THE ICOSSA PROJECT – AN IMPROVED OMNIDIRECTIONAL SOUND SOURCE FOR ROOM ACOUSTIC TESTING

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1 INTRODUCTION

One type of loudspeaker that is commonly used for room-acoustic measurements consists of 12 equally spaced drivers on a platonic solid shape - the "dodec". This loudspeaker is a twelve-sided (dodecahedron) enclosure, with each face holding typically a 125 mm to 200 mm direct-radiating driver as shown in Figure 1. This driver arrangement is intended to produce true omnidirectional radiation for measurement of room acoustic parameters such as strength, clarity, reverberation and lateral energy. Although this arrangement of drivers works well at low frequencies, it produces significant lobes in the radiation pattern at frequencies above 1.5 kHz, which causes inconsistencies in acoustic measurements.

Figure 1. Image of a typical "dodec"

The authors have developed an improved arrangement of drivers, which along with signal processing, produces a more consistent polar frequency response.

1.1 Drawbacks of the Dodec

The ISO standard 3382-1 specifies the the maximum deviation in decibels of the directivity of a room-acoustics sound source for excitation with pink noise and measured in free field in octave-wide frequency bands. These allowed deviations are stated in Table 1. These requirements are to be achieved by averaging SPL over gliding 30^o degree arcs. The reference level is the energy-averaged level over the full spherical area.

Table 1. Allowable deviations in directivity stated in ISO 3382-1

Frequency (Hz)	**125**	**250**	**500**	**1000**	**2000**	**4000**
Maximum deviation (dB)	±1	±1	±1	±3	±5	±6

The variations in directivity correspond to lobes in the spatial directionality of the loudspeaker's radiation. Given the extent of the directivity variations, the lobes produce differences in the pattern of reflections in the impulse response, depending on the orientation of the source. These differences will manifest as errors in acoustic metrics such as clarity, which are calculations based on the impulse response.

The variations in polar pattern in the Dodec are caused by the inter-driver distance that is sufficiently large in terms of wavelength to produce strong spatial aliasing, resulting in wide comb filters in the frequency and spatial domains. The main advantage of the Dodec, however, is that since each face is a pentagon, each (generally round) drive unit can take up a large amount of the available area. As a result, the performance in terms of low-frequency reproduction is relatively efficient.

Most commercially available Dodecs are sized to provide sufficient SPL and bandwidth for general use. These Dodecs create sufficient energy in the 125 Hz octave band to extract a meaningful signal to noise ratio in most circumstances. Secondary speakers are generally required for measurements at lower frequencies. This approach compromises the polar response at the higher frequencies, as can be seen in the published data in Figure 2. Nevertheless, commercially available Dodecs meet the ISO standard requirements for polar response of an omni-directional source. Papadakis and Stavroulakis [1] present an interesting review of alternatives to dodecahedron loudspeakers.

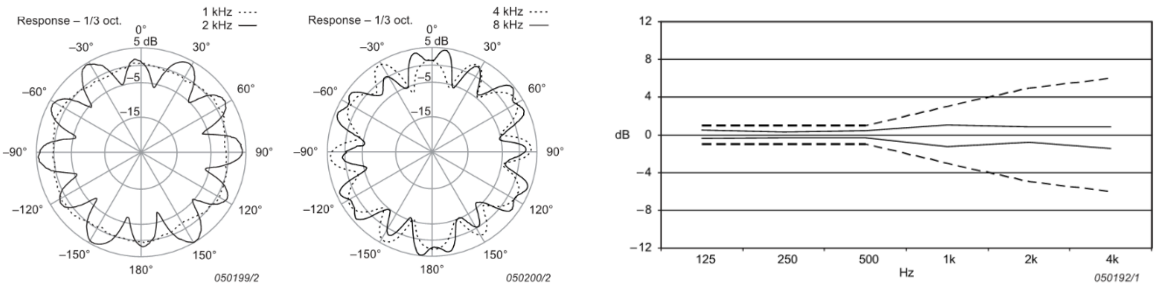


Figure 2: Commercially available Dodec polar response (left) and results according to ISO requirements (right)

2 A NEW APPROACH

To improve the directional consistency of the radiation we have used three techniques:

i) Increased the density of drivers for a given diameter of device by employing a 20-sided platonic polyhedron called an icosahedron, now referred to as the "Icossa".

ii) Provided multiple signal feeds to the device, by identifying adjacent driver patterns.

iii) Decorrelated the signal feeds to drivers at frequencies where destructive interference occurs using a bespoke algorithm.

To compare results, two loudspeakers were constructed of similar overall dimensions: a Dodec and an Icossa. Identical drivers were used in these devices.

2.1 Decorrelation algorithm

This algorithm (or filter) creates a dense set of pseudo-random phase shifts at frequencies (i.e signal delays) above a specified frequency. When this filtered signal is fed to a driver that is adjacent to another with a different set of phase shifts, a dense set of comb filters in the spatial frequency response is produced. The energy average of all these comb filters over a given frequency bandwidth (for example, one third octave) is much more consistent than if no decorrelation filter was applied.

The algorithm is based on diffuse signal processing (DiSP), which was first described by Harris and Hawksford for use with arrays of Distributed Mode Loudspeakers with the aim of minimizing coherent interference [2] and refined by Moore and Hill for use with conventional loudspeakers, with a specific focus on subwoofer systems [3]. DiSP operates through the synthesis of unique temporally diffuse impulses (TDIs), which contain an initial impulse followed by rapidly decaying random phase noise tails (Figure 3). This phase noise is generated in the frequency domain to allow for precise control of frequency-dependent decay to avoid perceptual coloration of the resulting signal [4].

DiSP is available in two forms: static and dynamic. Static DiSP requires a single TDI for each degree of freedom within a sound reproduction system and ensures decorrelation between all direct sounds. Dynamic DiSP is required when decorrelation is required between the direct sound and early reflections and therefore requires a library of pre-generated TDIs for each degree of freedom within a sound reproduction system. An element's TDI library is cycled through over time, using interpolation to avoid perceptual artifacts when switching between successive TDIs [5]. In this work, static DiSP has been implemented, as the focus is on the decorrelation between the direct sounds emanating from the loudspeaker's multiple drive units.

