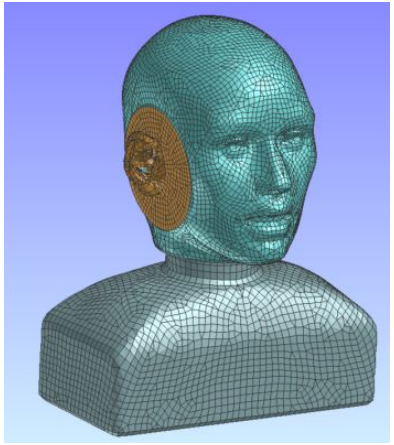
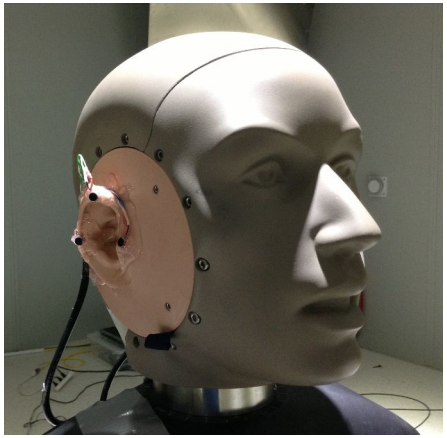
Binaural Beamformer: An early Proof of Concept for Wearables Audio Devices





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October 6h, 2023

Introduction

I. Concept – Array characteristics – Boundary Element Model

II. Simulations – Validations

III. GSC Algorithm (Generalized Sidelobe Canceller)

IV. Demo- Recordings

I. Concept - Array Characteristics

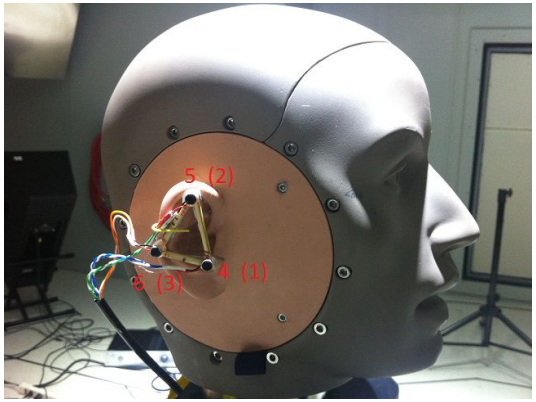
Configuration of microphones

- 6 microphones - 3+3 symmetrical
- Initially for Behind The Ear (BTE) hearing aids.
- 5CB Artificial Head (GRAS, Holte, Denmark).

Presentation is more oriented AR, Immersion and detection of sound sources in noisy environment.

- Both arrays are connected
- 6 microphones are combined at all times.
- Frequency range: 150 – 7000 Hz

- Monaural beamformer output
- Binaural synthesis with HRTFs
- Very noisy - Aggressive environments



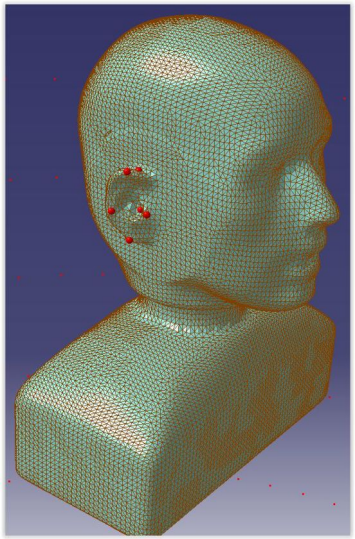
Boundary Element Model

Minimum variance distortionless response (MVDR) beamformer

- **Fixed beamformer**
- Definition of a Noise Field
- Optimal filters for various look direction d_0
- Only adaptive algorithm would be "beamsteering".

$$min_w \; w^H \Gamma_{\nu\nu} w \;\; \text{subject to} \;\; w^H d_0 = 1$$

$$w_{opt} = \frac{\Gamma_{\nu\nu}^{-1} d_0}{d_0^H \Gamma_{\nu\nu}^{-1} d_0}$$



Generalized Sidelobe Canceller (GSC) implementation

- Additional constraints
- Linear Constrained Minimum Variance (LCMV) Beamforming

FEMAP Finite Element Modeling Postprocessing software (Simcenter Femap/NASTRAN XaaS)

Acoustic field surrounding the head for noise and speech sources.

