ISVR Consulting
Consultants in Noise and Vibration

# Consultancy Report
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# Acoustic characterisation, directivity and Speech Transmission Index measurements of *earHD* technology prototypes

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## 1. Introduction

ISVR Consulting was engaged by Flare Audio to perform acoustic tests on their new *earHD* 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.

*earHD* technology is understood to be a passive acoustic device designed to manipulate the natural directivity of the ear and thereby to improve the wearer's ability to focus on sounds arriving from the front quadrant, ± 45-degree azimuth, whilst discriminating against sound/noise components from other directions. This technology may also influence the frequency response of the ear. In other words, sound pressure level reaching the eardrum may be altered by the presence of the device. The design of the *earHD* technology is intended to passively enhance high frequency sounds, aiding the user of the device.

A bespoke measurement schedule was established in order to test the *earHD* and to assess its performance in meeting these design goals. The first set of tests used the large anechoic chamber of the University of Southampton and were based on frequency response measurements using a studio grade loudspeaker as the excitation source and a Head and Torso Simulator that models the characteristics of the human ear. In the second part of the project, three loudspeaker units were added to the test system in order to produce unwanted noise around the Head and Torso Simulator. Speech transmission index (STI) measurements were then carried out to further investigate the *earHD* technology's capabilities to suppress noise/unwanted sounds from certain directions.

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.

## 2. Measurement set-up

All tests were performed in ISVR Consulting’s acoustic laboratories on the 3rd and 4th of July 2019. 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 the ISVR’s large anechoic chamber at the University of Southampton. This is a room in which the walls, floor and ceiling are lined with sound absorbing material, glass-fibre wedges. The lining prevents the reflection of sound from the room boundaries so that ‘free-field’ conditions exist. Sound measurements are not influenced by the room surfaces, therefore it ensures that the angle of sound incidence can be precisely controlled during the measurements and that the measured frequency responses are not coloured by any image sources. The required free-field conditions in ISVR’s chamber exist at frequencies above 80 Hz.

### 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’s presence in a given sound field and it also creates an ideal platform to investigate the changes that the *earHD* 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’ 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 November 2017. The B&K pistonphone was calibrated at a UKAS accredited test house in March 2018.

The ear simulators accurately imitate the human ears' (standardised) acoustic transfer impedance up to the frequency of 10 kHz in compliance with BS EN 60318-4:2010. Results above this frequency fall outside the range of the standard and may not be counted as an accurate human ear simulation, however comparative conclusions are made in this report up to 20 kHz by relating recordings with and without *earHD* in the exact same conditions.

An electronic turntable was used to rotate the HATS in the horizontal plane relative to the fixed source position. This allowed the angle of sound incidence to be changed in 10-degree increments*. The source of excitation was chosen to be a Genelec 8020D bi-amplified, 2-way studio monitor loudspeaker.

A list of the equipment used is provided in Table 6 of the appendix.

### 2.3 Measurement Software

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

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* The co-ordinate system used in this report for the HATS tests is as follows:

0 ° is directly in front of the head, sometimes referred to here as on-axis;
90° refers to the direction of a sound source on the same side of the head as the ear (ipsilateral),
180° is directly behind the head;
270° refers to the direction of a sound source on the opposite side of the head to the ear, ie with the head between the ear and the sound source (contralateral).

Thus the co-ordinates are defined relative to the ear under test, assuming symmetry, and not relative to the manikin's left and right sides. Other reports may use different co-ordinates.

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 Speech Transmission Index (STI) calculations were also performed by the Dirac measurement software in accordance with BS EN 60268-16:2011 [4]. The octave filters used in the STI calculations also conform to BS EN 61260-1:2014 [5].

# 3. Measurement procedure

## 3.1 Frequency response and directivity

The primary aim of this test was to measure and characterise how wearing *earHD* influences the sound pressure reaching the eardrum in a given sound field. These measurements were performed by determining the impulse response between the external excitation loudspeaker and the corresponding microphone recordings of the ear simulator, with and without the *earHD* prototypes ‘worn’ by the HATS.

Measurements performed without the device are also known as the Head-Related Transfer Functions (HRTFs) and they provide the baseline or reference against which any measurements with a 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 obtained at the eardrum. For each angle of sound incidence, the only difference between the *earHD* and HRTF measurements is the presence of the device, so the effect of wearing the device can be clearly determined.

Using the impulse response measurements ensures that all measurements are directly comparable. Further reference measurements of the loudspeaker in free-field conditions (without the HATS in place, using an omni-directional reference microphone) allow correction for the characteristics (any colouration) introduced by the loudspeaker used as the sound source. Therefore, when the coloration and frequency response of the source loudspeaker are compensated for, the resultant frequency response functions (FRFs) presented in this report show sound pressure levels observable at the eardrum due to a perfectly even, broadband external sound spectrum between 80 Hz and 20 000 Hz.

Baseline measurements were obtained with the sound source at 0° sound incidence, i.e. directly in front of the manikin at ear height. The acoustic centre of the excitation loudspeaker was placed 1.2 m away from the centre of the HATS (midway between the two ears). The direction of the HATS was also aligned so both ears were the same distance from the centre of the speaker.

This measurement setup is shown on Figure 1.

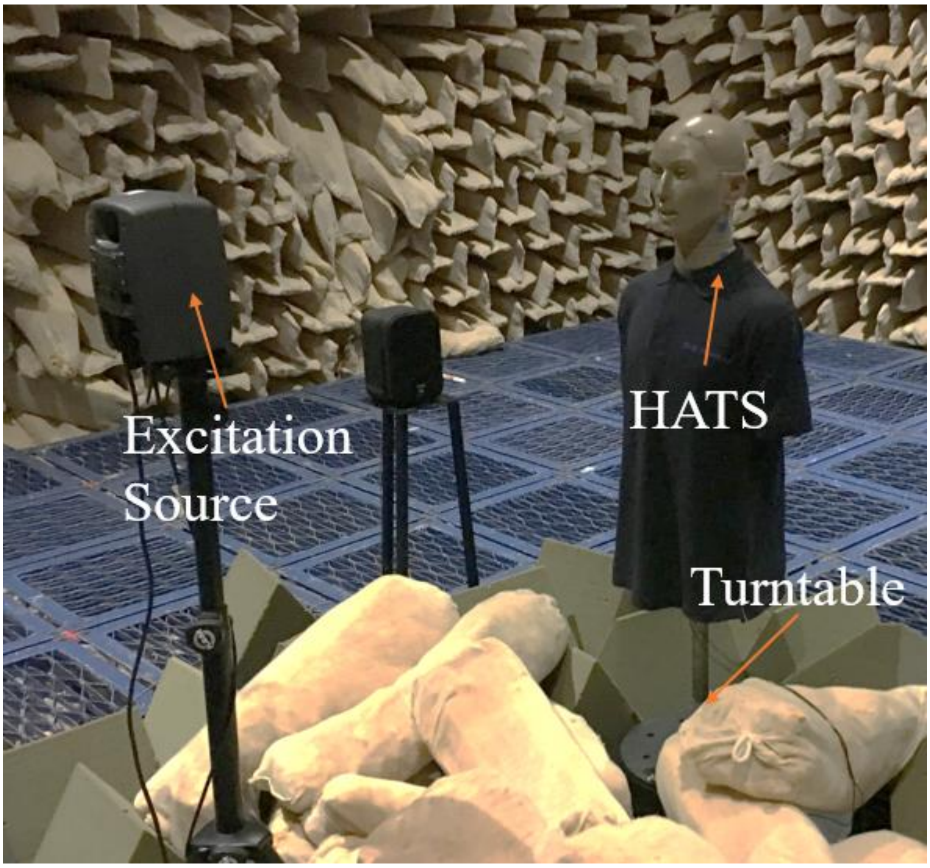

**Figure 1: FRF measurement set-up (on-axis sound incidence)**

After obtaining the baseline results, the electronic turntable allowed the HATS to be turned on its vertical axis. With the fixed source this results in a variable azimuth angle and hence the directivity of the *earHD* was measured. These directivity measurements were performed at 10° increments on the full 360° rotation.

