Simulating & Evaluating HOA Planar Arrays

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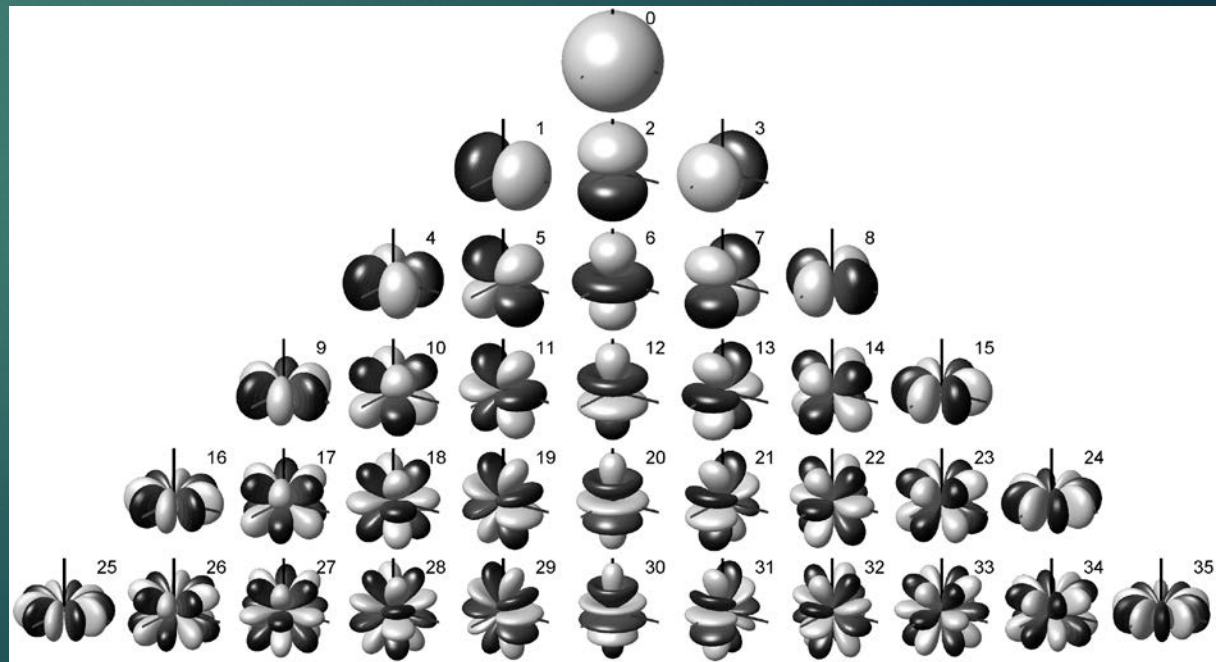
What is HOA?

- Higher Order Ambisonics
- Based on spherical decomposition of a sound field
- Driving function for surround speaker arrays
- Array agnostic
- Flexible



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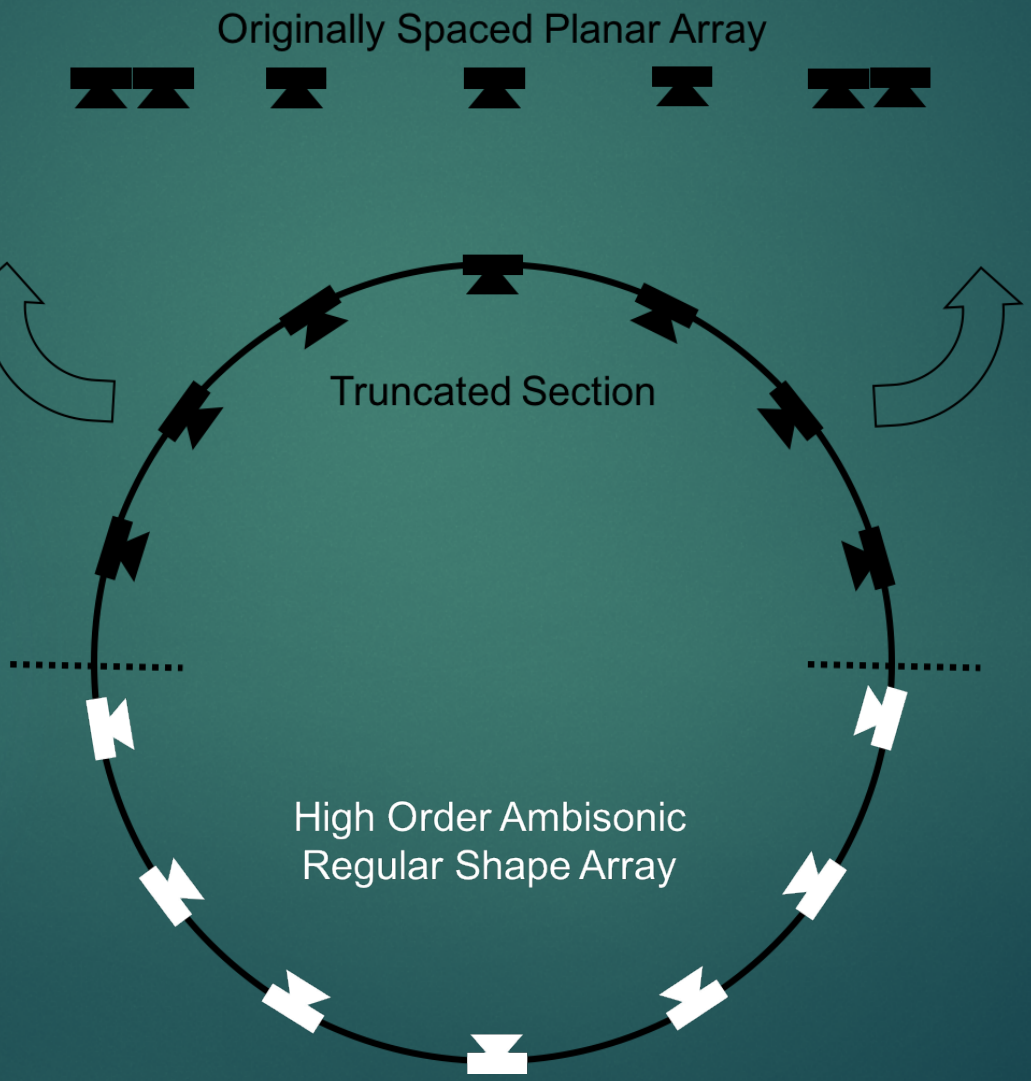
Why Planar?

- From now this array configuration will be referred to as originally spaced as it keeps the x-axis coordinates as if still a circular array



