Generalised Sidelobe Canceller for Noise Reduction using an External Microphone

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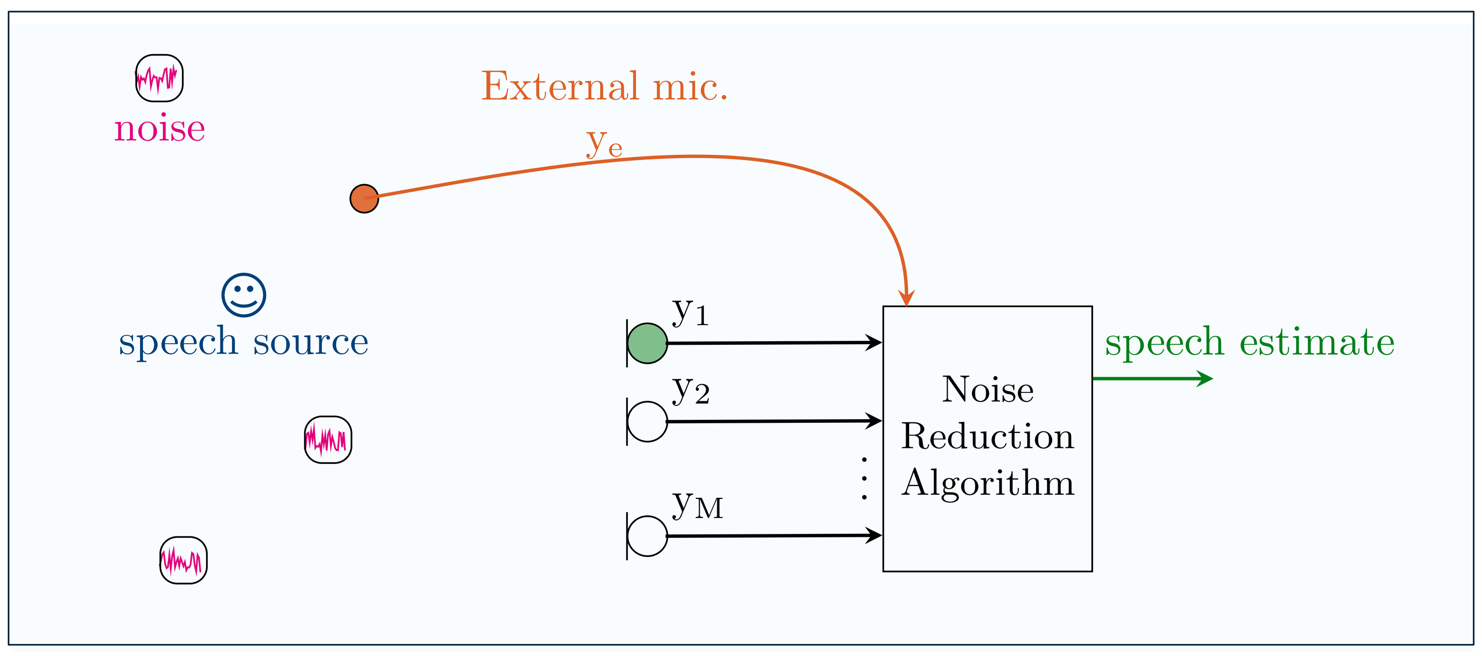
Noise Reduction Problem



STFT Model

$$\mathbf{y}(k,l) = \mathbf{h}(k,l)s_1(k,l) + \mathbf{n}(k,l)$$

$$\mathbf{y} = \begin{bmatrix}\mathbf{y_a} \\ y_e\end{bmatrix} \quad \mathbf{h} = \begin{bmatrix}\mathbf{h_a} \\ h_e\end{bmatrix} \quad \mathbf{n} = \begin{bmatrix}\mathbf{n_a} \\ n_e\end{bmatrix}$$

Local Mic. Array Signals

External. Mic. Signal

Processing with Local Mic. Array (LMA)

MVDR Beamformer (MVDR-LM)

- Minimise noise, while preserving response in specified direction

$$\mathbf{w_a} = \frac{\mathbf{R}^{-1}_{\mathbf{n_a n_a}}\tilde{\mathbf{h}}_\mathbf{a}}{\tilde{\mathbf{h}}^H_\mathbf{a}\mathbf{R}^{-1}_{\mathbf{n_a n_a}}\tilde{\mathbf{h}}_\mathbf{a}}$$