## 3.2 Speech Transmission index (STI) measurements

The speech transmission index (STI) is a widely used metric to assess a range of hearing related equipment with regards to their speech transmitting capabilities related to speech intelligibility. STI is expressed as a value between 0 and 1 (worst to perfect intelligibility) and considers most conditions that can cause deterioration in one’s ability to understand speech, including competing background noise and reverberation. A classification table to interpret various STI values is provided in Table 7 of the Appendix.

A number of STI measurements were made to evaluate whether the *earHD* technology can improve intelligibility of speech. As discussed in the introduction of this report, the *earHD* is intended to enhance sounds from the front, within an azimuth of ±45°, and to discriminate against sound arriving from other directions. To test this, three secondary loudspeakers were added at 90°, 180° and 270° relative to the HATS. This test is based on the assumption that sound/noise arriving from these directions is unwanted and may deteriorate desired speech or other sounds from the front. The updated test arrangement is presented on Figure 2.

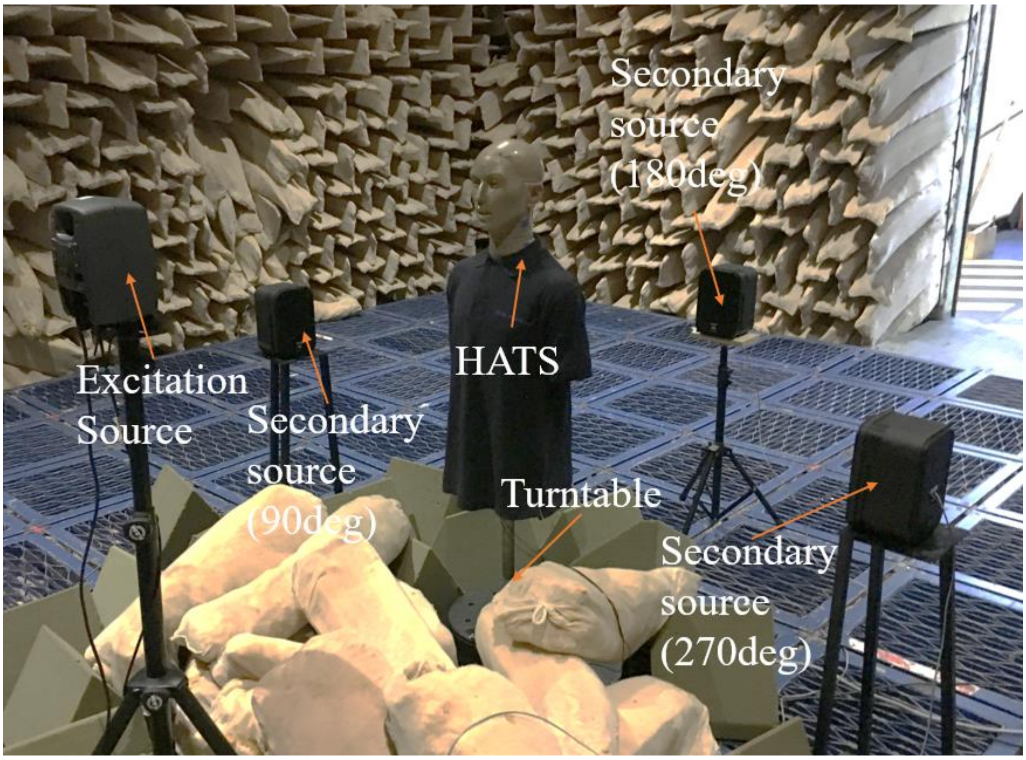

**Figure 2: STI measurement set-up**

An on-axis impulse response measurement was performed from the excitation source, exactly as in the FRF measurements, however the secondary speakers were used to generate background noise levels around the head.  Because the *earHD* is designed to discriminate against sounds from the sides and rear, when the background noise from the secondary sources is present, the STI should be higher when the *earHD* is worn than when the ear is open.

The secondary noise sources emitted time-invariant broadband noise. The spectral content and level of this signal was adjusted experimentally until a 0 dB (±2dB) signal-to-noise ratio (SNR) was achieved in all octave bands of interest in the impulse response when measured without the *earHD* device. This served as the reference set-up for the STI evaluation. Measurements performed with the device inserted into the artificial ears were evaluated against this baseline.

Whilst the STI was calculated by the Dirac software in accordance with the appropriate standard, the measurements here differ from the more usual set up, in which a speech level or source level is defined. The 'desired' source level and spectral content were not changed (with respect to the FRF measurements), rather the background noise levels were tuned freely to the selected reference. The lack of calibration means that the obtained STI values cannot be related to a 'real' background noise level or profile, and are therefore comparative or relative, dependent on the specific set-up, rather than absolute. However, this ensures comparability with the FRF measurements and guarantees sufficient control over the artificially introduced background noise.

The STI calculation distinguishes speech intelligibility for a typical male voice and female voice spectrum. These values are obtained by varying weightings of different octave bands in the calculation.

## 3.3 Fit and averaging

Any variability in the fitting of the *earHD* prototypes to the HATS can significantly influence the measurement results in all tests, particularly at high frequencies. In order to minimise measurement errors related to the fitting of devices, 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. Size of the ear-tips were selected specifically to best fit the HATS
3. Preliminary measurements were taken with approximately 10 refits to observe variations that different fits introduce
4. Every fit was visually examined to ensure proper seal in the simulated ears

Once various fit properties were observed and reasonable consistency was achieved, two sets of directivity and STI measurement were performed with a refit between them. Using the left and right units individually, presented results are based on the average of 4 (refitted) measurements.

A typical fit of *earHD* is shown on Figure 3.

