Speech Enhancement Using Masking for Binaural Reproduction of Ambisonics Signals

Moti Lugasi and Boaz Rafaely

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facebook Reality Labs

School of Electrical and Computer Engineering
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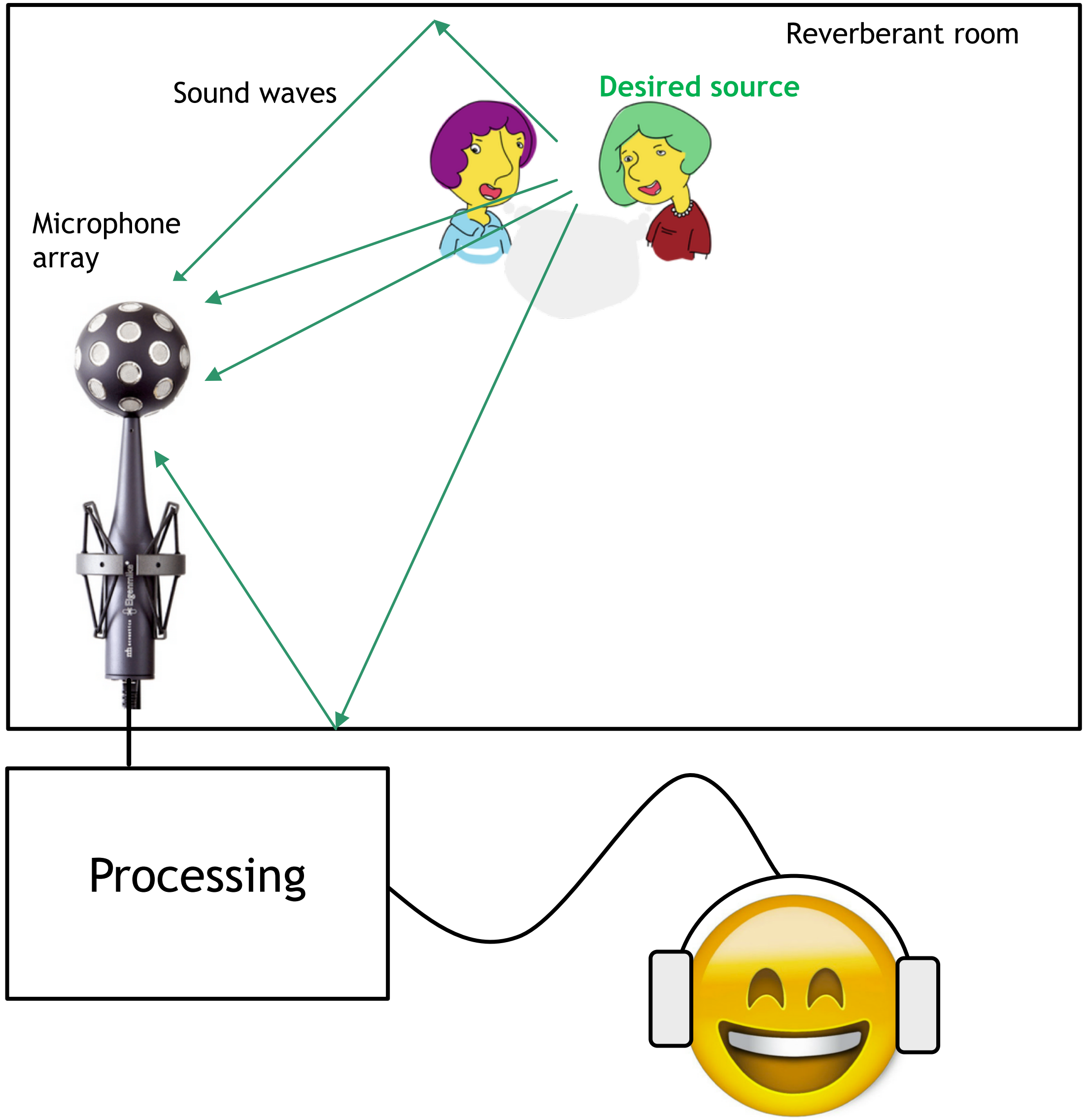
Contents

- The problem - noisy Ambisonics signals
- The aim - enhancement of these signals
- The method - masking the noise
- Objective analysis
- Conclusions

The problem – noisy Ambisonics signals



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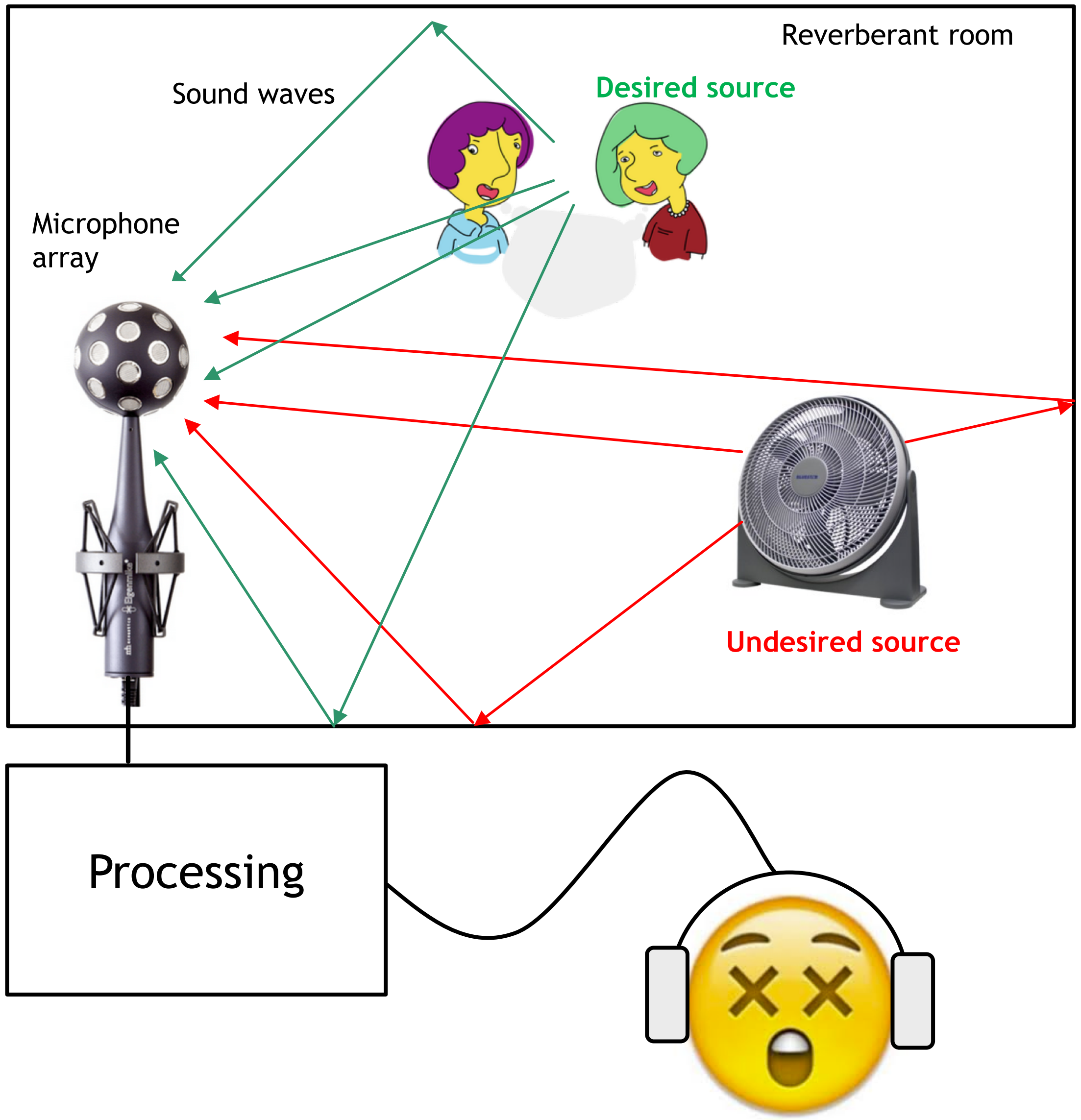

The research aims

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- Attenuate the undesired components

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- Preserve the desired components

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- Attenuate the undesired components
- Preserve the desired components
- Preserve the spatial cues of the acoustic scene

Current methods for speech enhancement

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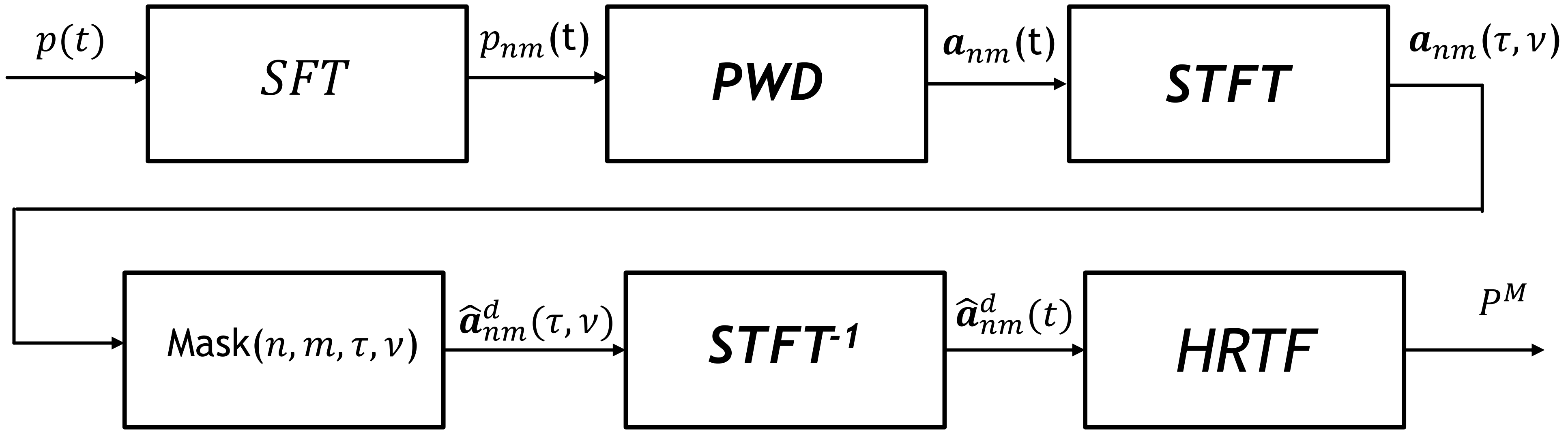
Wiener mask in the SH domain - TFSH