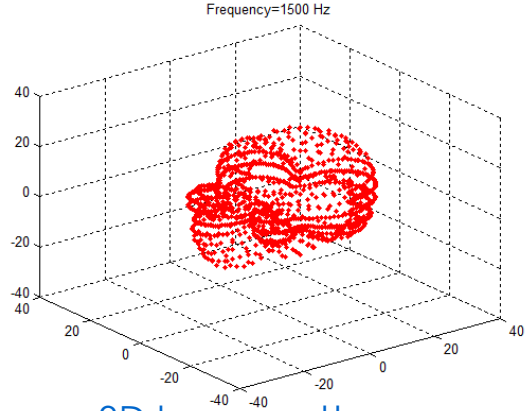
II. Simulations – Validations

Anechoic Chamber *(100 m^3)*
ETS Montreal

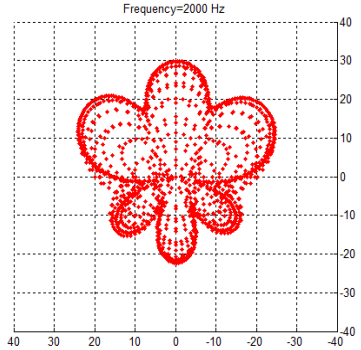
1 meter in the plane of the array

- TFs
- HRTFs
- Beampatterns every 10 deg in the Horizontal plane of the array

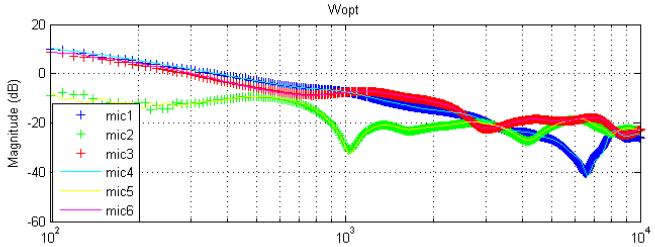
Simulations – Typical results



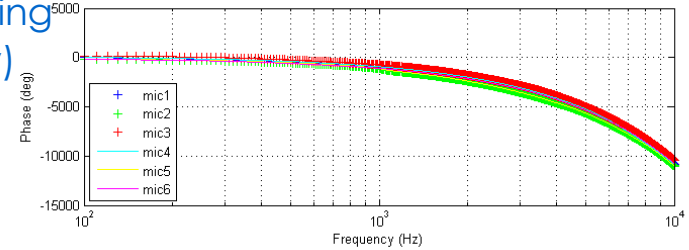
3D beampatterns



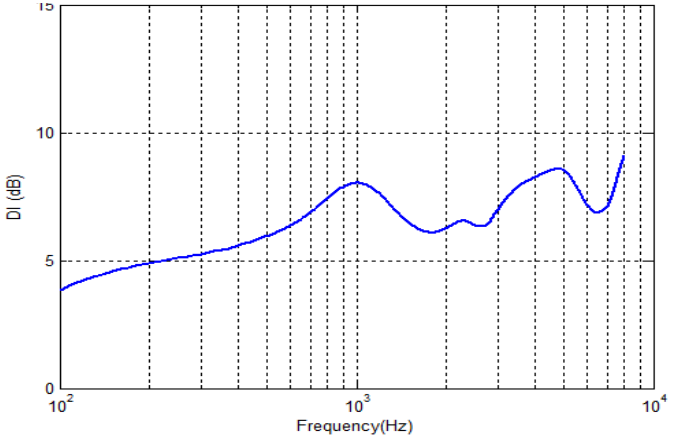
2D beampatterns



Optimal beamforming Filters (frequency)

