Reducing Modal Error Propagation Through Correcting Mismatched Microphone Gains using RAPID

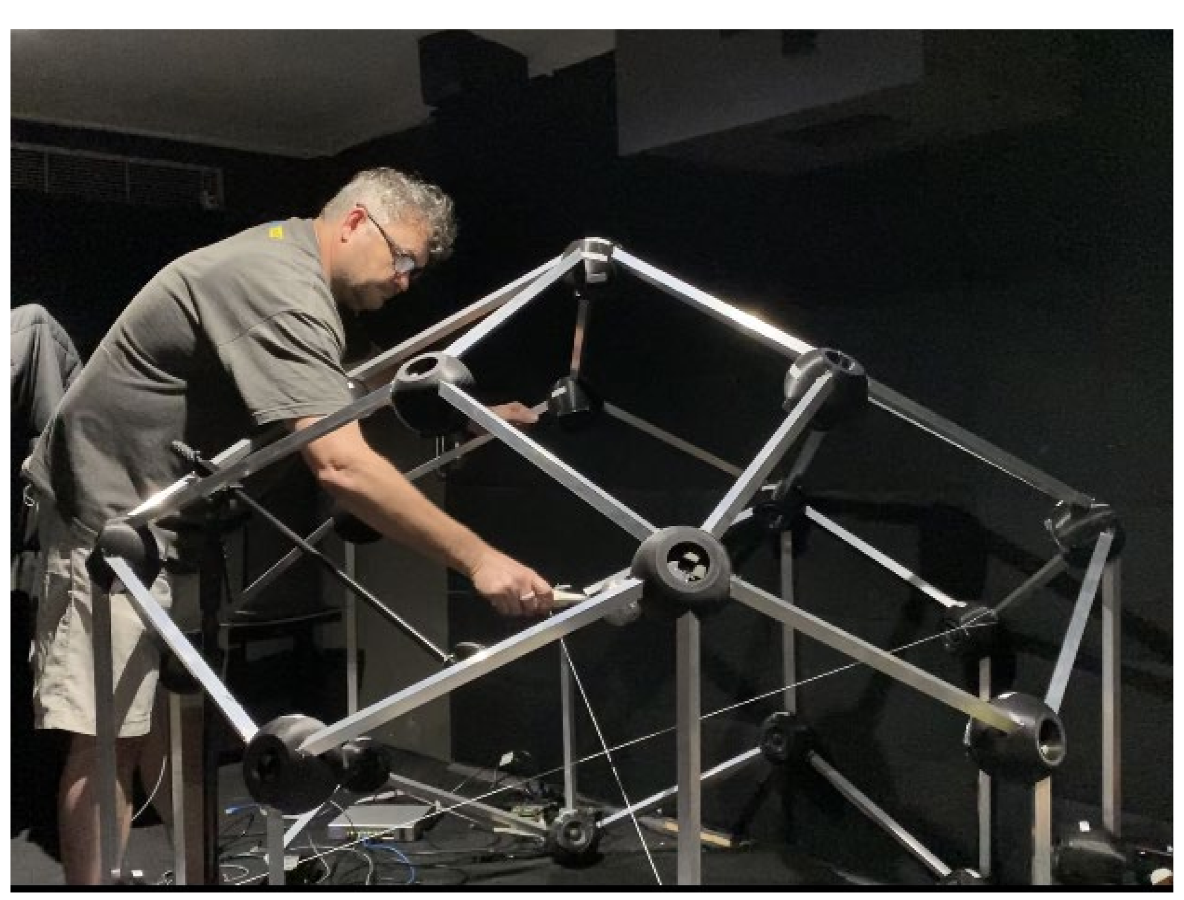
Noman Akbar*, Glenn Dickins*, Mark R.P. Thomas†, Prasanga Samarasinghe*, Thushara Abhayapala*
*Research School of Electrical Energy and Materials Engineering, The Australian National University
†Dolby Laboratories USA

Abstract

- Spherical microphone arrays are commonly used for capturing higher order soundfields
- Existing spherical harmonic -based algorithms assume that the conversion from microphone to modes is perfect
- The error propagation from microphones to modes is not well-understood in literature
- Error propagation may limit the performance of any spherical harmonic -based algorithms
- This work investigates modal error propagation and reduce it using a simple and straightforward RAndom PerturbatIons for Diffuse -field (RAPID) calibration.