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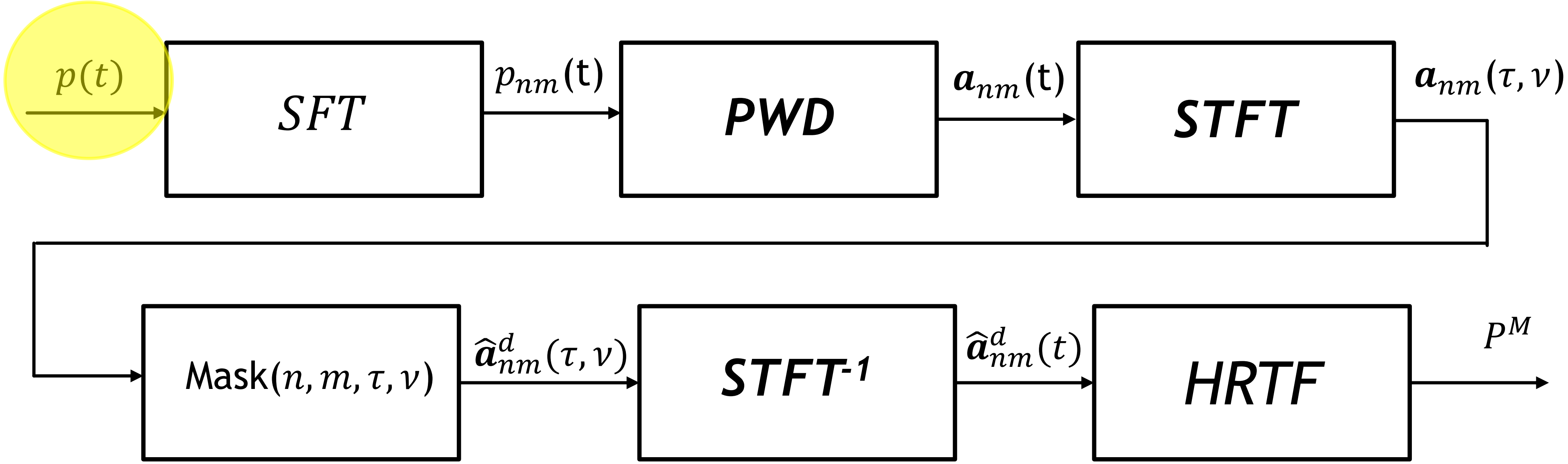
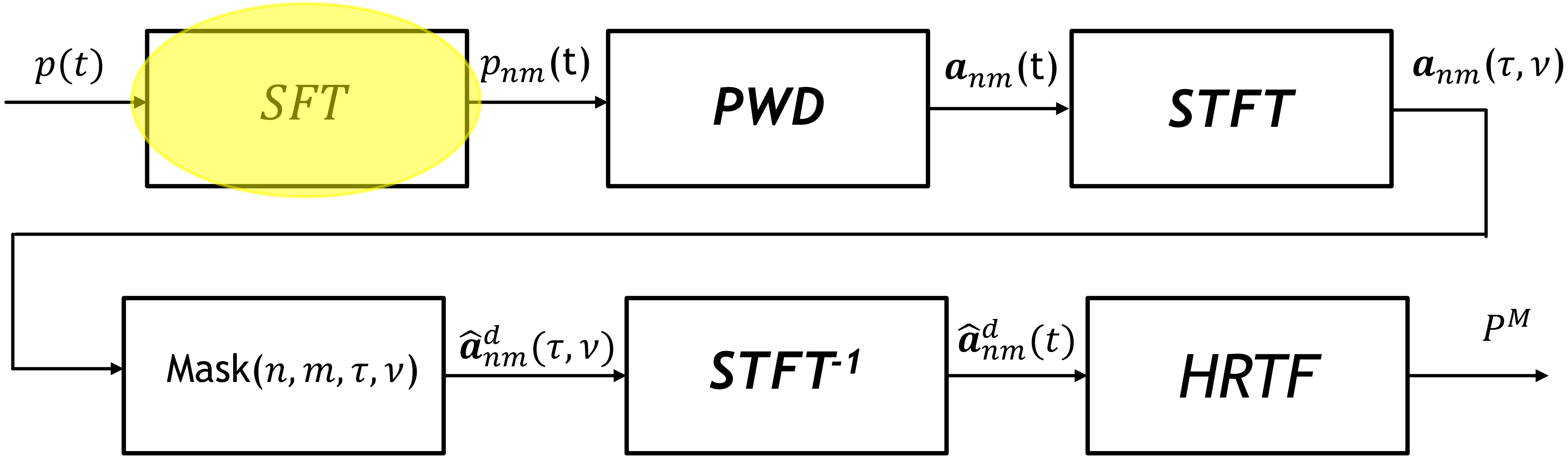


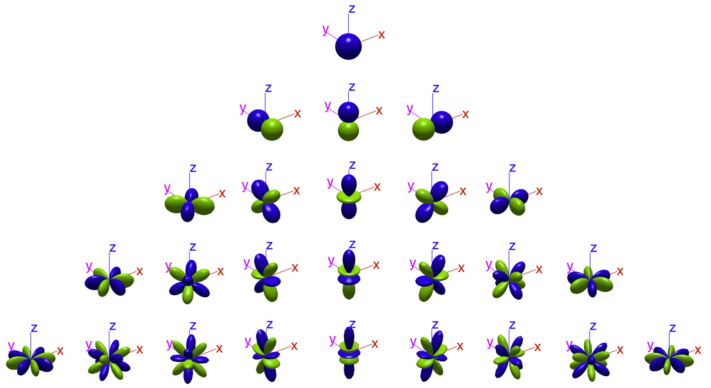
Microphone
input signals

$$p(t) = p_d(t) + p_u(t)$$

Wiener mask in the SH domain - TFSH



Spherical
Fourier
Transform



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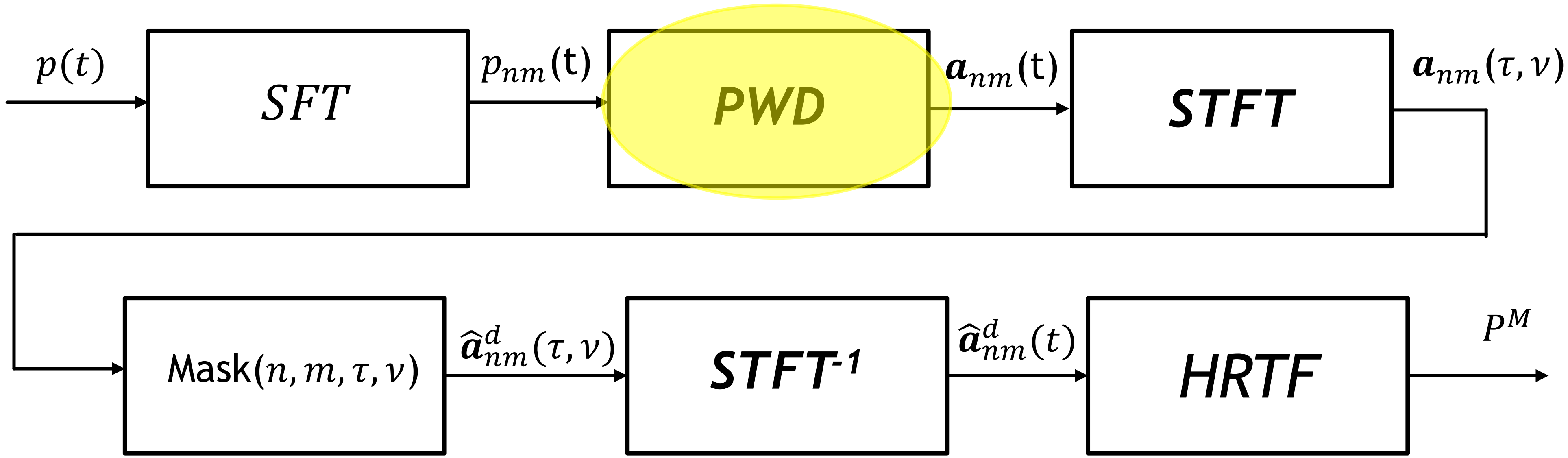
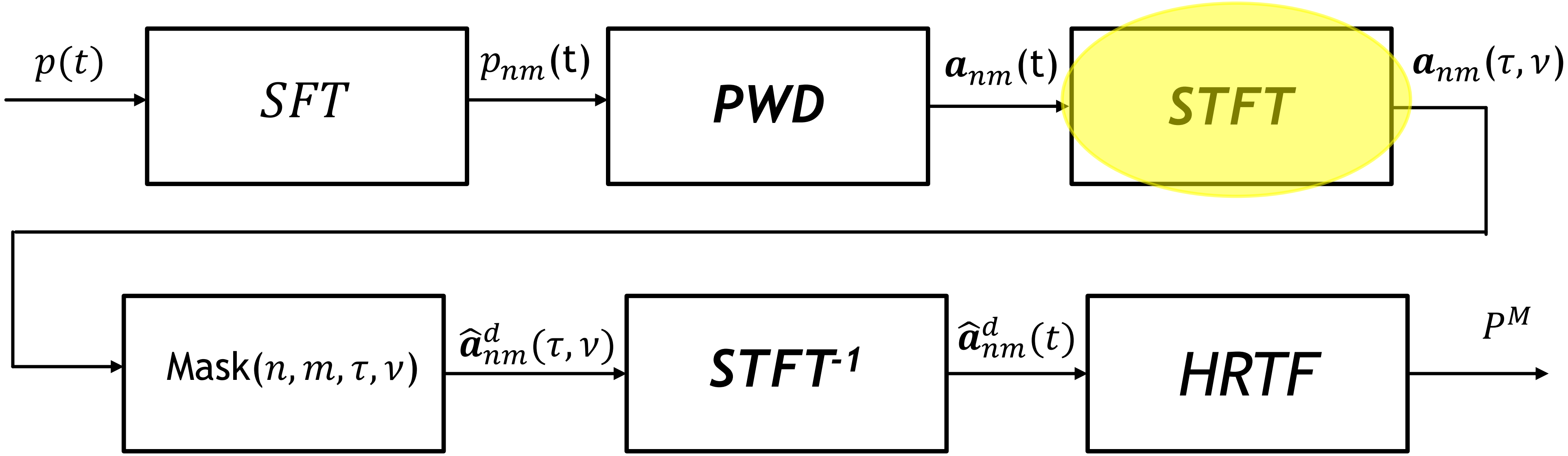