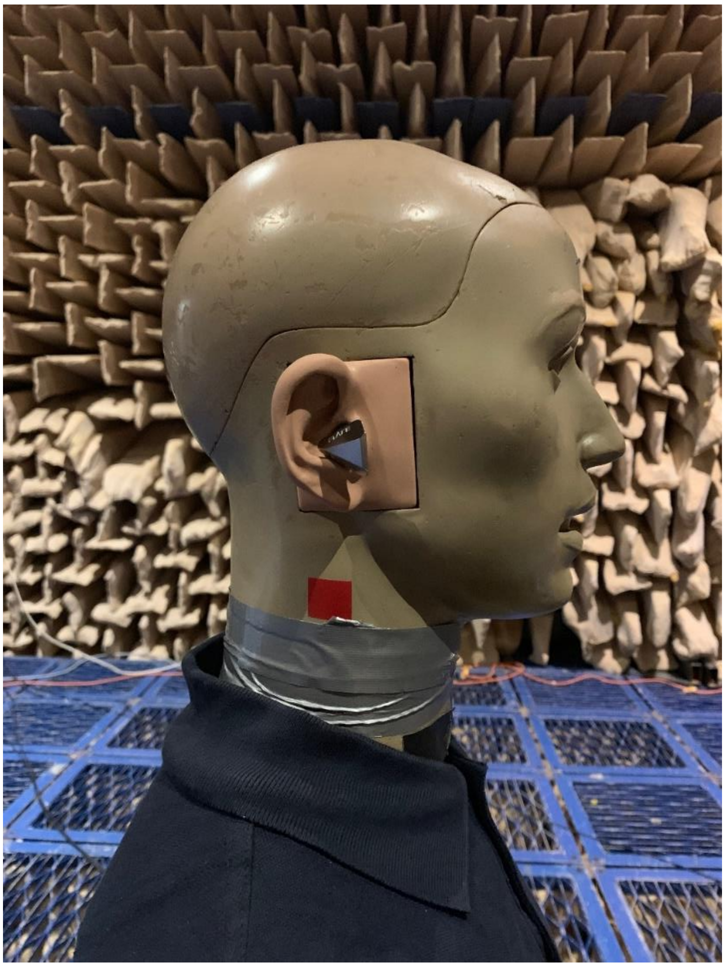

**Figure 3: HATS wearing *earHD***

# 4. Results

On-axis and directivity measurements were processed using a 131072-point FFT analysis to obtain the corresponding frequency response functions. All results were corrected for the characteristics of the excitation source using the free-field reference measurements.

It was observed 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 results are presented as 1/3rd octave smoothed data. All presented averages are based on 4 individual measurements, including averaging left and right recordings in identical conditions and angular position towards the excitation source. 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 50 Hz without the *earHD*.

Individual results of on-axis frequency response measurements with 1/24th octave smoothing are presented in the Appendix.

## 4.1 On-axis frequency response

Figure 4 presents the magnitude of the measured frequency response function of the *earHD* technology applied to the HATS at 0° azimuth. The measurement result without the device is also provided for comparison.

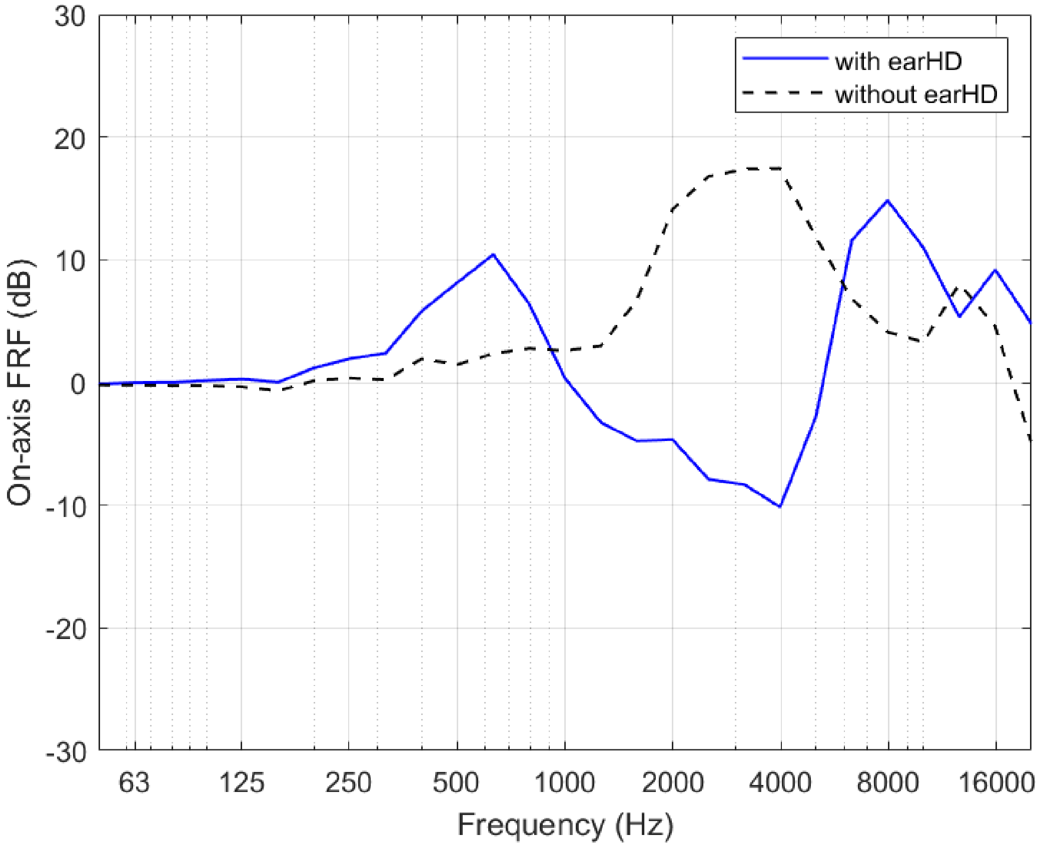

**Figure 4: On-axis frequency response magnitude of *earHD* measured using a head and torso simulator**

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

At frequencies below 200 Hz, *earHD* 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 the devices or the ears and the head.

Beyond this low frequency range, a dampened resonance of approximately 8 dB at 630 Hz is introduced by the addition of the *earHD* to the HATS. It can be concluded that in this frequency region, perceived sound pressure levels would be higher when *earHD* devices are worn. Figure 9 and Figure 10 in the appendix confirm that this resonance is not unique to the on-axis arrival of sound, however the magnitude of this feature varies with different azimuths.

Considering the measurement results without *earHD* in Figure 4, one can examine the frequency response of the typical, unaided human ear in the sound field established in this experiment. It can be observed that the 3 kHz 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 kHz. 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.

According to the test results, the inserted *earHD* devices appear to largely influence these naturally occurring acoustic phenomena and it is observed that this technology significantly modifies most of these effects. The amplification by the ear canal resonance observed around 3 kHz without the device is removed by the *earHD* device, and levels reaching the eardrum are attenuated by the earHD by approximately 4.6 dB and 8.3 dB at 2 kHz and 3 kHz respectively (with respect to the 0 dB reference).

At frequencies of approximately 6 kHz and above the *earHD* technology increases the sound levels in the ear. Analysis of the 6 300 Hz, 8 000 Hz and 10 000 Hz third octave bands shows an average gain of 7.7 dB in recorded sound levels achieved by *earHD* in these bands.

It is important to note that the response of the ear simulators in the HATS are not defined above 10 kHz in BS EN 60318-4:2010, however a comparative analysis of the

12 500 Hz, 16 000 Hz and 20 000 Hz third octave bands was performed, accepting that these were outside the usual range. In these bands the *earHD* achieved an average gain of 3.8 dB in the sound level in the ear.

