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Beamforming in Binaural Hearing Aids

Effect of quantization errors

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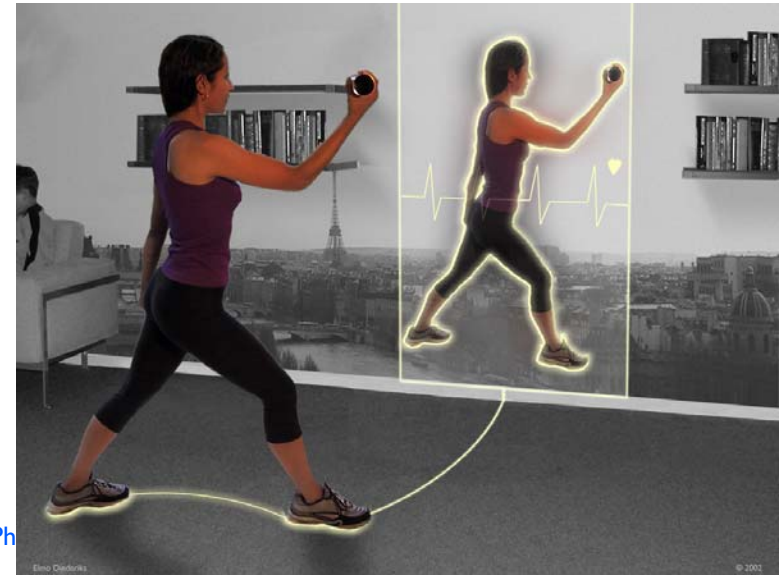


Carelab

Binaural hearing aids

- Small battery operated devices - perform amplification, noise reduction etc.
- Only 1 out of 5 people who could benefit from a hearing aid wears one
- Recent interest in binaural solutions – two collaborating hearing aids form a body area network






Images from Starkey Inc.

Speech enhancement in hearing aids

- Intelligibility of speech in noise among most sought after features by hearing aid users

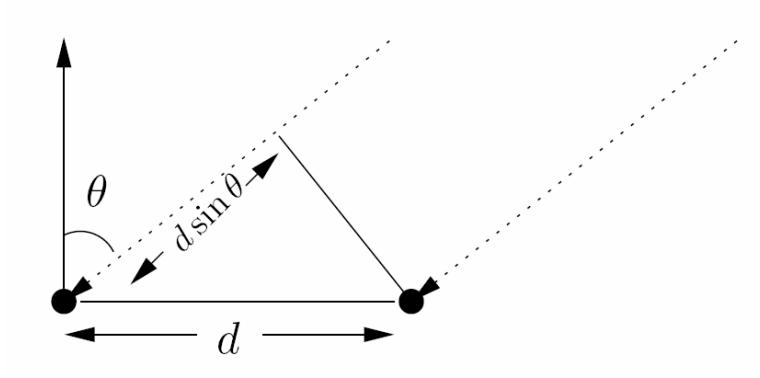
- Single-microphone enhancement improves speech quality, but not necessarily intelligibility