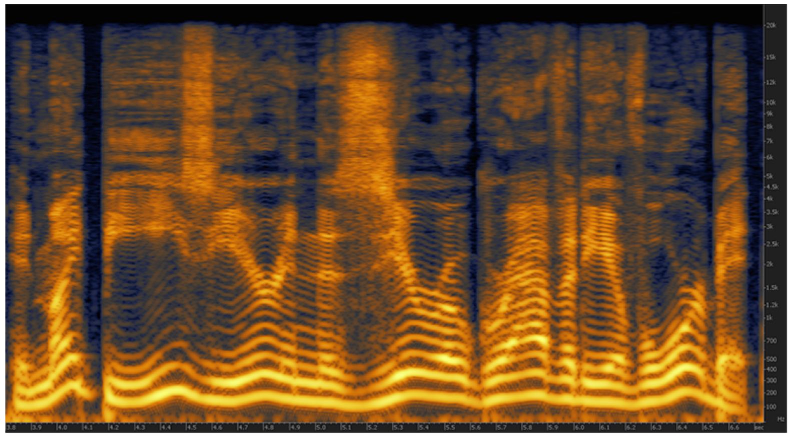
Plane Wave
Decomposition

Wiener mask in the SH domain - TFSH



Short Time Fourier Transform

$$\boldsymbol{a}_{nm}(\tau,\nu) = \boldsymbol{a}^{\mathrm{d}}_{\mathrm{nm}}(\tau,\nu) + \boldsymbol{a}^{\mathrm{u}}_{\mathrm{nm}}(\tau,\nu)$$



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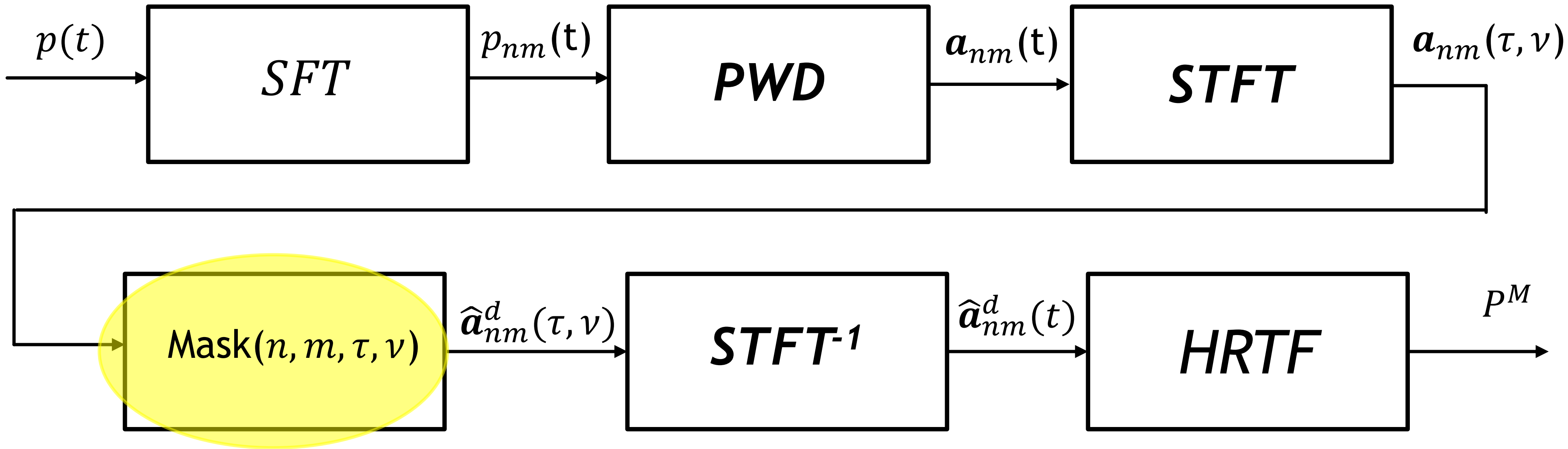
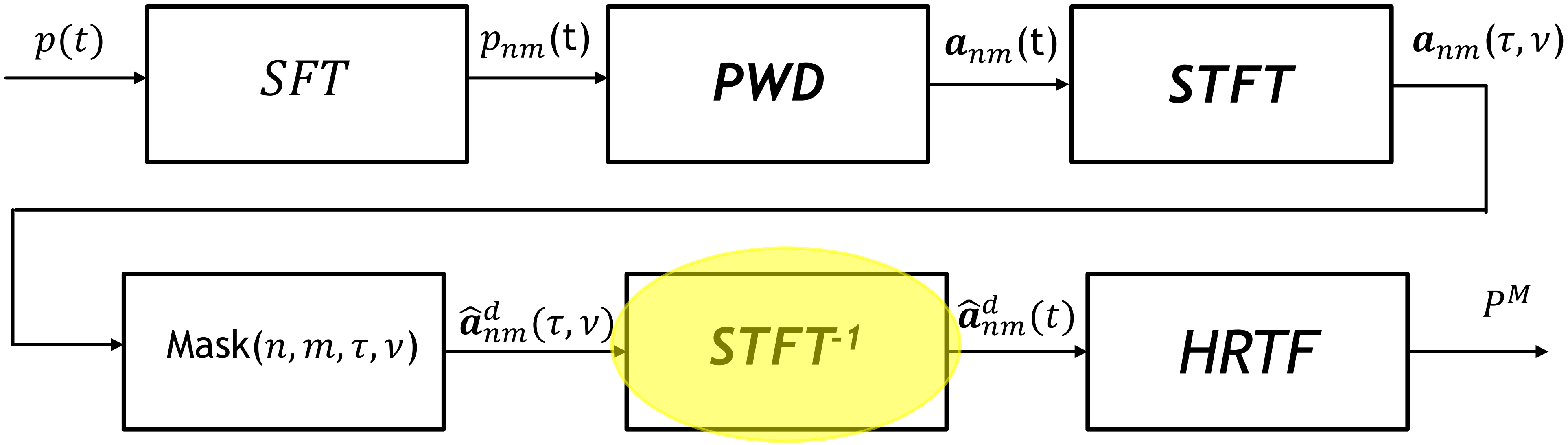


Wiener masking

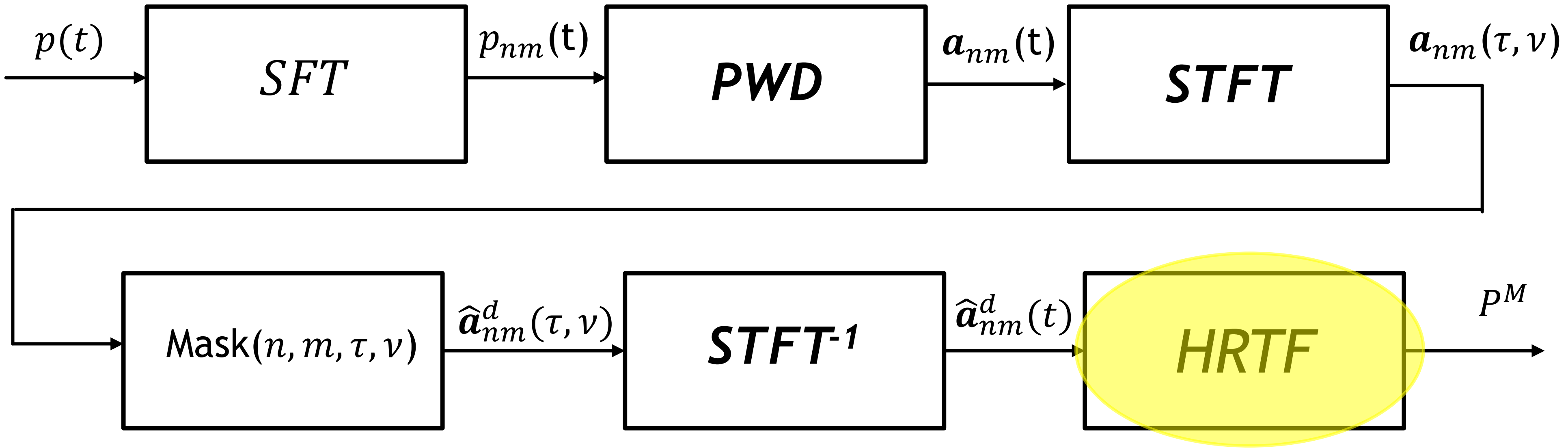
$$Mask(n, m, \tau, \nu) = \frac{SNR(n, m, \tau, \nu)}{SNR(n, m, \tau, \nu) + 1}$$