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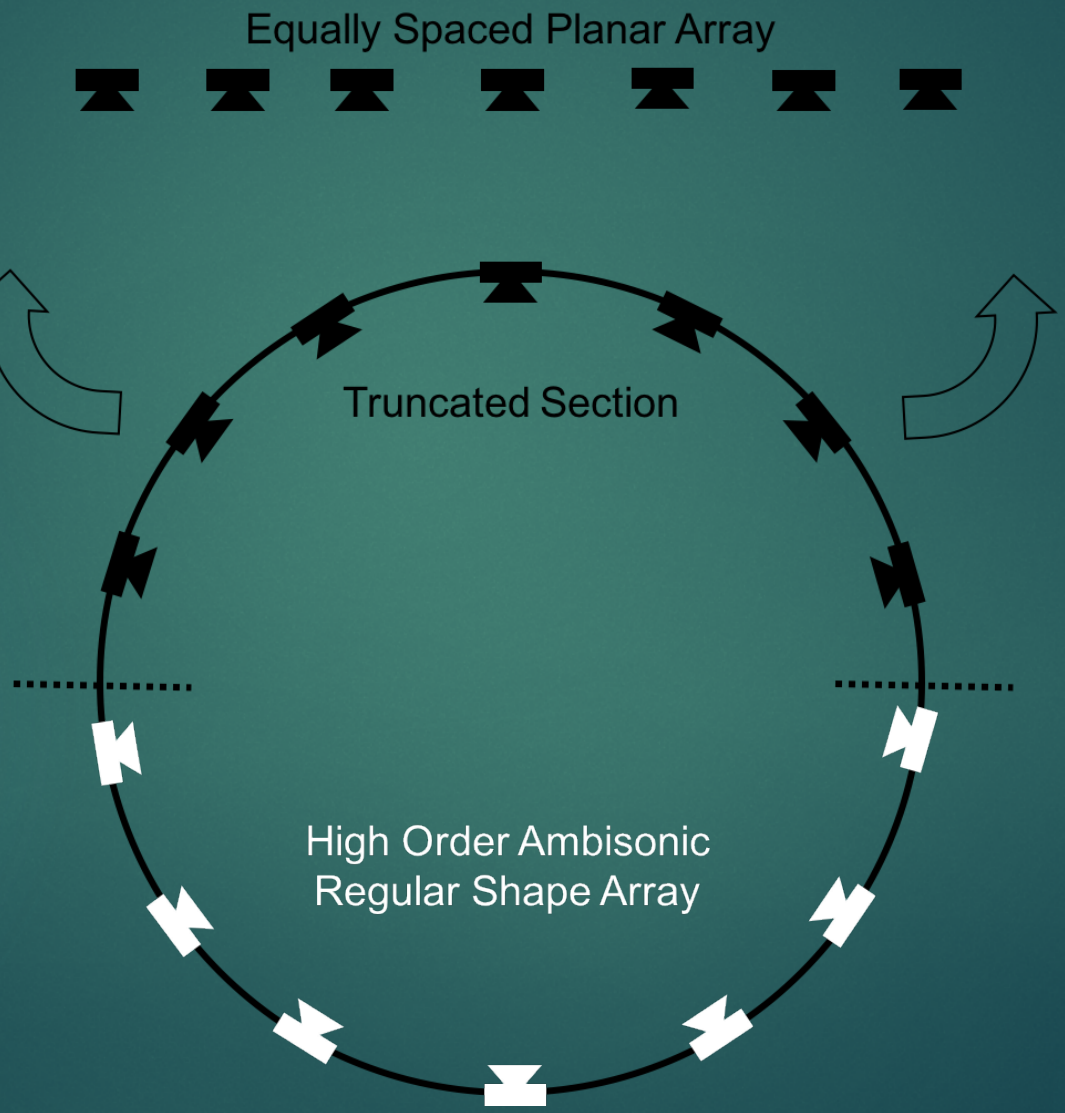
- This version will be referred to as equally spaced as they have been spaced equidistant in the 4m array



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Simulation Aims

- Matlab script simulating 1st, 3rd and 5th order ambisonics
- Evaluate Pressure, Extended Energy Vector (EEV) and localisation error
- HRTF Inter Aural Level Difference (ILD) analysis
  - Shows ILD cues at each synthesised virtual source position compared to a real source in same position
- HRTF Inter Aural Time Difference (ITD) analysis
  - Shows ITD cues at each synthesised virtual source position compared to a real source in same position

Simulation Process

- First calculate number of speakers and their position
- Encode a virtual source at position (*x*,*y*)
- Encode speaker (secondary source positions)
- Use psuedo inverse method to create ambisonic decoder
- Use these gain coefficients in plotting the pressure wave
- Evaluate simulation area with EEV and Localisation Error
- HRTF Analysis

What is the Extended Energy Vector?

- EEE developed by Peter Stitt[1]
- Method of predicting localisation
- EEE improves prediction at off centre listening positions
- Perceptual weight (the extended bit) is assigned to each loudspeaker gain in relation to relative arrival times, levels and direction of the loudspeaker signals

$$\mathbf{E} = \frac{\Sigma_{i=1}^{N} |w_i(\alpha) G_i / r_i|^2 \mathbf{u}_i}{\Sigma_{i=1}^{N} |w_i(\alpha) G_i / r_i|^2} \quad (1)$$

where $w_i(\alpha)$ is the precedence effect weighting, G_i is the loudspeaker gain, r_i is the loudspeaker distance from the listening position, N is the total number of loudspeakers and $\mathbf{u}_i$ is the unit vector in the direction of the i-th loudspeaker.

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[1] Extended Energy Vector Prediction of Ambisonically Reproduced Image Direction at Off-Centre Listening Positions, Peter Stitt, Stéphanie Beret, and Maarten Van Walstijn, AES Journal 64, No.5, May 2016

Psychoacoustic Optimisation

- MaxRe and In-Phase are psychoacoustic optimisation methods
- Both aim to improve off centre listening and general reproduction of frequencies above 500Hz
- MaxRe optimises the energy vector to improve ILD reproduction at HF whilst maximising the energy in the source direction
- In-phase decoding eliminates all negative gains, meaning no out of phase components are emitted from the speakers

2D max-rE:

$$rE = cos(\pi/2N + 2)$$
$$g_n = cos(n\pi/(2N + 2))$$

2D in-phase:

$$g_n = \frac{(N!)^2}{(N+n)!\times(N-n)!}$$

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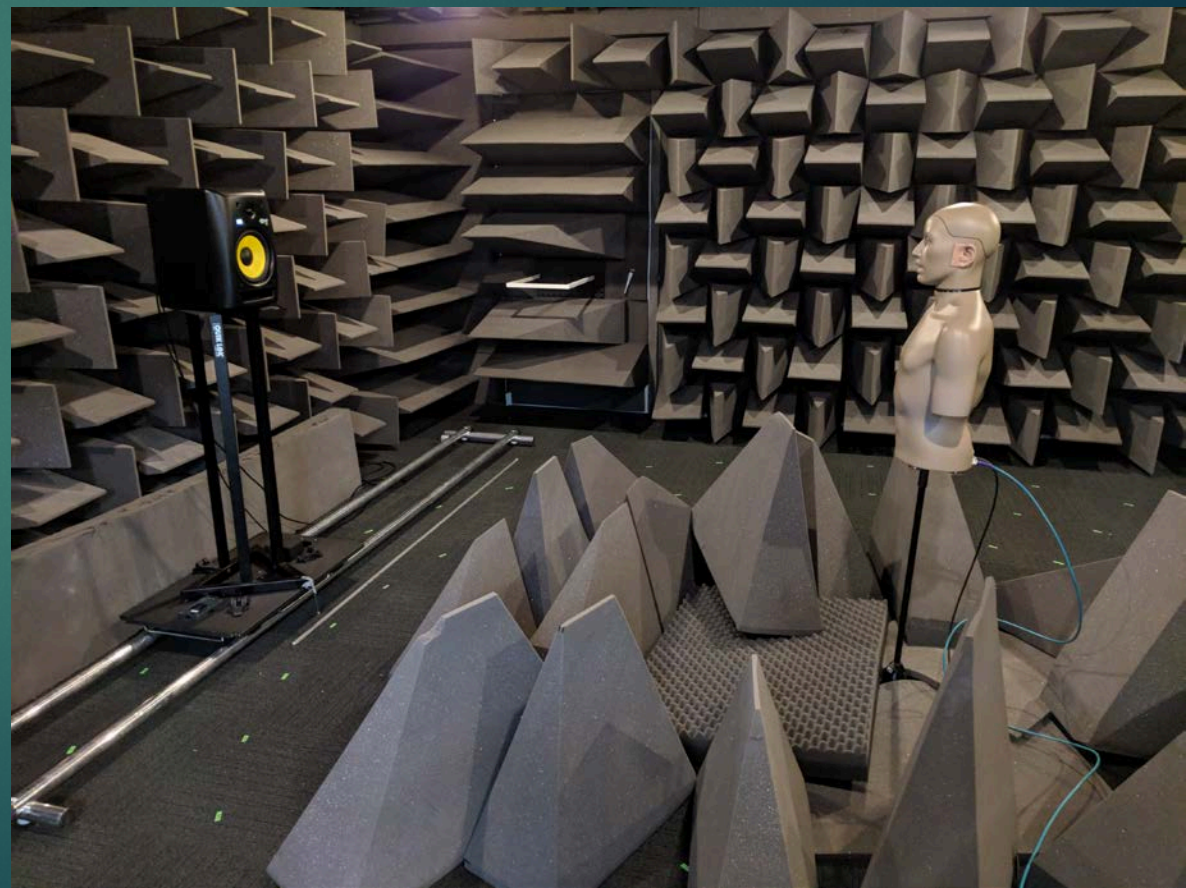
HRTF Capture