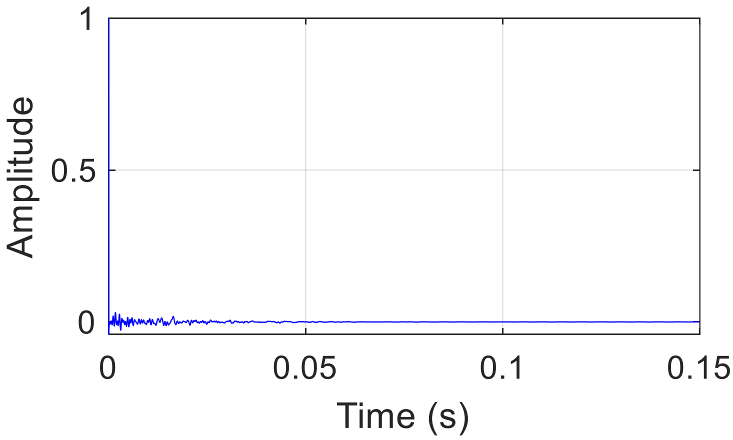


Figure 3: Example of temporally diffuse impulse (TDI) used within diffuse signal processing (DiSP)

Due to the random nature of the TDI synthesis, optimization is often required. For this work, such optimization involved inspection of a given set of TDIs when applied to a loudspeaker. If significant irregularities are observed, then a new set of TDIs is synthesized and retested. While such a process can be automated, in this case, this process was carried out manually.

Initial measurements showed that the transition from true omnidirectional radiation of the Dodec and Icossa to radiation that was spatially aliased was quite rapid with frequency, necessitating the use of TDIs with rapid-onset of phase shift to not affect omnidirectionality at lower frequencies whilst simultaneously improving omnidirectionality at higher frequencies. The limited time for this study precluded the development of such a TDI set, and a crossover (XO) arrangement was implemented to allow the TDIs to operate at the higher frequencies (above the crossover point). The low frequency signal was then summed with the TDI to create a full range signal.

2.2 Channel allocation

Ideally, the Icossa system would employ 20 unique filters that are fed via 20 amplifiers to the 20 drivers. As this is an inefficient use of amplifiers, five driver groups in the Icossa enclosure can be formed, whereby each driver's signal can have a different amplifier feed than its direct neighbours.
The amplifier channel allocation to non-adjacent drivers is described pictorially in Figure 4 below.

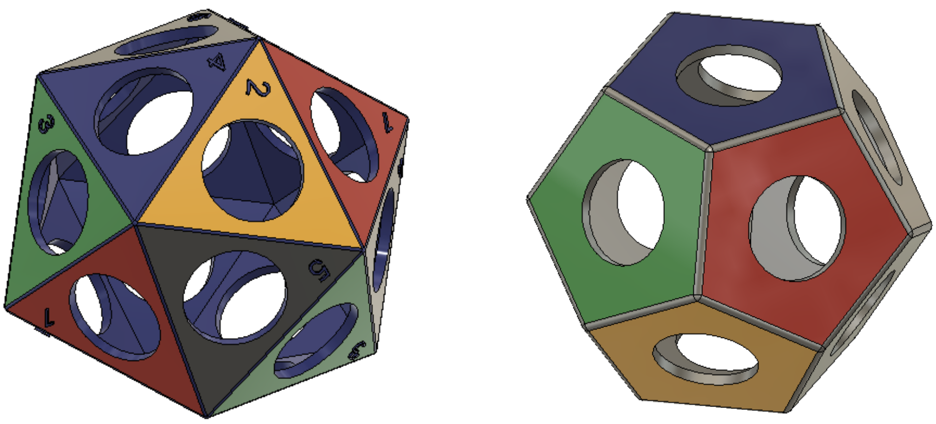


Figure 4: Icossa (left) and Dodec (right) models indicating non-adjacent drive chains

For the Dodec, four unique channels are sufficient (similar channels are like-coloured in the figure) to ensure that no adjacent drivers are driven by the same signal. Three drivers per channel are wired in parallel at low impedance. For the Icossa, five discrete channels are required using a series/parallel wiring (2+2) configuration.

3 MEASUREMENTS

3.1 Comparing Systems

To compare the directional consistency of a Dodec with the Icossa, we constructed dodecahedral and icosahedral enclosures of external diameter 180 mm with 38 mm drivers on all faces (Figure 4).

The speaker driver employed for both speakers is a 1.8” diamter BMR (Balanced Mode Radiator) driver made by Tectonic – model TEBM28C10-4A (Figure 5). Both enclosures were 3D printed using PLA+ material and packed with sound absorbent insulation.

Figure 5: Tectonic BMR driver used for testing

Four systems were measured and compared.

1. Dodec with all drivers fed with identical signals
2. Icossa with all drivers fed with identical signals
3. Dodec with groups of three drivers being fed with a uniquely processed signals (four channels of amplification were required)
4. Icossa with groups of four drivers being fed with uniquely processed signals (five channels of amplification were required)

Measurements were made in an environment with limited space around the loudspeaker at 500 mm from the surface of the loudspeaker. The impulse response was first captured and windowed to a length of 7.5 ms and the frequency response computed via FFT. Measurements were made using a turntable system on one plane of rotation from 0 to 355 degrees in 5-degree increments .

The resulting frequency responses were smoothed over a 1/3rd octave bandwidth and exported at 48 points per octave. The polar plots were normalised to the maximum level (no matter where that maximum occurs). Polar surface plots are presented both of raw data and normalised data.