Wiener mask in the SH domain - TFSH



Inverse Short Time Fourier Transform

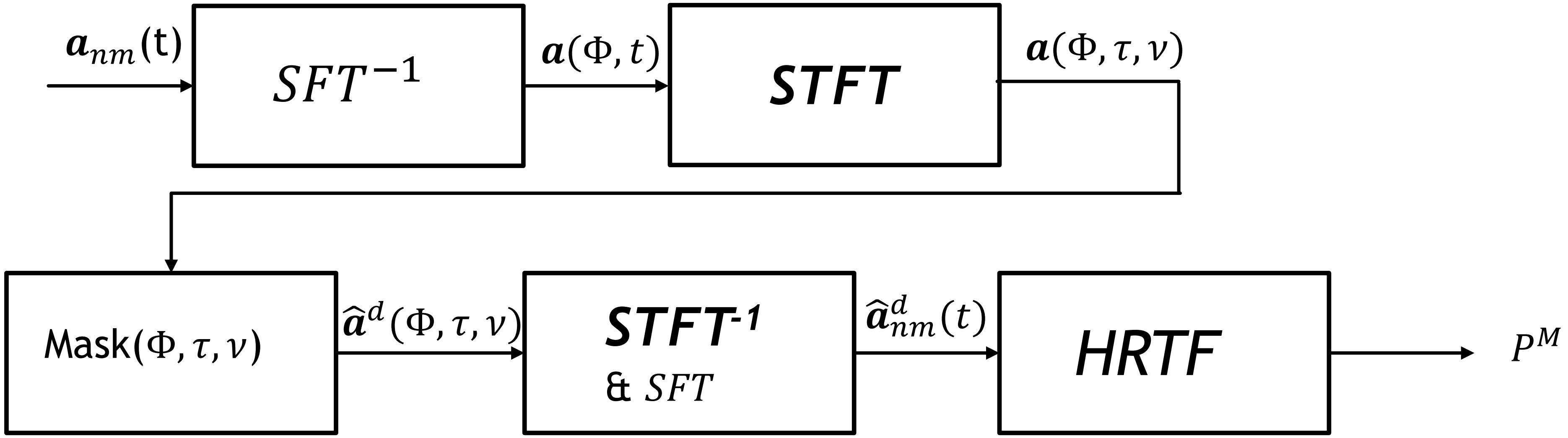
Wiener mask in the SH domain - TFSH



Head Related Transfer Function

$$P^M = P^{Md} + P^{Mu}$$

Wiener mask in the spatial domain - TFS



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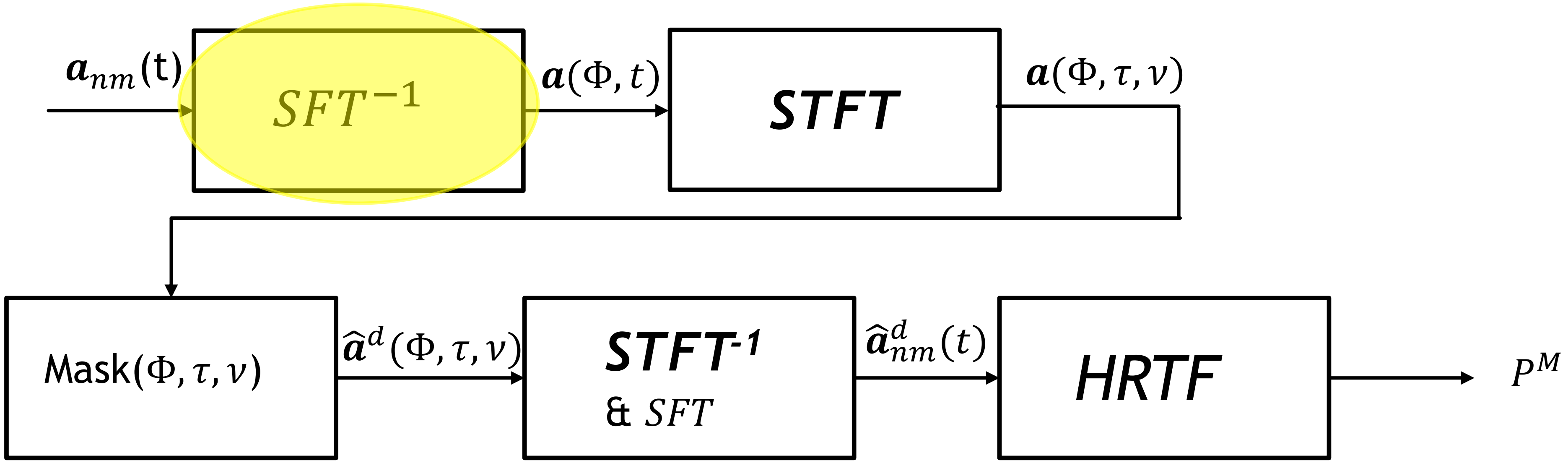
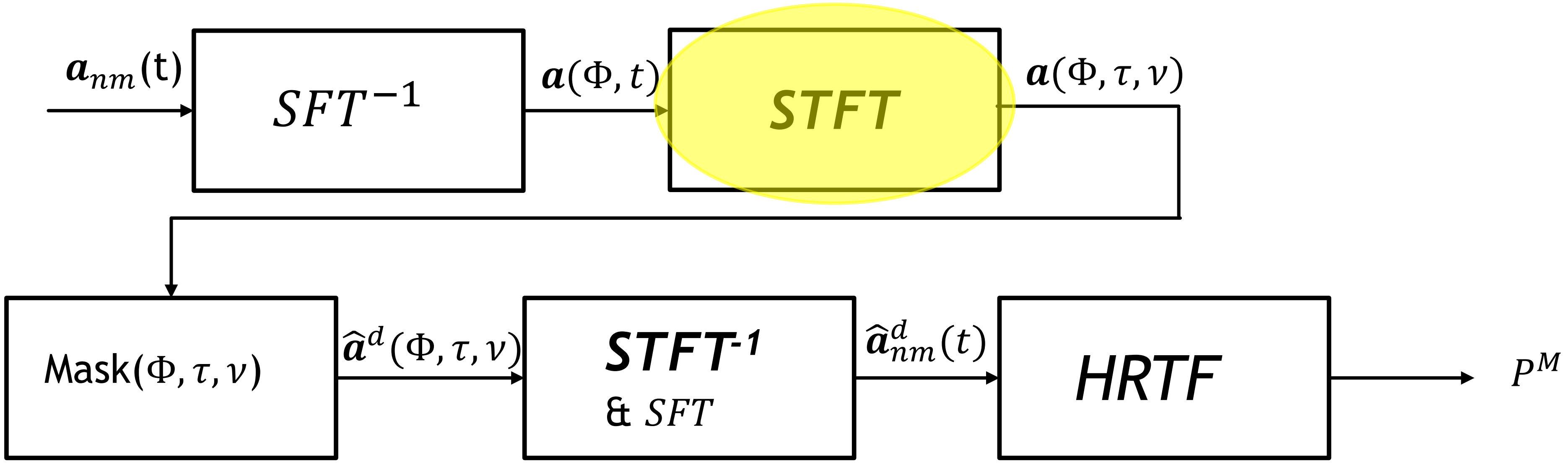


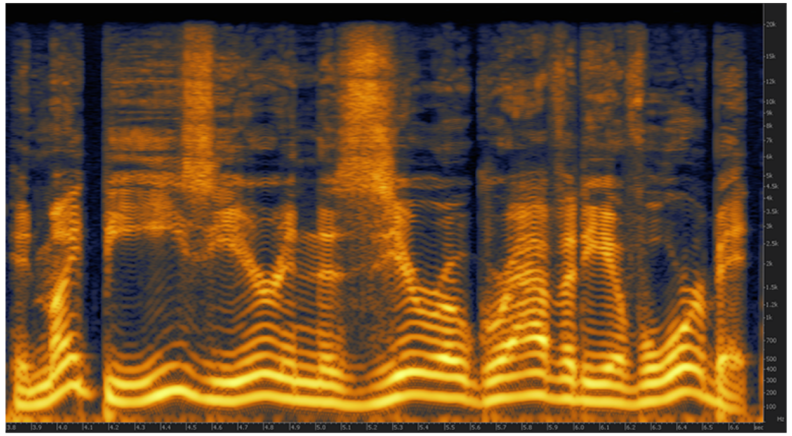
Inverse Spherical Fourier Transform

Wiener mask in the spatial domain - TFS



Short Time Fourier
Transform

$$\boldsymbol{a}(\Phi, \tau, \nu) = \boldsymbol{a}_d(\Phi, \tau, \nu) + \boldsymbol{a}_u(\Phi, \tau, \nu)$$



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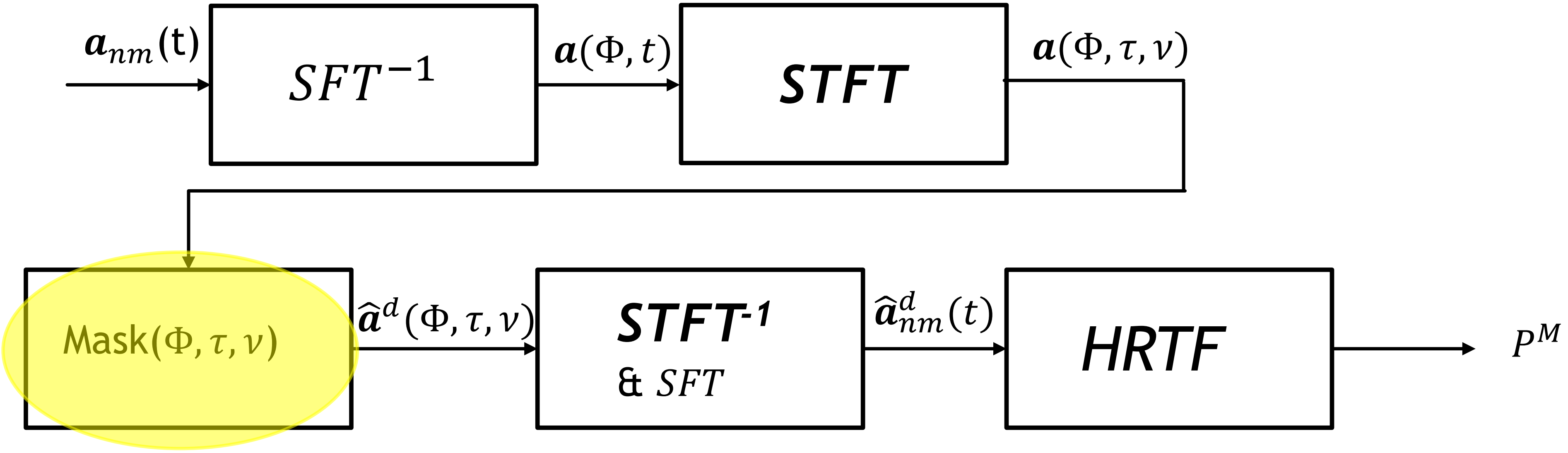

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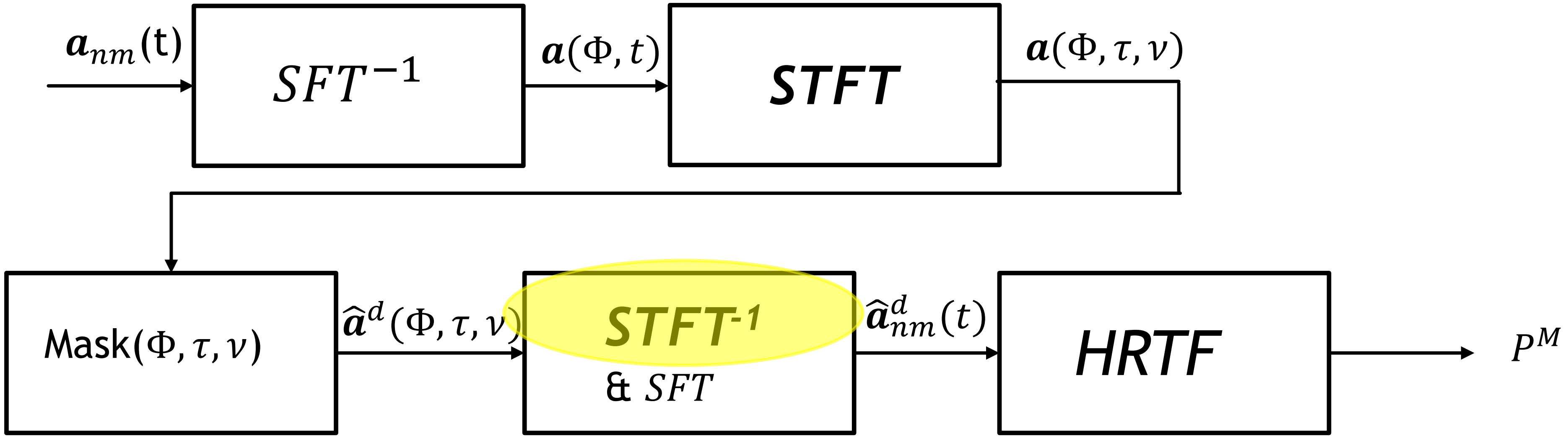