- Assuming symmetry of 4m array – so recording 0-2m
- Camera slider to ensure movement in only one dimension
- KRK ROKIT 8 Source
- Audomatica CLIO FW 10
- KEMAR Head and Torso Simulator
- Record one IR (each ear channel) then move speaker to next position



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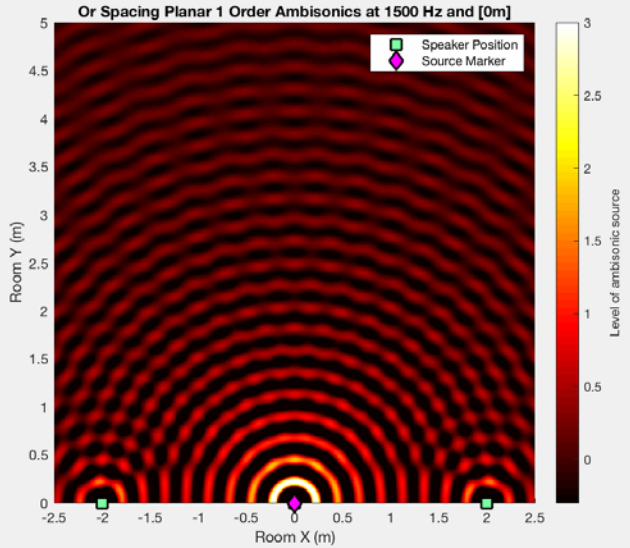
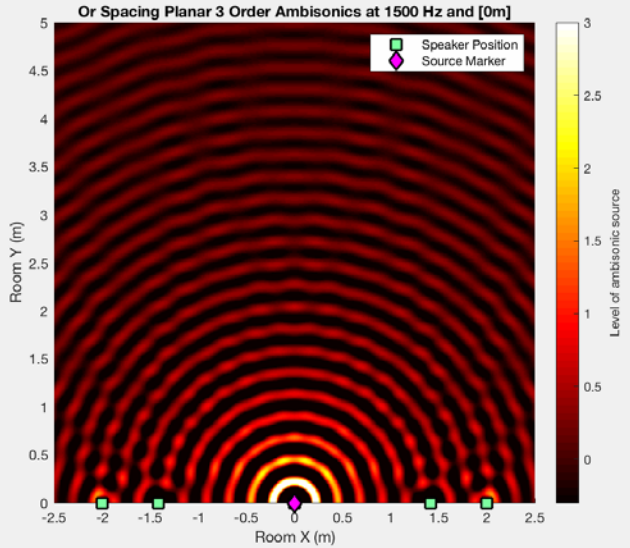
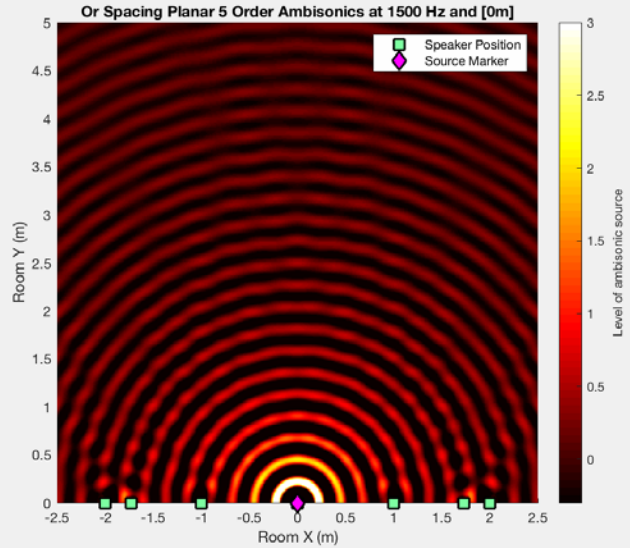
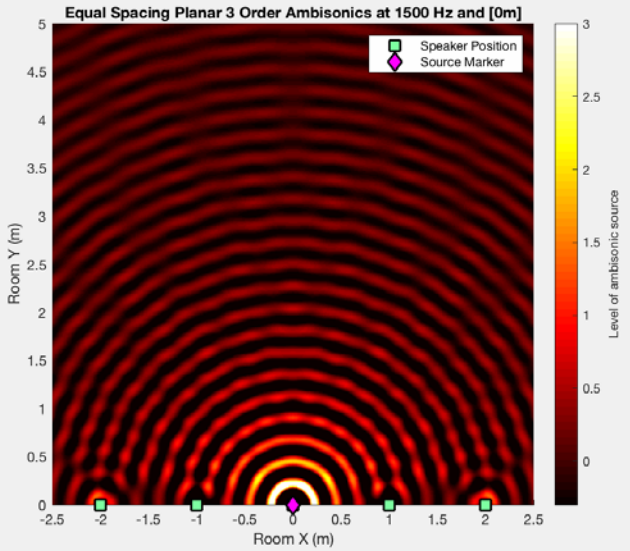
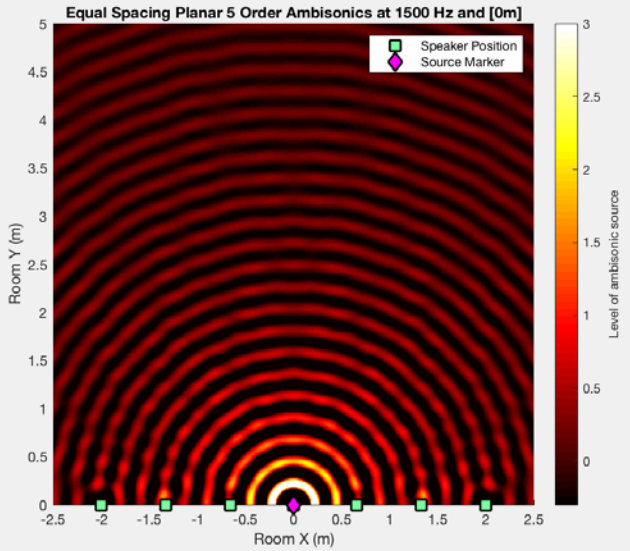
Original Spacing vs Equal Spacing