The Diffuse Field Calibration using RAPID

- RAndom PerturbatIons for Diffuse -field (RAPID), is a novel method for diffuse field calibration
- Diffuse field response of a microphone array can be obtained in an untreated room by random perturbation and rotation of an array while recording a test signal
- Requires minimal hardware setup and is shown to match the spatial correlation characteristics of a diffuse field response
- A video presentation describing RAPID is available at https://vimeo.com/426669671 . Furthermore, a demo of RAPID is available at https://vimeo.com/426668134 .



Error Propagation in Modes Caused by Mismatched Microphones Gains

- Consider a spherical microphone array of radius r capable of capturing an order N soundfield , the sound pressure S at x is represented as

$$S\left(\mathbf{x},\frac{w}{c}\right)=\sum_{n=0}^{N}\sum_{m=-n}^{n}\alpha_{nm}\left(\frac{w}{c}\right)b_n\left(\frac{w}{c}r\right)Y_{nm}(\theta,\phi)$$

- Sampling in D directions, a matrix of spherical harmonic functions up to order N is written as

$$\mathbf{Y}_D(\Omega)=[Y_N(\Omega_1),\ldots,Y_N(\Omega_D)]^T$$

- A suitable encoding matrix E satisfies the weighted least-square criteria

$$\arg\min_{\mathbf{E}}\|\mathbf{E}\mathbf{H}_D-\mathbf{Y}_D^T\|_F^2.$$

- A regularized solution is obtained as

$$\mathbf{E}=\mathbf{Y}_D^T\mathbf{W}_D\mathbf{H}_D^H\left(\mathbf{H}_D\mathbf{W}_D\mathbf{H}_D^H+\lambda\mathbf{I}_S\right)^{-1}$$

- Let K be a diagonal matrix of arbitrary microphone gains. This produces perturbed transfer functions

$$\widehat{\mathbf{H}}_D=\mathbf{K}\mathbf{H}_D$$

- From the equations above, ignoring the regularization term, we obtain

$$\mathbf{E}\widehat{\mathbf{H}}_D=\mathbf{Y}_D^T\mathbf{W}_D\mathbf{H}_D^H\left(\mathbf{H}_D\mathbf{W}_D\mathbf{H}_D^H\right)^{\dagger}\mathbf{K}\mathbf{H}_D,$$
$$=\mathbf{Y}_D^T\mathbf{H}_D^{\dagger}\mathbf{K}\mathbf{H}_D,$$

- Assuming that there is no microphone gain mismatch, i.e., $K = I$, we obtain

$$\mathbf{E}\widehat{\mathbf{H}}_D\,\breve{=}\,\mathbf{Y}_D^T$$

- Notably, K is not equal to I yields incorrect basis functions
- Perturbation in just one microphone in the microphone array will result in errors propagation to every mode

Experimental Evaluation of Spherical Microphone Array Directivity Pattern

- The following apparatus was used in the experiments
- A 3D printed two-axis turntable
- A Dickins Audio 1.8 m radius rhombic triacontrahedron loudspeaker array (DAARRT26 1318)
- Reference microphone (DBXRTA-M)
- Eigenmike (SN37)
- All experiments were performed in a well-treated room
- A well-treated environment is not essential for repeatable measurements with RAPID

