Array microphones in hearing aids

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Problem: Hearing in Noise

- **Signal-noise-ratio (SNR)**
  - Relative difference in dB between a sound of interest and a background of noise
  - Individuals with typical hearing require a positive SNR for easy communication
  - Individuals with cochlear or neural hearing loss require a more positive SNR to approach similar speech recognition
Solution: Directional Microphones

- Directional microphones pick up sounds from a desired direction more effectively than from other directions, improving the SNR in noisy environments.

The desired signal

The noise
Conventional wisdom

- Directional microphones are the only proven way to increase SNR with a wearable hearing aid (without adding external accessories such as remote microphones or FM).
- If SNR can be increased, speech intelligibility can improve.
- Directional microphones don't eliminate all of the noise, but their benefit is well substantiated by research under laboratory conditions.

Why use directional microphones?

- Increasing signal-to-noise ratio (S/N or SNR, that is, the level of speech relative to the level of noise)
- Can improve word recognition
- Addresses that number one complaint: speech intelligibility in noise

Improving SNR gives you a lot of bang for your processing buck. About 10% improvement in intelligibility per dB!
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Recorded September 12, 2012

**Directional Microphone**

Directional Microphone Technology
- Clinically proven as most effective way to provide speech intelligibility in background noise.

**Microphone Polar Patterns**

- Polar directivity plots, typically measure in an anechoic chamber, are graphic representations of the effectiveness of a directional system.
- The concentric circles represent decreasing signal level relative to the outer circle, calibrated in dB.
The null in each pattern shows the position and degree of the greatest directional effect. For example, a cardioid pattern has a null at 180 degrees, in this case ~25 dB down from the outer ring. In another example, a supercardioid pattern has two nulls at about 120 and 240 degrees azimuth.

The directivity index or DI is a simple single-measure for comparison. The DI is the ratio of energy from a sound straight ahead to the energy of sounds from all directions. Expressed as the decibel improvement in signal-to-noise ratio over that expected for an omnidirectional microphone.
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Microphone Polar Patterns

- Super- or hypercardioid polar patterns have a DI approaching 6.0 dB, the maximum achievable in a first-order directional system
- Good DI in diffuse noise environments

Common Types of Directional Designs

1: Differential (passive or acoustic) directional system

- One mic with two ports
- Acoustic resistance in rear port creates a delay
- Sound from the rear to the forward port is delayed by the port separation distance
- When internal delay equals external delay, the pressures to the membrane are oppositional and cancel

Anatomy of a Differential Directional Microphone
Anatomy of a Differential Directional Microphone

External time delay

Common Types of Directional Designs
2: Electrical dual-omni directional system

- Two omni mics
- Signal from rear port is delayed electrically or digitally
- Summed electrical signals from front and rear mics cancel each other when input is from the rear
- Allows for adjustable polar patterns by altering phase of signals

Common Types of Directional Designs
Both types use a delay-and-sum method
Inherent limitations

- Normal variations in temperature and humidity cause microphone drift and mismatches, which can compromise directional performance of some dual omni systems
- Debris occlusion of microphone ports has been shown to be a major factor in compromising directional microphone performance of all design types

Example of Sensitivity Mismatch in a Dual-OmniSystem

Hypercardioid Pattern  Degraded Pattern due to 0.6-dB Sensitivity Mismatch

Polar nulls are loq DI drops by 2 dB

Example of Sensitivity Mismatch in a Dual-OmniSystem

Hypercardioid Pattern  Degraded Pattern due to Phase Mismatch: 1°

Lobe shifts in wrong direction
Considerations

- Microphone mismatch isn’t a problem we expect in all systems, but it underscores some design limits that the delay-and-sum method offers.
- Different designs may bring us better beam forming, and better high frequency responses.
- Polar plots shown are 2D and in a free field. We live in a 3D world with hearing aids worn on and in the ear.

3D Analysis

- Designed to be worn on the human head (torso).
- ANSI S3.35 requires directional analysis at only 48 points.

3D Analysis

- More precise analysis is by analyzing 614 directional points.
  - KEMAR rotates in 10 degree steps.
  - Speaker rotates in 10 degree steps.
  - Measures 200 – 10,000 Hz.
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What Do We Know About typical Directional Microphones?
- They have been around for a long time
- They work
  - In 1984, two independent labs reported a positive signal to noise ratio benefit when comparing hearing aids with omnidirectional microphones to directional microphones.

