ADAPTIVE DIFFERENTIAL MICROPHONE ARRAY WITH DISTORTIONLESS RESPONSE AT ARBITRARY DIRECTIONS FOR HEARING AID APPLICATIONS

Hala As'ad, Martin Bouchard (University of Ottawa), Homayoun Kamkar-Parsi (Sivantos Group)

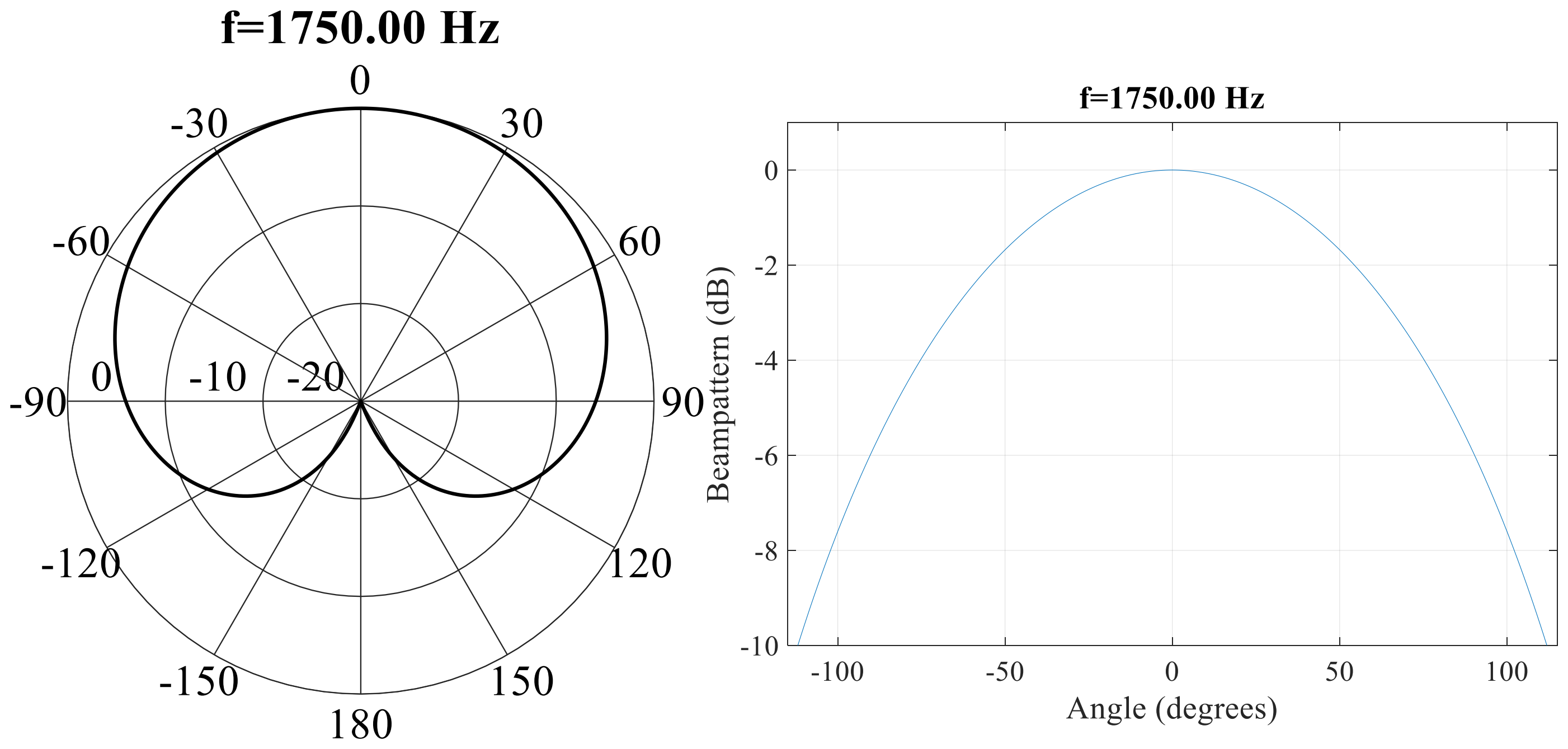
Introduction

- The current state of art ADMA beamformers used in hearing aids have a distortionless response for a frontal direction (0 degree).