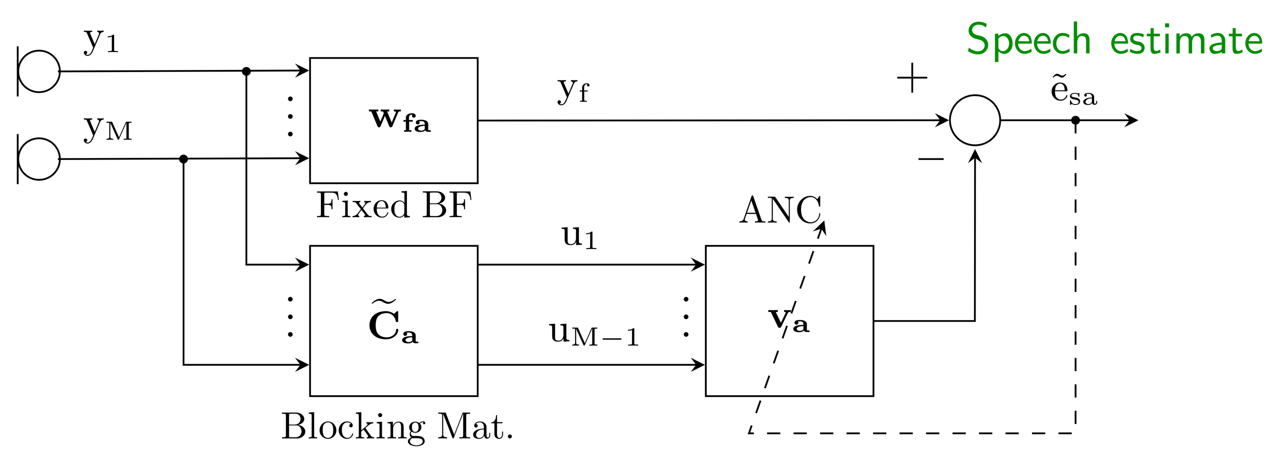
M x M Noise correlation matrix

RTF vector for LMA

Speech estimate ⟶ $\tilde{s}_a = \mathbf{w}^H_\mathbf{a}\mathbf{y_a}$

GSC – Adaptive Implementation (GSC-LM)

- Define fixed beamformer and blocking matrix from $\tilde{\mathbf{h}}_\mathbf{a}$
- Adaptive filter to minimise noise



Inclusion of an External Microphone (XM)

MVDR-XM

$$\mathbf{w} = \frac{\mathbf{R}^{-1}_{\mathbf{nn}}\hat{\mathbf{h}}}{\hat{\mathbf{h}}^H\mathbf{R}^{-1}_{\mathbf{nn}}\hat{\mathbf{h}}}$$

(M+1) x (M+1) Noise correlation matrix

New RTF vector w/ XM contribution

- Position of XM relative to array is generally unknown, hence:
  - i) Estimate entire RTF vector OR
  - ii) Preserve existing processing with LMA, and only estimate RTF component for XM

$$\hat{\mathbf{h}} = \begin{bmatrix}\tilde{\mathbf{h}}_\mathbf{a} \\ \hat{h}_e\end{bmatrix}$$

M x 1 vector known from LMA

1 component to estimate

- Use the speech estimate from the MVDR-LM as a speech ref.
- Least squares estimate with XM signal

