On High Frequency Reproduction in Binaural Ambisonic Rendering

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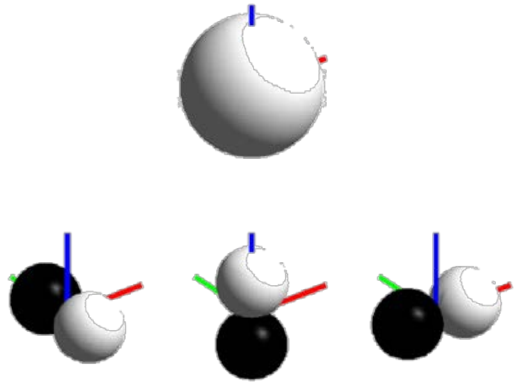
- Funded by a Google Faculty Research Award
- Supervisors: Dr. Gavin Kearney and Prof. Damian Murphy

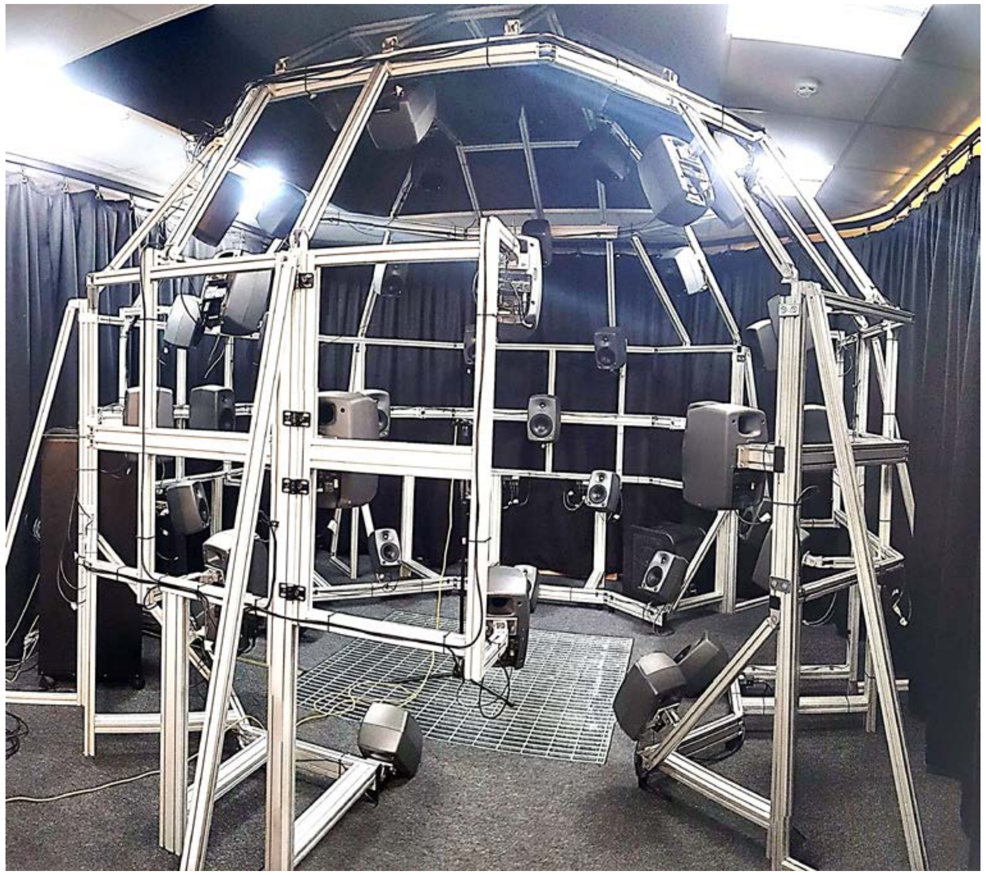
(audio test)

Art Blakey & the Jazz Messengers – Moanin'

Background – Ambisonics

- Sound field sampling and reconstruction method
- Based on spherical harmonic representation of sound fields
- Playback can be over many different speaker configurations
- Can be reproduced over headphones (binaural Ambisonic rendering)





Background – High Frequency Reproduction in Ambisonics

- Ambisonic sound fields are only reproduced accurately at low frequencies
- Up to the spatial aliasing frequency
- Which is around 700 Hz for 1st order systems
- This causes inaccurate timbre and localisation
- Implementing ‘Max rE’ weighting above 700 Hz improves high frequency horizontal localisation
- But how do we improve high frequency timbre?

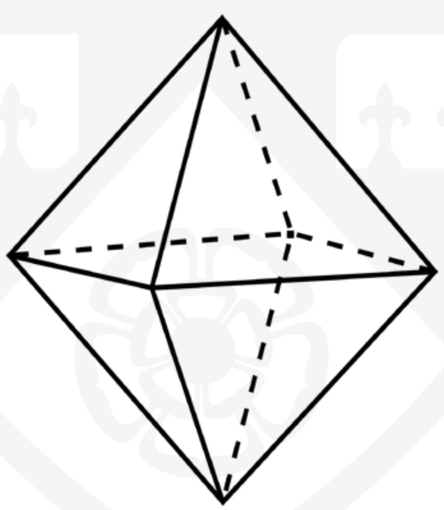
J. S. Bamford, J. Vanderkooy, “Ambisonic Sound for Us,” presented at the 99th Convention of the Audio Engineering Society (1995), preprint 4138.
J. Daniel, Representation de Champs Acoustiques, Application a la Transmission et a la Reproduction de Scenes Sonores Complexes dans un Contexte Multimedia, Ph.D. thesis, l’Université Paris (2000).

Example – Timbre in Ambisonics

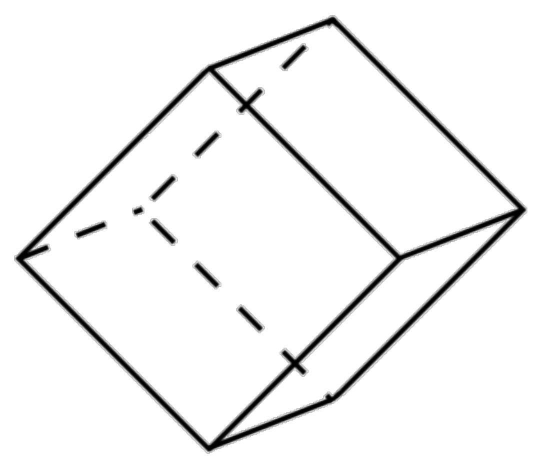
- Pink noise and music rendered in 1st order Ambisonics (binaural)
- 0° azimuth, 0° elevation
- Three loudspeaker configurations:
  - Octahedron
  - Bi-rectangle
  - Cube