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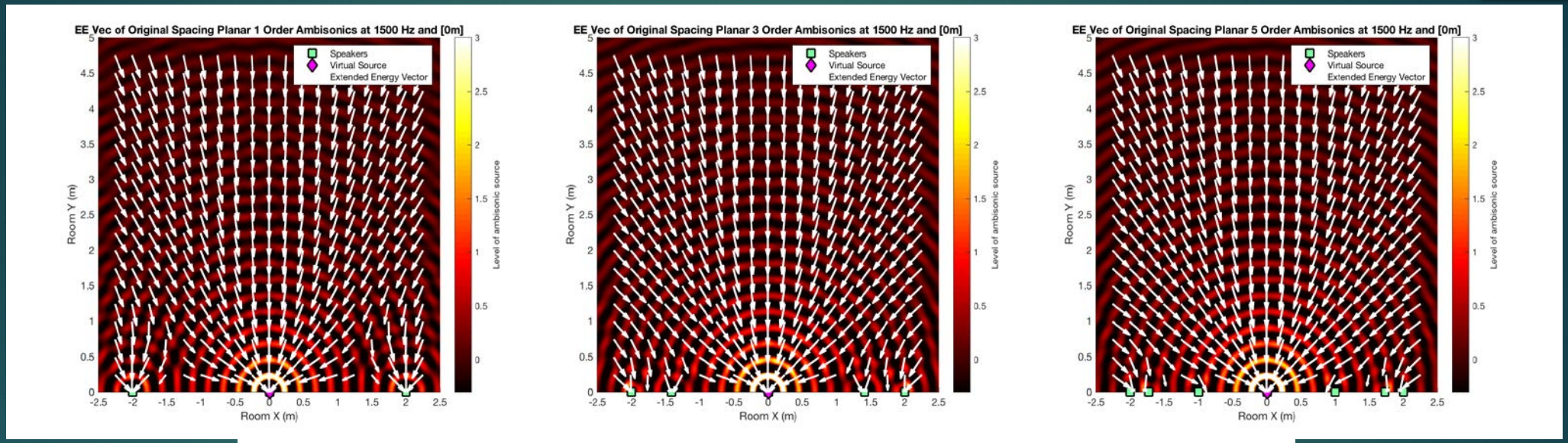
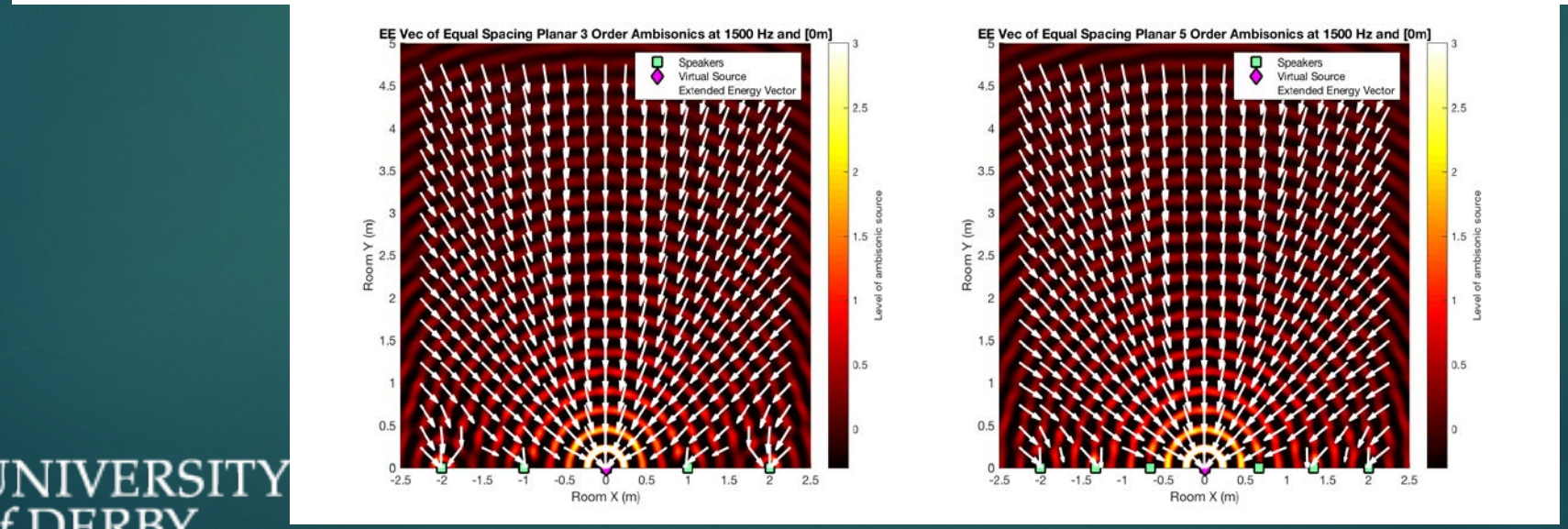
Original Spacing vs Equal Spacing Cont.





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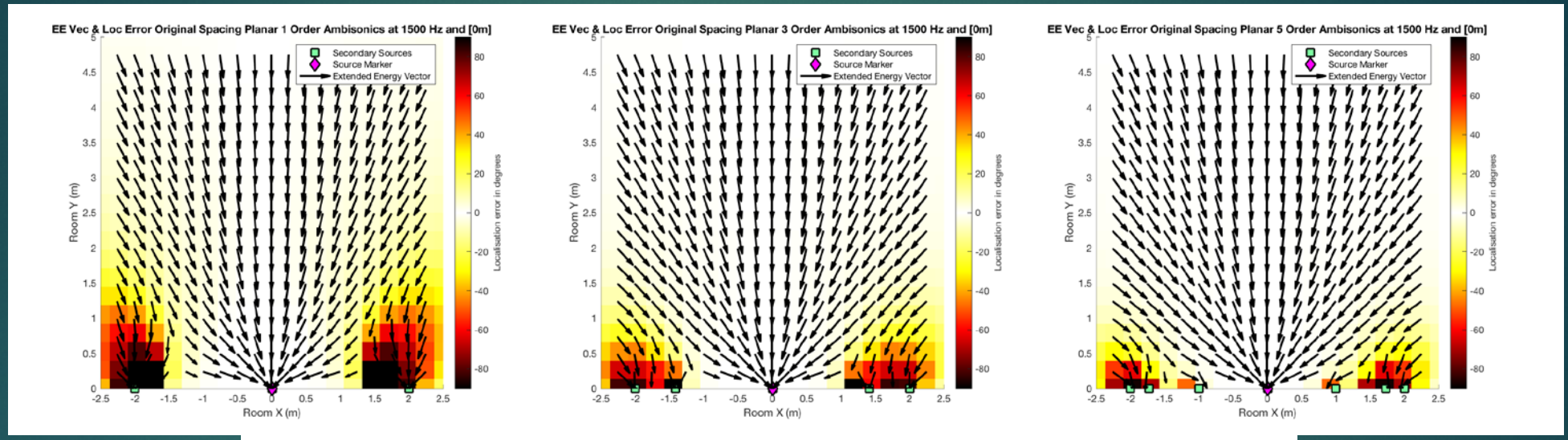
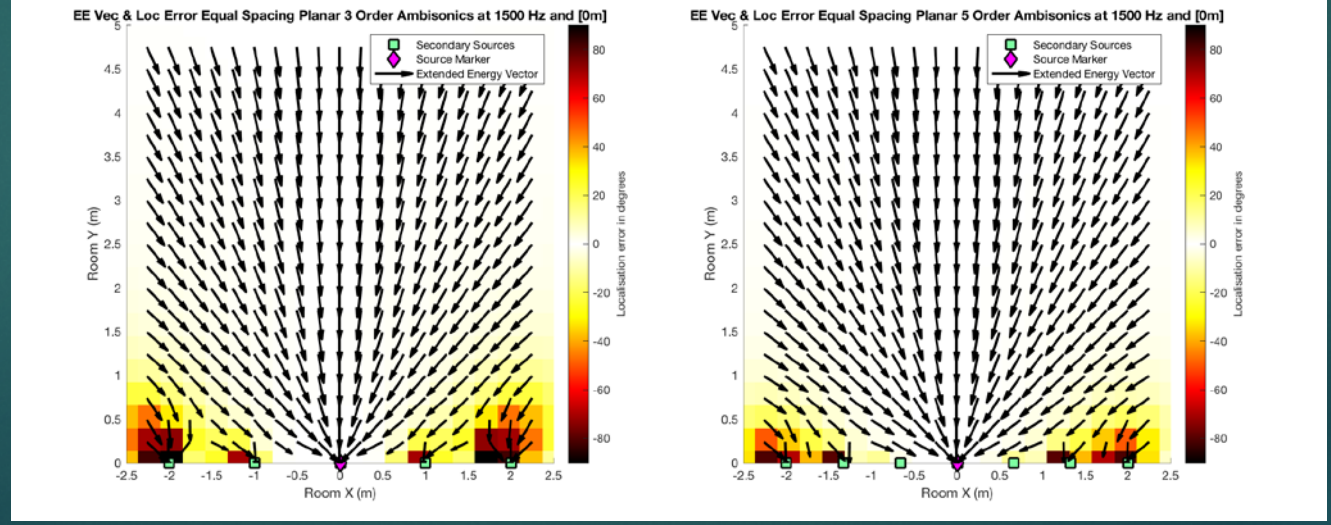
Extended Energy Vector & Localisation Error