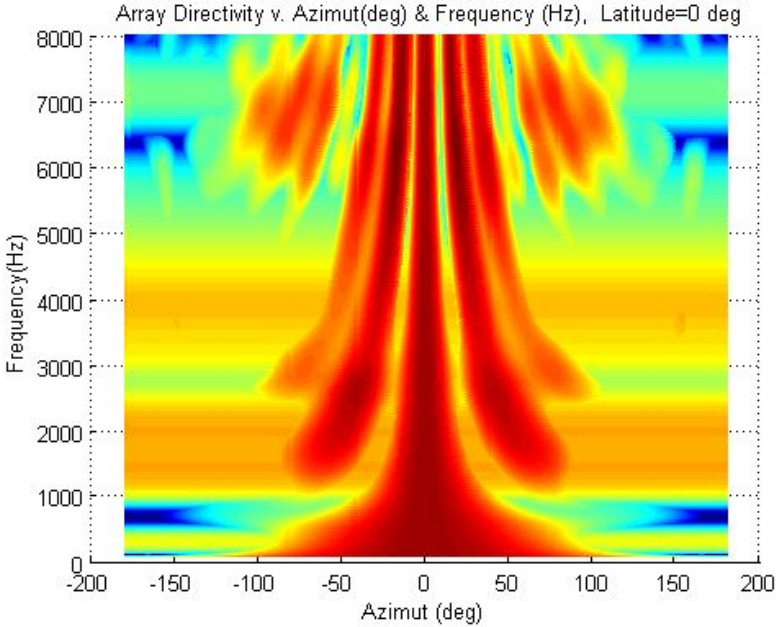


Directivity Index (dB) Look direction 0 deg

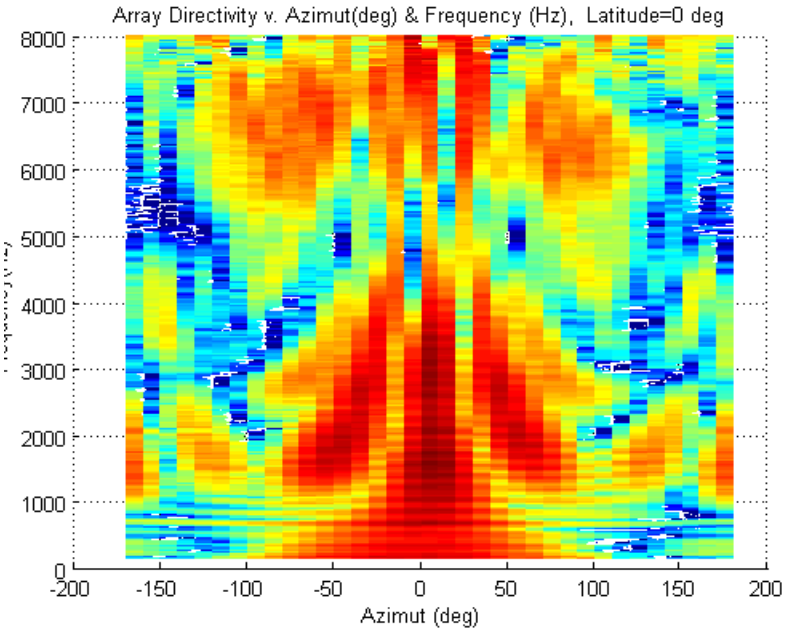


Array Directivity v. Frequency

Look direction: 0 deg



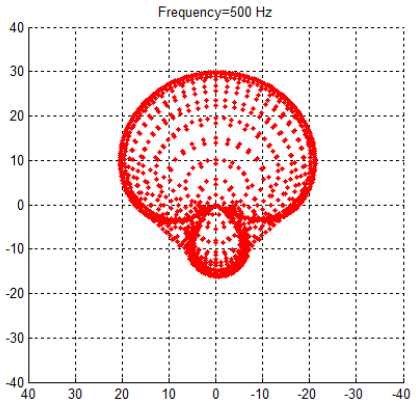
Simulation

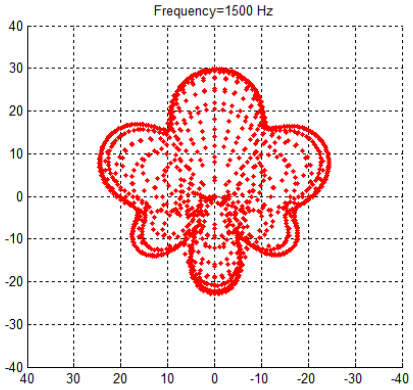


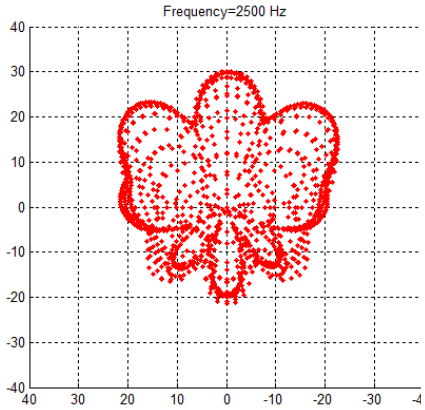
Measurement

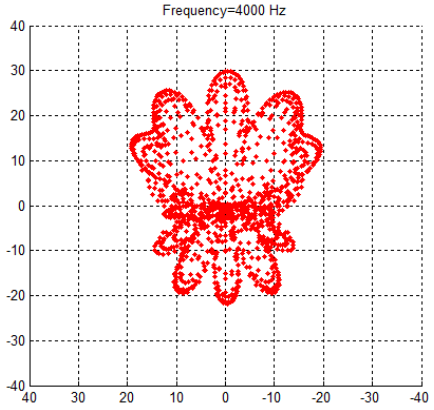
Beampatterns – Main Beamformer

look direction= 0 deg