Pink noise

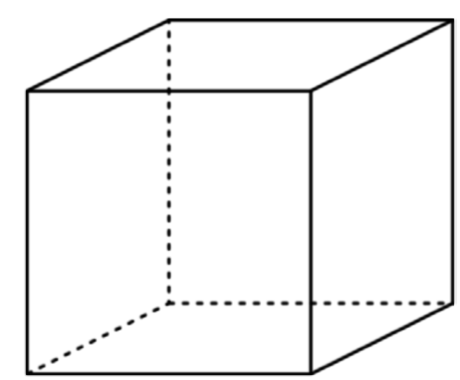
Music



Octahedron



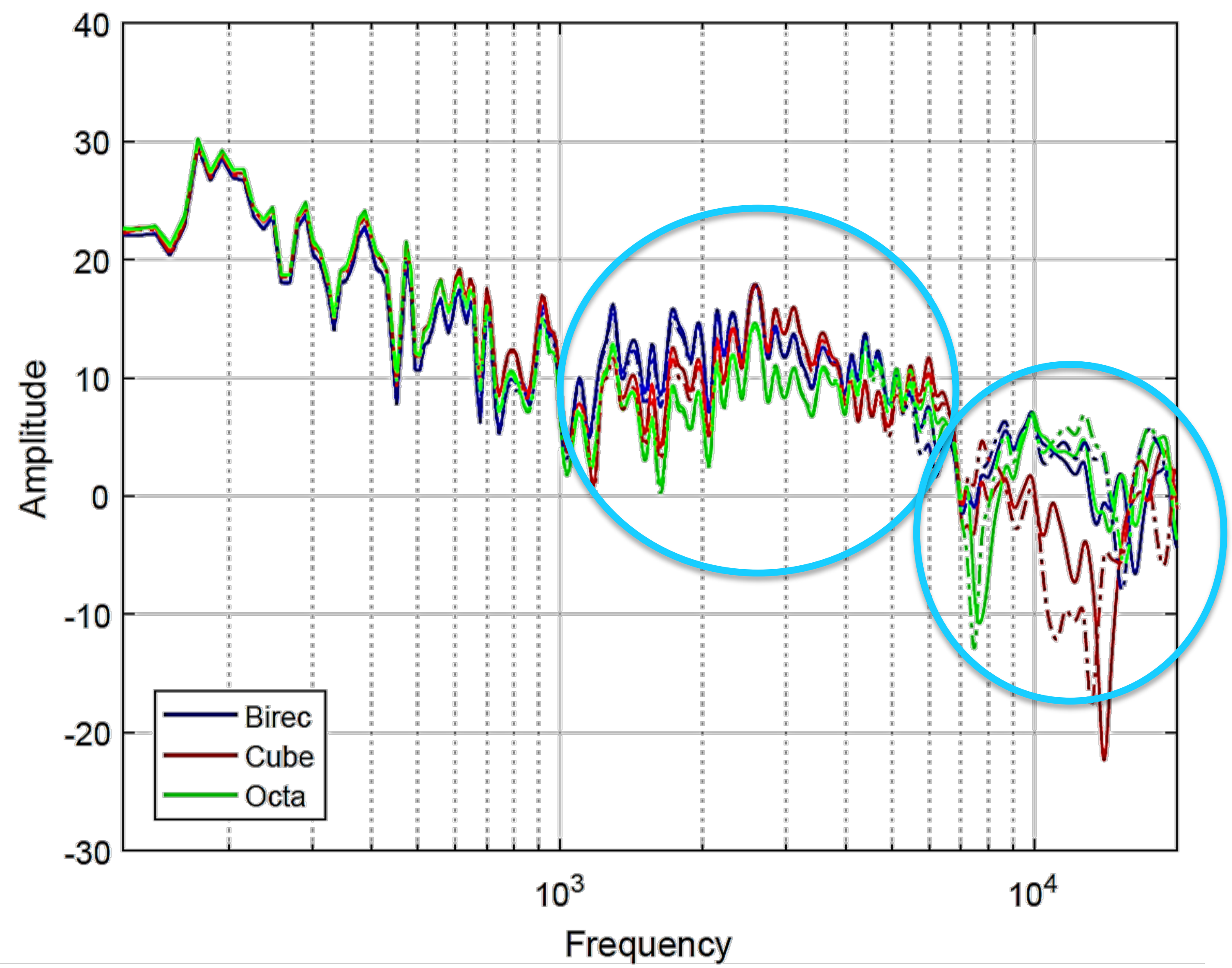
Bi-rectangle



Cube

Timbre in Ambisonics

- Mid and high frequencies vary in examples
- Ambisonics only accurate up to a certain frequency
- Inconsistency in timbre in higher frequencies due to comb filtering
- Caused by multiple loudspeakers playing at the same time

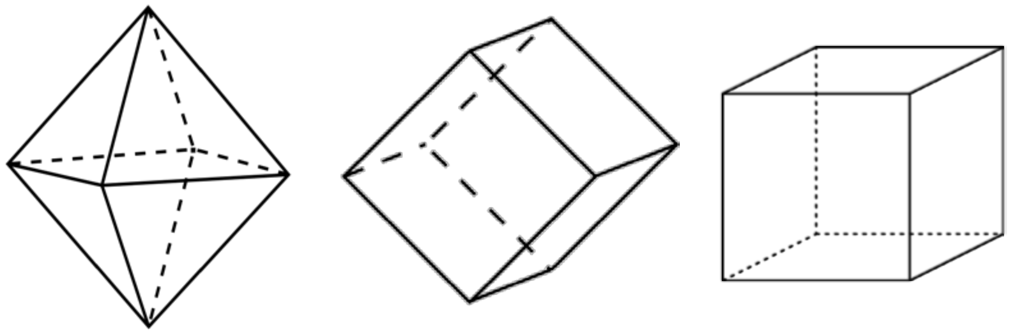


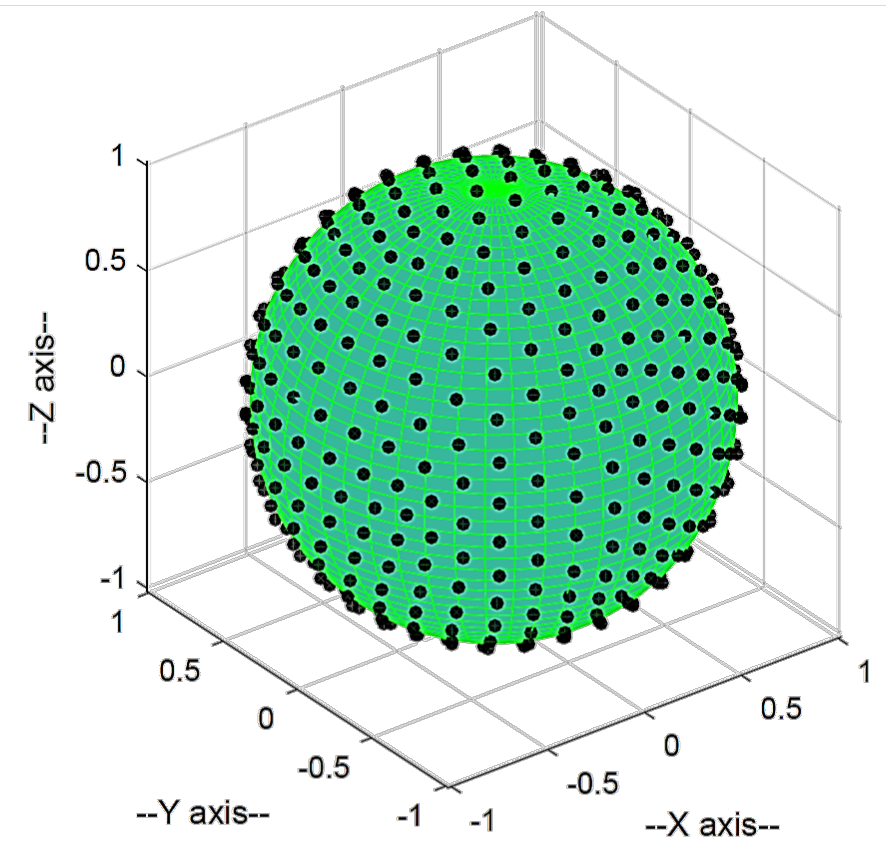
Timbre in Ambisonics

- A 'diffuse-field' response is the average frequency response over all directions
- Diffuse-field equalisation is the removal of this direction-independent response
- Most HRTF sets implement diffuse-field equalisation
- Can it be applied to binaural Ambisonic rendering?