Equal spacing performs better, less localisation error at the edges of the array





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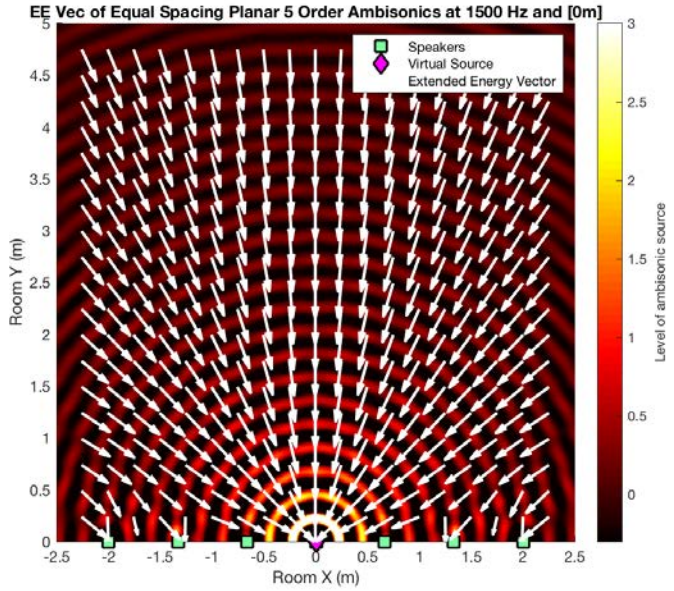
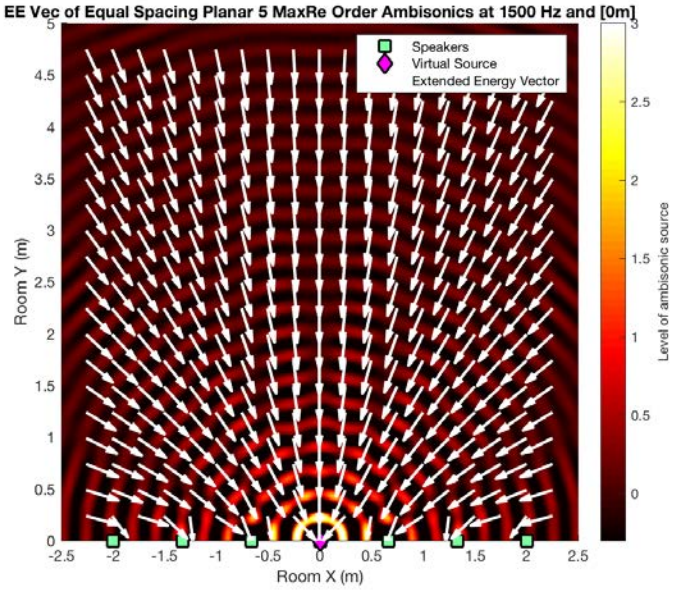
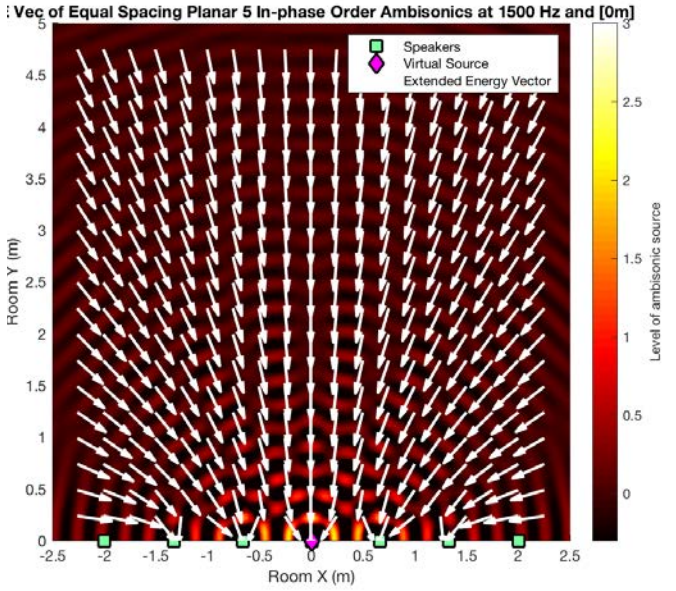
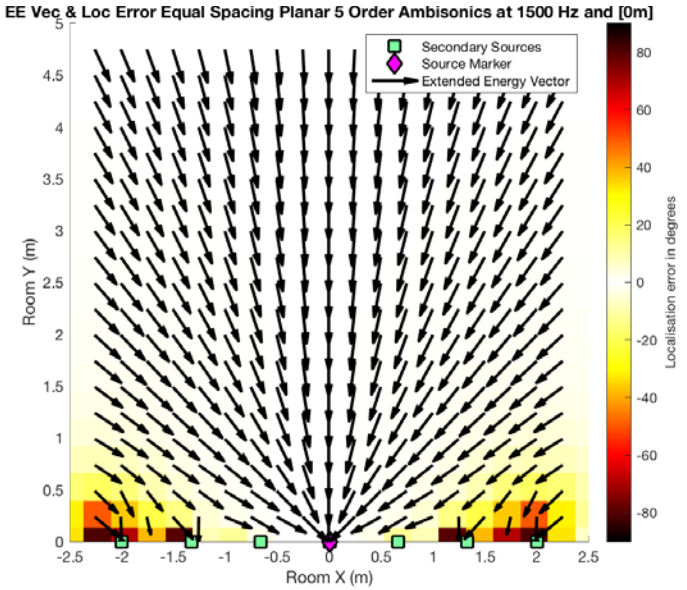
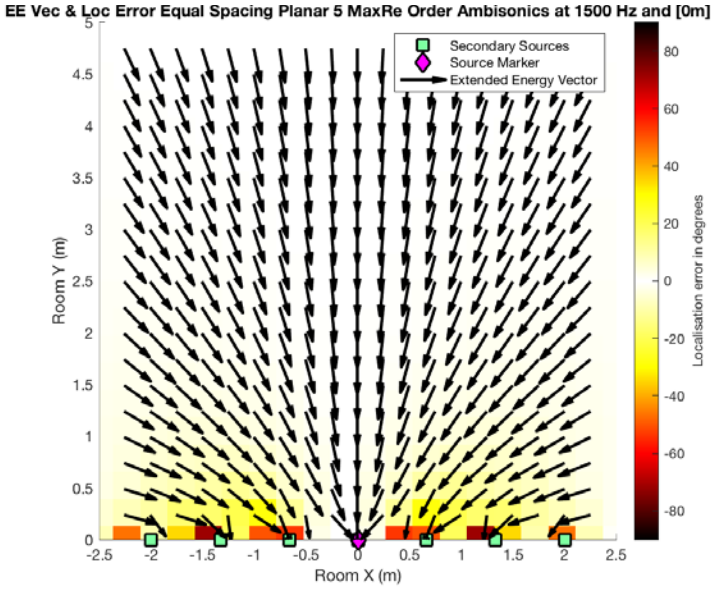
Basic Decoding/MaxRE/In-phase at 5th Order