Inverse Short Time Fourier Transform

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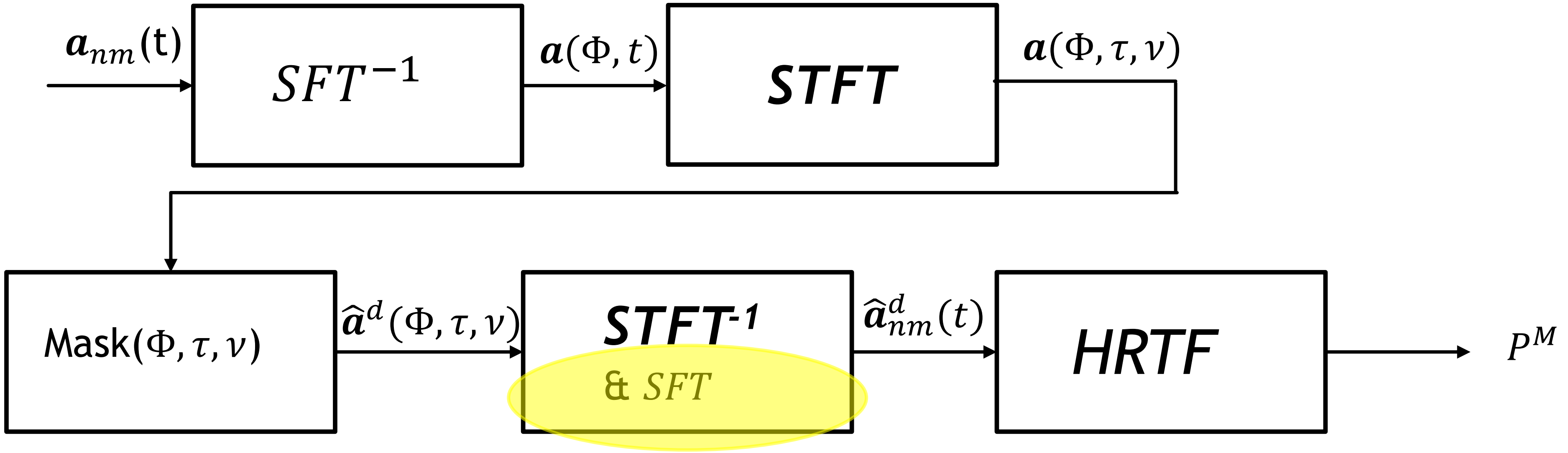
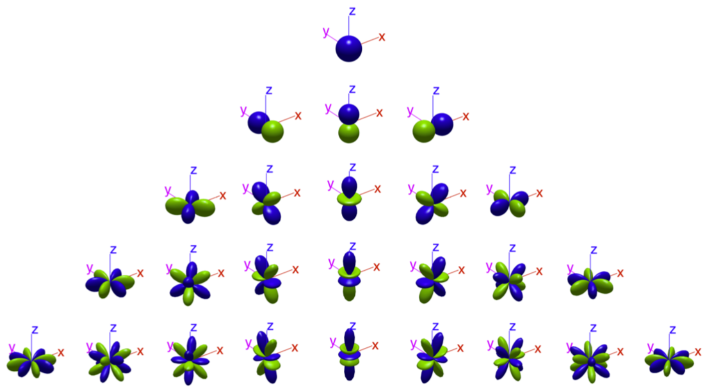


Spherical Fourier Transform



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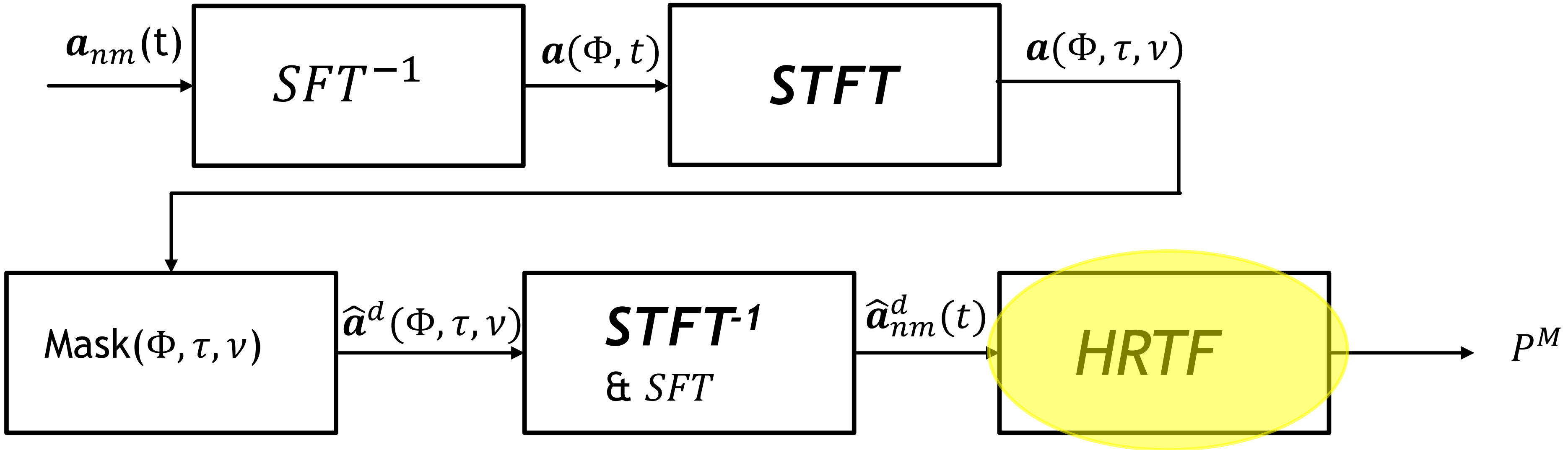

Head Related Transfer Function

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Objective performance measures

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  - Signal to noise ratio gain (G_{SNR}):

$$G_{SNR} = \frac{SNR_{out}}{SNR_{in}}, \qquad SNR_{out} = \frac{||P^{Md}||^2}{||P^{Mu}||^2}, \qquad SNR_{in} = \frac{||P^{d}||^2}{||P^{u}||^2}$$

- P^{d}- unprocessed desired binaural signals
- P^{u}- unprocessed desired binaural signals
- P^{Md}- masked desired binaural signals
- P^{Mu}- masked undesired binaural signals

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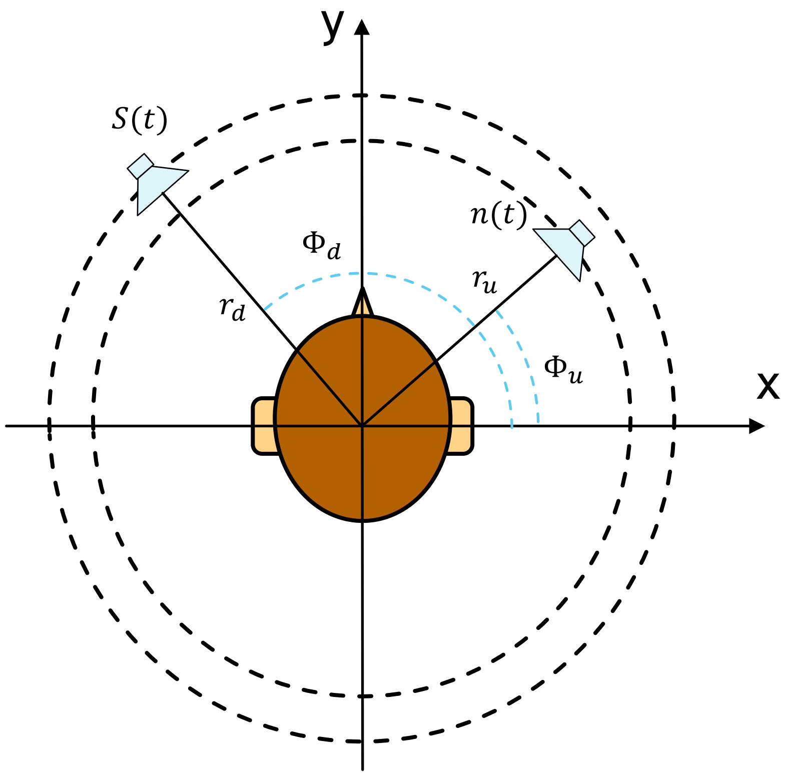
- Spatial cues of the residual noise:
  - Inter-aural level difference (ILD) - for $f > 1{,}500 H_z$
  - Inter-aural cross correlation time (IACC_t) - for $f < 1{,}500 H_z$

Monte Carlo simulation - setup

- This simulation is repeated for various:
  - Speakers
  - SNRin values
  - Noise types
  - Rooms
  - Source directions (Φ_d, Φ_u)
  - Source distances (r_d, r_u)
- Total of 1728 realizations for all combinations