Method – Diffuse-Field Calculation

- 492 points on a sphere – calculated from Icosahedron division
- Encoded into 1st order Ambisonics
- Decoded to three loudspeaker configurations:
  - Octahedron
  - Bi-rectangle
  - Cube
- Rendered binaurally using Neumann KU100 HRTFs

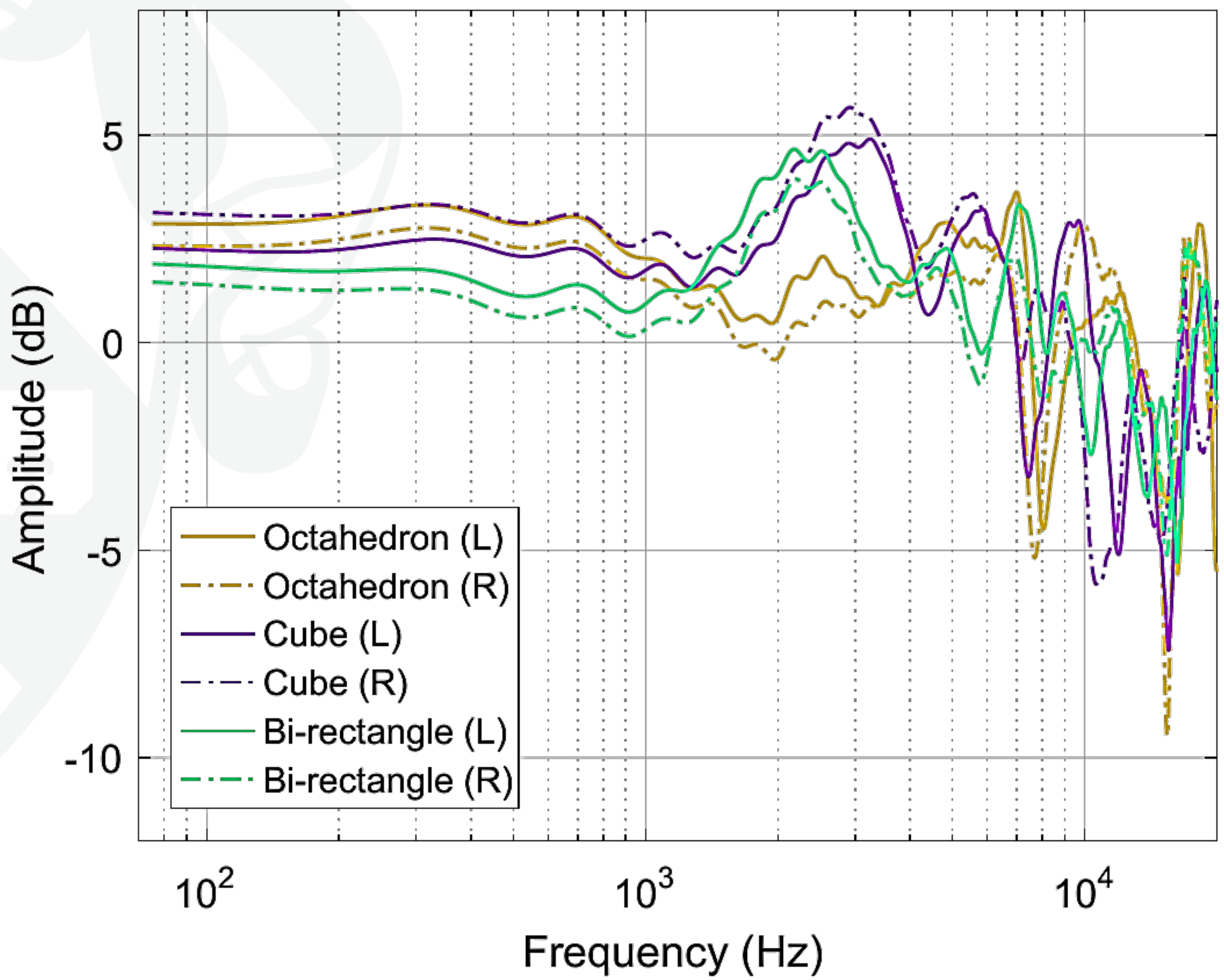




John Burkardt, "SPHERE_GRID - points, lines, faces on a sphere," Available at http://people.sc.fsu.edu/˜jburkardt /datasets/sphere_grid/sphere_grid.html, accessed February 09, 2017.

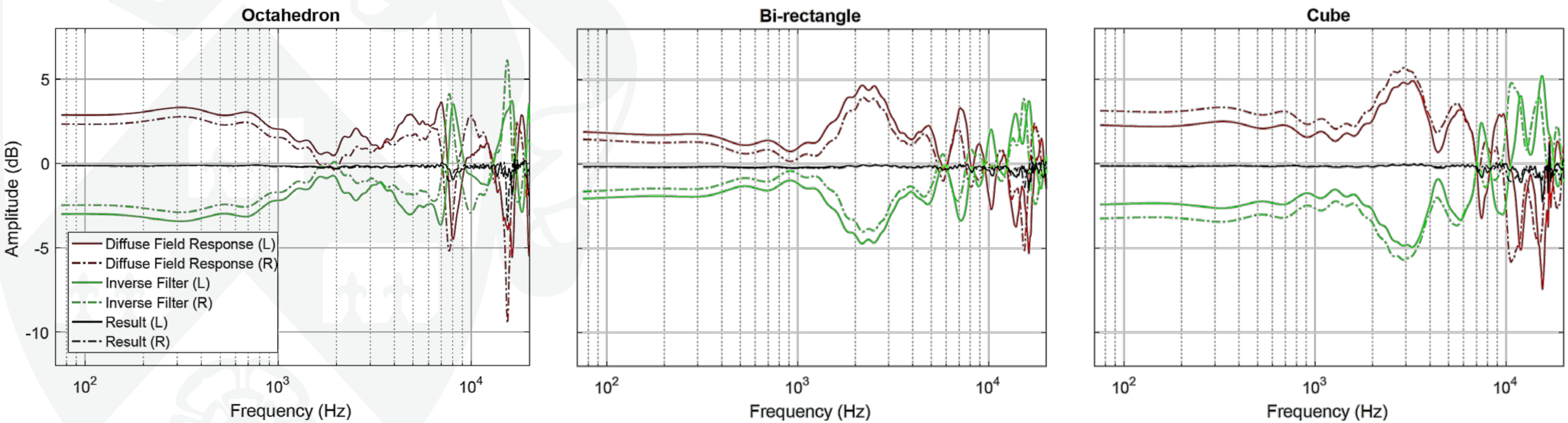
Method – Diffuse-Field Calculation

- Diffuse-field response calculated from the root-mean-square (RMS) of the 492 renders
- Can see the significant variation above 1 kHz



Method – Diffuse-Field Equalisation

- Inverse filters calculated using Kirkeby *et. al.* least-mean-square regularization
- ¼ octave smoothing



Kirkeby, O., Nelson, P. A., Hamada, H., and Orduna-Bustamante, F., “Fast deconvolution of multichannel systems using regularization,” *IEEE Transactions on Speech and Audio Processing*, 6(2), pp. 189–194, 1998.

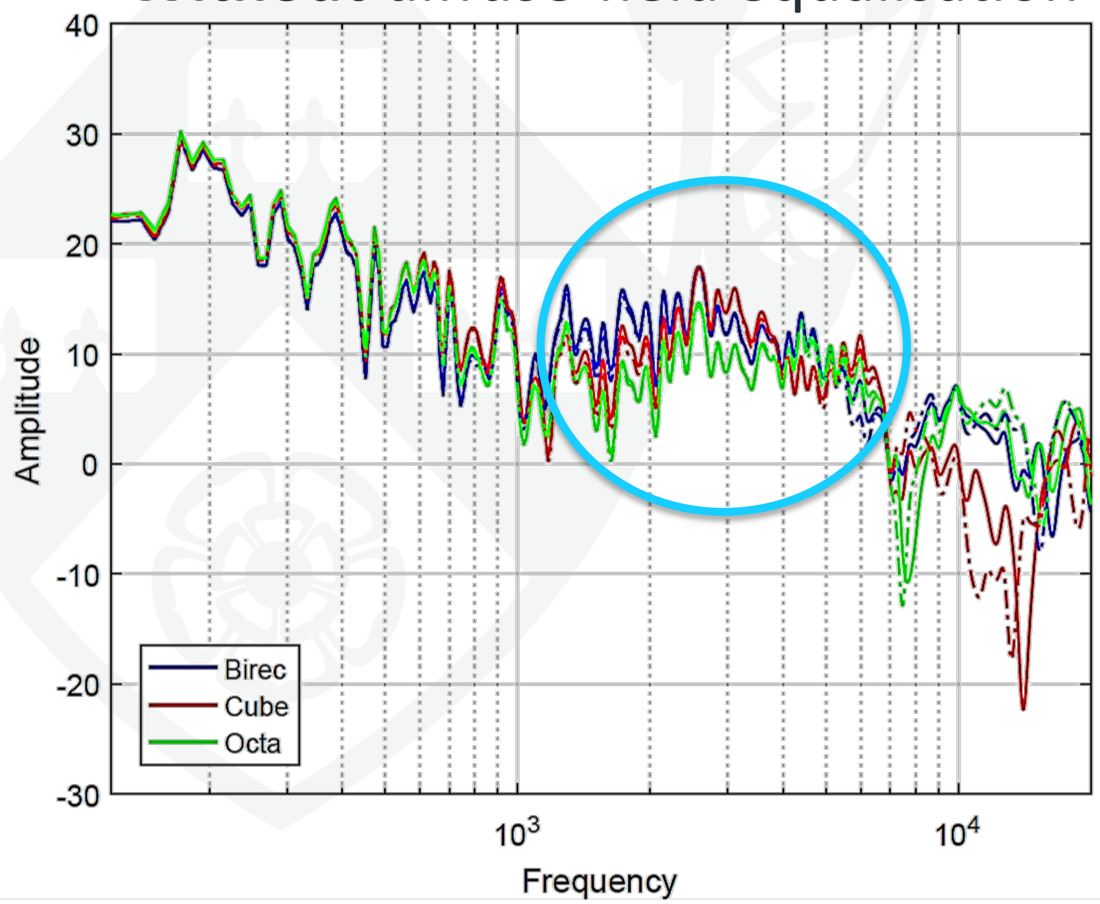
Example – Diffuse-Field Equalisation of First-Order Ambisonics