3.2 Measured Polar Responses

3.2.1 Dodecahedron without signal processing

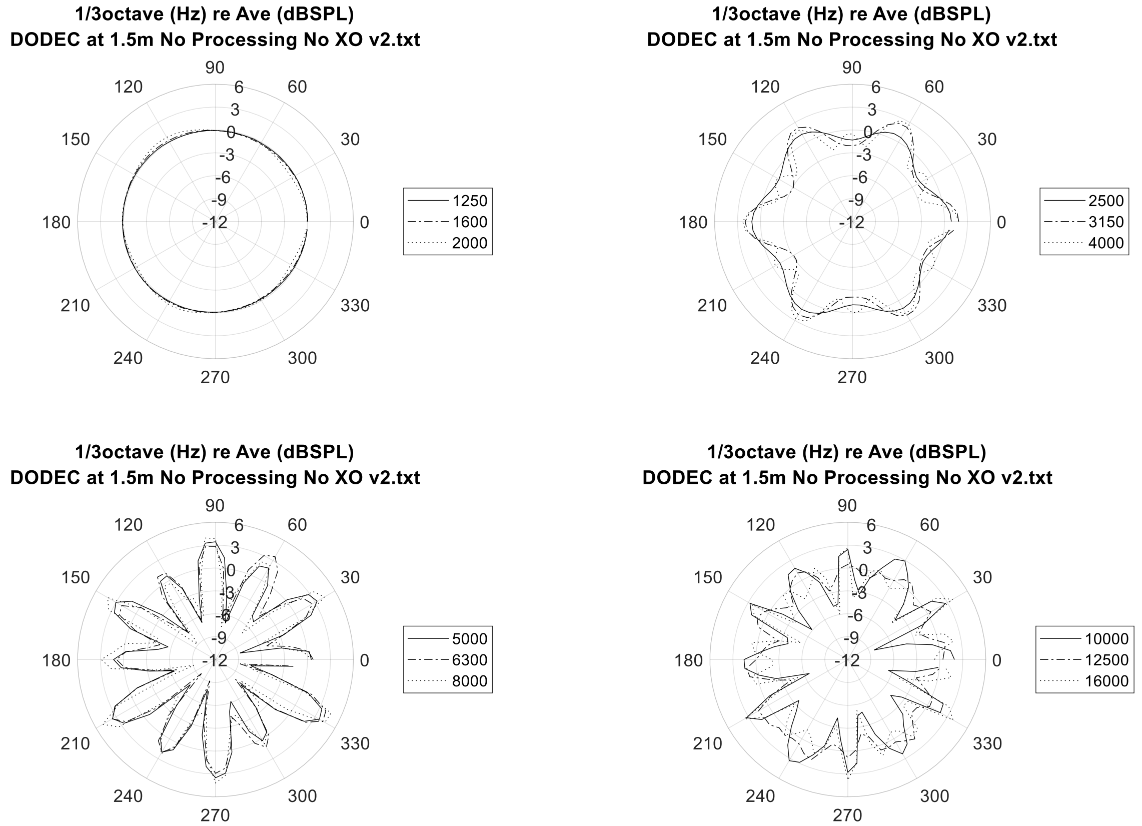


Figure 6: Polar plots in nine one-third octave bands of Dodec without signal processing

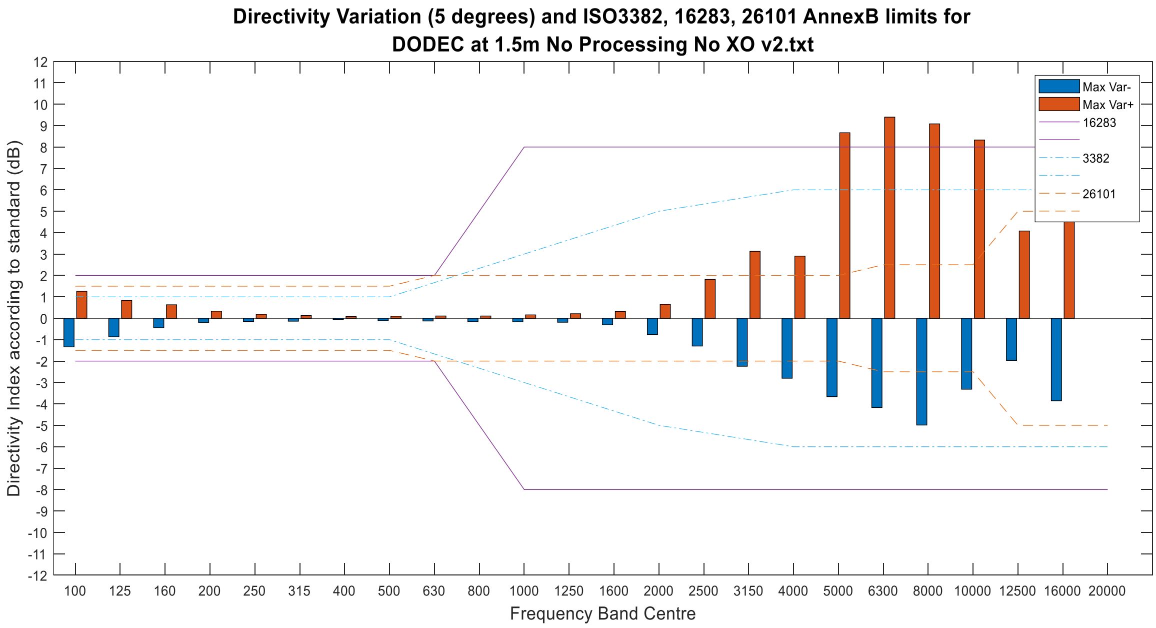


Figure 7: Variation of Dodec without signal processing (5 degree increments – not “gliding” method)

3.2.2 Icosahedron without signal processing

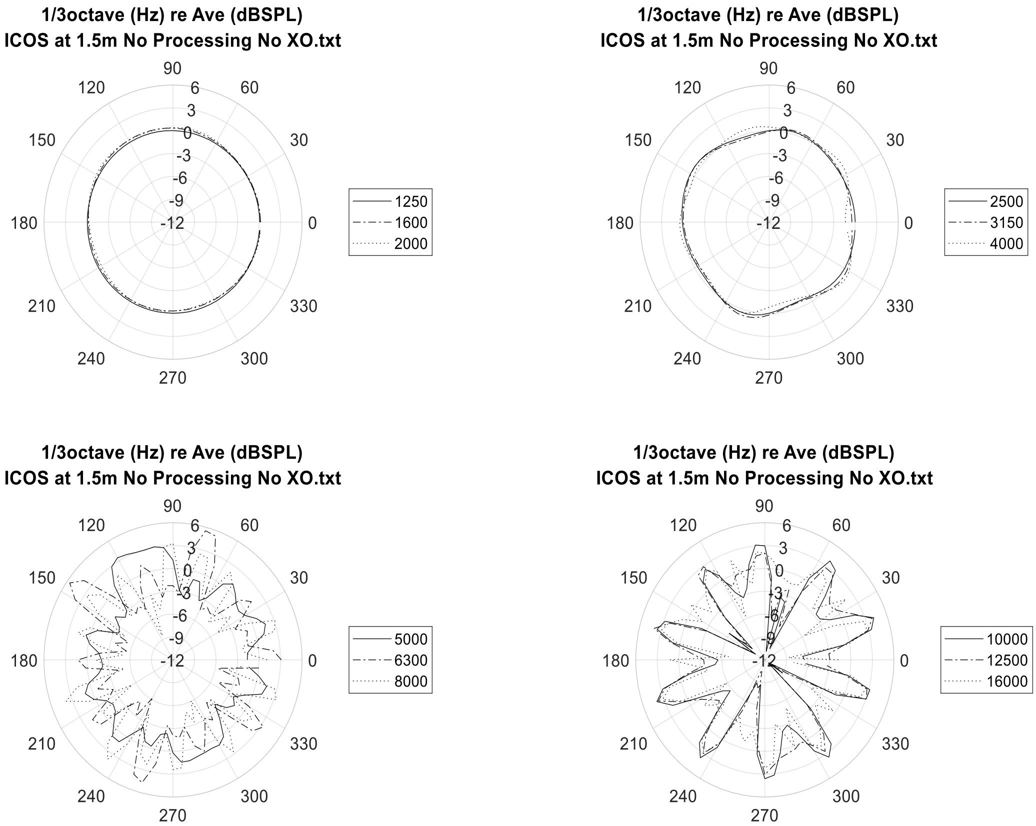


Figure 8: Polar plots in nine one-third octave bands of Icossa without signal processing.