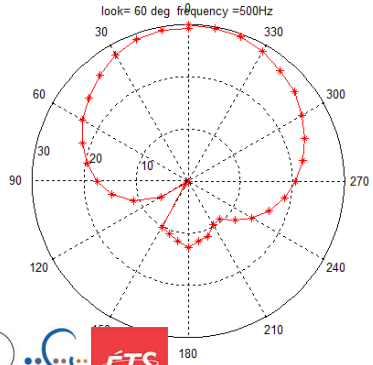




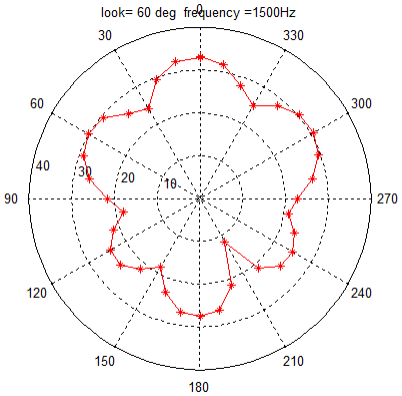




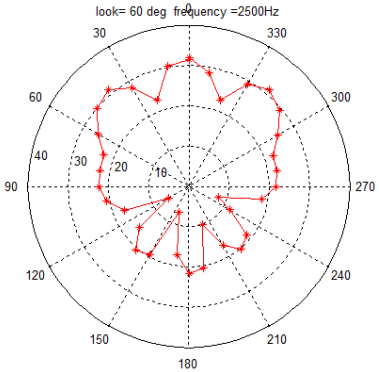
500 Hz



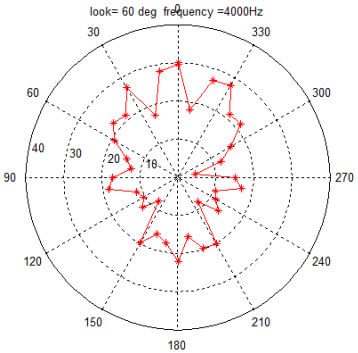
1500 Hz



2500 Hz



4000 Hz



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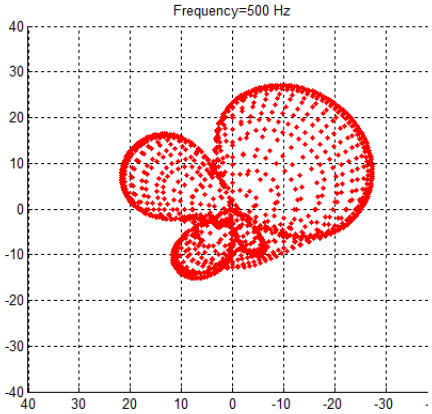
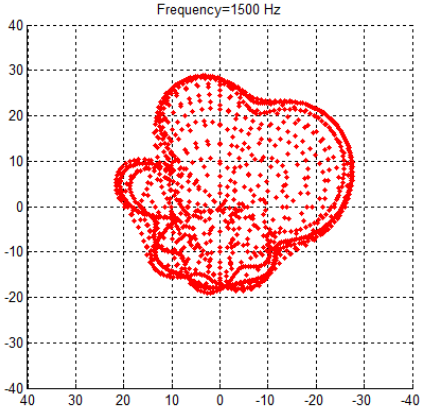
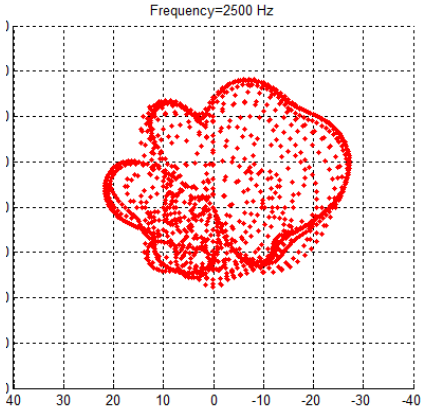
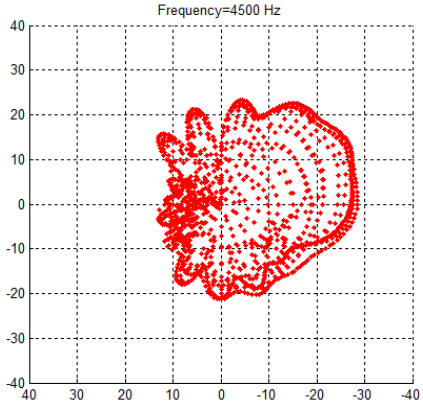
Beampatterns – Main Beamformer