- 0° azimuth, 0° elevation

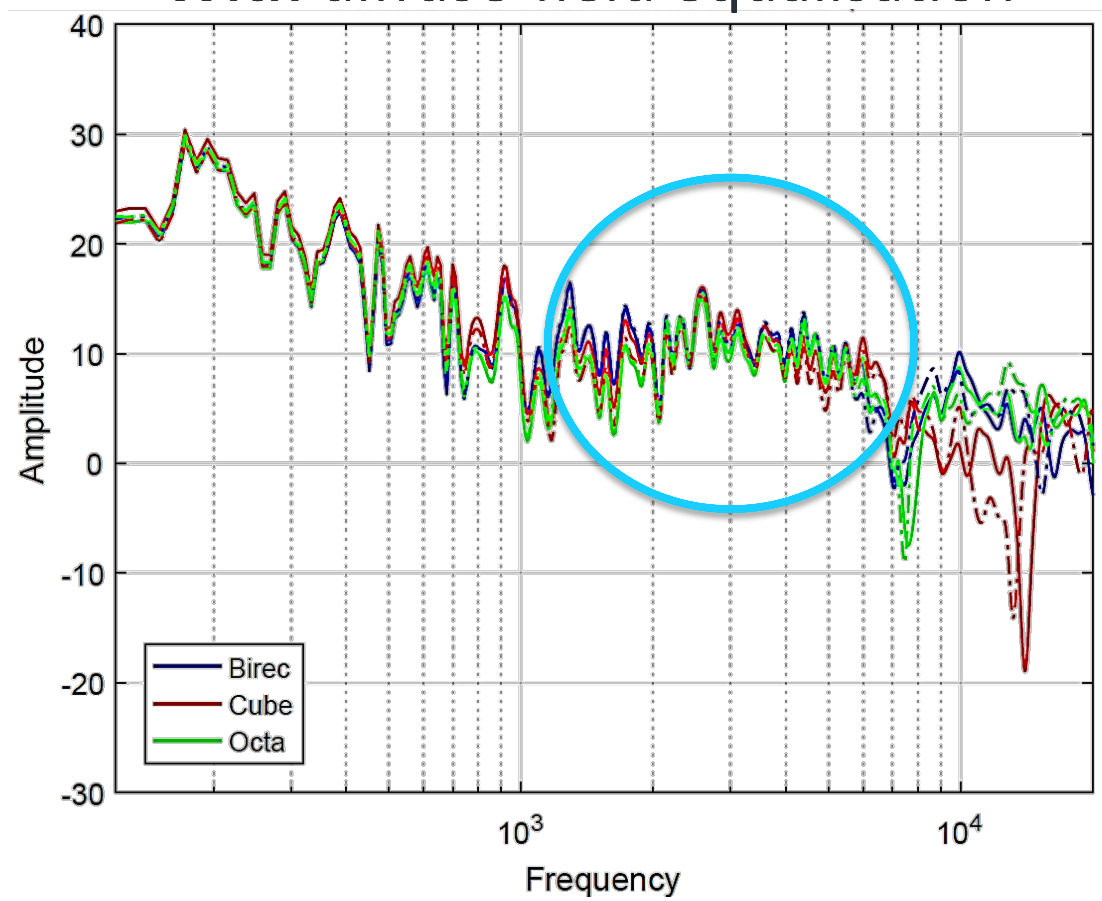
Pink noise **Music**

Pink noise **Music**

Without diffuse-field equalisation



With diffuse-field equalisation

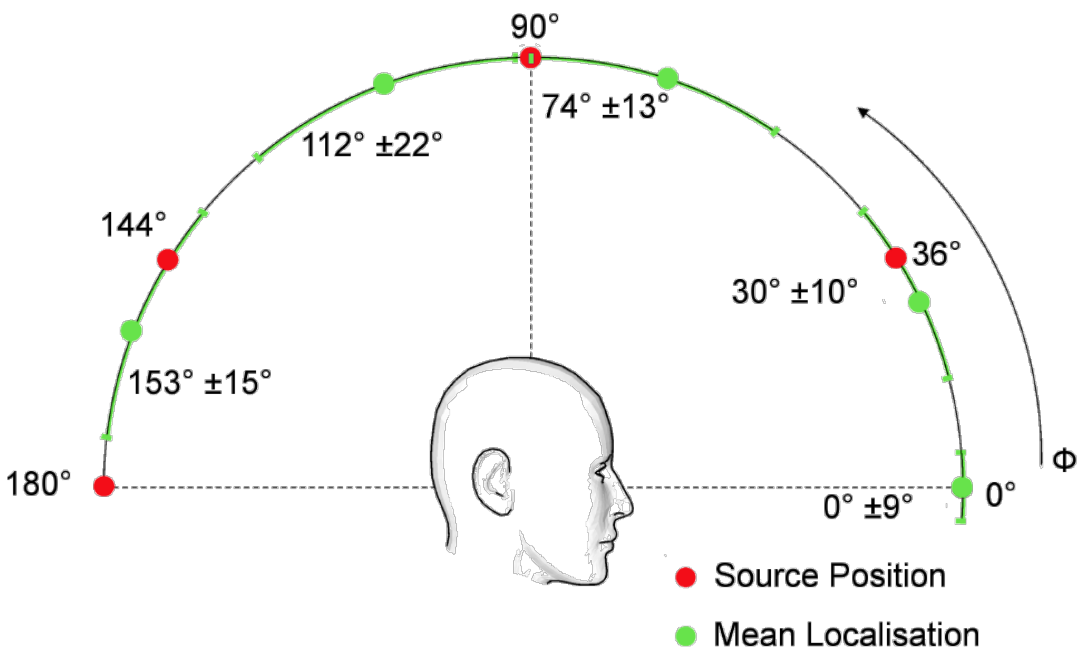


Conclusions

- Timbre varies between different Ambisonic loudspeaker configurations
- Diffuse-field equalisation can address this
- Improves timbral consistency between loudspeaker configurations
- Improves consistency between Ambisonic and HRTF rendering
- Conference paper presented at Digital Audio Effects (DAFx), September 2017, Edinburgh

Frontal Plane Reproduction in Ambisonics

- Diffuse-field equalisation shown to improve high frequency reproduction
- Human hearing more accurate at localising sounds in front
- By altering the method for diffuse-field equalisation of Ambisonics to emphasize improvement in front
- Can we further improve perceptual experience?