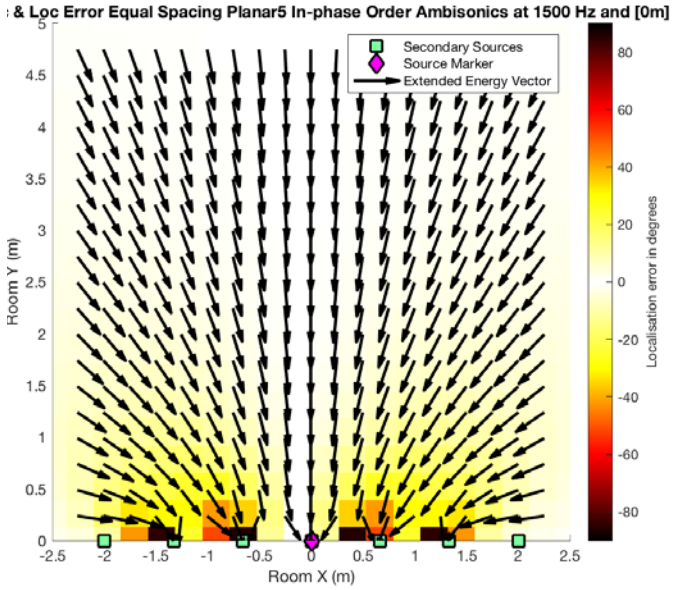




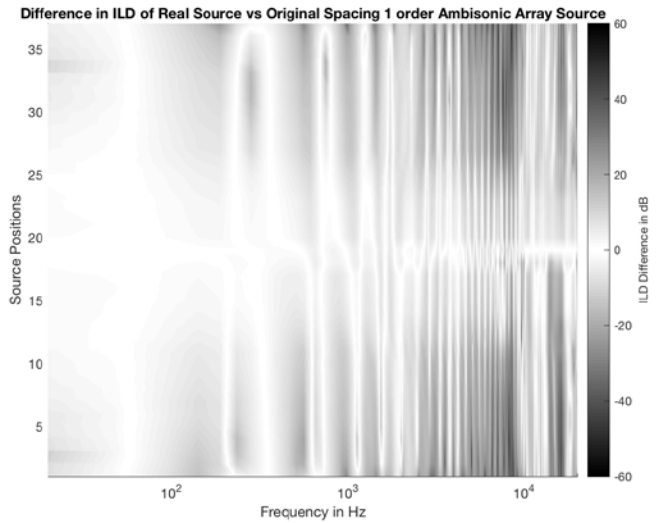


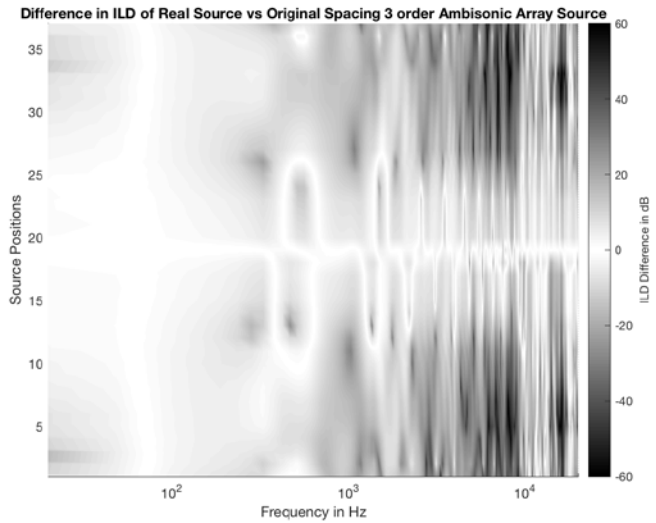


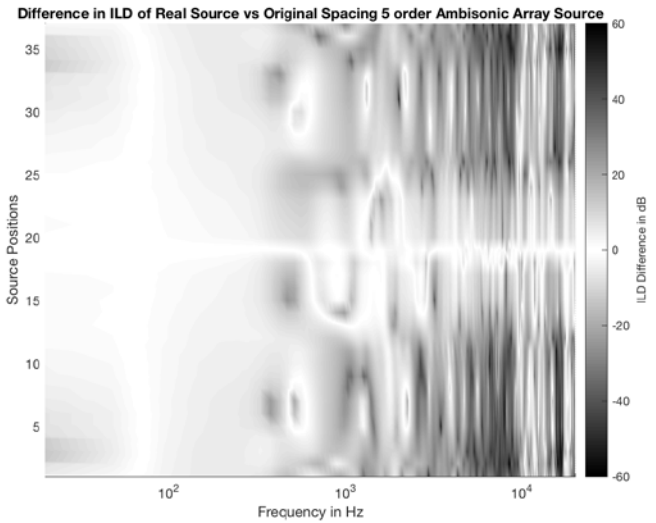


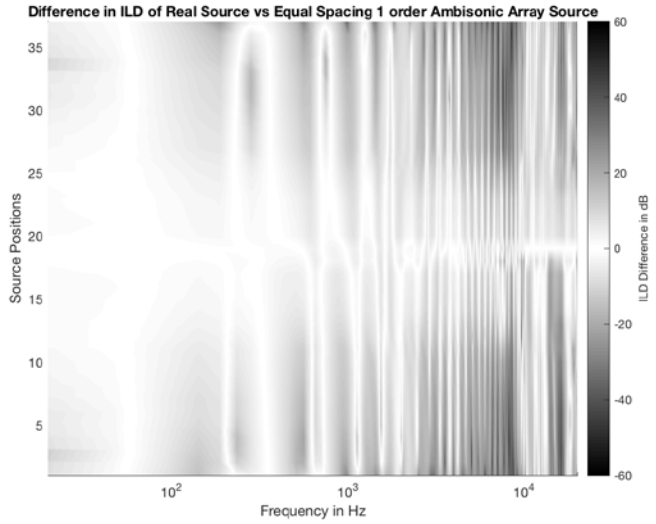


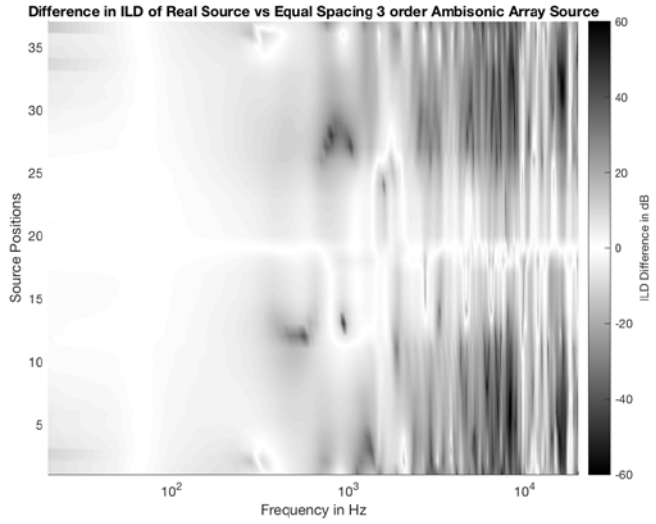
HRTF Analysis - Original VS Equally Spaced