look direction= 60 deg

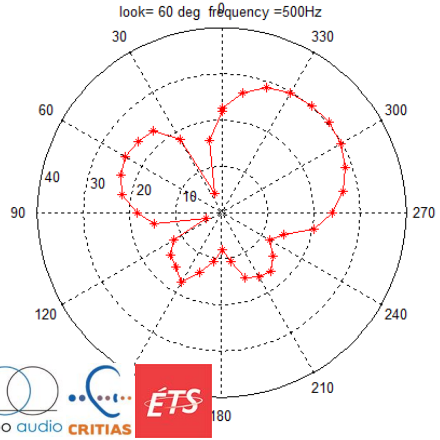




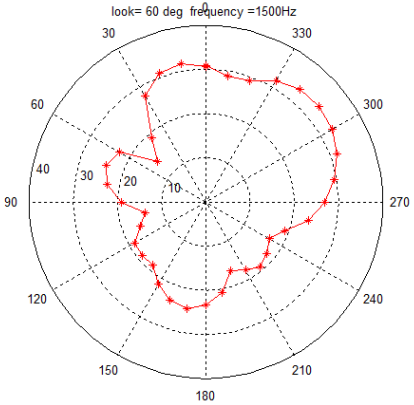




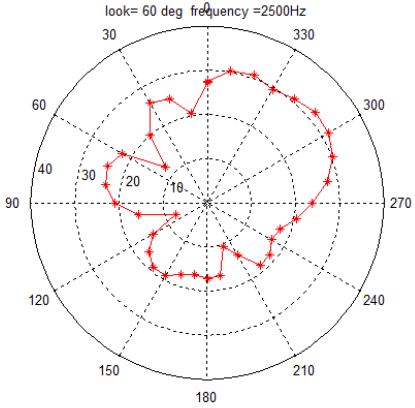
500 Hz



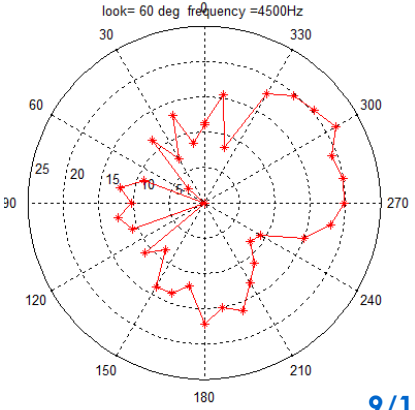
1500 Hz



2500 Hz



4000 Hz



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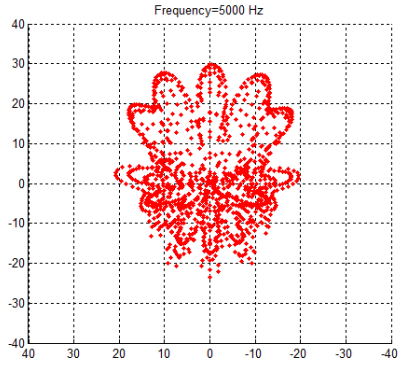
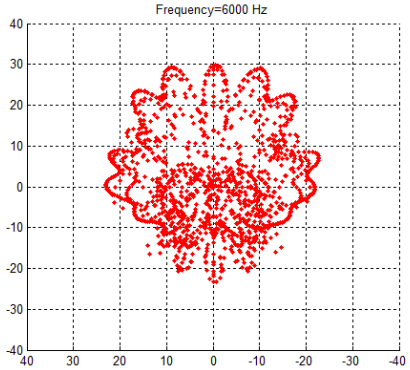
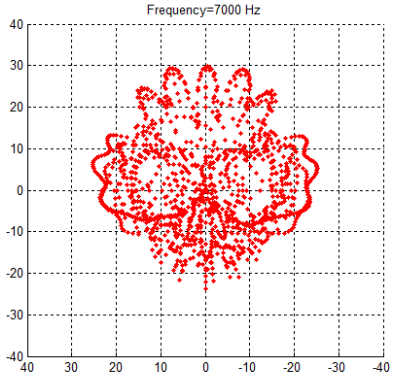
Beampatterns – Spatial Aliasing above 4 kHz