Analysis and identification of the *earHD*'s acoustic mechanisms fall outside the scope of this project. However, the results suggest that, for on-axis incidence of sound, the *earHD* can increase levels at frequencies above 6 kHz, most likely through the manipulation of the acoustic properties of the ear canal when the devices are inserted as well as potentially through passive amplification of frontal high frequency sounds by the entrance geometry of the device.

## 4.2 Directivity

As discussed in the introduction of this report, one of the *earHD* design goals was to 'focus' sound perception of the user of the device from the frontal quadrant, within an azimuth of ±45°. Frequency responses at various angles of sound incidence were measured to assess the effectiveness of the technology in this regard. Comparisons were made using measurement sets obtained with and without the *earHD*.

In order to assess the directivity of this device, the sound levels measured at various azimuths can be plotted relative to the corresponding on-axis sound levels at the same frequency as presented in Figure 4, and this can be done separately for the open ear and for the ear with an *earHD* device. This normalisation process allows sound levels and frequency responses at various angles to be compared to levels and response at 0° incidence.

Figure 5 shows the results of this analysis for azimuths between 0° and 180° (ipsilateral source to ear arrangement, ie. the sound source is on the same side of the head as the ear at which measurements are made). At each angle, positive values in these plots show sound levels from that direction are higher than the sound levels from the front, 0°. Negative values show sound levels from that direction are lower than the sound levels from the front.

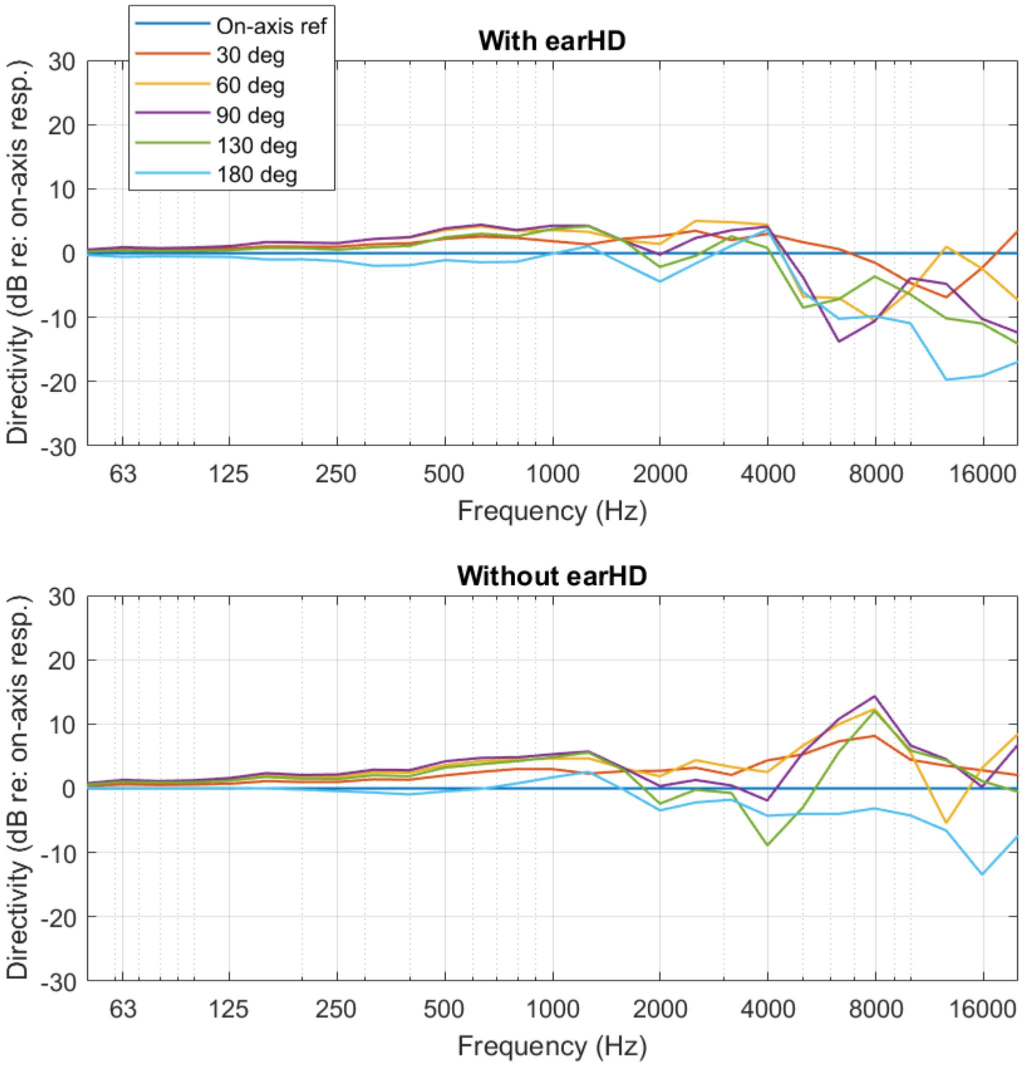

**Figure 5: Directivity response magnitude of *earHD* measured using a head and torso simulator, normalised to on-axis measurement results. (0-180 degrees)**

The scenario presented in Figure 5 corresponds to the physical arrangement when the HATS's ear is turned towards the excitation source in the 30° to 90° range. In this range the entrance of the ear canal gradually gains a direct path to the excitation source and is not 'shadowed' by the head or the ears. At angles from 90° to 180°, this direct path becomes progressively obstructed by the pinna until the entrance of the ear canal is completely in the shadow of the pinna.

The acoustic effect of this physical arrangement manifests itself on the lower graph of Figure 5, for the open ear. For angles of incidence between 30° and 90°, relative gains vary, however one may conclude that the observed responses at these angles are generally increased compared to the on-axis reference case. The most significant gain is observed at frequencies higher than 4 kHz and at angles of incidence from 60° to 130°. The highest relative response of 14.3 dB was measured at 8 kHz at 90°.

Examining the upper graph of Figure 5 presents the directivity effect that the *earHD* introduces to the system. Above 4 kHz, the calculations mostly show negative gain readings at all angles of incidence presented. This result implies, that at these frequencies, the 0° response remains dominant with responses at other angles suppressed, and that *earHD* effectively ‘focuses’ sounds from the front. Table 1 presents the average improvement in ‘focus’ between 4 kHz and 20 kHz. These are calculated as the difference between normalised measurements with and without the devices fitted, averaged over the designated frequency range.

**Table 1: Average improvement in directivity of *earHD* compared to on-axis reference case, calculated in the 4 kHz to 20 kHz range**

| Angle of sound incidence (degrees) | Average improvement in 'focus' (-dB) |
|---|---|
| **0** | 0.0 |
| **30** | 5.6 |
| **60** | 9.7 |
| **90** | 12.8 |
| **130** | 9.6 |
| **180** | 5.3 |

Comparison of the two presented cases on Figure 5 also shows that, below 4 kHz, differences in directivity introduced by the *earHD* remain insignificant. In this frequency range, it can be deduced that the *earHD* technology does not have a significant influence on the directivity features of hearing.