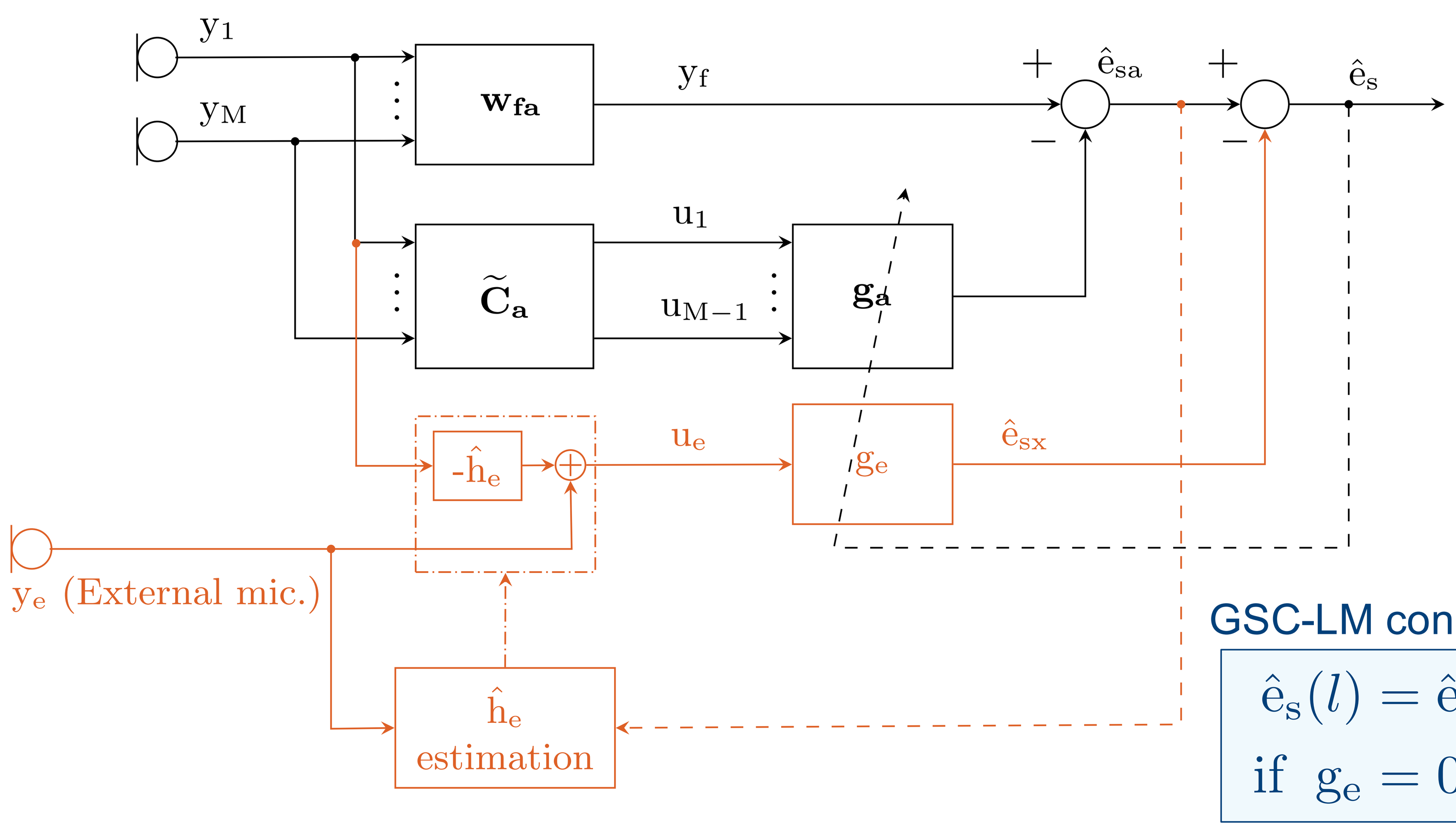
$$\min_{\hat{h}_e} \mathbb{E}\{|\hat{h}_e\tilde{s}_a - y_e|^2\} \longrightarrow \hat{h}_e = \frac{\mathbb{E}\{y_e\tilde{s}^*_a\}}{\mathbb{E}\{\tilde{s}_a\tilde{s}^*_a\}}$$

GSC-XM

- Use Fixed BF from MVDR-LM – satisfies distortionless constraint
- Use $\hat{e}_{sa}$ or y_f as a speech ref. to update $\hat{h}_e$ in speech only periods
- Use $\hat{h}_e$ to form additional noise reference

Speech estimate:

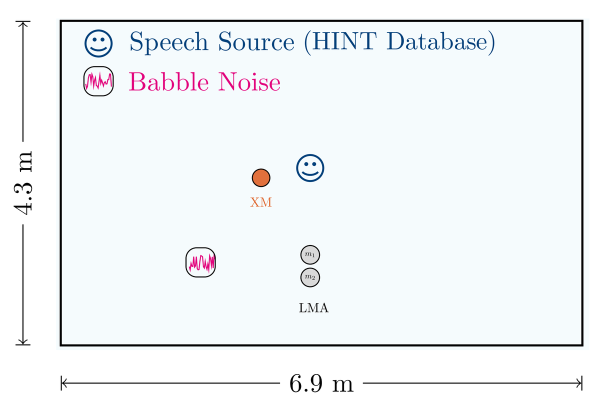
$$\hat{e}_s(l) = \underbrace{y_f(l) - \mathbf{g}^H_\mathbf{a}(l)\tilde{\mathbf{C}}^H_\mathbf{a}(l)\mathbf{y_a}(l)}_{\text{speech reference, } \hat{e}_{sa}(l)} - \underbrace{g^*_e(l)(y_e(l) - \hat{h}_e(l)y_1(l))}_{\text{XM contribution, } \hat{e}_{sx}(l)}$$