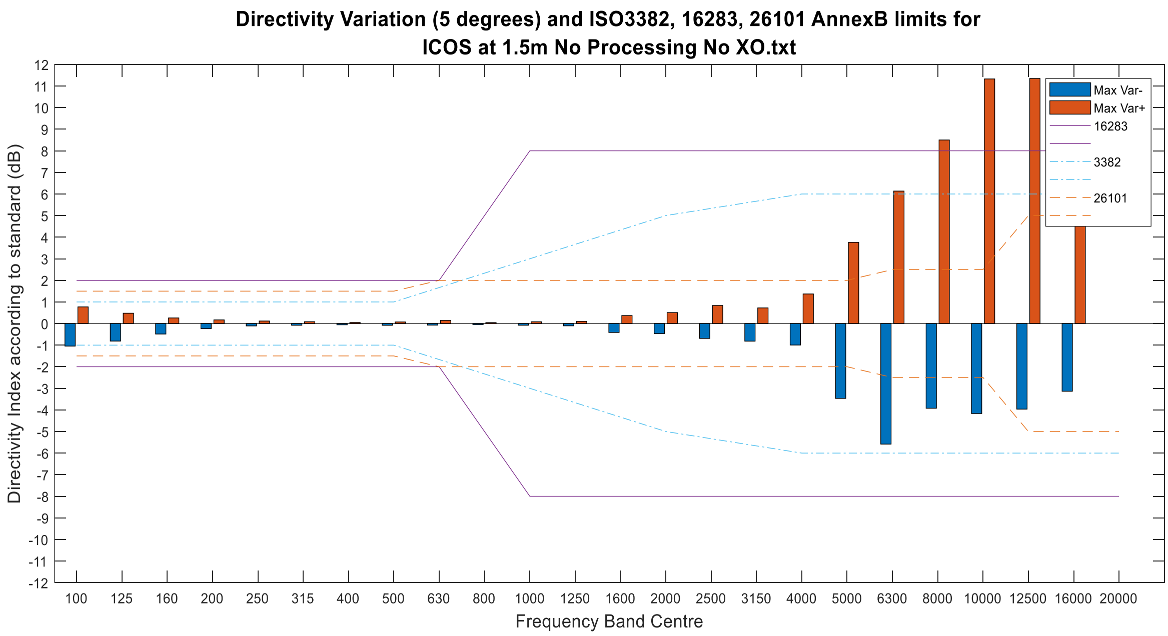


Figure 9: Variation of Icossa without signal processing (5 degree increments – not “gliding” method).

3.2.3 Dodecahedron with signal processing

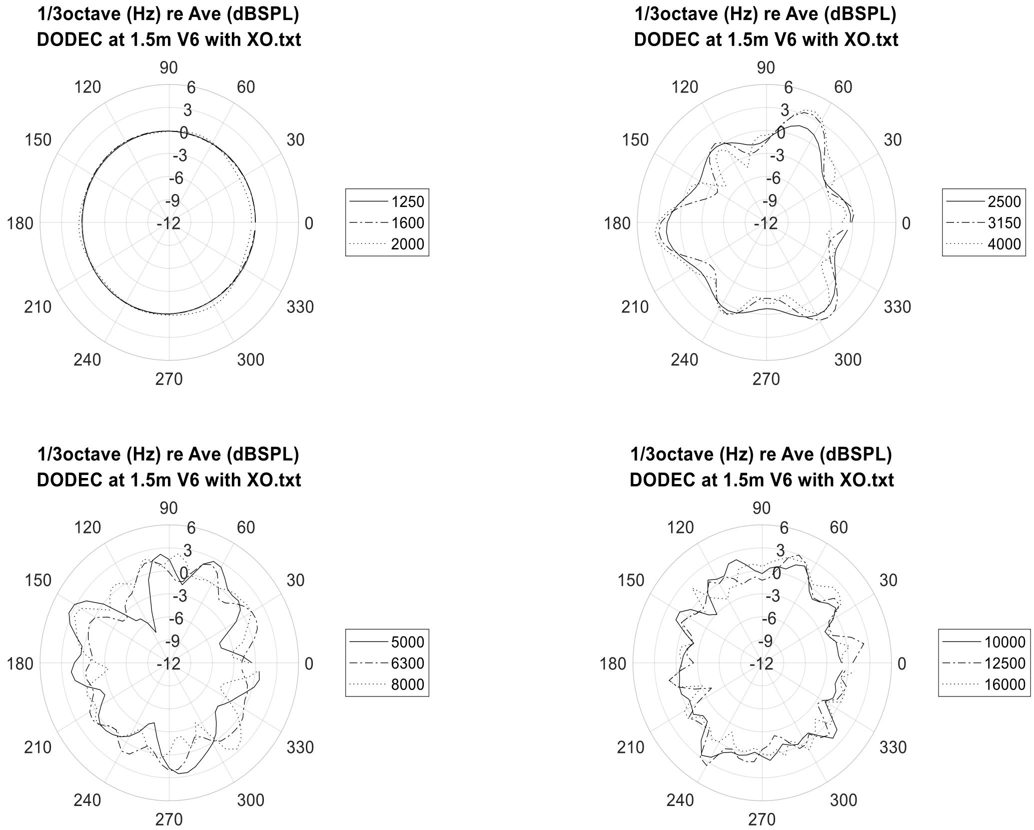


Figure 10: Polar plots in nine one-third octave bands of Dodec with signal processing