look directions= 0 deg & 60 deg

0 deg

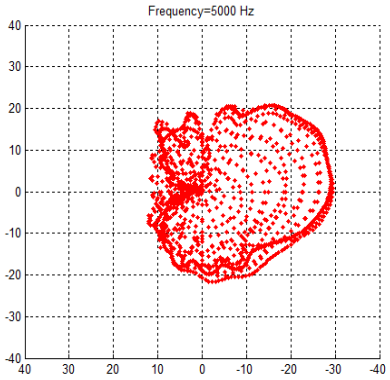


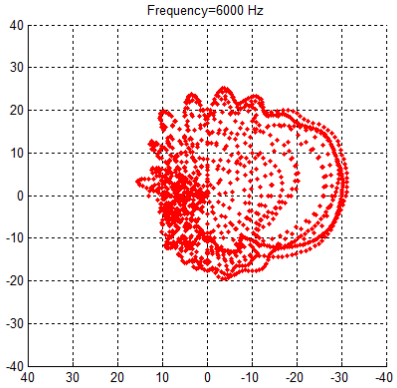


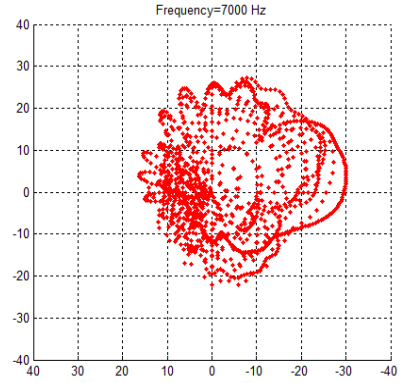


5000 Hz **6000 Hz** **7000 Hz**

60 deg



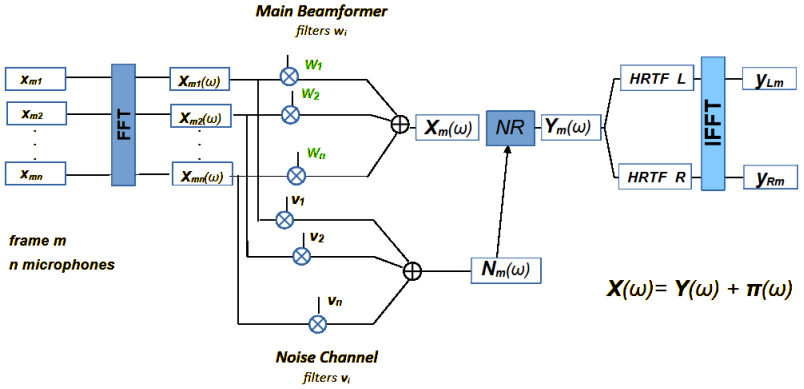




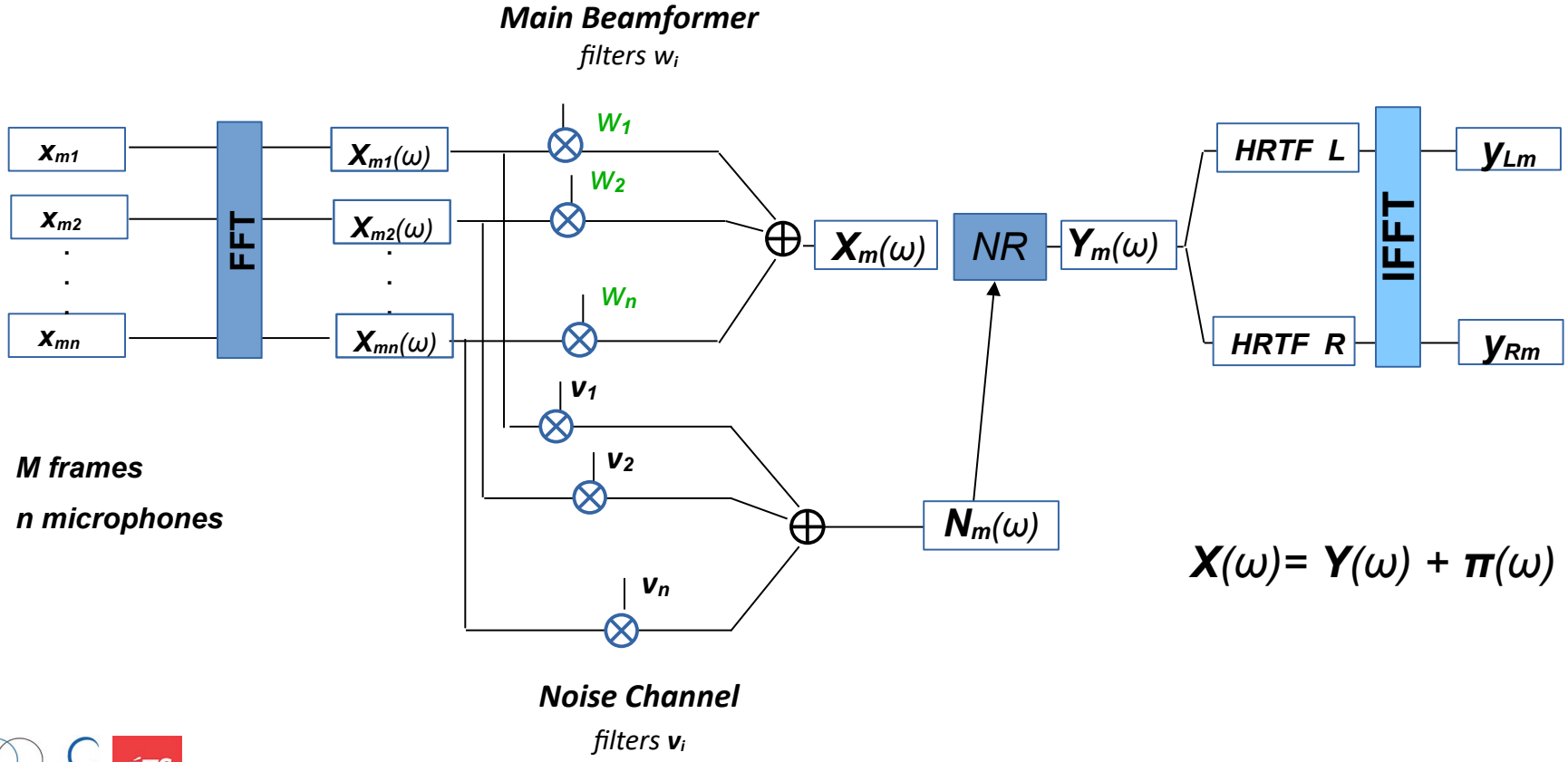
III. Generalized Sidelobe Canceller - Implementation