- The ADMA beamformer [1] leads to distorted/attenuated responses over most of frequency components when the target signal comes from non-frontal directions.

- In addition, free field environment is often assumed in the ADMA beamformer derivation.

- However, in hearing aids, the head shadow effect does not lead to a free field propagation model, and this can affect the performance of the ADMA.



(a) **(b)**

Fig.1: DMA response using two closely spaced microphones; a) polar coordinates b) rectangular coordinates

- In this work, monaural ADMA designs using two closely-spaced microphones are introduced.
  - The proposed designs have a distortionless response at arbitrary target directions in the frontal half-hemisphere.
  - The head shadow effect is considered in the ADMA design, by using anechoic Head-Related Transfer Function (HRTF) measurements.
  - A sub-band or time-frequency derivation for the algorithms is used, as it typically leads to lower complexity implementations.

Acknowledgement

Funding for this project was provided by Sivantos Inc., with partial funding from an NSERC Discovery grant.

Reference

[1] G. W. Elko and A.-T. N. Pong, “A simple adaptive first-order differential microphone,” in Proceedings of 1995 Workshop on Applications of Signal Processing to Audio and Accoustics, 1995.

Proposed Solutions

1. Free field-based ADMA with distortionless response at arbitrary directions (FF-ADMA-θ_x)

The ADMA design in [1] is extended to have a distortionless response at an arbitrary front hemisphere angle θ_x degrees instead of 0 degree.

The forward cardioid $c_f(f,t)$ equation is:

$$c_f(f,t) = y_1(f,t) - e^{-j2\pi fT} y_2(f,t)$$

and the backward cardioid $c_b(f,t)$ equation is:

$$c_b(f,t) = y_2(f,t) - e^{-j2\pi fT\cos(\theta_x)} y_1(f,t)$$

where, $y_1(f,t)$ is the noisy signal at the front microphone, $y_2(f,t)$ is the noisy signal at the rear microphone, f is the frequency , t is the time (frame index), and T is the propagation delay between the microphones.

The beamformer output $z(f,t)$ has a null in the back hemisphere. The null location depends on the value of β

$$z(f,t) = c_f(f,t) - \beta(f,t) c_b(f,t)$$

To achieve a distortionless response (unit gain with no phase shift) at angle θ_x degrees over all frequencies:

$$z^{'}(f,t) = z(f,t) \Big/ \left(1 - e^{-j2\pi fT(1+\cos(\theta_x))}\right)$$

2. HRTF-based ADMA with a distortionless response at arbitrary directions (HRTF-ADMA-θ_x)

- In hearing aids, propagation model should include head shadow effect and other acoustic effects.
- The previous ADMA design with distortionless response at an arbitrary angle is generalized using anechoic HRTFs.
- Alternatively, a design similar to the design in [1] is obtained, but using HRTFs instead of a free field propagation model. In such case, the design is only target distortionless for a target at 0 degree.

3. Free field-based ADMA / HRTF-based ADMA with compensation gain (FF-ADMA-CG / HRTF-ADMA-CG)

- To mitigate the target distortion generated from the ADMA with distortionless response at 0 degree in the case of non-frontal targets, a frequency dependent complex compensation gain is proposed to be used after the ADMA.
- The aim is to have output target components after compensation which are the same as the target components at the frontal microphone .

Results

The performance of six different variations of ADMA designs are tested and compared in Fig.2 under two acoustic scenarios:

- A target at 90° and a single interferer at 200 degrees.
- A target at 90°, interferers at 225° and 180°, and diffuse-like noise (14 dB below the target and interferers levels).