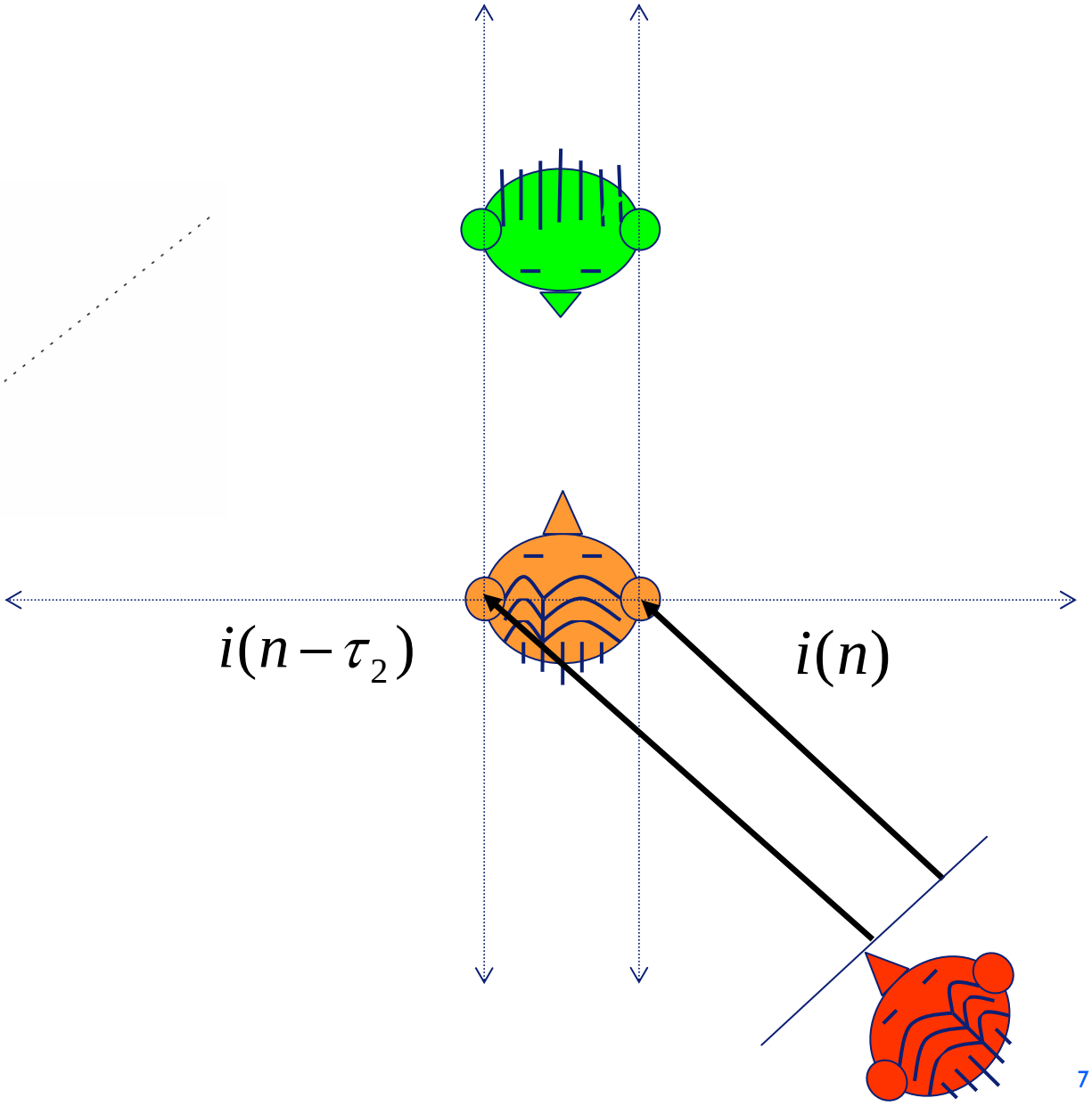
- Multi-microphone adaptive beamforming is promising

Binaural system - challenges

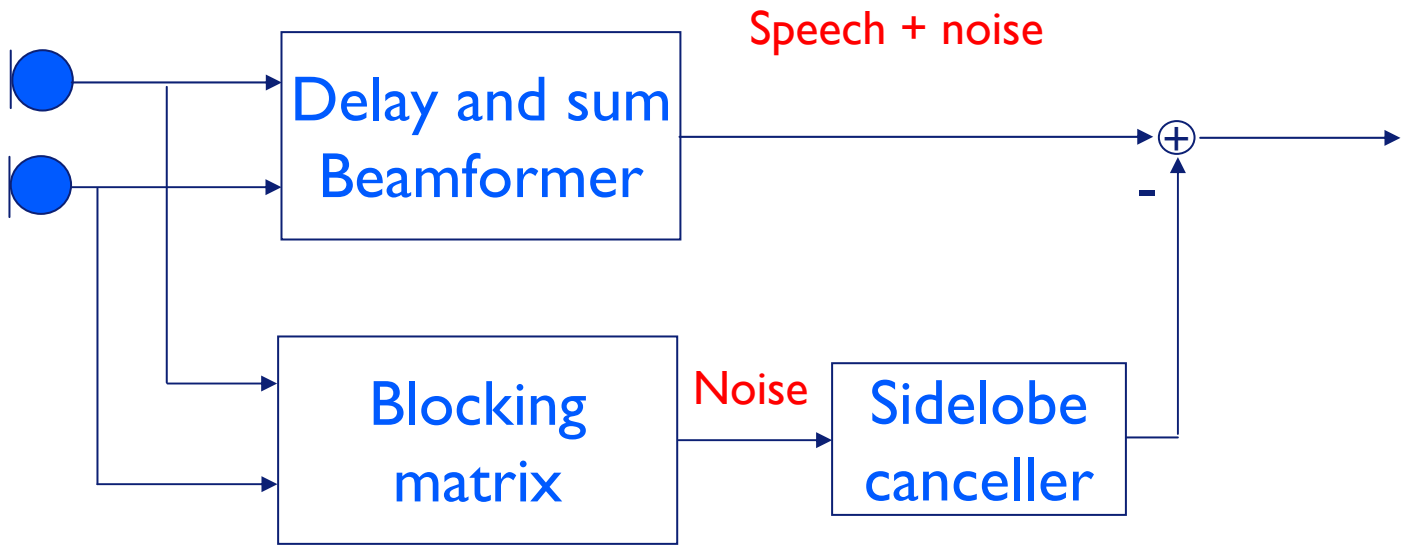
- Wired connection not feasible due to aesthetic reasons
- Bandwidth constraints
- Power constraints
- So, we look at effect of quantization errors