- GSC implementation
- Main Beamformer
- Define a Noise Channel: Reject sources in the look direction
- Noisy environment – **no VAD**
- Attenuates Reverberations

Not for hearing aids.



GSC Implementation



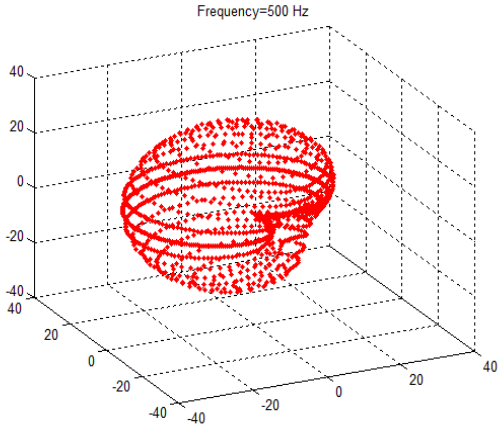
$$X(\omega) = Y(\omega) + \pi(\omega)$$

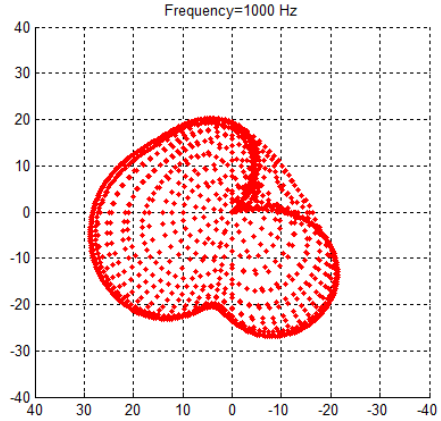
Beampatterns – “Noise channel”