Figure 6 shows results of the directivity measurements obtained on the second half of the rotation between 180°-360° (contralateral source to ear arrangement, with the head interposed between the source and the ear being measured). The 180° result from Figure 5 is included for comparison.

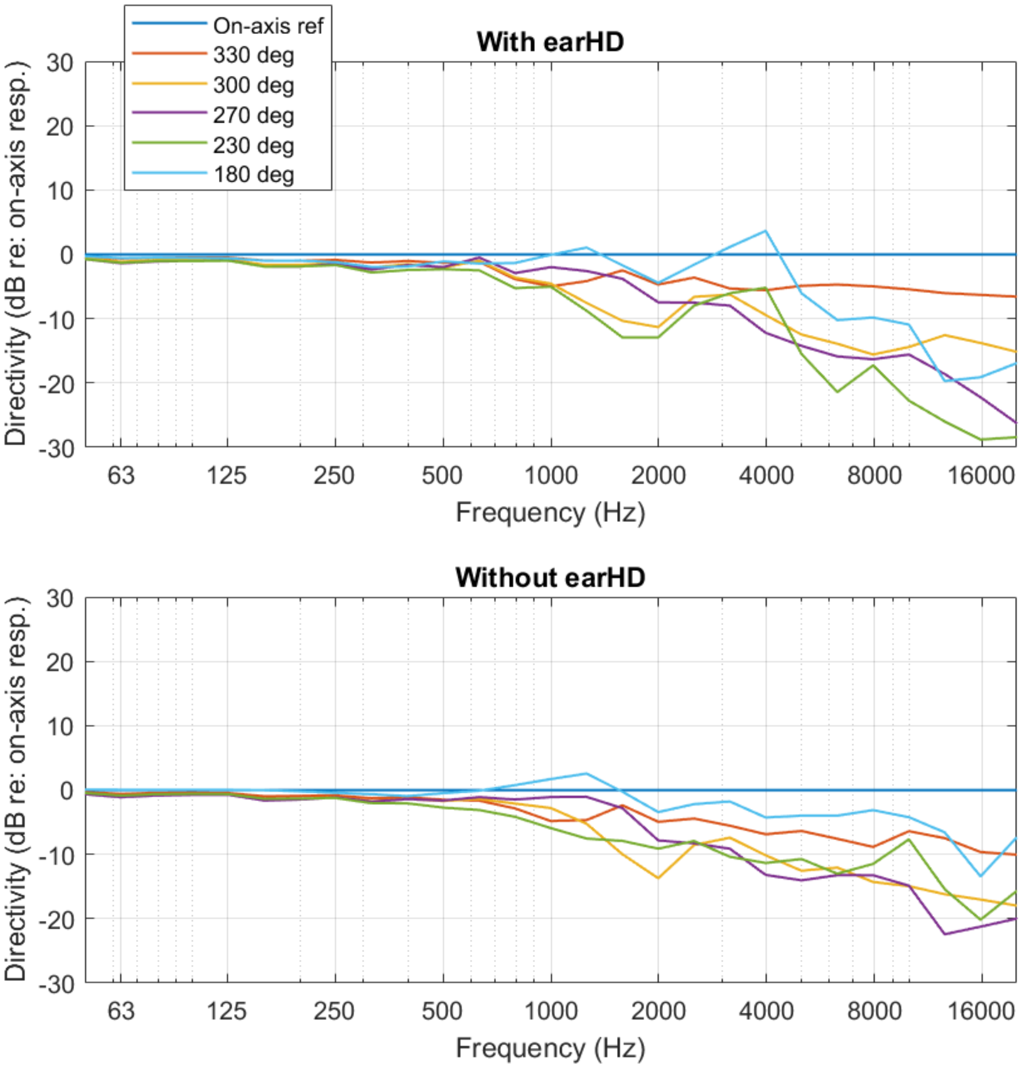

**Figure 6: Directivity response magnitude of *earHD* measured using a head and torso simulator, normalised to on-axis measurement results. (180°-360°)**

This scenario corresponds to the case as the ear moves away from the loudspeaker until the rotation is completed at 360°. At all these angles there is no direct path from the ear to the loudspeaker as it is always ‘shadowed’ by the head or the pinna. Consequently, relative responses appear to be negative in the whole measured range, with or without the *earHD*. At 230°, between 4 kHz and 20 kHz, an average improvement in ‘focus’ of 7.5 dB was observed (shown as a negative value in the plots), however further rotation of the system resulted in figures less than 1.2 dB.

At an angle of incidence of 330°, a positive averaged difference of 2.3 dB was noted. This angle falls into the desired ‘focus’ range of *earHD* and in this physical arrangement, the unaided ear is still shadowed by the head. The positive gain observed in this scenario suggests that *earHD* can achieve a minor boost of high frequencies from a contralateral excitation source within the designed range of focus, which may be a further benefit of the technology.

## 4.3 STI results

This section of the report details the results of the STI and corresponding SNR measurements as described in section 3.2. Table 2 and Table 3 provide a comparison of the observed signal-to-noise ratios with and without the *earHD* devices worn by the HATS. All other conditions are identical throughout these measurements.

**Table 2: Signal-to-noise ratio measurement results with *earHD***

| **SNR (dB)** | **125 Hz** | **250 Hz** | **500 Hz** | **1000 Hz** | **2000 Hz** | **4000 Hz** | **8000 Hz** |
|---|---|---|---|---|---|---|---|
| *earHD* measurement 1 (left) | 0 | -1 | 0 | 2 | -1 | 9 | 19 |
| *earHD* measurement 1 (right) | 1 | -1 | 0 | 2 | 0 | 11 | 20 |
| *earHD* measurement 2 (left) | 0 | -1 | 0 | 2 | -1 | 8 | 17 |
| *earHD* measurement 2 (right) | 0 | -1 | -1 | 1 | 0 | 7 | 21 |
| **Average** | **0** | **-1** | **0** | **2** | **-1** | **9** | **19** |

### Table 3: Signal-to-noise ratio measurement results without *earHD*

| **SNR (dB)** | **125 Hz** | **250 Hz** | **500 Hz** | **1000 Hz** | **2000 Hz** | **4000 Hz** | **8000 Hz** |
|---|---|---|---|---|---|---|---|
| Without *earHD* (left) | 0 | -2 | -1 | -1 | 0 | 1 | -1 |
| Without *earHD* (right) | 0 | -2 | -1 | -1 | 0 | 0 | -2 |
| **Average** | **0** | **-2** | **-1** | **-1** | **0** | **1** | **-2** |

Comparison of averaged results from Table 2 and 3 indicate that the *earHD* technology improved SNR in the 1 000 Hz, 4 000 Hz and 8 000 Hz octave band by 3 dB, 8 dB and 21 dB respectively. The most improvement was achieved at frequencies above 4 kHz. This appears consistent with findings presented in the directivity measurements (section 4.2), where the off-axis high frequency reduction and the relative on-axis high frequency 'boosting' capabilities of this device were highlighted. It can also be concluded that the presence of *earHD* in the HATS did not pose a significant negative effect on the SNR in any measured octave band.