Signal model





Beamformer – Generalized sidelobe canceller (GSC)



The GSC – a closer look

- Signal model

$$x_1(n) = s(n) + i(n) + u_1(n)$$
$$x_2(n) = s(n - \tau_1) + i(n - \tau_2) + u_2(n)$$

- Beamformer – delay and sum

$$\frac{x_1(n - \tau_1) + x_2(n)}{2}$$

Desired signal is preserved

- Blocking matrix – delay and subtract

$$x_1(n - \tau_1) - x_2(n)$$

Speech free noise reference

GSC under quantization errors

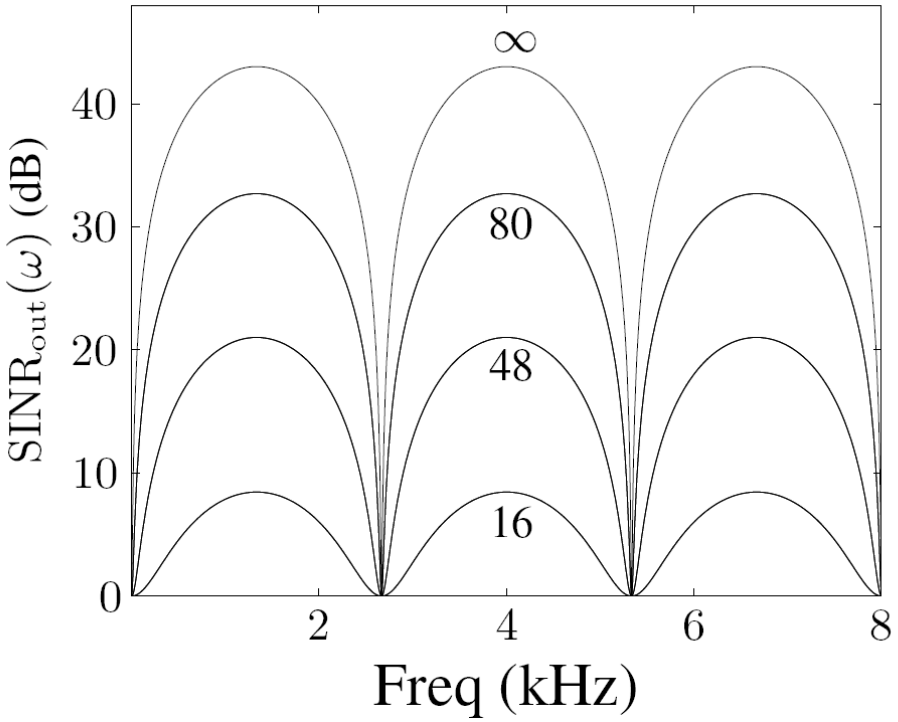
- Left ear device quantizes and transmits signal to right ear device
- Signal received at right device suffers from quantization errors
  - Desired signal in beamformer output is suppressed
  - Noise reference is no longer free from desired signal

Performance analysis

- Desired source at 0 deg., interferer at 40 deg., microphones separated by 20 cm.
- Assume Gaussian sources: R(D) well defined
- Study dependency on signal-to-interference ratio (SIR) and signal-to-noise ratio (SNR)
- Measure output signal-to-interference-plus-noise ratio (SINR)