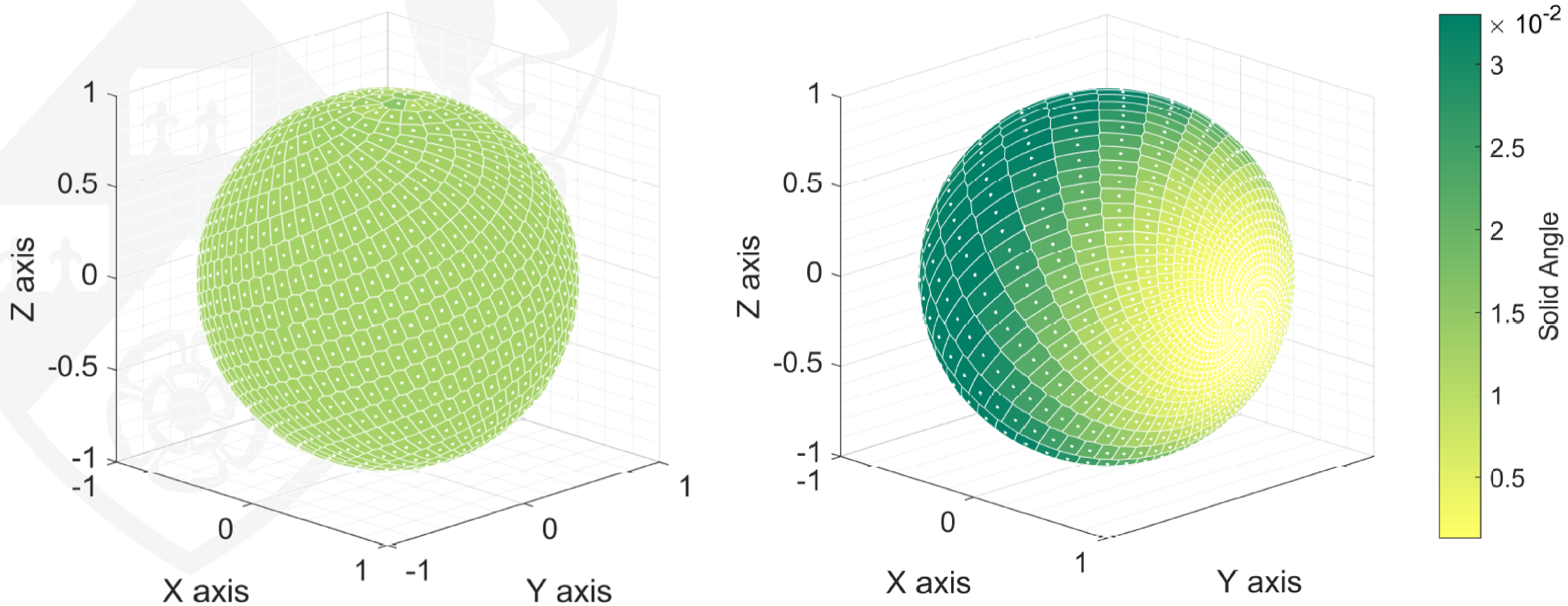
Damaske, P. and Wagener, B., "Richtungshorversuche uber einen Nachgebildeten Kopf [Investigations of Directional Hearing using a Dummy Head]," Acustica, 19, pp. 198–213, 1969.

Frontal Plane Reproduction in Ambisonics

- Diffuse-field equalisation flattens out the average response
- We want to make the frontal response closer to the reference HRTF
- Two ways:
    - Directional biasing of the points on the sphere used in diffuse-field response calculation
    - Additional equalisation to get closer to reference HRTF
- No longer ‘diffuse-field’ equalisation
- We call it direction biased equalisation (DBE)

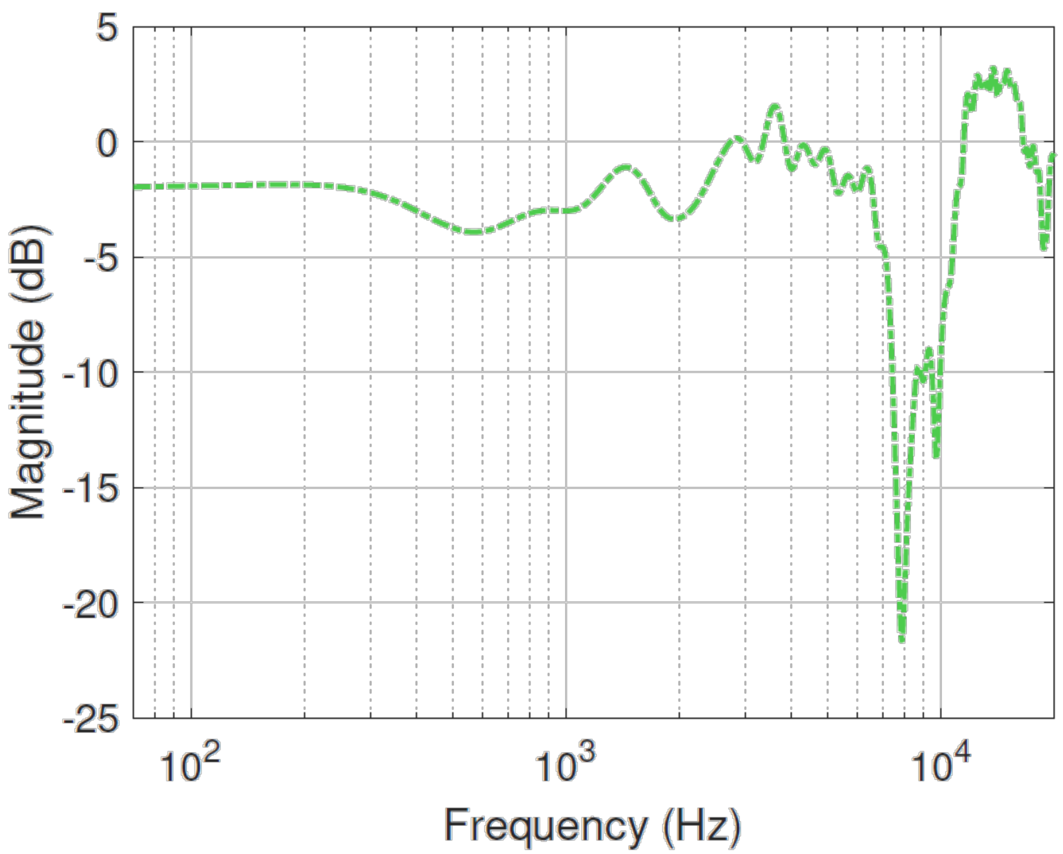
Directional Biasing of RMS response calculation

- Higher concentration of points at the front
- Direction biased ('diffuse') RMS calculation will more represent the frontal response
- Equalising this will flatten out the spectrum of frontal renders