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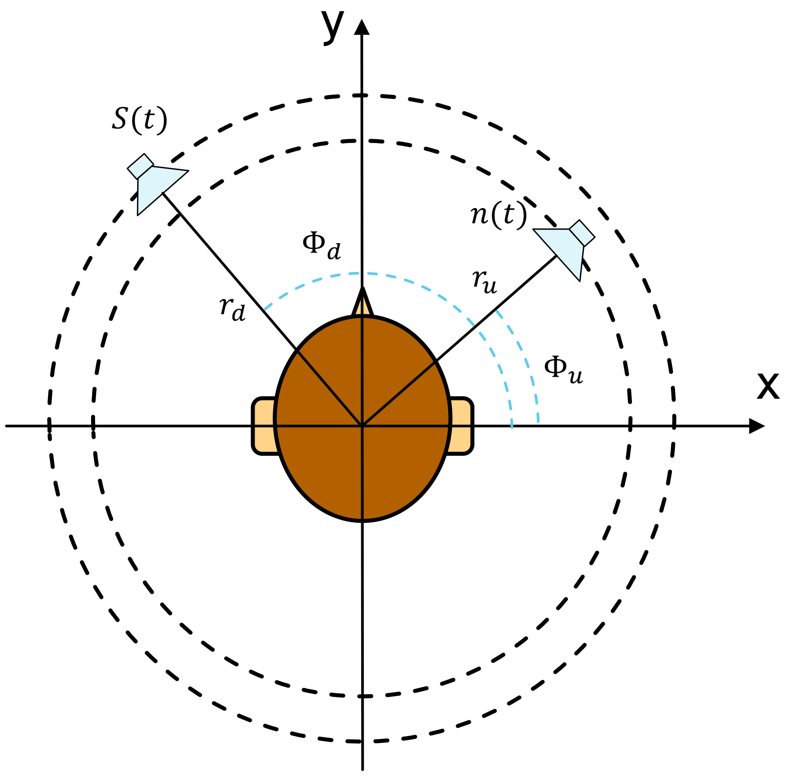
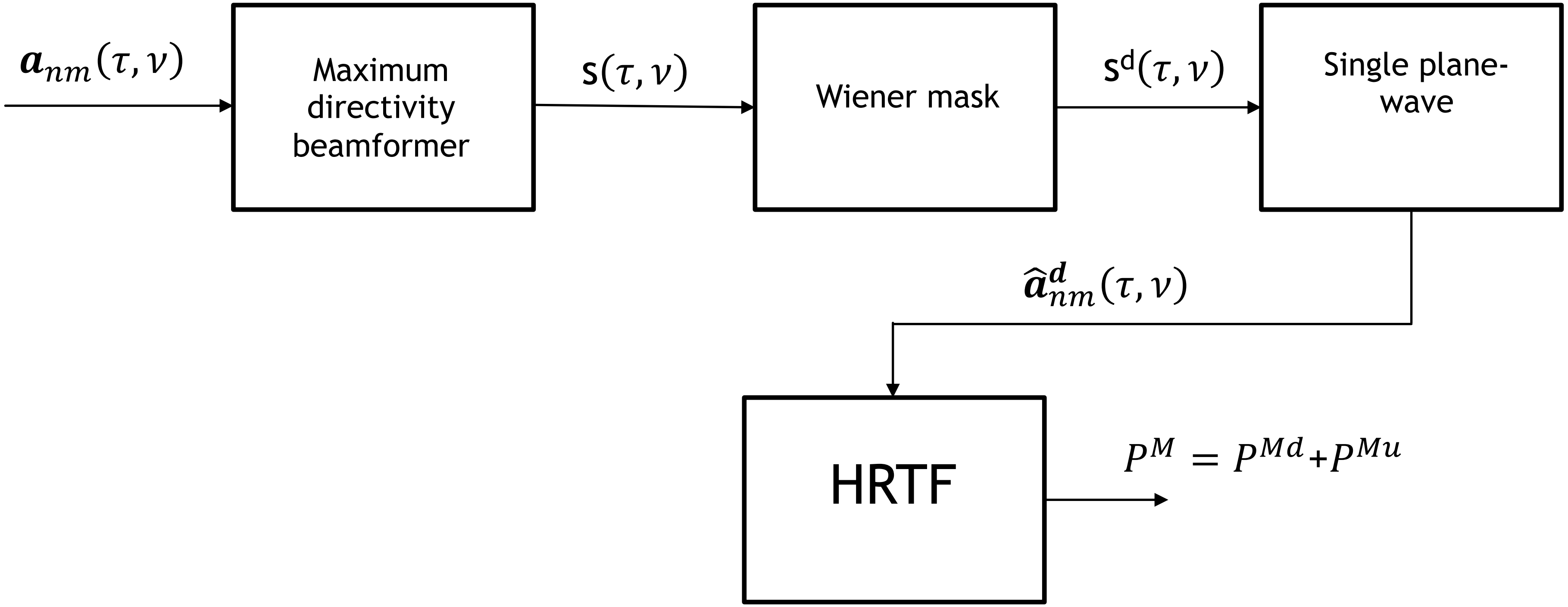
  - Rooms
  - Source directions (Φ_d, Φ_u)
  - Source distances (r_d, r_u)
- Total of 1728 realizations for all combinations
- Three methods investigated:
  - TFS masking
  - TFSH masking
  - Beamforming + TF masking

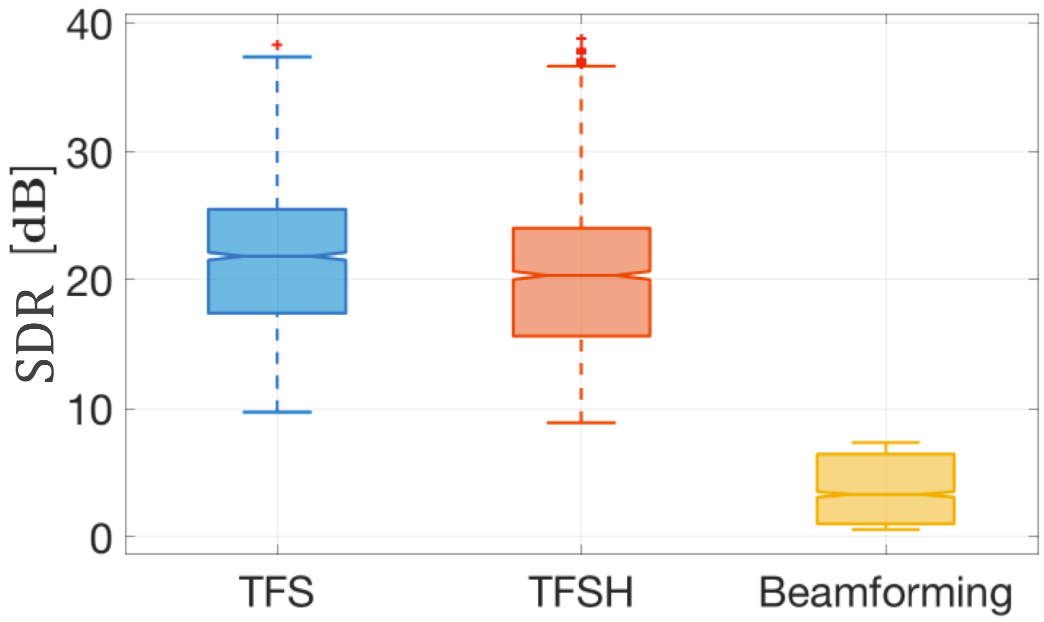


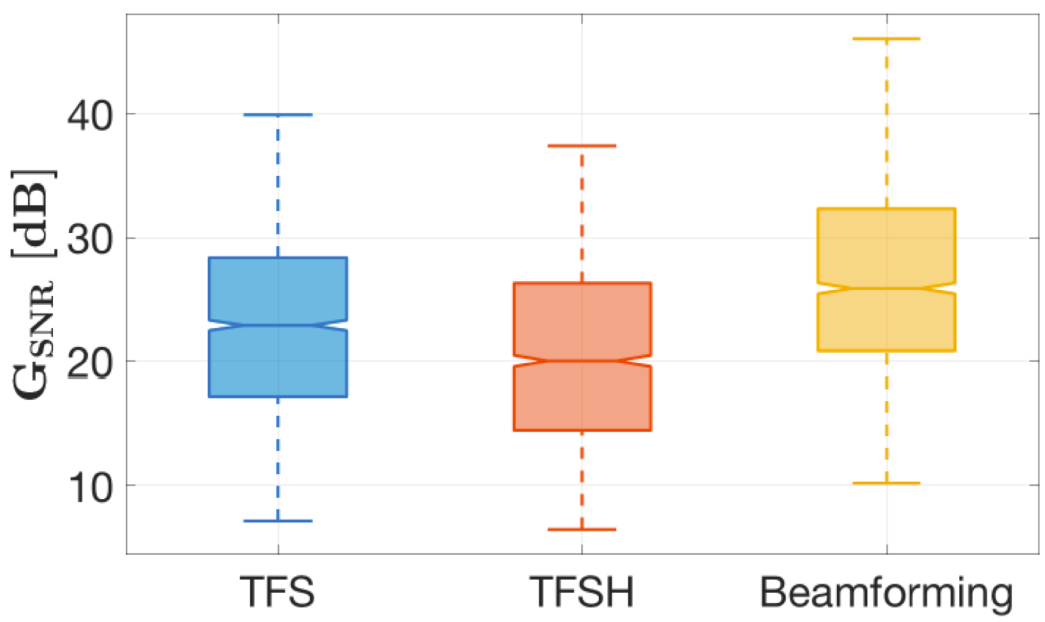
Beamforming – low-end reference



Moore, Alastair H., et al. "Binaural mask-informed speech enhancement for hearing aids with head tracking." *2018 16th International Workshop on Acoustic Signal Enhancement (IWAENC)*. IEEE, 2018.

Distortion and SNR gain





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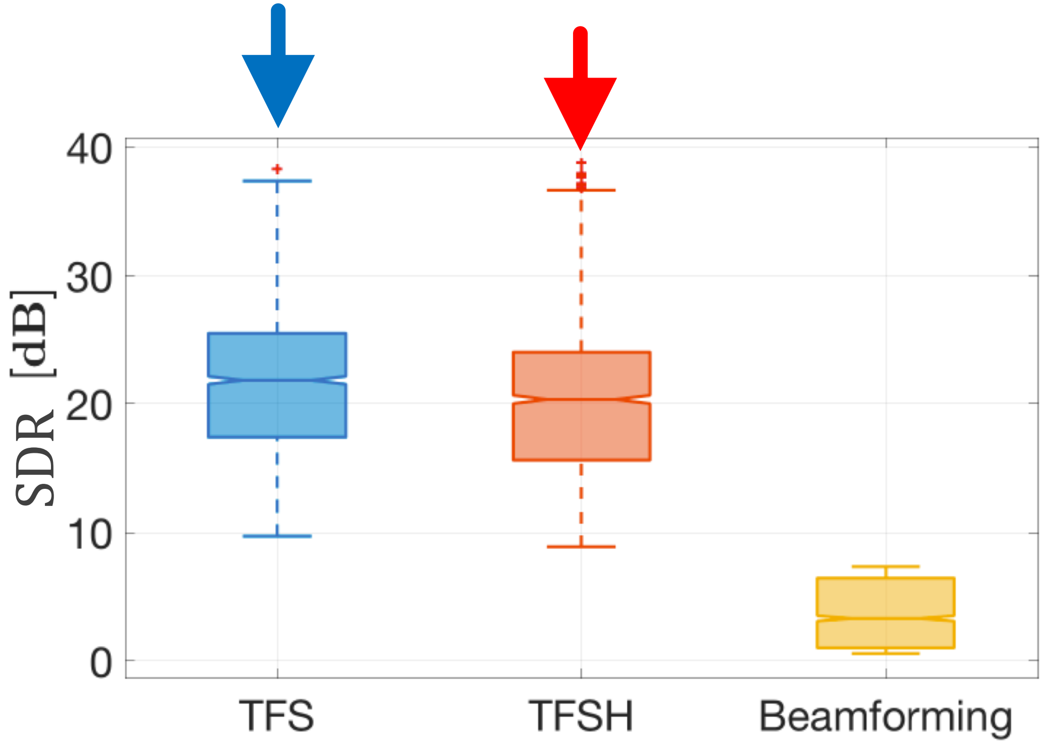