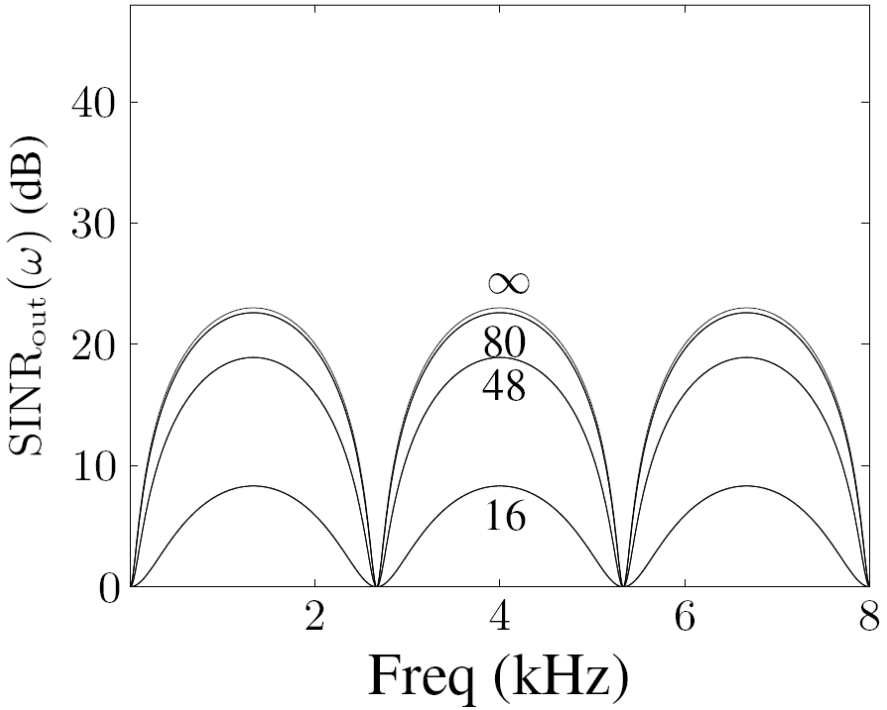
GSC performance at different bit rates

- Input SIR 0 dB, SNR 40 dB ⟹ SINR ~ 0 dB
- Output SINR (dB) at different bit rates (kbps)
- Nulls correspond to spatial aliasing



SNR dependency

- Input SIR 0 dB, SNR 20 dB (higher level of uncorrelated noise)
  - ➡ SINR ~ 0 dB
- Other conditions as in previous case

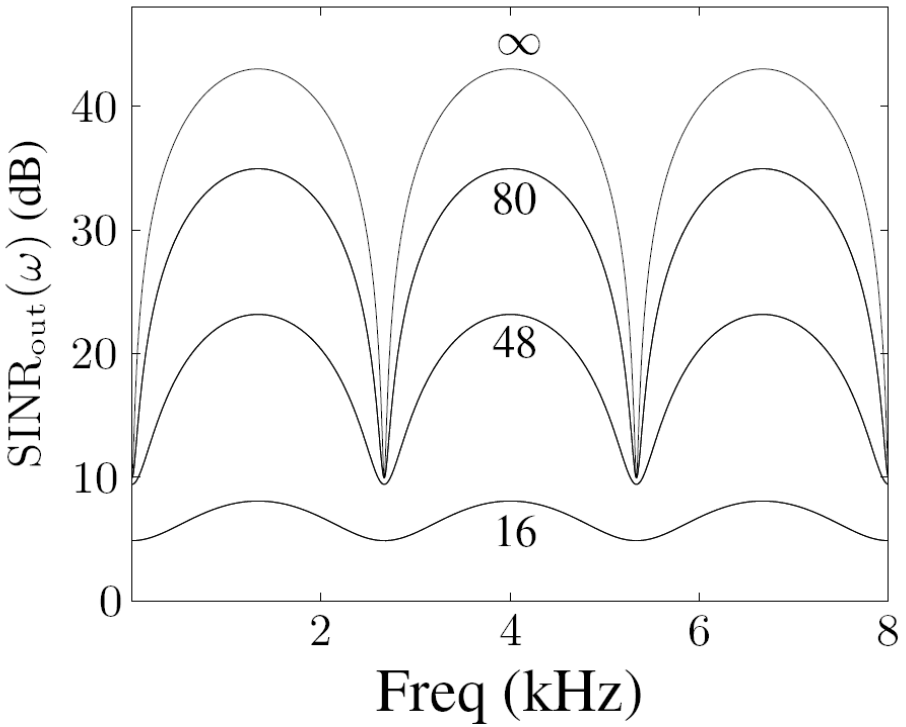


SIR dependency

- Input SIR 10 dB, input SNR 40 dB (interfering signal is less strong)