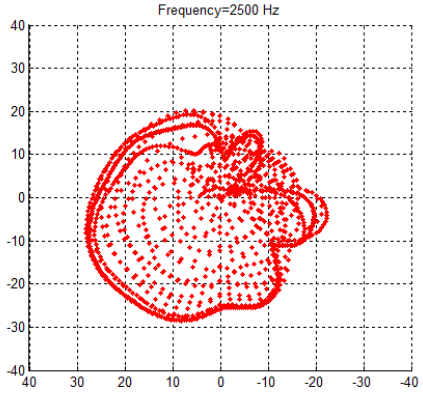
Look direction= 60 deg

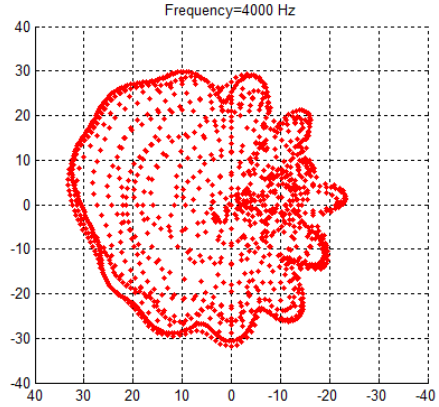
- Linear Constrained Minimum Variance (LCMV) Beamforming

- Definition of beampatterns is not unique.
- Creative with constraints.
- Capture as much as interfering noise + reverberations as possible
- Generalization of the blocking matrix in usual GSC implementations.









IV. Demo - Experimental set-up

- Large Reverberation Chamber (ETS – Montreal)
- Interfering noise: 4 large loudspeakers

- Source: loudspeaker at 1 meter
- -90, -60, -30, 0, 30, **60**, 90 deg

- 8 channels USB Sound Card (M-Audio Ultra8R)
- Laptop
- Post processing with Matlab/Octave

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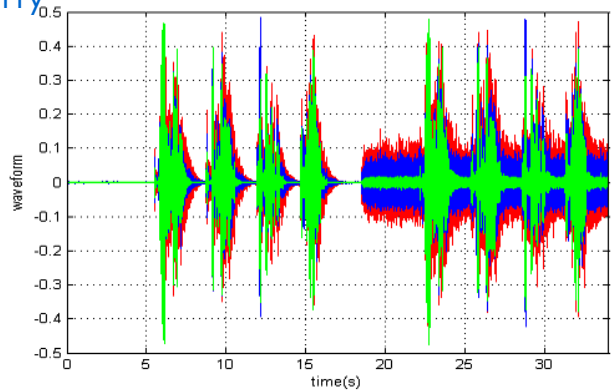
Demo – Speech+Noise in a reverberation chamber

Utterances in French:

U1: “Le clown est vraiment drôle” - “The clown is really funny”
U2: “Le coq réveille le village” - “The rooster awakes the village”
U3: “Le marchand vend des bonbons” - “The merchant sells candies”
U4: “Le chien dormait dehors” - “The dog was sleeping outside”

4 different conditions with reverberations:
Silence(reverberation)- White noise – Industrial noise – Cocktail Party

Binaural - Look direction: 60 deg
1) Left/Right microphones
2) Beamformer output (MVDR)
3) Generalized Sidelobe Canceller



Conclusions

- BEM is powerful tool for designing optimal beamformers.
- Satisfying Validations
- Development of simple GSC strategy without VAD.
- Significant noise and reverberation attenuation.
- HRTF - 3D perception

Applications:

- Not suited for hearing aids.
- Application for AR, : immersion in noisy environments.
- Industrial noise, combat zone
- Speech recognition in quieter environments (MVDR alone). No distortion.
- Intelligibility in aggressive environment (GSC strategy). Speech distortion.

Future work

- 2 channels noise reduction. SVD.
- VAD at the GSC output (further speech distortion).