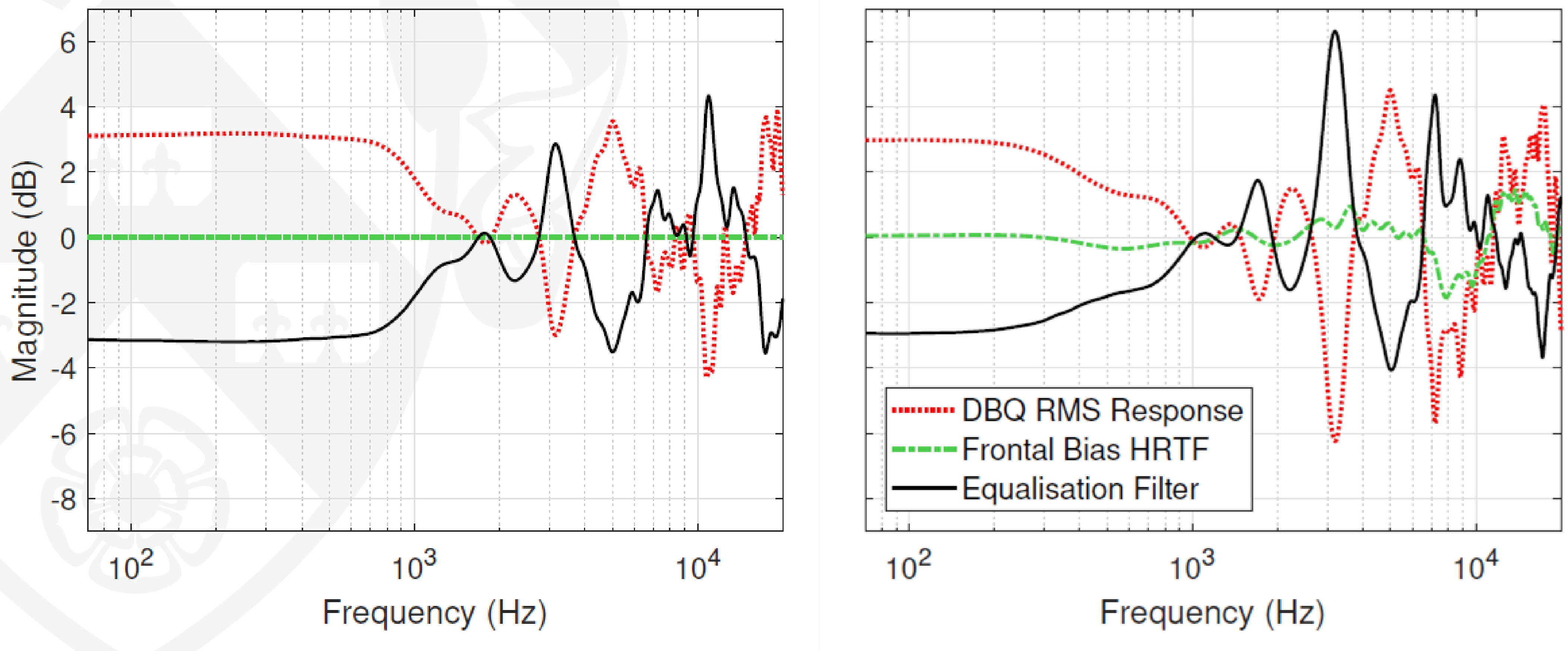
Frontal Bias HRTF Equalisation

- Therefore an additional equalisation stage is required
- Frontal equalisation by convolution with frontal reference HRTF
- Amount of equalisation based on amount of directional biasing
  - No bias ➔ gain of 0
  - Infinite bias ➔ gain of 1



Direction Biased Equalisation

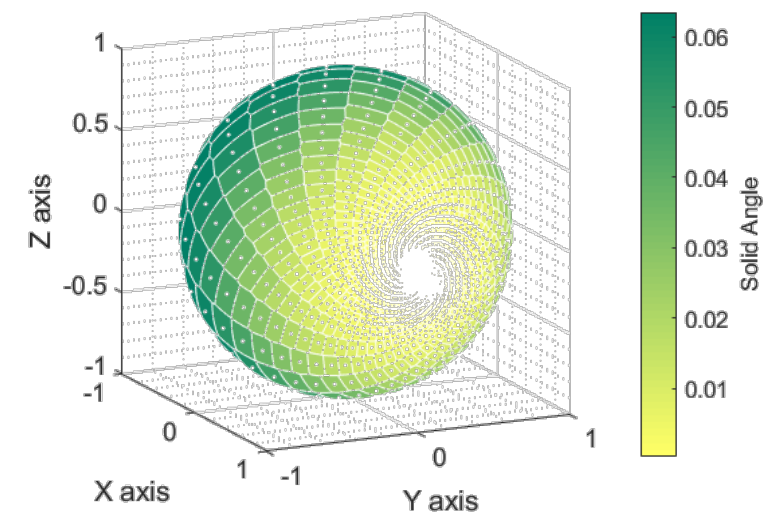
- As bias increases, frontal renders become closer to reference HRTF response
- But renders at other directions will get less accurate as a result



(a) $\kappa = 1$ (no bias) **(c)** $\kappa = 3.4$

Example: Direction Biased Equalisation

- Bias factor *K* = **3.4** (frontal bias direction)
- 0 azimuth, 0 elevation --- Equalised version should be *better*!