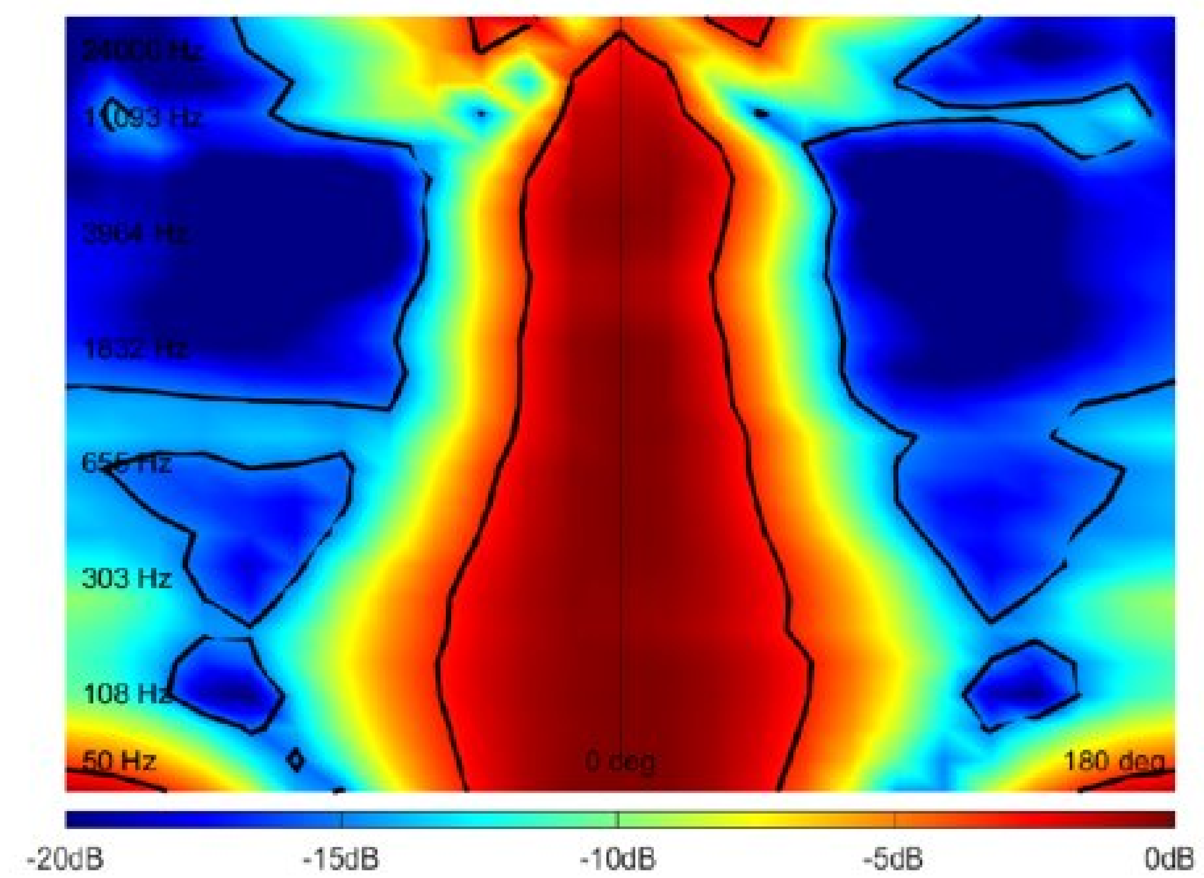


Fig. 1: The directivity pattern of a synthesized supercardioid using the em32 microphone array with factory calibration applied using EigenStudio®.

Experiment 1: Uncalibrated Directivity Pattern of Eigenmike Obtained using EigenStudio

- Deviations are observed especially at lower frequencies. For example, the calibration applied by EigenStudio struggles to reliably capture signals below 300Hz.
- The errors propagates into modes and affect the performance of all modal -based algorithms.
- Notably, the scattering from the turntable can be observed around 11kHz.

