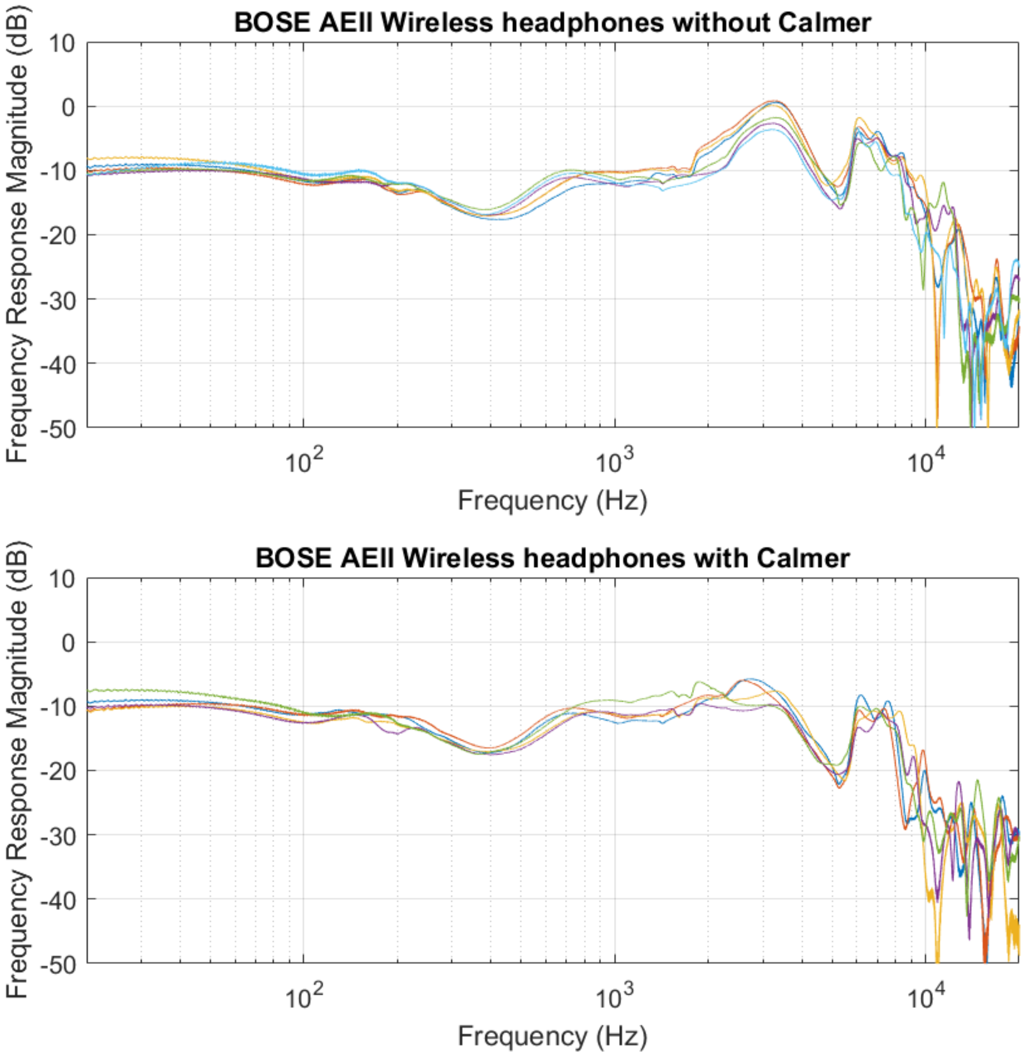

Figure A1: Individual frequency response measurements of BOSE AEII headphone

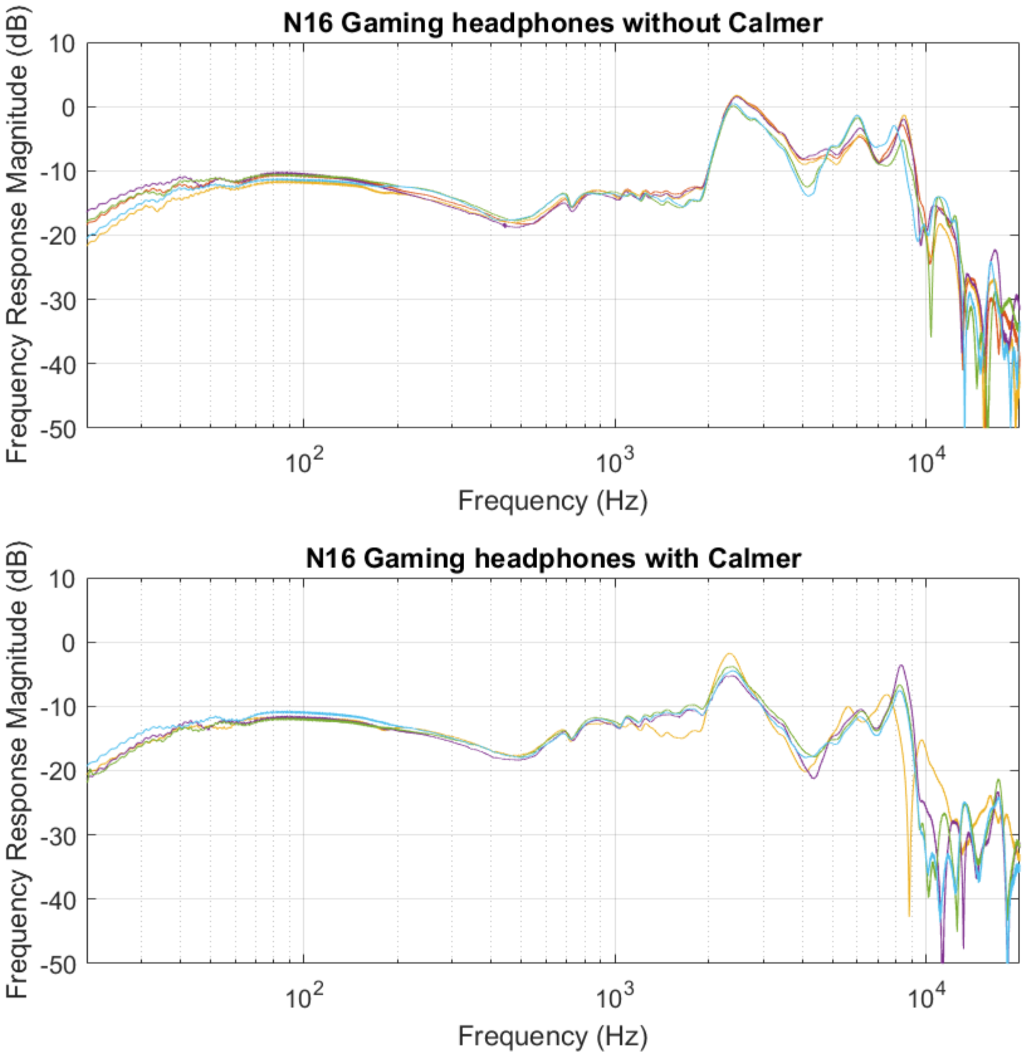

Figure A2: Individual frequency response measurements of N16 Gaming headphone

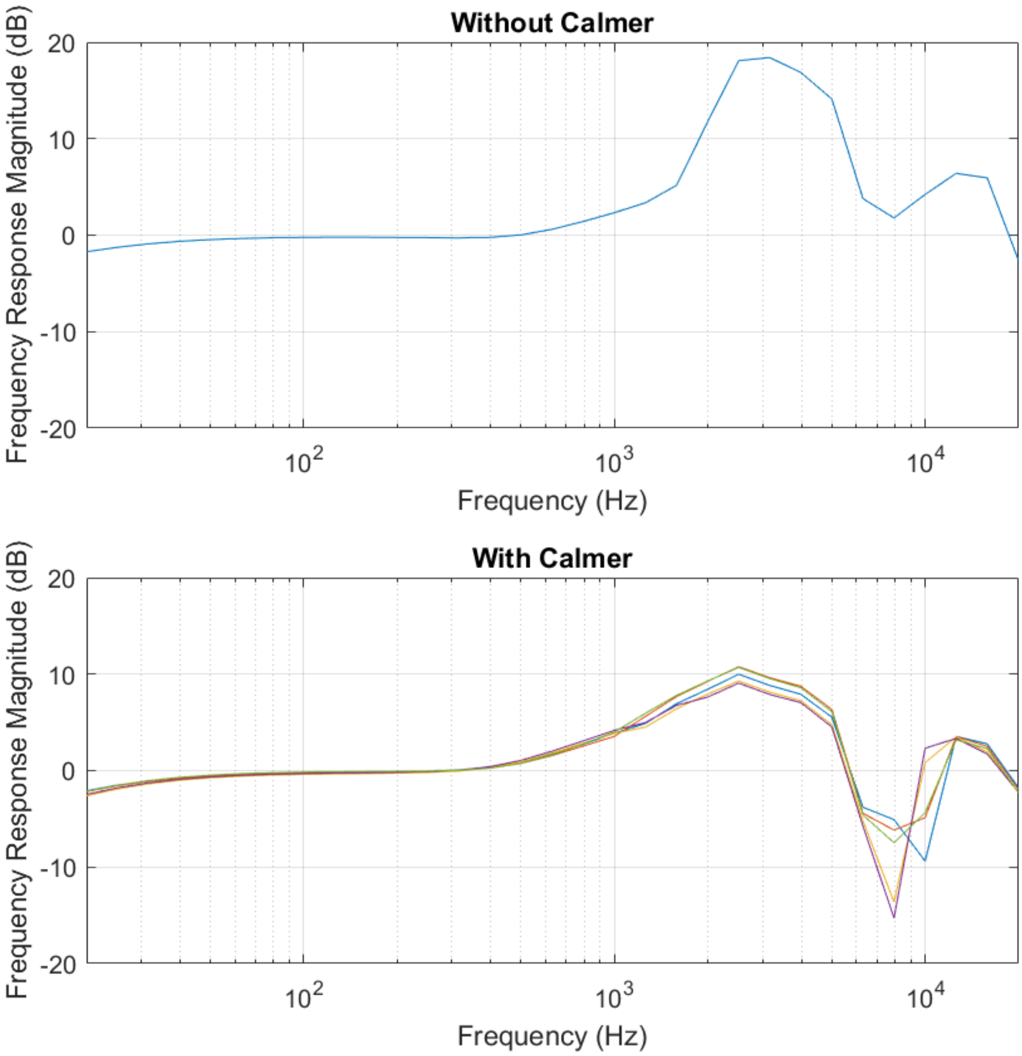

Figure A2: On-axis frequency responses with and without Calmer with simulated anechoic processing and loudspeaker response correction (data used for averaged results)

6.3 TD measurement results

Table A2: TD measurement results of N16 headphone

N16			
Calmer	Input, mV	TD Left	TD Right
off	10	-26.1	-26.8
off	10	-25.5	-26.6