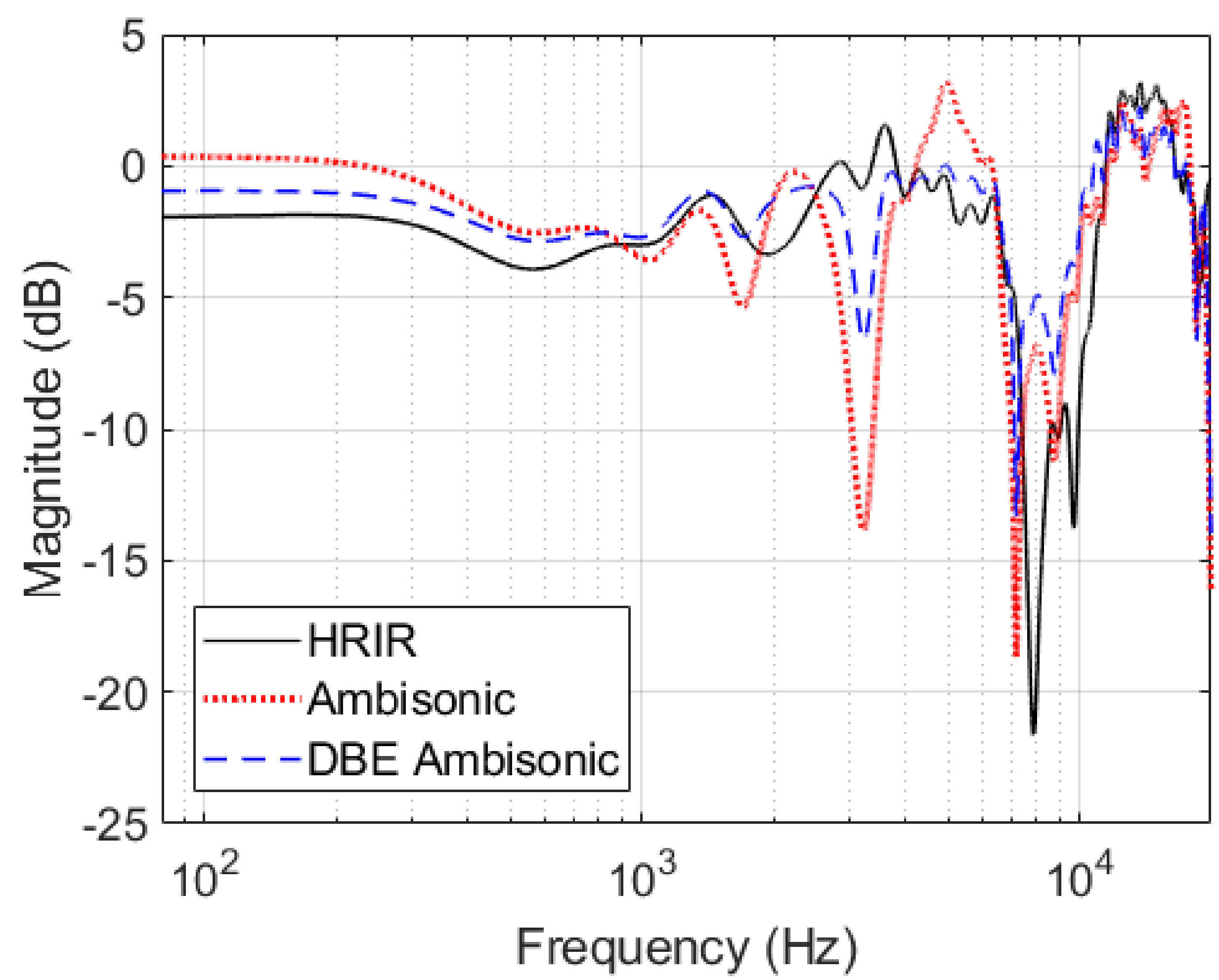


Pink noise **Jazz music**

Ambisonic

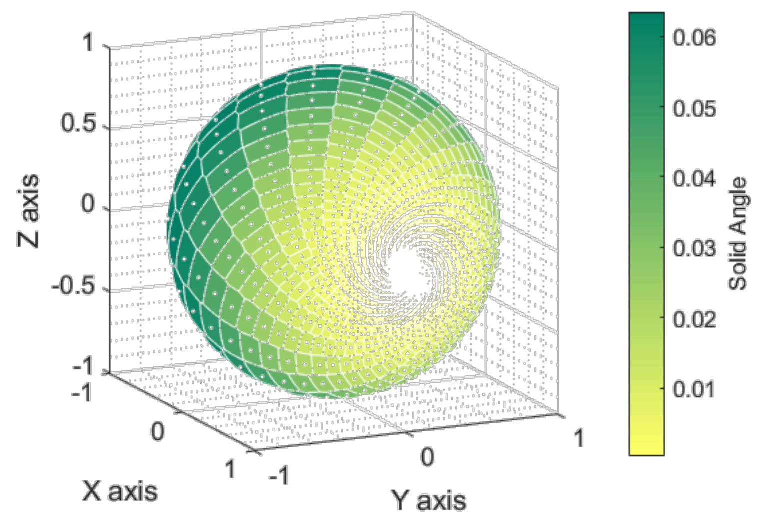
DBE Ambisonic

HRTF convolution

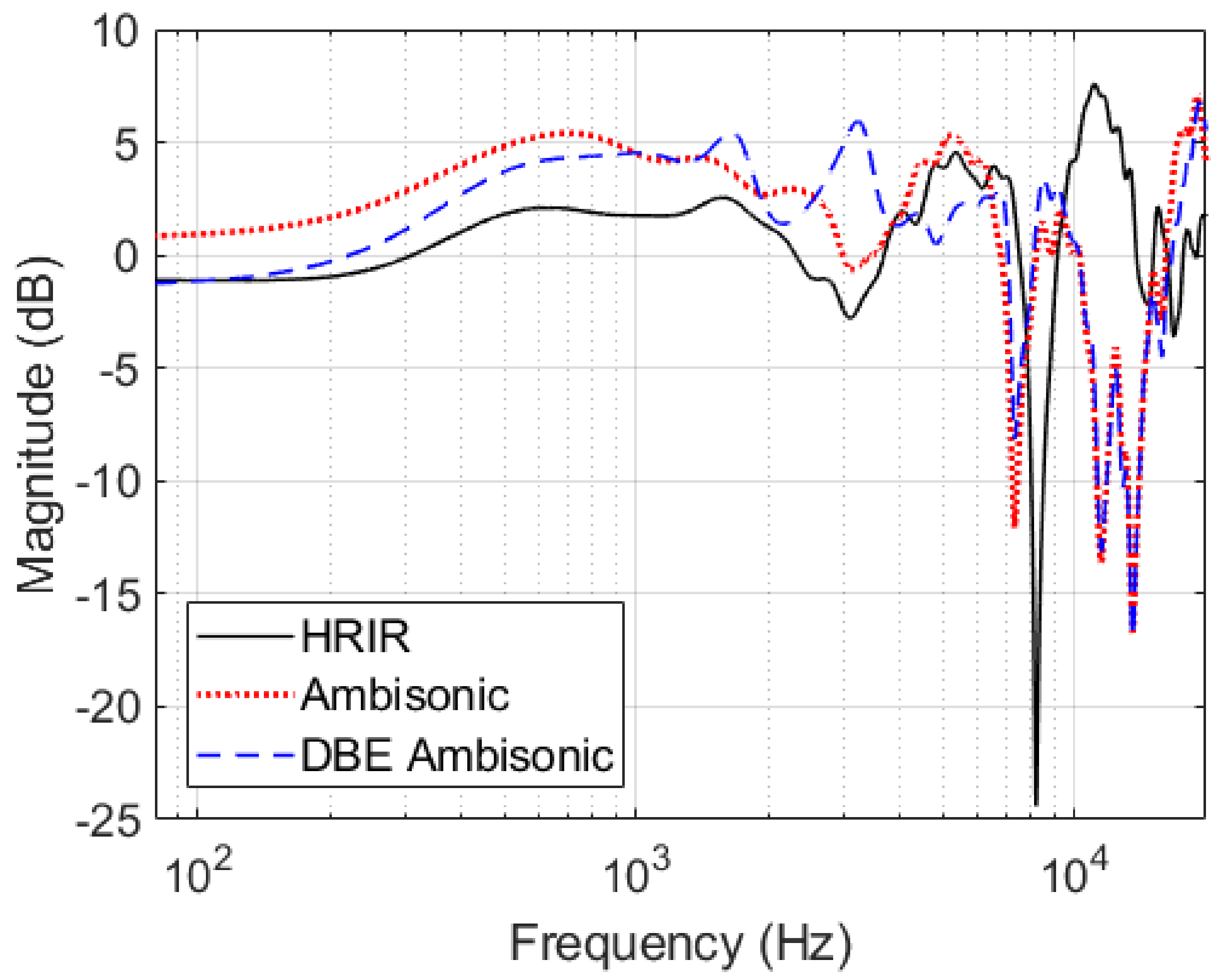


Example: Direction Biased Equalisation

- Bias factor *K* = **3.4** (frontal bias direction)
- 90 azimuth, 0 elevation --- Equalised version may be *worse*!

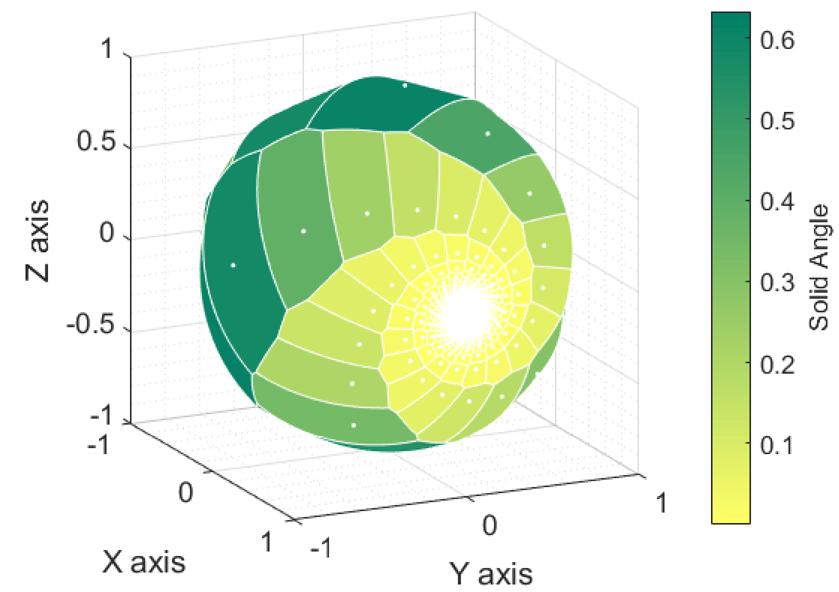


Pink noise		Jazz music
	Ambisonic	
	DBE Ambisonic	
	HRTF convolution	



Example: Direction Biased Equalisation (fun)

- Bias factor K = **20** (aggressive frontal bias!)
- 0 azimuth, 0 elevation --- Equalised version should be *better*!