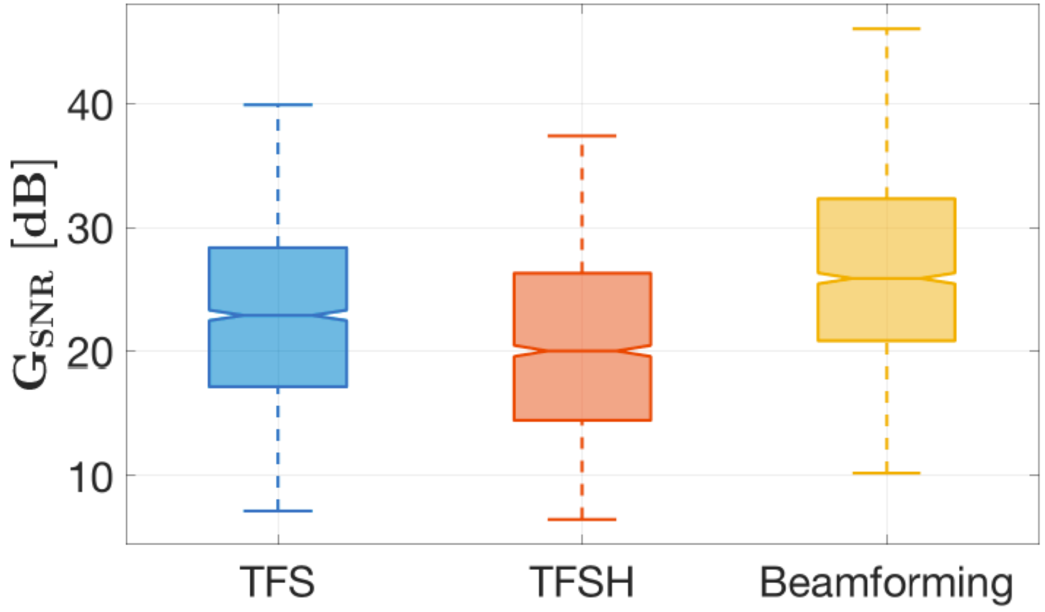

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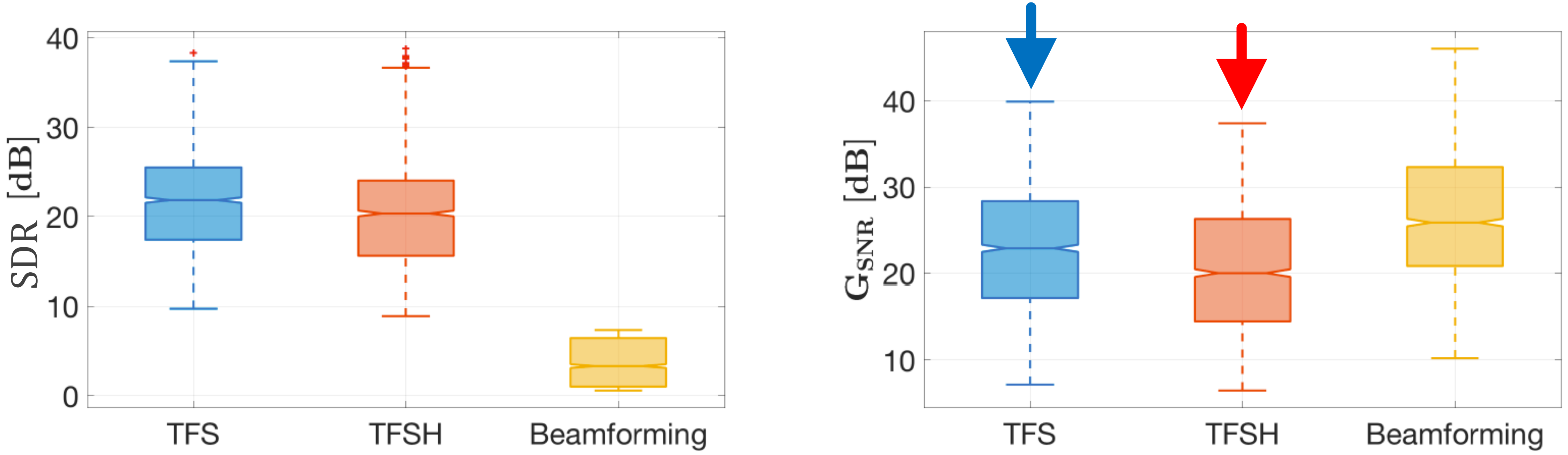

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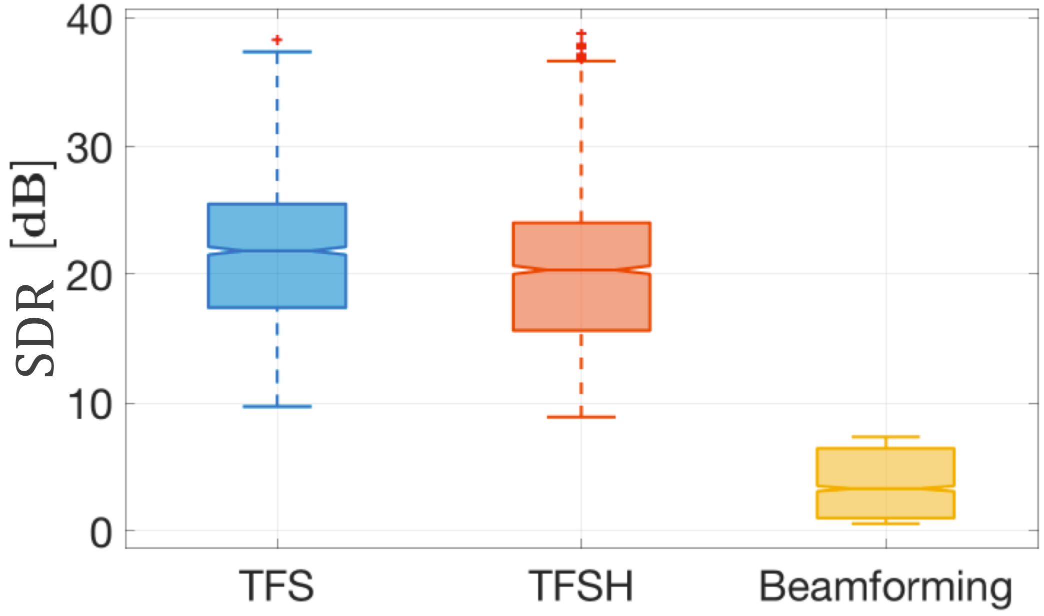

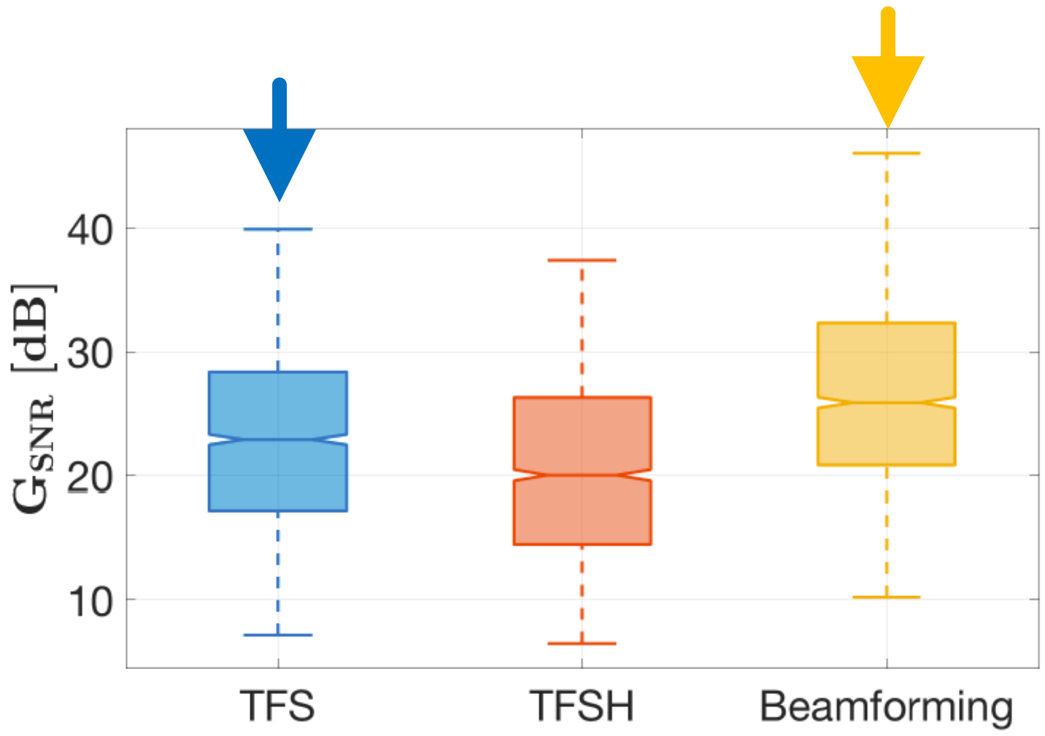

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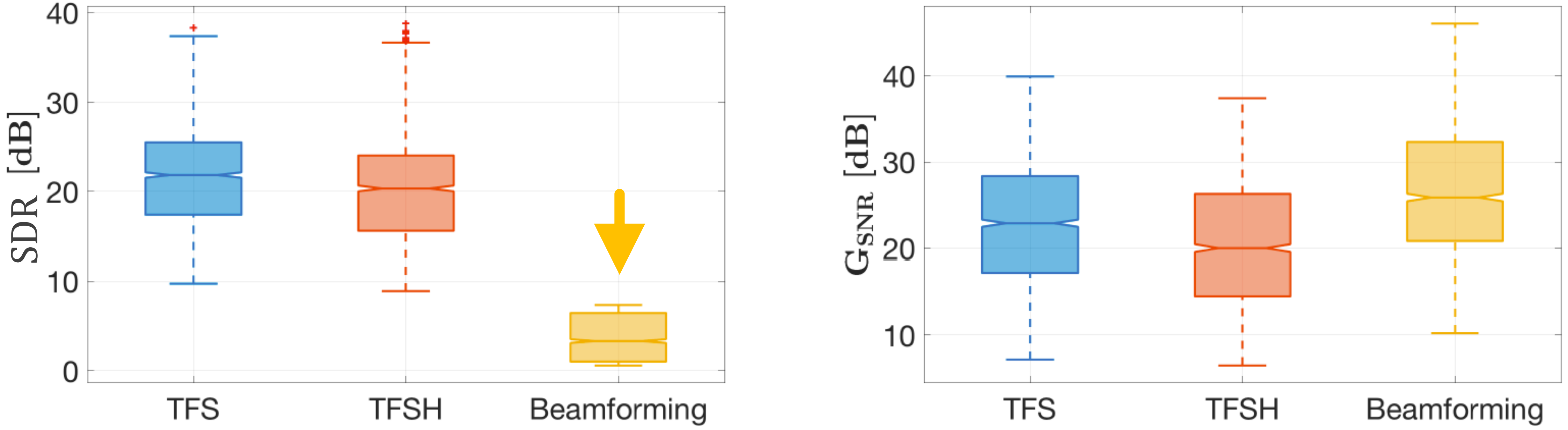

IACCt and ILD of the residual noise

- The same methods are applied only to the undesired sound field:
  - TFS
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  - Reference - unprocessed sound field generated by the noise source