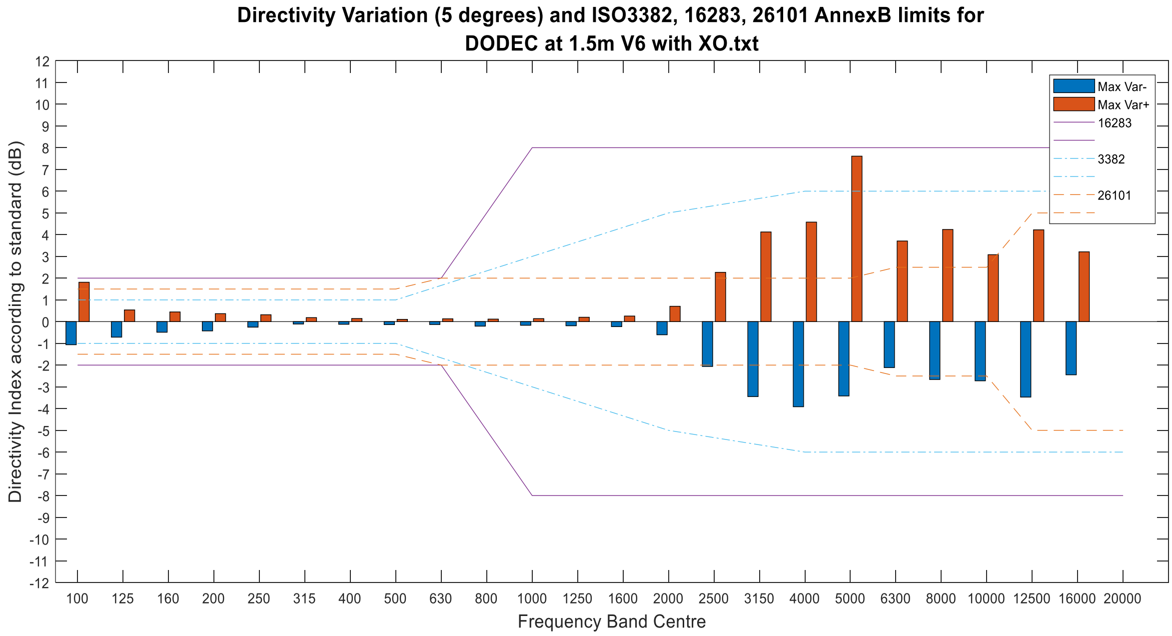
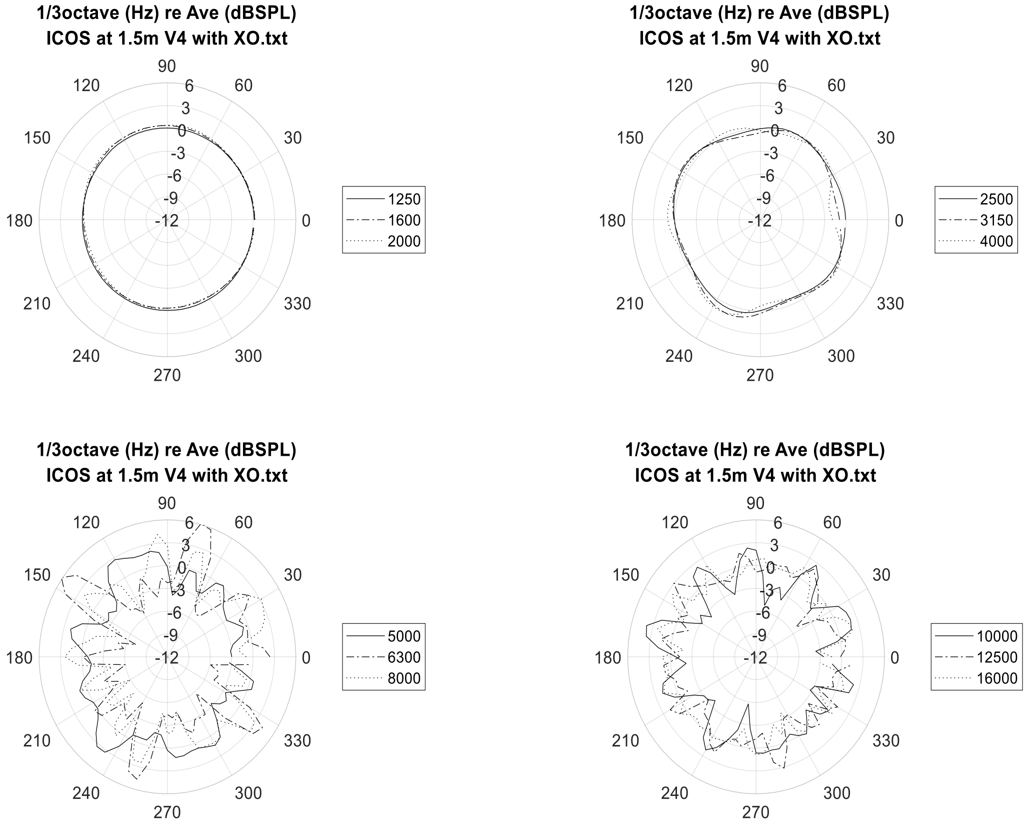


Figure 11: Variation of Dodec with signal processing (5 degree increments – not "gliding" method).

3.2.4 Icosahedron with signal processing



[6]

Figure 12: Polar plots in nine one-third octave bands of Icossa with signal processing

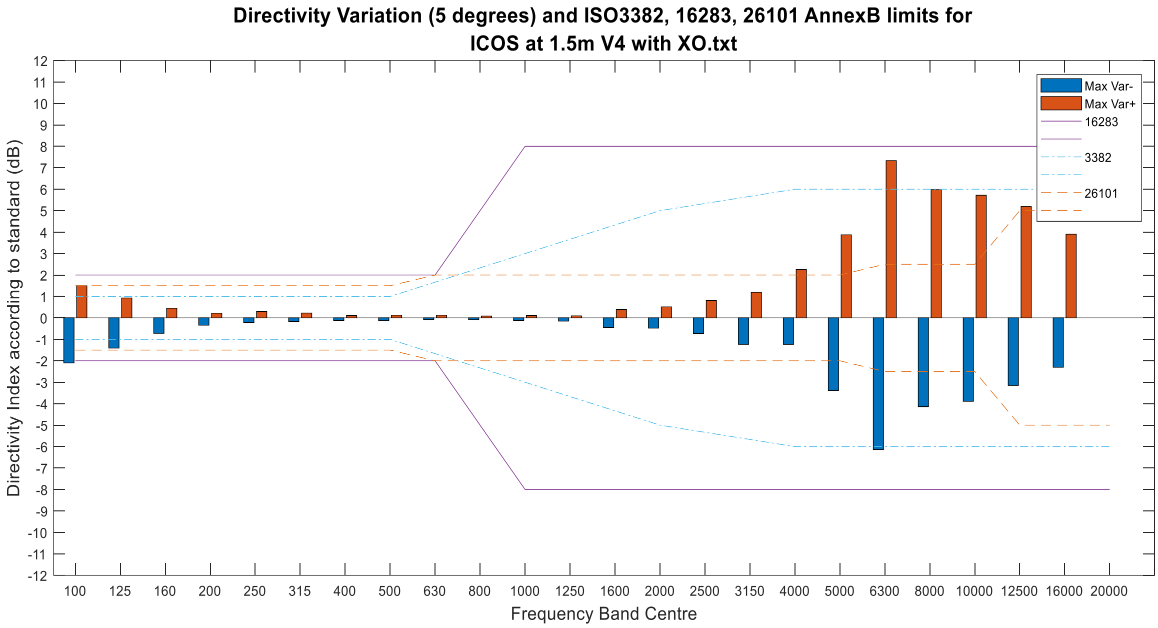


Figure 13: Variation of Icossa with signal processing (5 degree increments – not “gliding” method).

The Appendix shows polar maps of the four systems.

3.3 Room Acoustic Measurements

Tests were conducted using the four systems (Dodec and Icossa, with and without processing) at 3.5 metres between source and receiver in an office. Measurements were taken at 25 degree angular increments between 0 degrees and 175 degrees source angle.