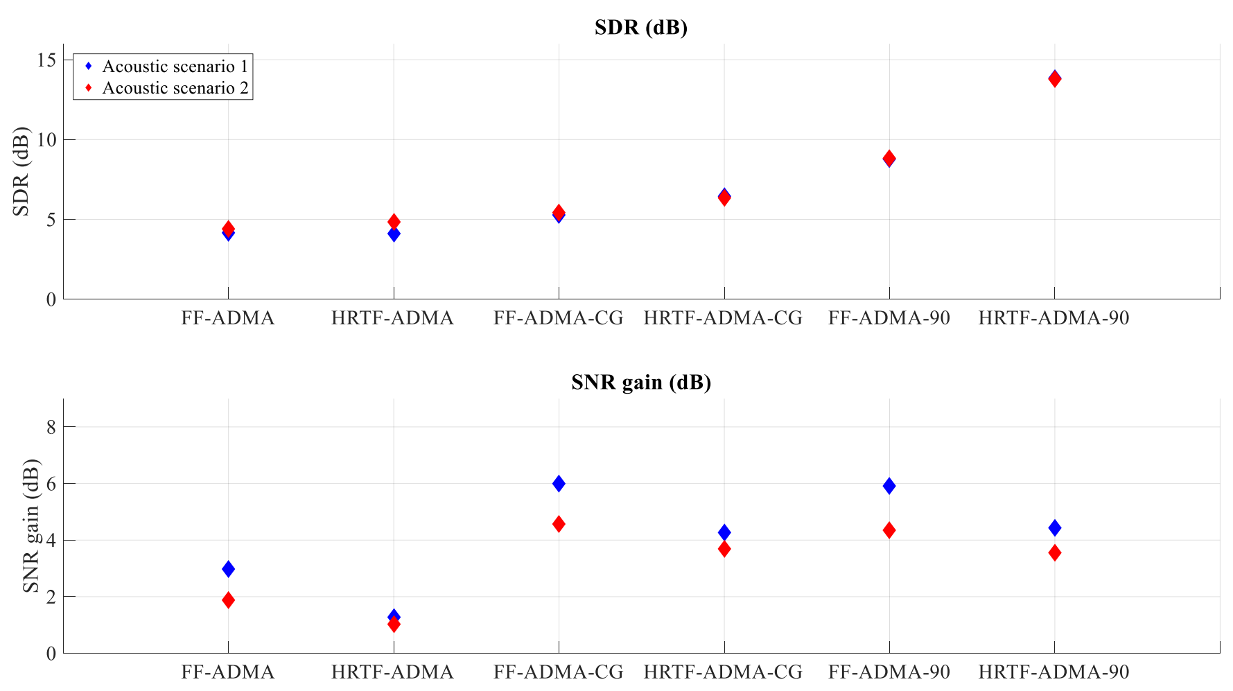


Fig. 2:Performance of ADMA designs under two acoustic scenarios in terms of target distortion and noise reduction

Resulting performance metrics show:

- The HRTF-ADMA-90 and the FF-ADMA-90 provide the best tradeoff in terms of target distortion and noise reduction.
- The compensation gain approaches provide similar overall noise reduction compared to the HRTF-ADMA-90 and the FF-ADMA-90, but with more target distortion.

The performance of the FF-ADMA-90 and HRTF-ADMA-90 designs are compared in details with the benchmark FF-ADMA [1] under the second complex acoustic scenario.

- HRTF-ADMA-90 outperforms the FF-ADMA-90 and the FF-ADMA in terms of SDR and SDmag over almost all frequency components.
- Both the HRTF-ADMA-90 and FF-ADMA-90 significantly outperform the FF-ADMA [1] in terms of noise reduction up to 7 kHz.