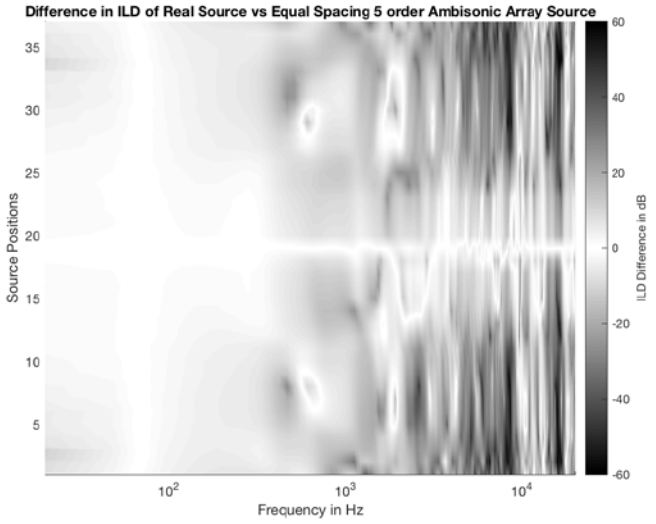












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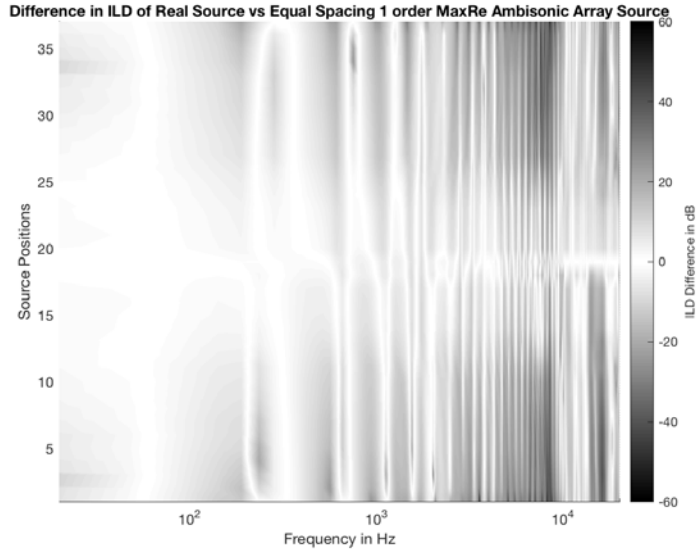
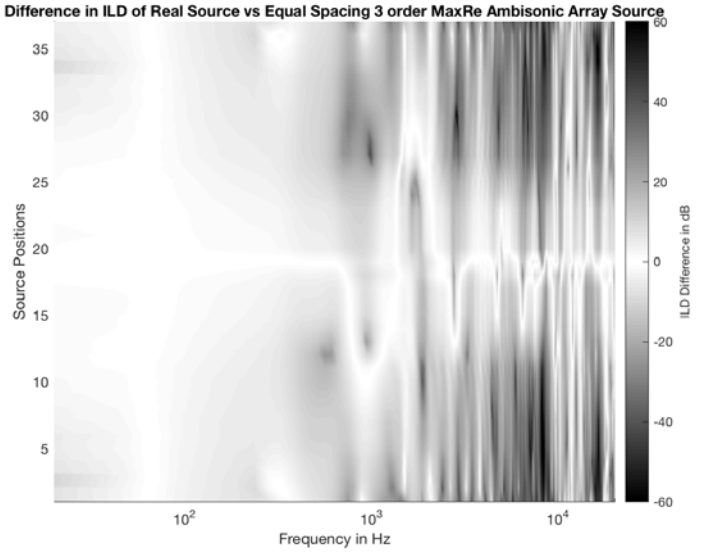
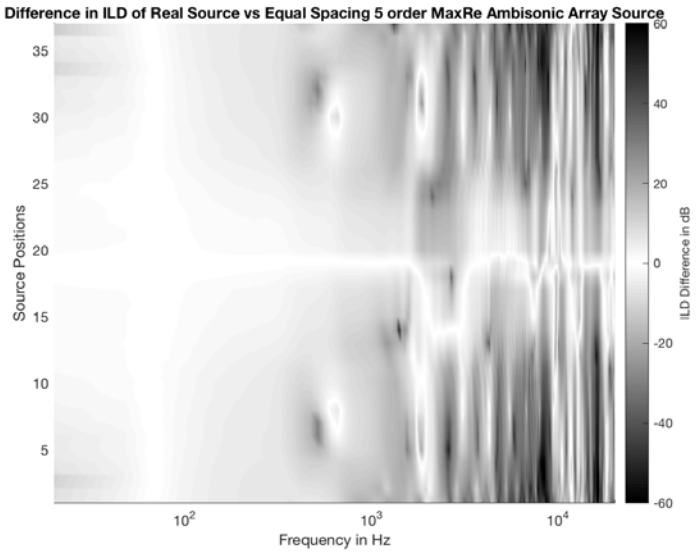
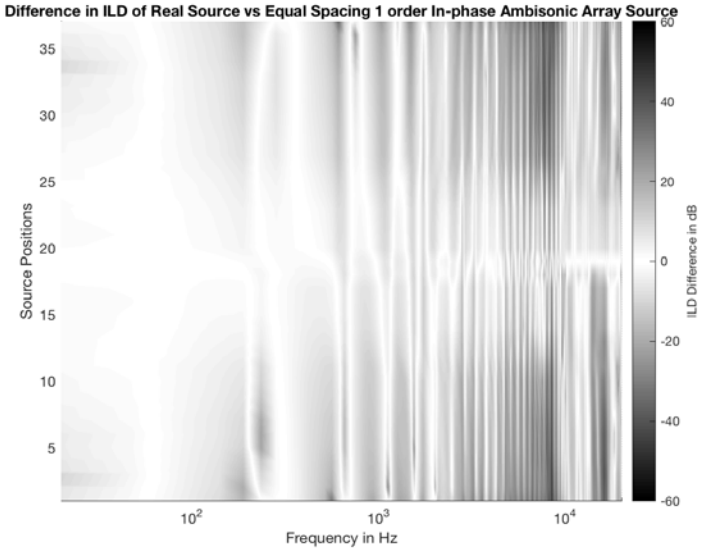
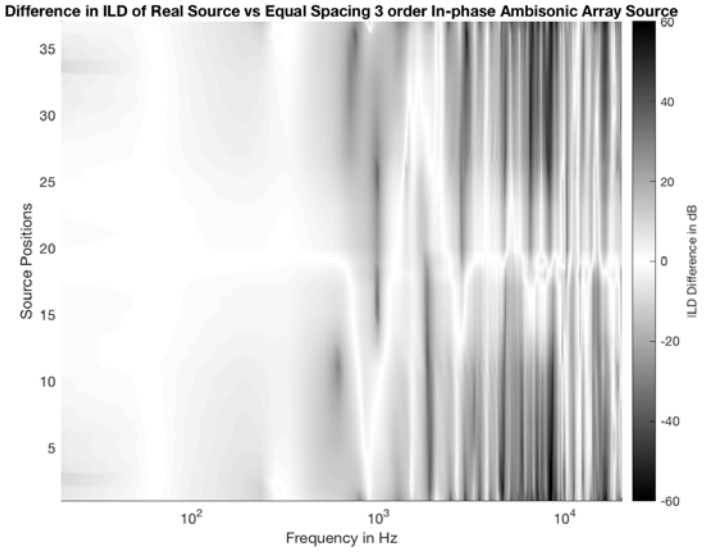
MaxRe vs In-phase