The signal processing, through the application of DiSP, isn't expected to significantly influence the calculation of the acoustic metrics, as the decorrelation is achieved through the low amplitude noise-like tail of each TDI (Figure 3), which by design acoustically sums with other TDIs to further reduce the amplitude of the resulting noise tail [2].

Using the REW measurement software [6], metrics were automatically calculated: EDT, T(opt) [an "optimised" RT measurements which accounts for individual signal to noise ratios in each one-third octave band] and C50. The mean and standard deviation (SD) for each metric was calculated in each one-third octave bands. Results are shown below in Figure 14 – 17. Table 2 presents t-test results which compare the means for the various systems in the 5000 Hz third-octave band.

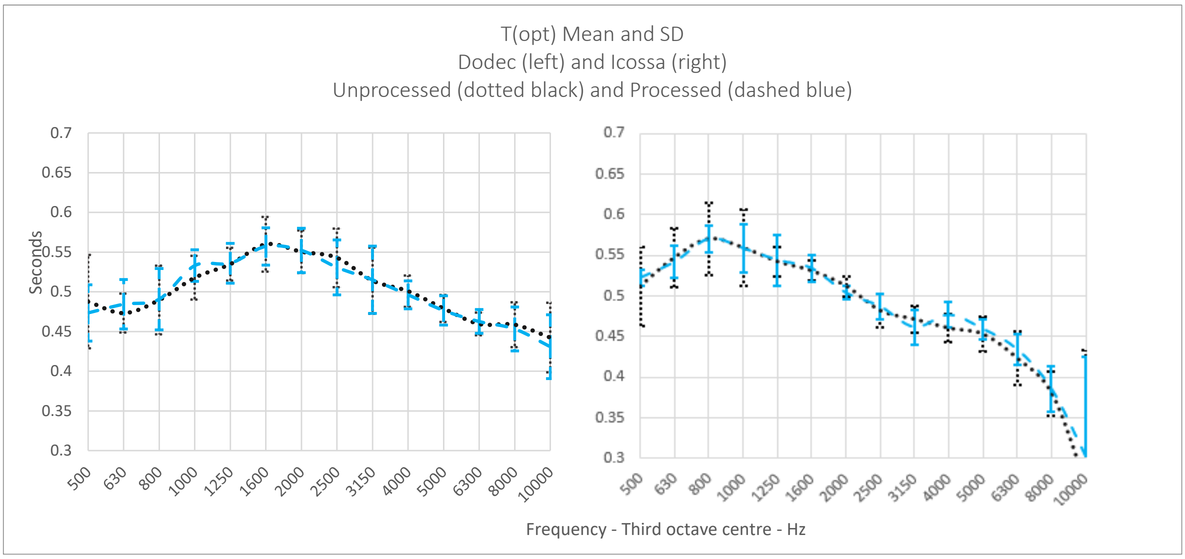


Figure 14: Calculated "T(opt)" for the four systems at 3.5 m with 8 source angles - average and +/- SD.

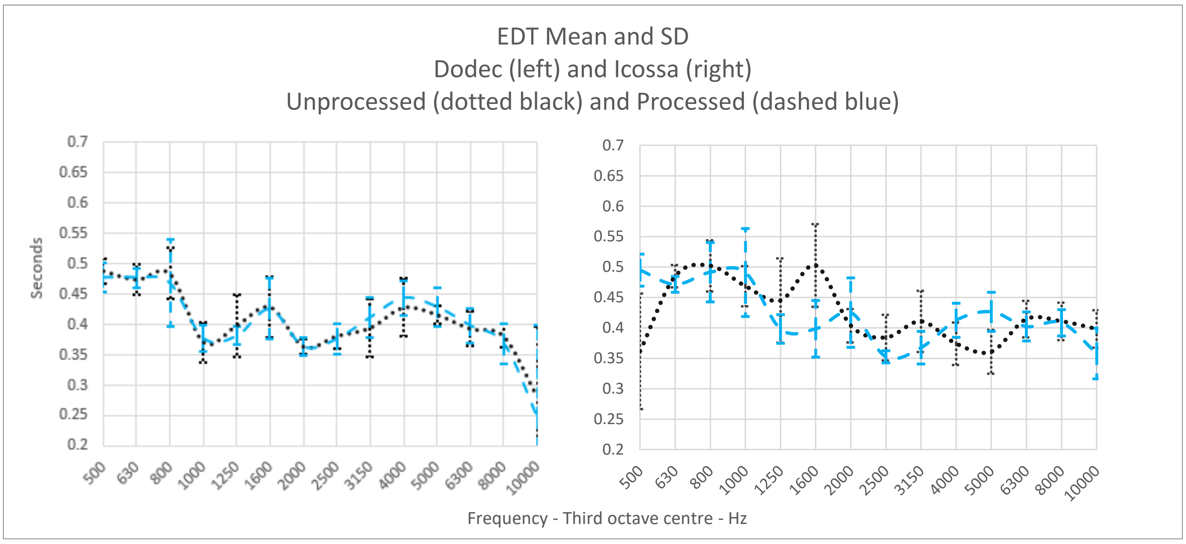


Figure 15: Calculated EDT for four systems at 3.5 m with eight source angles - average and +/- SD.

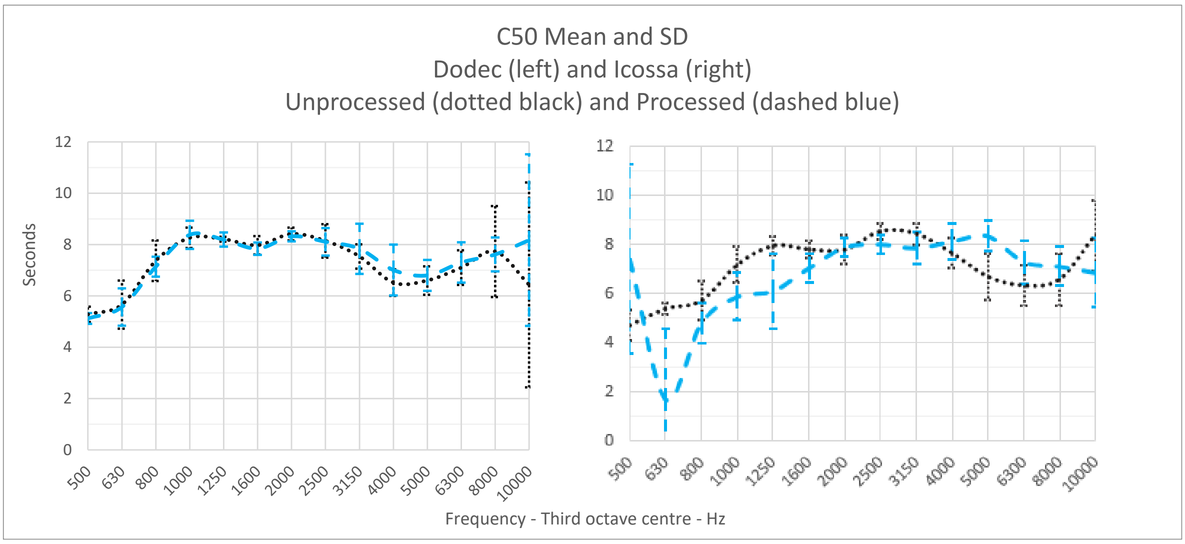


Figure 16: Calculated C50 for four systems at 3.5 m with eight source angles - average and +/- SD.