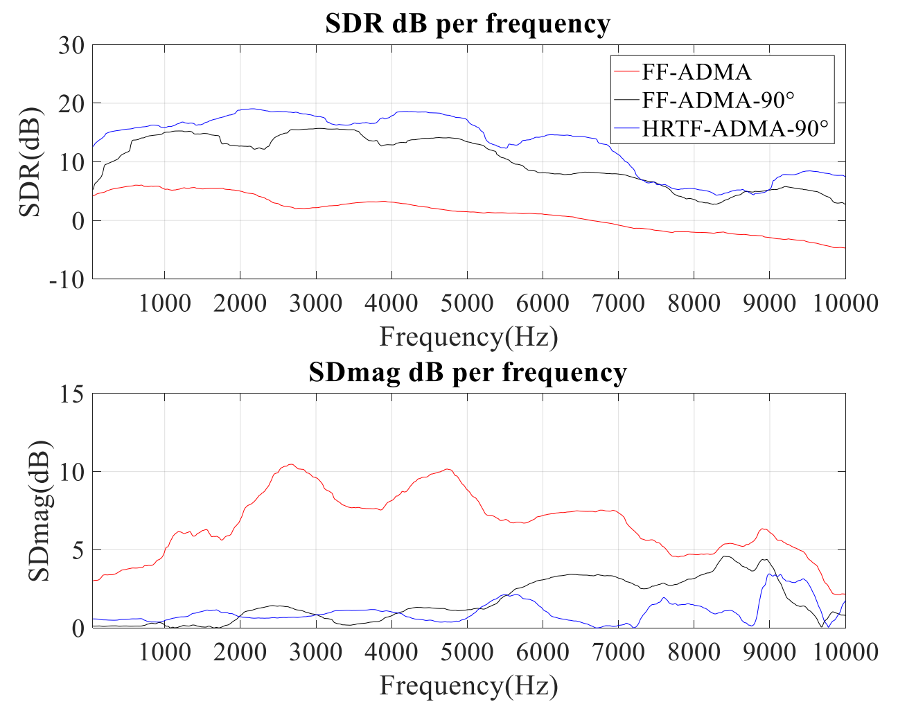


Fig.3:Target distortion

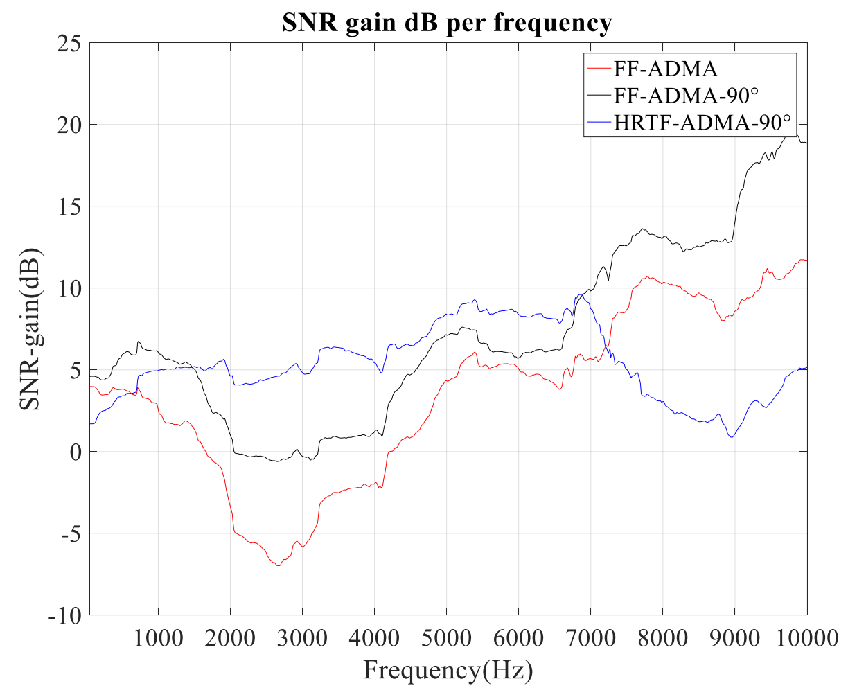


Fig.4: Noise reduction

Conclusion

- ADMA beamformers for hearing aids using two closely-spaced microphones are introduced to have a distortionless response at an arbitrary target direction in the frontal hemisphere.
- Four variations are proposed by assuming a free field environment or considering the head shadow effect.
- The best tradeoff between noise reduction and target distortion are achieved by HRTF-ADMA-90 and FF-ADMA-90.