  ⟹ SINR ~ 10 dB

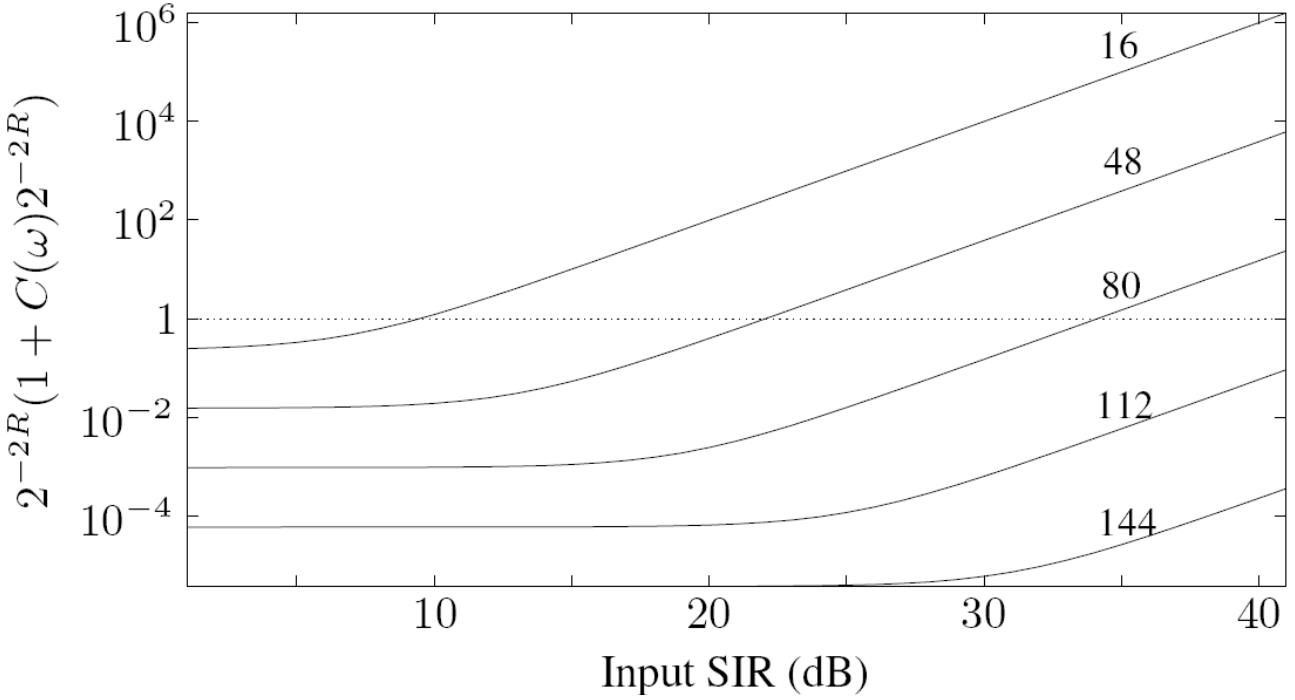
- At low bit rates, there is a decrease in performance!



Minimum bit rate to avoid degradation

To ensure SINR improvement, we need

$$2^{-2R}(1 + C(\omega)2^{-2R}) \leq 1 \quad \text{where} \quad C(\omega) = \frac{1}{2}\,\frac{\left(\sigma_s^2/\sigma_i^2\right)^2 - 1}{1 - \cos\omega(\tau_i - \tau_s)}$$



Conclusions

- At low input SINRs, good performance even at low bit rates, e.g., 16 kbps
- Higher bit rate needed at higher input SINRs
- Binaural beamforming is promising!
- Future work: reverberant environments, preservation of binaural cues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Incorporating a head shadow model

- SIR 0 dB, SNR 30 dB
- Nulls are not as sharp
- Dotted curve represents monaural system