In the 1 000 Hz octave band a minor improvement in SNR may be due to the resonance that the *earHD* system exhibits at 630 Hz. This suggests, that some improvement is achieved. However, because of the size of the device, no significant effect is accomplished below the 4 000 Hz octave band.

The STI measurement results are presented in Table 4 and Table 5.

### Table 4: STI measurement results with *earHD*

| **STI results** | **STI Female** | **STI Male** |
|---|---|---|
| *earHD* measurement 1 (left) | 0.64 (Good) | 0.62 (Good) |
| *earHD* measurement 1 (right) | 0.66 (Good) | 0.63 (Good) |
| *earHD* measurement 2 (left) | 0.63 (Good) | 0.61 (Good) |
| *earHD* measurement 2 (right) | 0.64 (Good) | 0.61 (Good) |
| **Average** | **0.64 (Good)** | **0.62 (Good)** |

**Table 5: STI measurement results without *earHD***

| **STI results** | **STI Female** | **STI Male** |
|---|---|---|
| Without *earHD* (left) | 0.49 (Fair) | 0.49 (Fair) |
| Without *earHD* (right) | 0.48 (Fair) | 0.49 (Fair) |
| **Average** | **0.49 (Fair)** | **0.49 (Fair)** |

Results of this test show that the *earHD* technology improved the speech transmission index measured for both female and male weightings in the calculation. The STI was improved by 15% for a female voice spectrum and by 13% for a male voice spectrum by fitting the *earHD* devices on the HATS. Both results signify a noteworthy improvement in the speech transmission indices. The system's classification increased from a lower 'Fair' intelligibility to a lower 'Good'. These improvements in STI scores are of course relative rather than absolute and will be dependent on the background noise levels that exist in any particular real-life situation.

Whilst the actual improvement in speech intelligibility experienced by the user of this technology principally depends on the acoustic characteristics of the wearer's environment and may significantly vary depending on these conditions, this experiment demonstrated and confirmed the capability of the *earHD* technology to selectively discriminate against noise arriving from certain angles of incidence.

Based on these test results, one may conclude that in scenarios with a significant amount of unwanted noise (noise sources behind the listener or strong reflections from rear walls in a reverberant space) *earHD* exhibits the potential to help the wearer to perceive a more intelligible speech or vocal signal.

## 5. Conclusions

Acoustic testing was performed on Flare Audio's new *earHD* technology prototypes. Measurements were carried out using an acoustic head and torso simulator under free-field conditions in an anechoic chamber. The effect of the *earHD* on the sound levels in the ear was evaluated for sounds arriving from various directions.

Measurements made with sound from the front, 0°,and without competing background noise showed the following:

- No alterations in response were observed below 200 Hz when the *earHD* was fitted on the HATS
- Wearing the *earHD* introduces a resonance, increasing sound level in the ear by approximately 8 dB at 630 Hz
- The *earHD* appears to remove the resonance which occurs naturally in the open ear between 1 kHz and 6 kHz.
- Fitting the *earHD* also resulted in further attenuation of sound (of approximately 4.6 dB at 2 kHz and 8.3 dB at 3 kHz) in the 1 kHz to 6 kHz region
- Above 6 kHz, the *earHD* increased sound levels in the ear by 7.7 dB on average over the 6300 Hz to 10 000 Hz third octave bands and gave an increase of 3.8 dB on average in higher frequency bands, compared to the open ear.

Measurements were also carried out to assess *earHD*'s 'focusing' ability to sounds incident from the front, at azimuths of ±45°. The following conclusions were made:

- Application of the *earHD* devices to the acoustic head and torso simulator did not influence the directivity of the system below 4 kHz. In this frequency range the *earHD* did not achieve significant 'focusing' of on-axis response compared to any angle of sound incidence
- In the 4 kHz to 20 kHz range, application of the *earHD* achieved relative attenuation of sound incident from 30° to 180° (ipsilateral source to ear arrangement), compared to the corresponding cases measured without the device. The *earHD* measurements showed that in this frequency range the on-

axis response remains dominant compared to response from other angles of incidence, hence the device achieved focusing as intended in this frequency range.

- In the 4 kHz to 20 kHz range, fitting the *earHD* attenuated sound incident from 180° to 230° (contralateral source to ear arrangement) relative to the open ear.
- In the 4 kHz to 20 kHz range, any relative attenuation observed remained insignificant for angles of sound incidence between 240° and 300°.
- In the 4 kHz to 20 kHz range, at 330° a minor relative boost was observed, compared to the corresponding open ear.

Further measurements were carried out to relate *earHD*'s 'focusing' capability to potential improvements in speech intelligibility using artificially raised background levels in the anechoic chamber. Additional loudspeakers emitting background noise were placed around the measurement system outside *earHD*'s designed 'focus range'. The following conclusions were made:

- Application of the *earHD* improved the signal-to-noise ratio of the on-axis impulse response measurements performed in increased background noise levels in the 1 000 Hz, 4 000 Hz and 8 000 Hz octave bands. This result is understood to be a manifestation of the alteration in directivity response that *earHD* achieves.
- Application of the *earHD* showed a 15% and 13% improvement in speech transmission indices for a typical female and male voice spectrum respectively.

*The actual auditory experience and the effectiveness of wearing the earHD may vary depending on the particular sound/noise field experienced by the listener.*

# 6. Appendix

## 6.1 Equipment list

Table 6: Details of measurement equipment used

| Equipment | Manufacturer | Type | Serial number | Measurement |
|---|---|---|---|---|
| **HATS** | G.R.A.S | KEMAR | 1043 | FRF, STI |
| **Left ear coupler** | G.R.A.S | RA0045 | 100378 | FRF, STI |
| **Left ear coupler microphone** | G.R.A.S | 40AG | 88384 | FRF, STI |
| **Left ear microphone preamplifier** | G.R.A.S | 26AC | 86190 | FRF, STI |
| **Right ear coupler** | G.R.A.S | RA0045 | 100376 | FRF, STI |
| **Right ear coupler microphone** | G.R.A.S | 40AG | 88469 | FRF, STI |
| **Right ear microphone preamplifier** | G.R.A.S | 26AC | 86191 | FRF, STI |
| **Left pinna simulator** | G.R.A.S | KB0066 | 96746 | FRF, STI |
| **Right pinna simulator** | G.R.A.S | KB0065 | 96722 | FRF, STI |
| **HATS microphone power supply** | Bruel &Kjaer | Nexus Type 2690 | 2572658 | FRF, STI |
| **Measurement frontend for B&K software** | Creative | X-Fi HD Sound card | N/A | FRF,STI |
| **Pistonphone (Ear Coupler calibrator)** | Bruel &Kjaer | 4220 | 966195 | FRF, STI |
| **Auxiliary microphone (for Loudspeaker response correction)** | Bruel &Kjaer | 4189 | 2539752 | FRF |

| | | | | |
|---|---|---|---|---|
| **½" microphone calibrator** | Bruel & Kjaer | 4231 | 241248 | FRF |
| **Main excitation source** | Genelec | 8020D | 8020DPM61120221 | FRF,STI |
| **Secondary loudspeakers for background noise** | JBL | 3 off Control 1 passive | N/A | STI |
| **Power amplifier for secondary loudspeakers** | Monacor | 2 off, SA-100 | N/A | STI |