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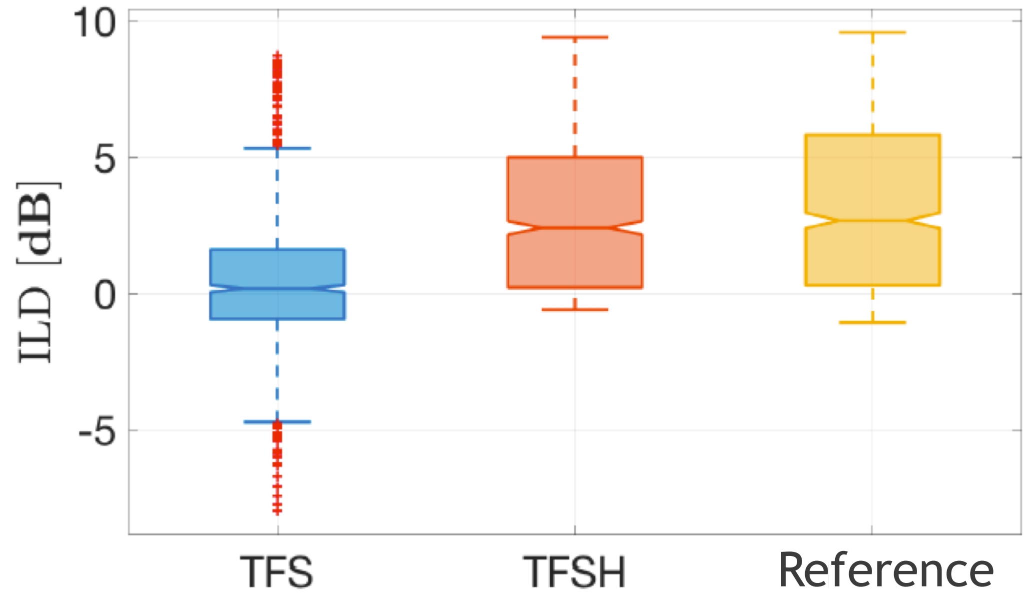

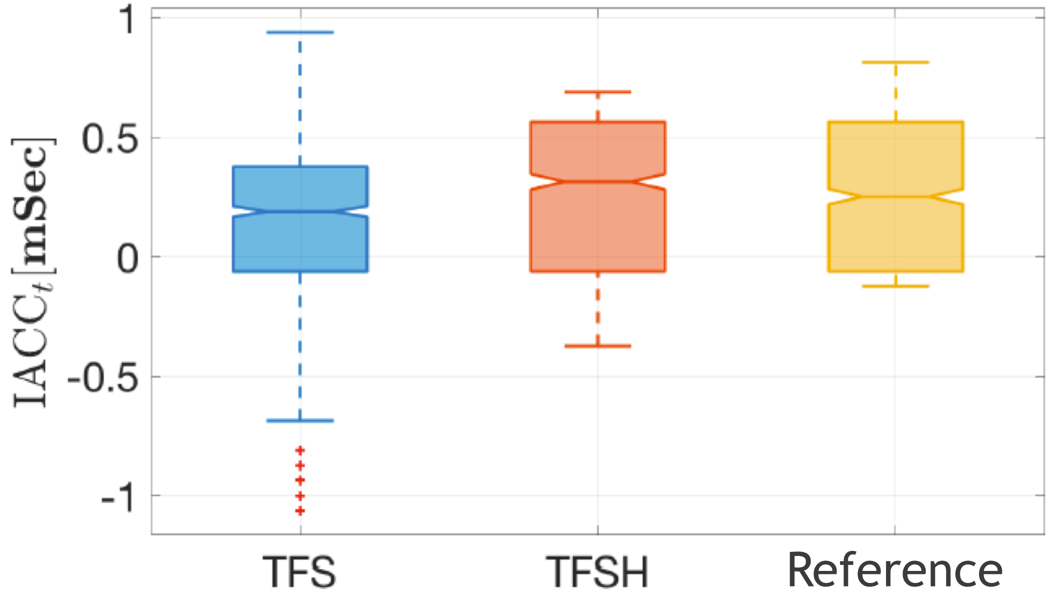

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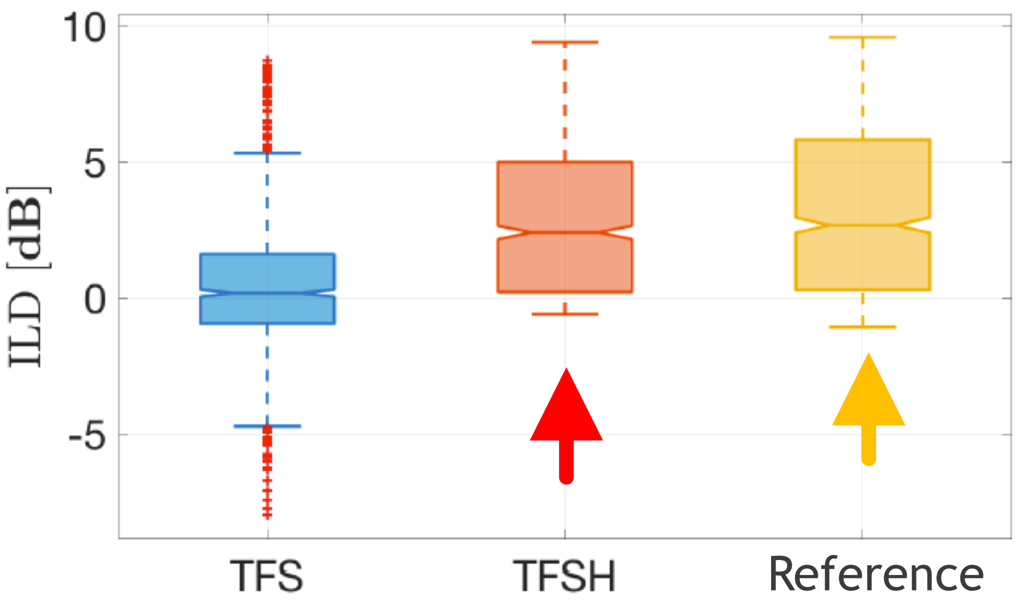
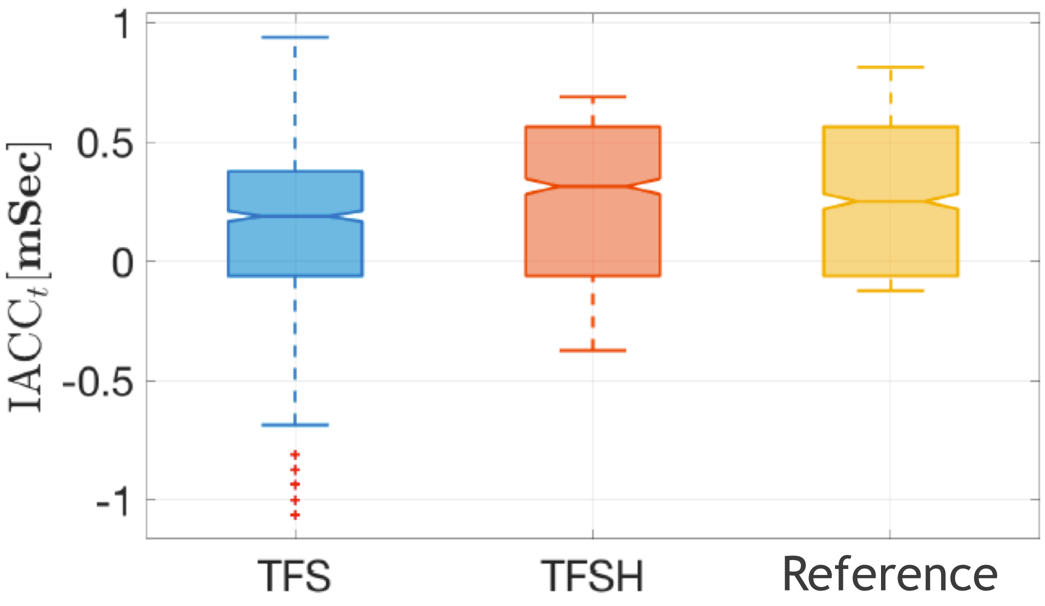
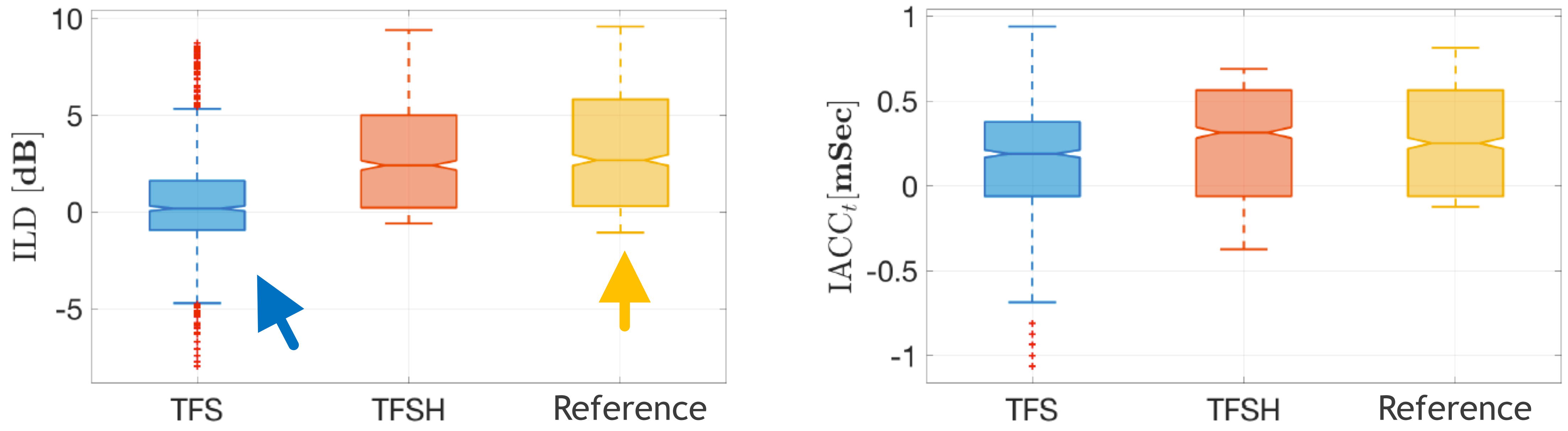
  - TFSH
  - Reference - unprocessed sound field generated by the noise source





IACCt and ILD of the residual noise

- The same methods are applied only to the undesired sound field:
  - TFS
  - TFSH
  - Reference - unprocessed sound field generated by the noise source



Listening tests

- Two listening tests were conducted
  - Listening test 1 – overall quality
  - Listening test 2 - residual noise DOA
- The results of these tests are correlated to the objective analysis
- Details in the paper

Conclusions

- The TFS method:
  - Preserves the desired sound field better than the TFSH method
  - May change the DOA of the residual noise
- The TFSH method:
  - Preserves the DOA of the residual noise
  - The preservation of the desired sound field depends on acoustic parameters

Thank you!