Experiment 2: Calibrated Directivity Pattern of Eigenmike Obtained using RAPID

- Fig. 3 shows the magnitude response offsets of the individual microphones of the em32 from the median response after RAPID
- Microphone 28 has approximately 5dB error
- The offset in one microphone was abnormal and not seen on other microphones, but used in this work for demonstrating the value in field testing and calibration
- Fig.4 shows FBFs for the calibration versus frequency
- RAPID provides 6dB improvement in the FBR compared to the uncalibrated case at low frequencies

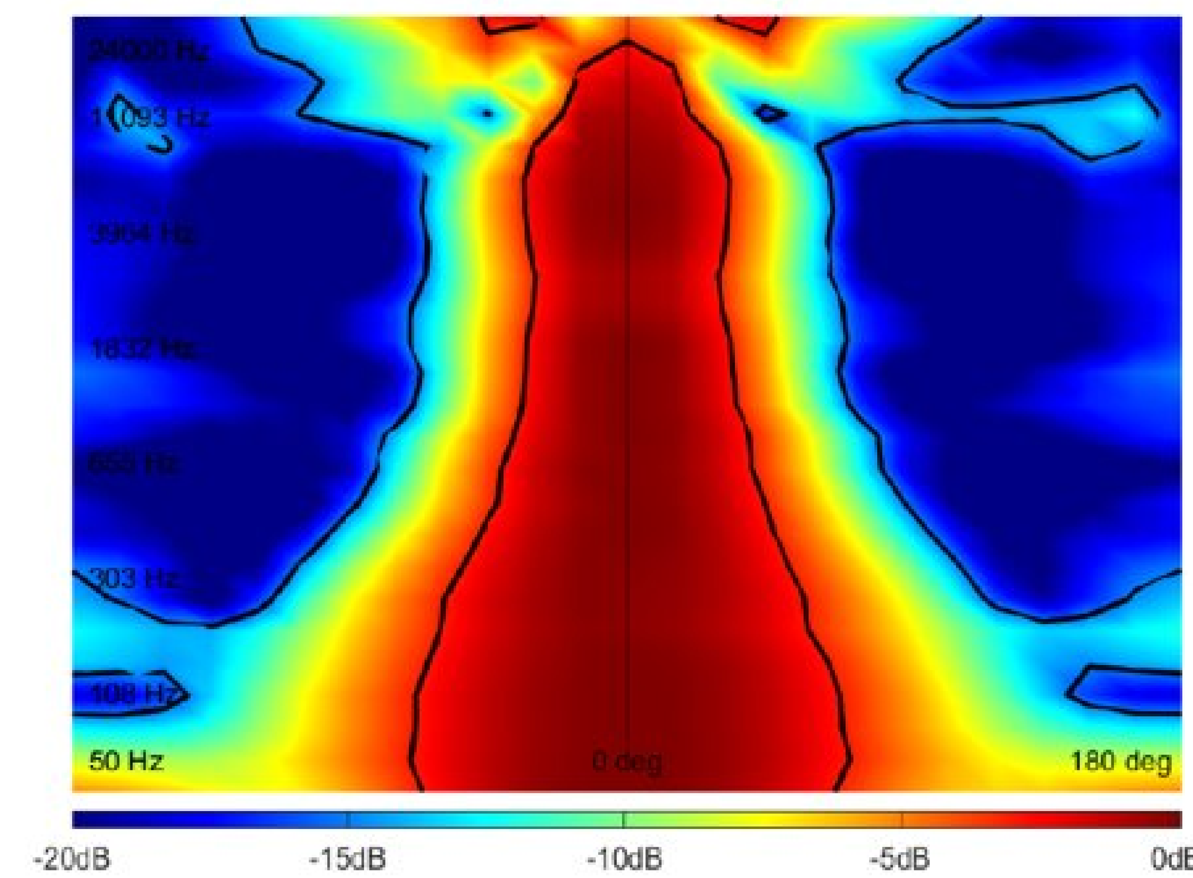


Fig. 2: The directivity pattern of the synthesized supercardioid obtained from the em32 with RAPID calibration. It shows a significant improvement in the response at low frequencies.