off	10	-26.5	-26.0
on	10	-31.8	-32.8
on	10	-31.7	-32.2
on	10	-30.7	-33.7
off	20	-21.4	-21.2
off	20	-19.8	-21.0
off	20	-18.1	-20.5
on	20	-24.8	-27.1
on	20	-25.0	-26.6
on	20	-26.6	-27.5
off	100	-8.5	-8.7
off	100	-7.2	-8.5
off	100	-5.6	-8.1
on	100	-13.0	-14.7
on	100	-13.4	-14.3
on	100	-12.7	-15.5

Table A3: TD measurement results of BOSE headphone

BOSE			
Calmer	Input, mV	TD Left	TD Right
off	10	-34.1	-35.9
off	10	-33.4	-35.0
off	10	-33.7	-35.9
on	10	-39.2	-40.4
on	10	-39.2	-41.4
on	10	-38.9	-40.1
off	20	-28.5	-30.8
off	20	-28.2	-29.9
off	20	-28.4	-30.6
on	20	-34.1	-35.1
on	20	-33.6	-36.1
on	20	-33.5	-34.7
off	100	-16.6	-18.8
off	100	-16.3	-18.1
off	100	-16.7	-18.9
on	100	-23.7	-23.9
on	100	-22.4	-24.7
on	100	-22.0	-23.9

6.4 A-Weighting values

1/1 Octave band centre frequencies Hz	1/3 Octave band centre frequencies Hz	A-weighting values dB
	50	-30.2
63	63	-26.2
	80	-22.5
	100	-19.1
125	125	-16.1
	160	-13.4
	200	-10.9
250	250	-8.6
	315	-6.6
	400	-4.8
500	500	-3.2
	630	-1.9
	800	-0.8
1000	1000	0
	1250	0.6
	1600	1.0
2000	2000	1.2
	2500	1.3
	3150	1.2
4000	4000	1.0
	5000	0.5
	6300	-0.1
8000	8000	-1.1
	10000	-2.5

7. References

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