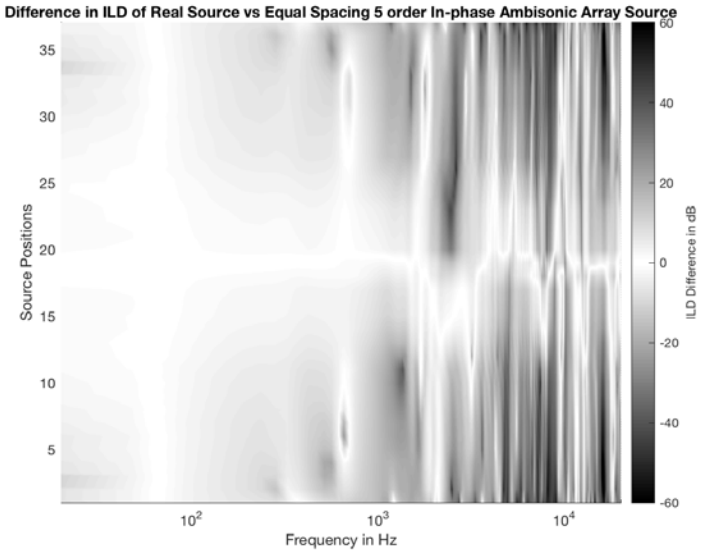












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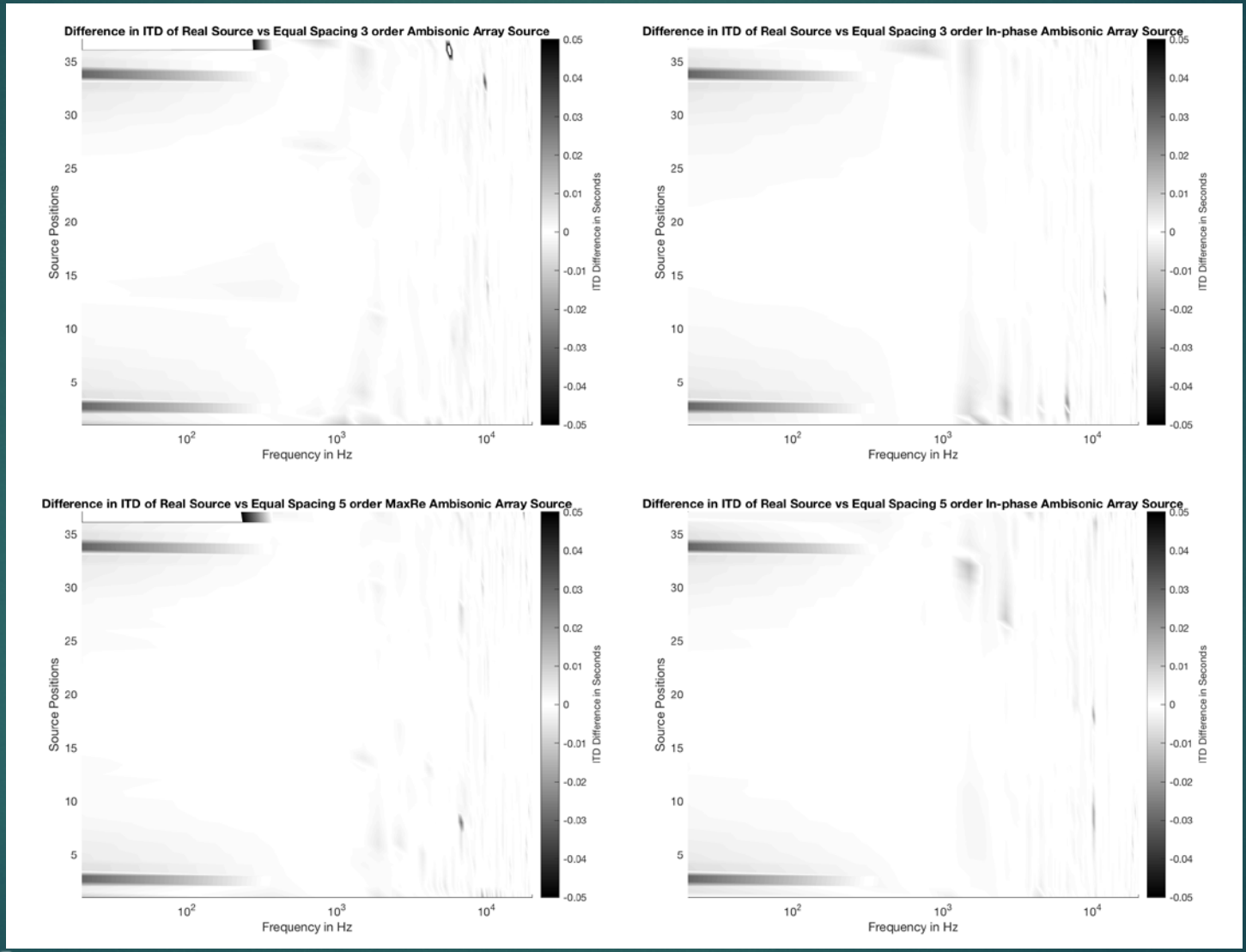
ITD Equal Spacing MaxRe vs In-phase



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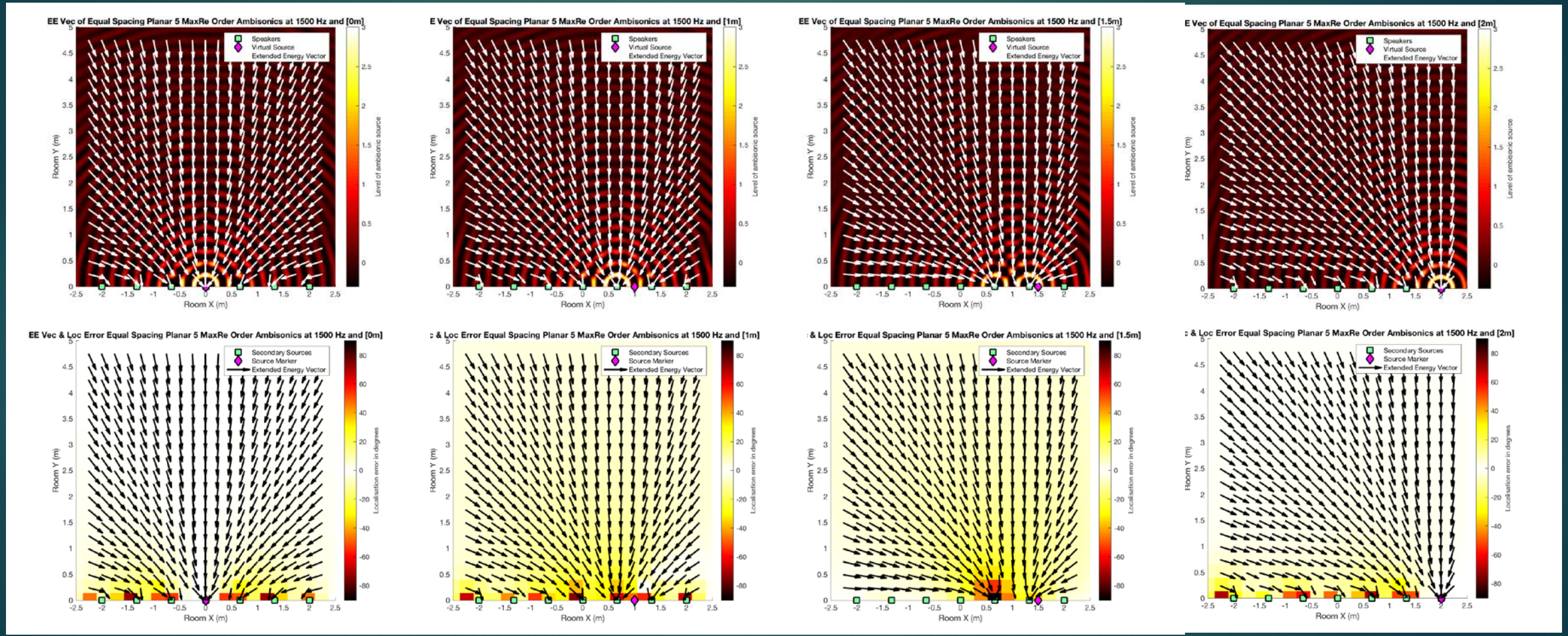
Off centre source?



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Summary

- Equally spaced performs better than originally spaced
- Good localisation cues up to 1500Hz, need denser arrays to increase frequency at which localisation cues are reproduced accurately
- Higher the order the better the reproduction of virtual sources
- MaxRE best compromise for psychoacoustic optimisation, not In-phase which creates smearing of source (which ambisonic equivalent panning developed by Neukom and Schacher uses)
- ITD not a useful metric at this frequency range

Further Work

- Create a percentage error metric to allow quantitative comparison instead of visual
- Subjective listening tests
- Bigger, faster and denser measurement of HRTF's for higher order planar arrays – arduino controlled motor for the camera slider (and publically release)
- Distributed Kemar HRTF receiver positions in order to analyse off-centre performance
- Model cardioid source, currently assumed omnidirectional
- Compare planar HOA to WFS
- Investigate beamforming of sources to create surround reflections
- Distance encoding implementation

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