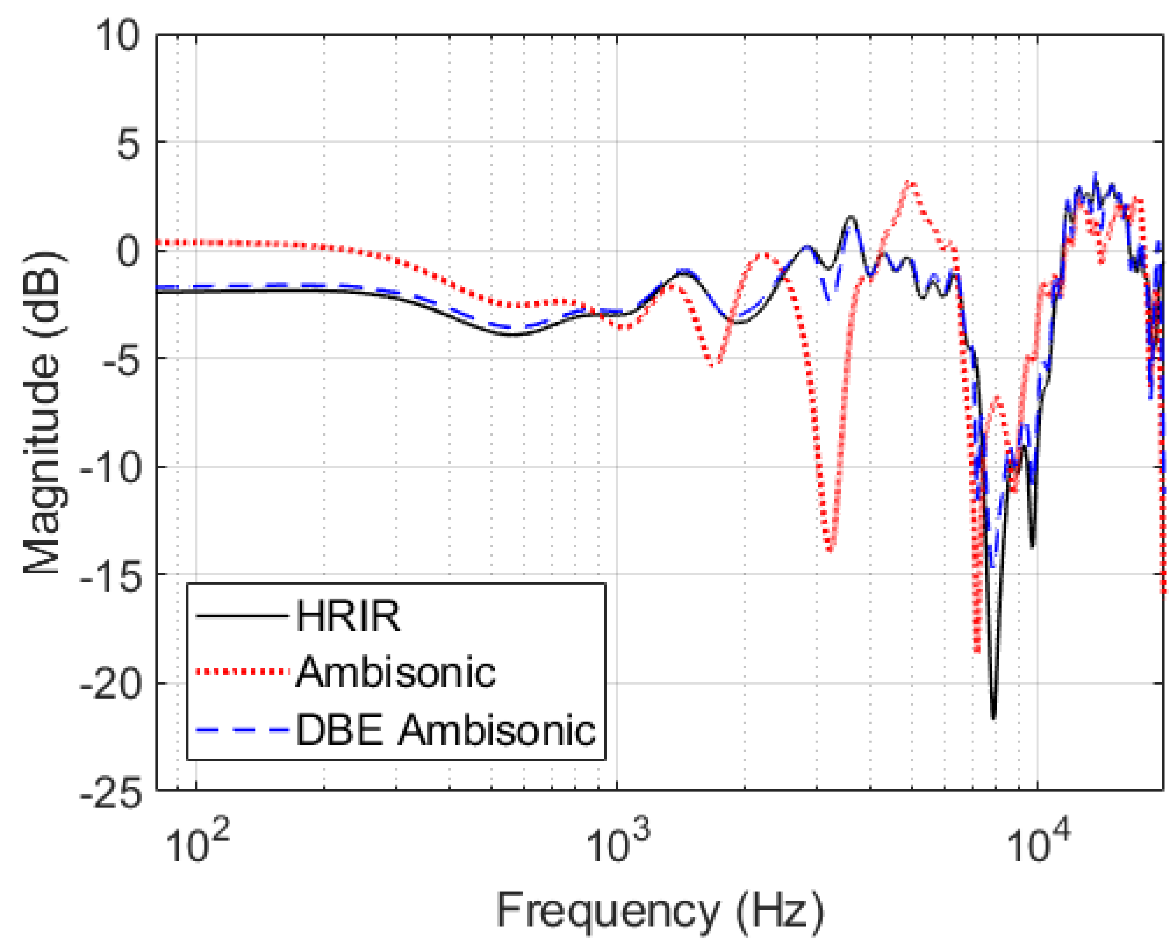


Pink noise **Jazz music**

Ambisonic

DBE Ambisonic

HRTF convolution



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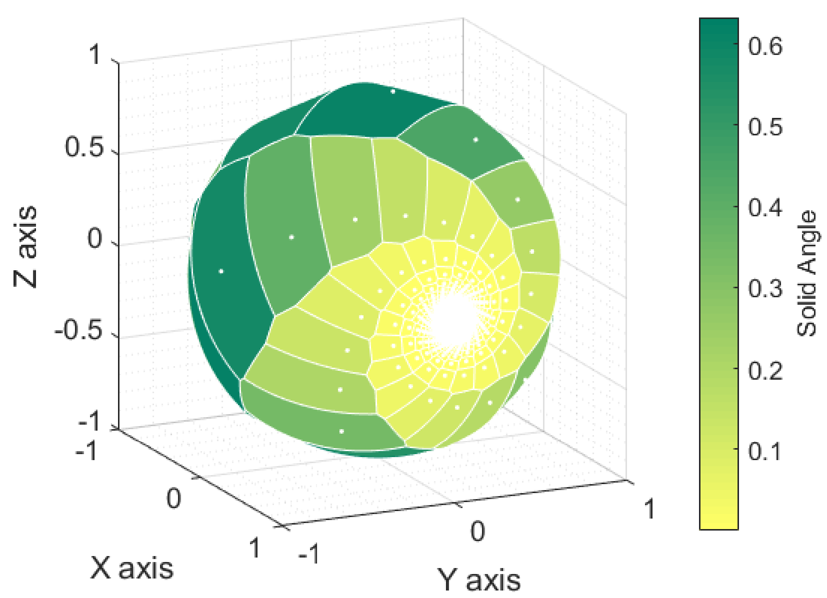
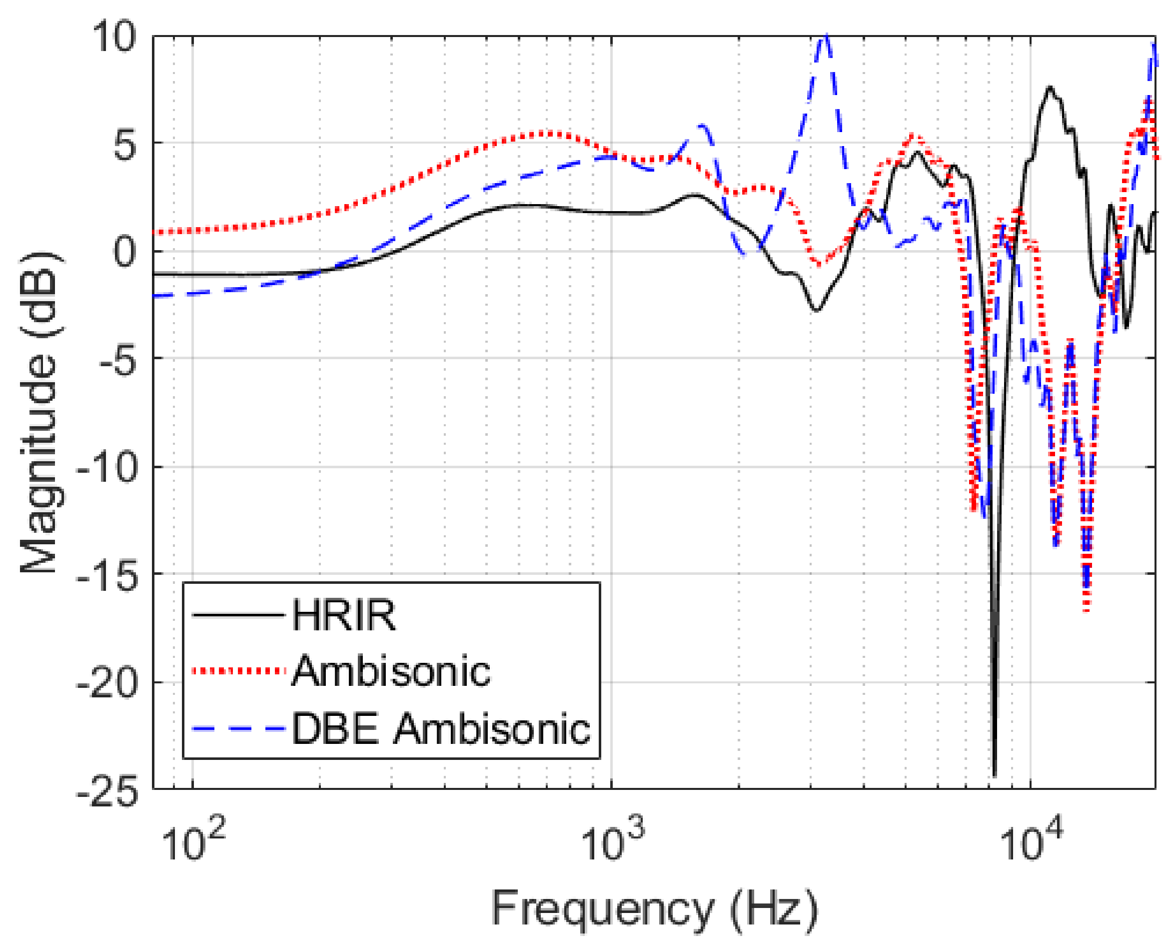


Pink noise | **Jazz music**

Ambisonic

DBE Ambisonic

HRTF convolution



Conclusions

- Introducing direction biased equalisation
  - Biasing of quadrature in 'diffuse-field' calculation
  - Additional frontal-bias HRTF equalisation
- Improves spectral reproduction in frontal plane
- To the detriment of lateral directions (as expected)
- A question remains as to the optimal bias factor
- Conference paper to be presented at AES Audio for Virtual and Augmented Reality (AVAR), August 2018, Redmond USA

Thanks for listening! Any questions?

- If you want to hear the sounds again with headphones come say hi afterwards!
- Please address correspondence to **ttm507@york.ac.uk**
- For more audio research goodness in England, the University of York is holding an AES conference in March 2019!