GSC-LM condition:

$$\hat{e}_s(l) = \hat{e}_a(l) \quad \text{if } g_e = 0$$

Simulations and Conclusions



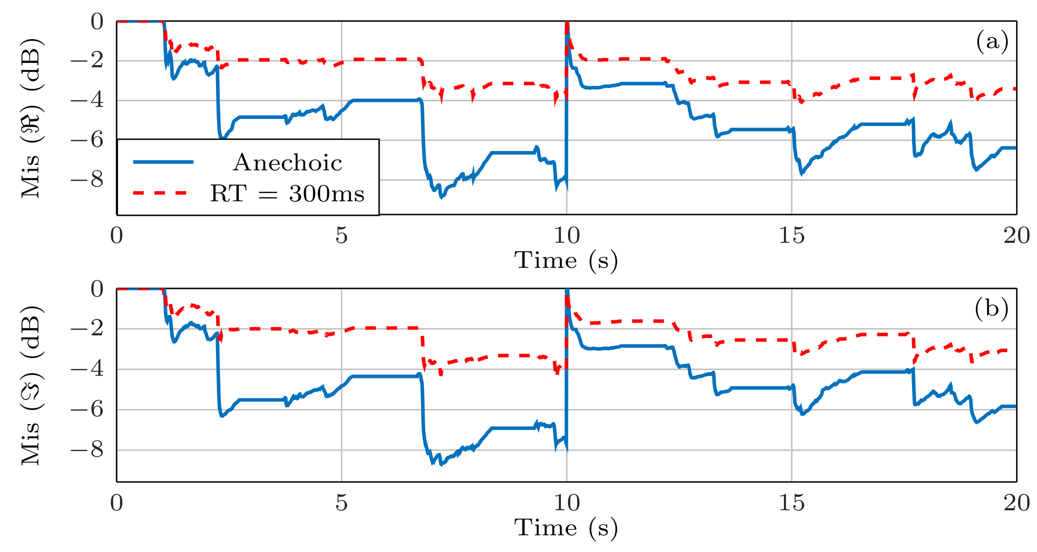
- LMA = 2 mics. w/ 1 cm spacing. 1 XM
- fs = 16kHz, nFFT = 256, WOLA method
- XM moved from 56 cm to 31 cm away from source after 10 s.
- SI-SNR @ m1 = 4 dB.
- Anechoic + Reverberant scenarios
- $\tilde{\mathbf{h}}_\mathbf{a}$ – Anechoic definition from end fire direction

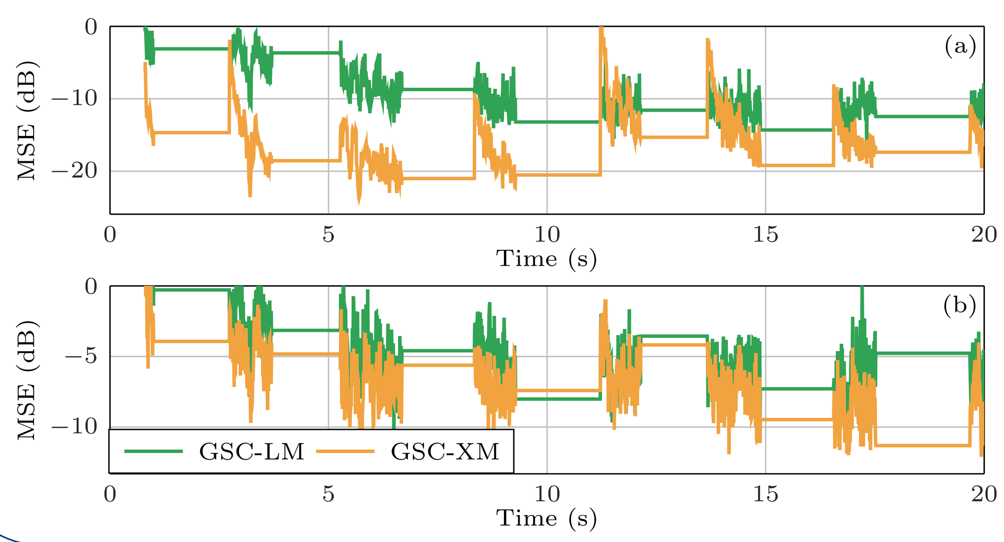
Misalignment of $\hat{h}_e$

(a) Real parts

(b) Imaginary parts

$$\text{Mis (dB)} = 10\log_{10}\frac{\sum_{k=1}^{K}|\bar{h}_e(k) - \hat{h}_e(k)|^2}{\sum_{k=1}^{K}|\bar{h}_e(k)|^2}$$





Mean Square Error (MSE)

(a) Anechoic

(b) RT = 300ms

$$\text{MSE (dB)} = 10\log_{10}\sum_{k=1}^{K}|\hat{e}_s(k)|^2$$

(in noise only periods)

Conclusions

- GSC-XM can be considered as an add-on to GSC-LM, requires:
  i) RTF estimation procedure ii) Additional noise reference
- GSC-XM ≥ GSC-LM, can adapt to XM changes
- Can revert to GSC-LM if desired.

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