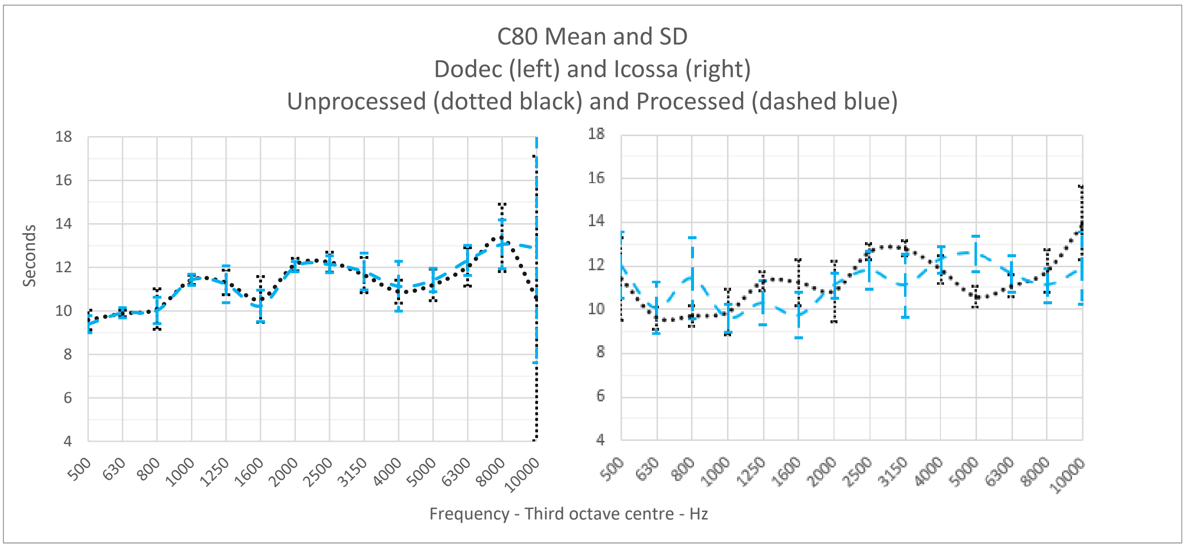


Figure 17: Calculated C80 for four systems at 3.5 m with eight source angles - average and +/- SD.

Table 2: T-test analysis of means in the 5 kHz 1/3rd octave band using the eight, 3.5 metre distant measurements. P>0.05 indicates a significant difference between the means.

2 Sample T-test - comparison of Means	T(opt)		EDT		C50	
	P value	Different	P value	Different	P value	Different
DODEC Uprocessed vs DODEC Processed	0.407	TRUE	0.263	TRUE	0.346	TRUE
DODEC Uprocessed vs ICOSSA Unprocessed	0.002	FALSE	0.012	FALSE	0.843	TRUE
ICOSSA Unprocessed vs ICOSSA Processed	0.739	TRUE	0.004	FALSE	0.012	FALSE
DODEC Processed vs ICOSSA Processed	0.111	TRUE	0.902	TRUE	0.005	FALSE

3.4 Discussion

3.4.1 Polar pattern regularisation

The Dodecahedral speaker layout, as discussed by Knüttel et al [7], exhibits periodic directionality with peaks in the response at 60-degree intervals between 2500 Hz and 5000 Hz, then at 30-degrees between 5000 Hz and 12000 Hz. Above 12000 Hz, the lobing becomes less regular. The compact size of the tested Dodec means that the frequency at which periodicity commences, is substantially above where it would commence in larger commercially-available units (around 1000 Hz). The small drivers in the experimental setup are limited in their bass response and their capacity to produce high SPL.

The polar periodicity can cause differences in the early part of a gathered impulse, depending on the aiming of the Dodec loudspeakers, leading to incorrect calculation of metrics [7] such as EDT and clarity. The addition of DiSP filtering to the Dodec makes the polar response more regular, removing the polar periodicity.

Polar periodicity in the Icossa at frequencies above 8000 Hz is at about 37.5 degrees, and at slightly lower frequencies at about 75 degrees. When DiSP processing is introduced, the periodicity reduces, and is confined to a smaller range of frequencies, between 6000 and 8000 Hz.

It is likely that the periodicity could be further reduced by optimisation of the algorithm in dedicated software, rather than the iterative process undertaken for the purpose of the experiment. A longer DiSP filter could also be used to generate a more consistent polar response.

Examination of the polar maps in the Appendix reveal that the processed Icossa map is significantly more consistent than the other three systems.

3.4.2 Acoustic metrics

The impact of sound source directivity on standard acoustic metrics has been discussed by San Martin and Arana [8], including the impact of various sound sources on just noticeable differences (JND) across an audience area, with the authors concluding that “the use of typical dodecahedral sources could lead to high deviations in wide areas of audience zones…for speech and music.”

Measurements undertaken at 3.5 metres highlight the variability in the measurement of acoustic metrics (in general), and the need for sufficient measurements to create a meaningful average result. The t-test analysis suffers from too few measurements in the data set and shows that source orientation should be taken into account when acquiring acoustic measurements.

At present, only the variability in source-receiver position is specifically required to be accounted for when making room-acoustic measurements. A more consistent omnidirectional source will reduce variability in acoustic measurements. In relation to the differences in metrics calculated using processed or un-processed sources, the t-test results are not conclusive and should be a topic for further study.

In general, acoustic metrics relying on the first portion of the impulse response (EDT and C50) appear less reliable than calculations based more on later-arriving sound (T(opt) and C80).

4 CONCLUSIONS AND FURTHER WORK

This paper presents a novel method for achieving an improved omnidirectional response at higher frequencies, as compared to a typical dodecahedron loudspeaker, by using an icosahedron loudspeaker with a bespoke signal decorrelation algorithm applied to groups of non-adjacent drive units. The polar pattern of the icosahedron was less periodic than the dodecahedron and provided a true omnidirectional performance out to a higher frequency. When processed, both sources produced a power response closer to omnidirectional. There was a reduction of periodicity in all cases, which could likely be minimized through further optimization of the decorrelation algorithm. (Time limitations for this work prevented significant optimization of the TDIs).