## 6.2 STI classification chart

| STI | Speech intelligibility |
|---|---|
| **0.00 - 0.30** | Bad |
| **0.30 - 0.45** | Poor |
| **0.45 - 0.60** | Fair |
| **0.60 - 0.75** | Good |
| **0.75 - 1.00** | Excellent |

**Table 7: Classification of STI values**

## 6.3 On-axis FRF measurement individual measurement results (1/24th octave smoothing)

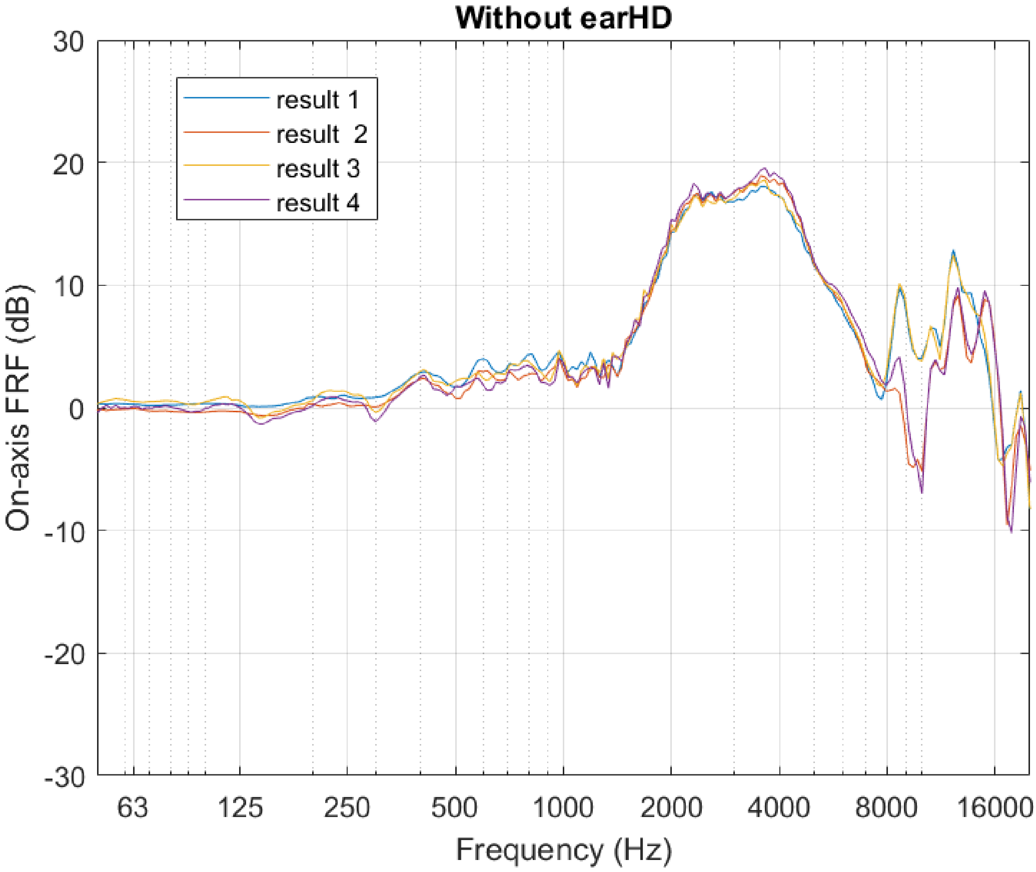

**Figure 7: On-axis frequency responses without *earHD* (data used for averaged results)**

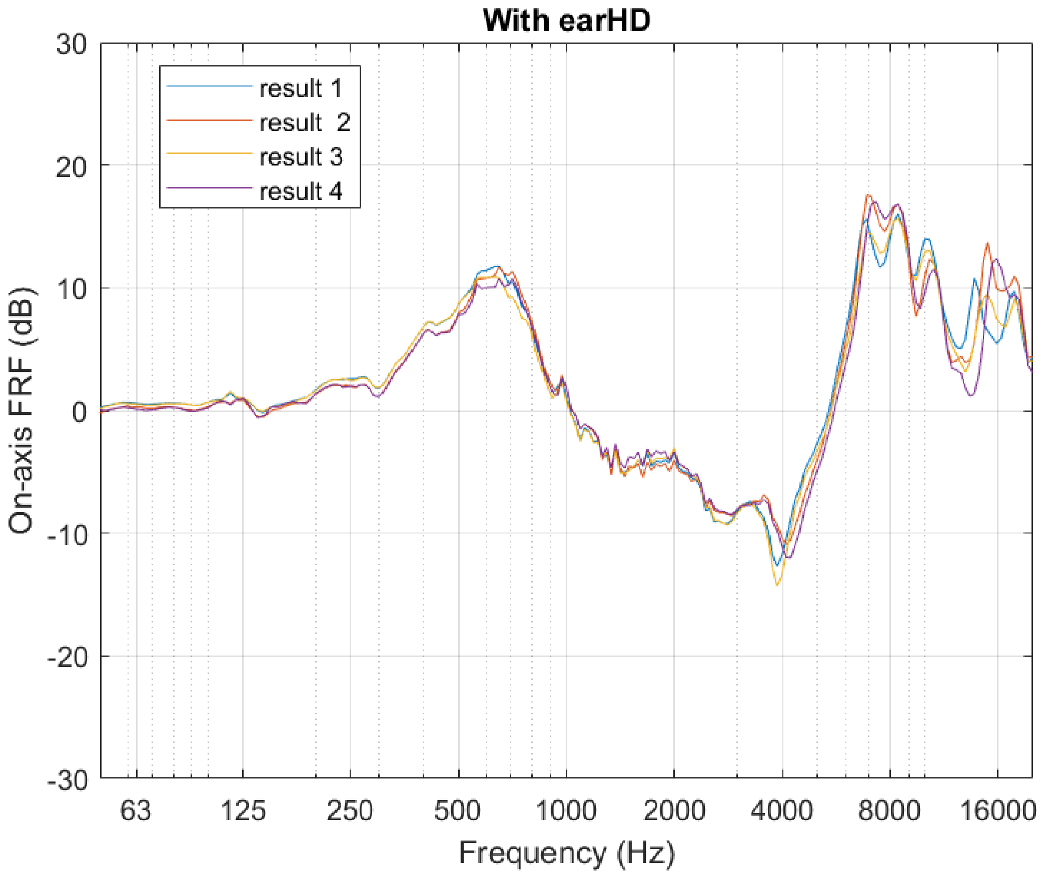