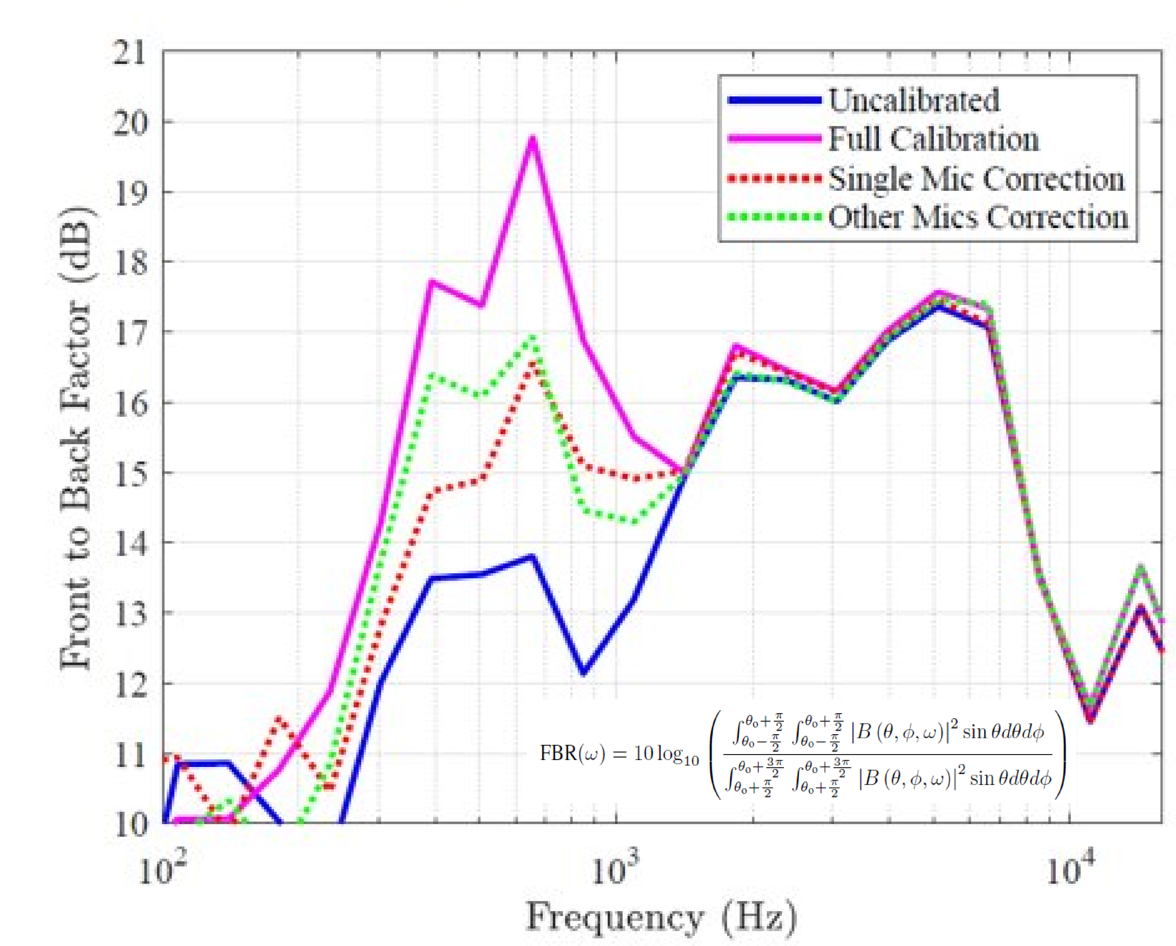


Fig. 4: Front back factors for uncalibrated case and when RAPID calibration is applied. Furthermore, impact of single microphone correction (microphone 28) and correction for all microphones except microphone 28 is also shown.

Conclusions

- Directivity patterns of a synthesized supercardioid were compared using RAPID and factory calibration
- The directivity pattern revealed the limitations of the factory calibration in capturing low frequency content with high fidelity
- Using RAPID for diffuse field calibration extended the measurement capability of to lower frequencies

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