Further investigation is required to provide numerical evidence of the advantages for the use of a processed icosahedron over a regular dodecahedron loudspeaker and to fine tune the decorrelation algorithm’s optimization routine, which may require lengthening of the TDI filters to produce denser spectral and polar notches.

5 APPENDIX

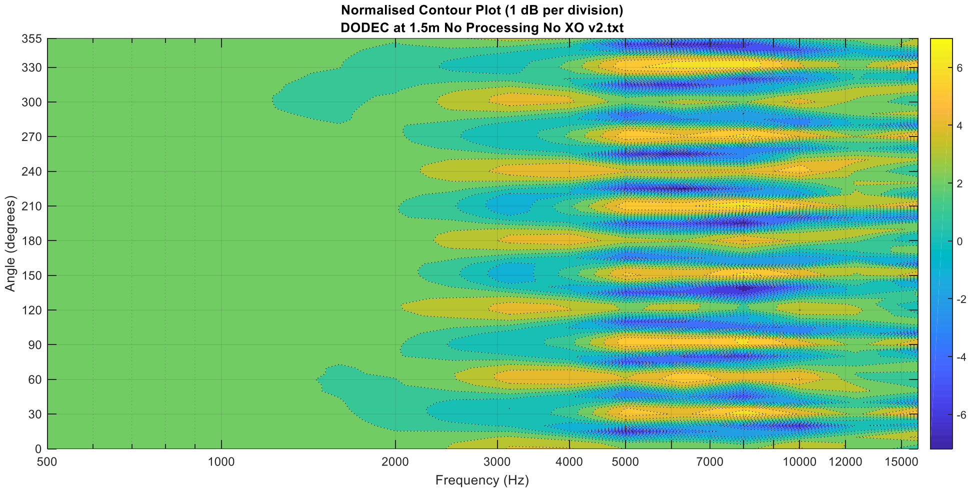


Figure 18: Polar map of Dodec without processing, normalised in each third-octave band

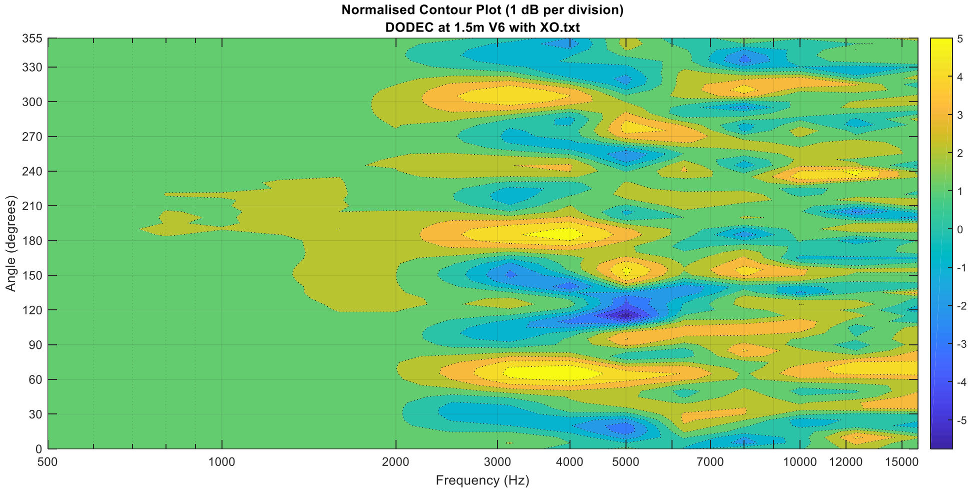


Figure 19: Polar map of Dodec with processing, normalised in each third-octave band

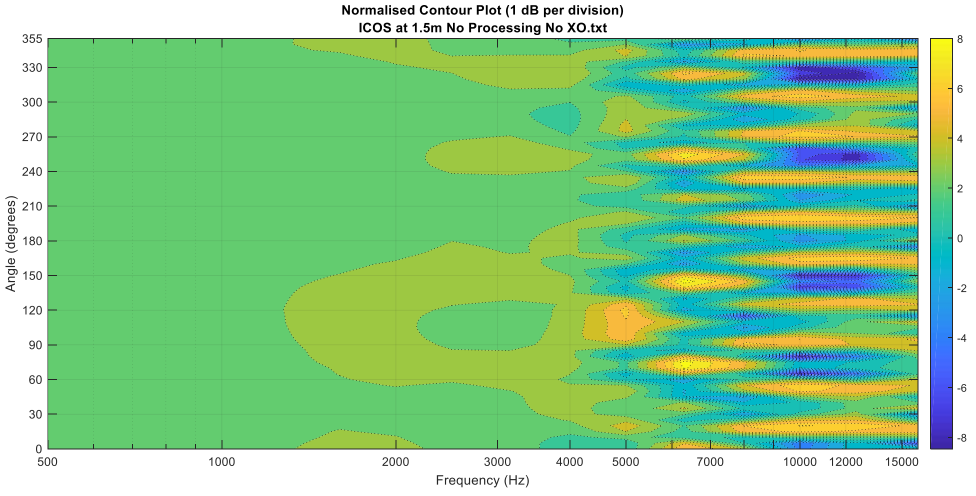


Figure 20: Polar map of Icossa without processing, normalised in each third-octave band

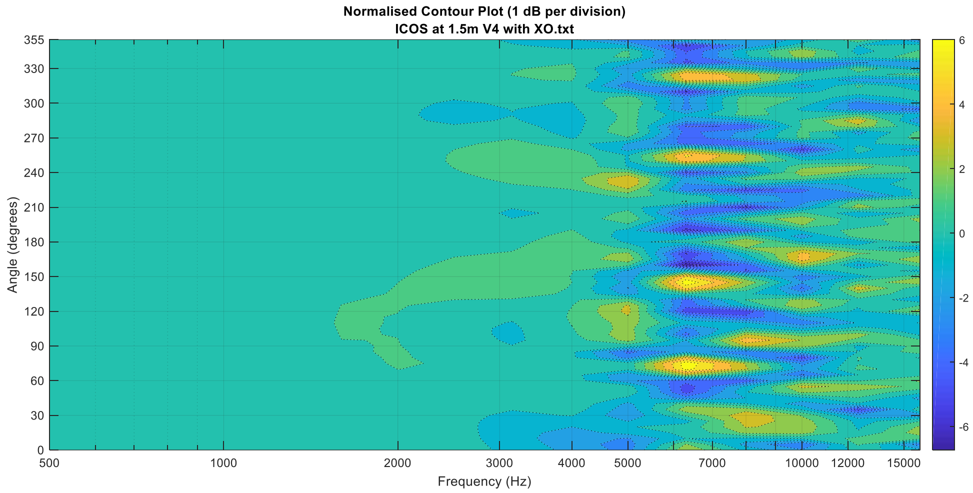


Figure 21: Polar map of Icossa with processing, normalised in each third-octave band

6 REFERENCES

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