**Figure 8: On-axis frequency responses with *earHD* (data used for averaged results)**

## 6.4 Directivity response

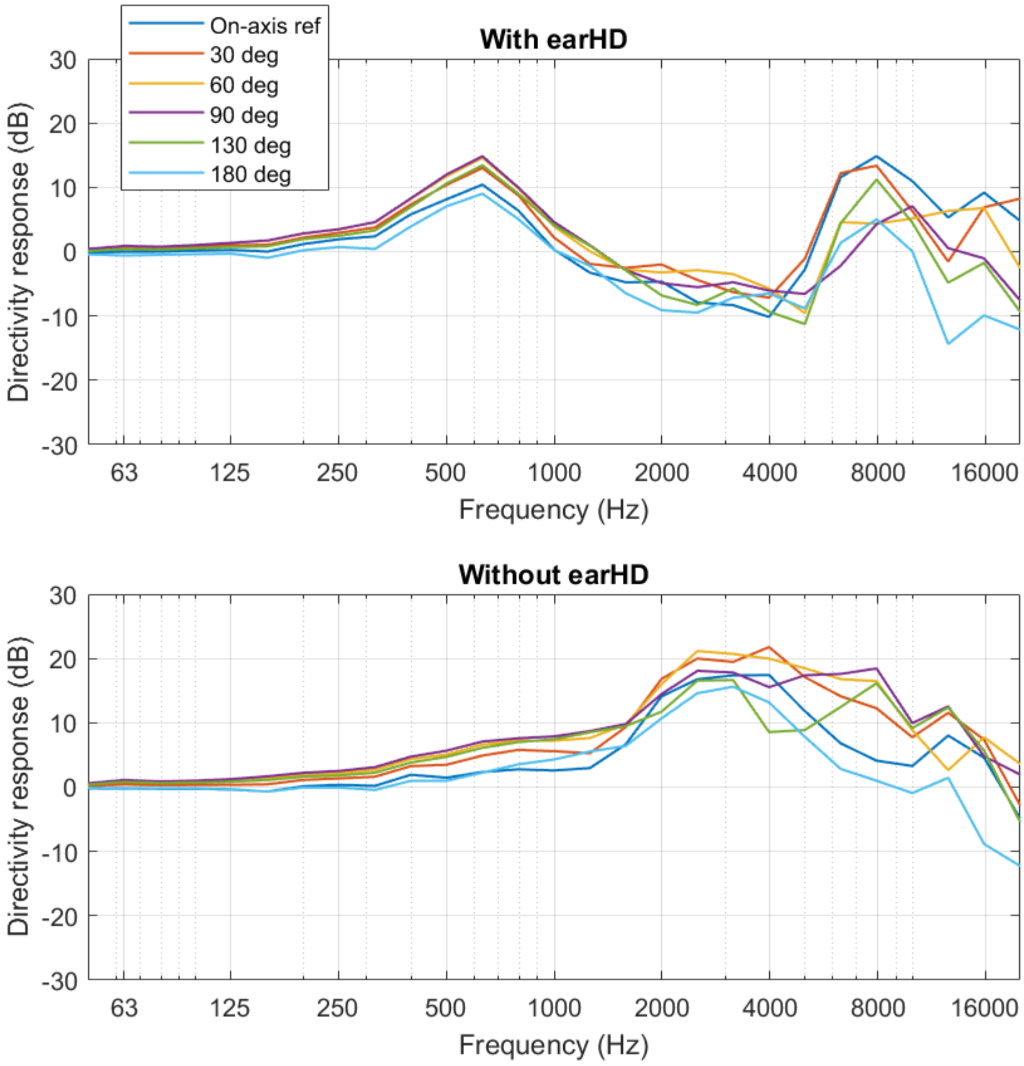

**Figure 9: Directivity response magnitude of *earHD* measured using a head and torso simulator. (0°-180°)**

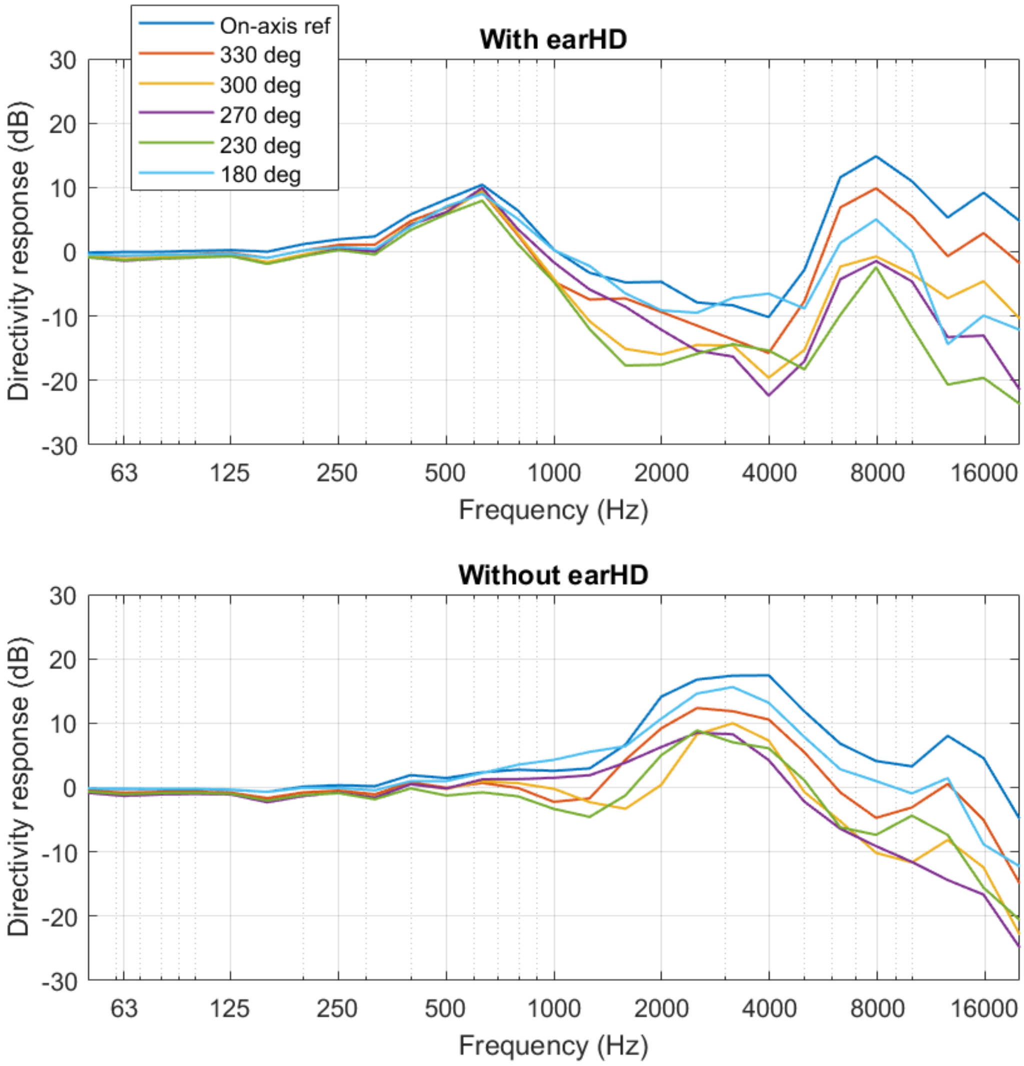

**Figure 10: Directivity response magnitude of *earHD* measured using a head and torso simulator. (180°-360°)**

## 7. References

1. Burkhard, M D, and Sachs, R M, 1975; Anthropometric manikin for acoustic research. *Journal of the Acoustical Society of America*, 58, 214 – 222.
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