Hawkins DB, Yacullo WS. Signal-to-noise ratio advantage of binaural hearing aids and directional microphones under different levels of reverberation. J Sp Hear Disorders. 1984;49,278-286
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But…
- 1. Directional microphones work better in the test booth than they do in everyday listening situations.
- 2. Environmental acoustics often limit the effectiveness of directional microphones in everyday listening.
- 3. Directional microphones work effectively only when a specific set of environmental conditions exists.
- 4. The omnidirectional mode is the appropriate default setting for most hearing-impaired patients.


Directional Mic needs:
- Best Directivity Index (DI) possible
- Tighter directional beam
- Good high frequency response in noise
- Mechanical design for utility of use and cosmetic appeal
- Manual switching capability and good switching algorithms
- Manageable current drain

If we use directional mics…
Birth of the microphone array 1917

- H.C. Hayes

Dr. Harvey C. Hayes (1878 - 1960) | US Navy Experimental Station
1917-1918 | New London, CT

- Submarine Detection
- Gun-Range Vessel
- Range to Target
- Eliminate Own Ship Noise
- No amplifiers

USN Jouett

Fig. 1. Hayes's new Eel sonar system, 1917.

USS Jouett in 1912

12 hydrophones in each of the towed arrays
Switching and comparing acoustically determined angle and distance
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Towed Array
Several miles long.
2000 hydrophones.
Hundreds of miles away!

Bow Array
12,000 hydrophones
Active array
Passive array
Chin array
Circa 1990
Simple delay and sum techniques don't work in such a complicated system. The sensitivity of each microphone is adjusted or "shaded" to fine tune the response and to accommodate for reflections from the hull of the ship.

Sounds reflected from the hull of the ship are effectively ignored by fine tuning the response, allowing for accurate beam formation.

Meanwhile, back at the pass...

"Head'em off at the pass?"
Slippery Rock: Goleta, CA
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Meanwhile, still trying to hear in noise...

• 2000: Starkey Labs introduces the Radiant Beam Array
  • Six mics
  • 8.1 to 10.7 DI
  • Inductive coupling to hearing aids
  • Not a commercial success
  • Consumers said "pass!"

...and still trying...

• 2002-2003: Etymotic research introduces the Link-IT
  • Inductively coupled to aids
  • Good performance
  • Not a commercial success
  • Consumers said "pass!"

Meanwhile, back to hearing aids...

• 2002: Siemens introduces the Triano 3
  • First 3 mic array in a conventional hearing aid form-factor
  • There was interest that sparked some interesting research
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Question 1: directional better than omni? (Stationary noise)

Question 2: Adaptive vs. fixed; 2 mic vs. 3? (moving noise)

Question: Which mode preferred?
Adaptive polar patterns or not?

- "...an adaptive advantage may be seen in cases of noise that arrives from a fairly discrete angle, especially in cases for which the noise is placed to the side(s) of the listener." (Ricketts, 2005)
- "Adaptive processing is unlikely to provide any benefits in reverberant situations in which the noise lies well beyond the critical distance." (Dillon, 2012)
- "...when the SNR is good, adaptive processing can decrease the SNR if adaptation occurs when the speech is present." (Dillon 2012)

2 microphone systems are technically arrays

- Lobe or null may be steered depending on goal of algorithm
  - Null is steered to avoid noise
  - Lobe is steered to (off axis) desired signal
  - Some select front to back; others offer left, right, front or back
2 microphone systems are technically arrays

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Ear to ear streaming brings other possibilities

- Reduce mic input on noisy side; stream signal from opposite side to offer bilateral input of desired signal

2010: wireless plus directional mics

- Phonak StereoZoom
- Binaural beamforming
- In Situ performance is good
- Designed for “as needed” use
- Requires ear to ear streaming and associated power consumption
- Expect to see other manufacturers offering binaural beamforming in the next year
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Bilateral directional processing

- Produces highly directional beams by combining inputs from both sides of the head
- Respects phase relationships to preserve localization
- Is dependent upon low power requirements, wide bandwidth, and an efficient bidirectional wireless link along with high speed processing ability
- We will see continual improvements in the near term as these requirements are met and enhanced

2012 - 2013

- Multi port array mics in 13 battery BTE or 312 RIC
- Very good Free field DI
- In-situ DI better than other available products in class
- Mechanical design allows for function and cosmetics on the ear; better reliability and performance
- Very good high frequency DI
- Will not use simple delay and sum techniques, but will employ some of the same techniques developed for submarine systems to produce a robust directional response

Q&A

To ask a question, please type your question into the chat box in the lower left corner of the screen and click on the “Send” button located right below the box.
Thank you!

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