Directionality Characteristics
of the Tympan Open-Source Hearing Aid and Earpieces

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Methods

- When possible, followed procedures outlined in **ANSI/ASA S3.35-2021**
    - *"Method of measurement of performance characteristics of hearing aids under simulated real-ear working conditions"*

- **Pink Noise Stimulus**
    - ≈85 dB SPL at hearing aid mic location
    - 5-second duration
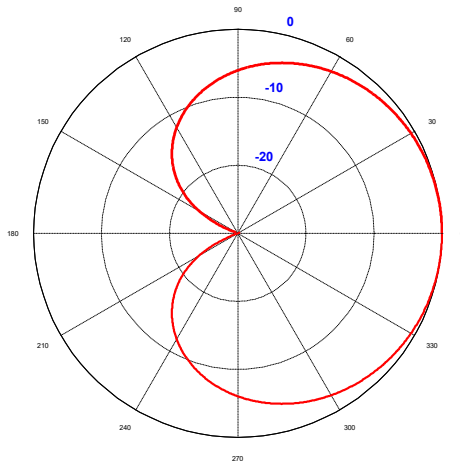   - Analyzed in 1/3-octave bands

Set up

- KEMAR centered in a double-walled sound booth (2.13 m x 2.44 m)
  - Rotated in 10° increments
  - **Left earpiece was tested**

- Hafler M5 Reference Monitor sound field loudspeaker
 - Flat frequency response

Test ear

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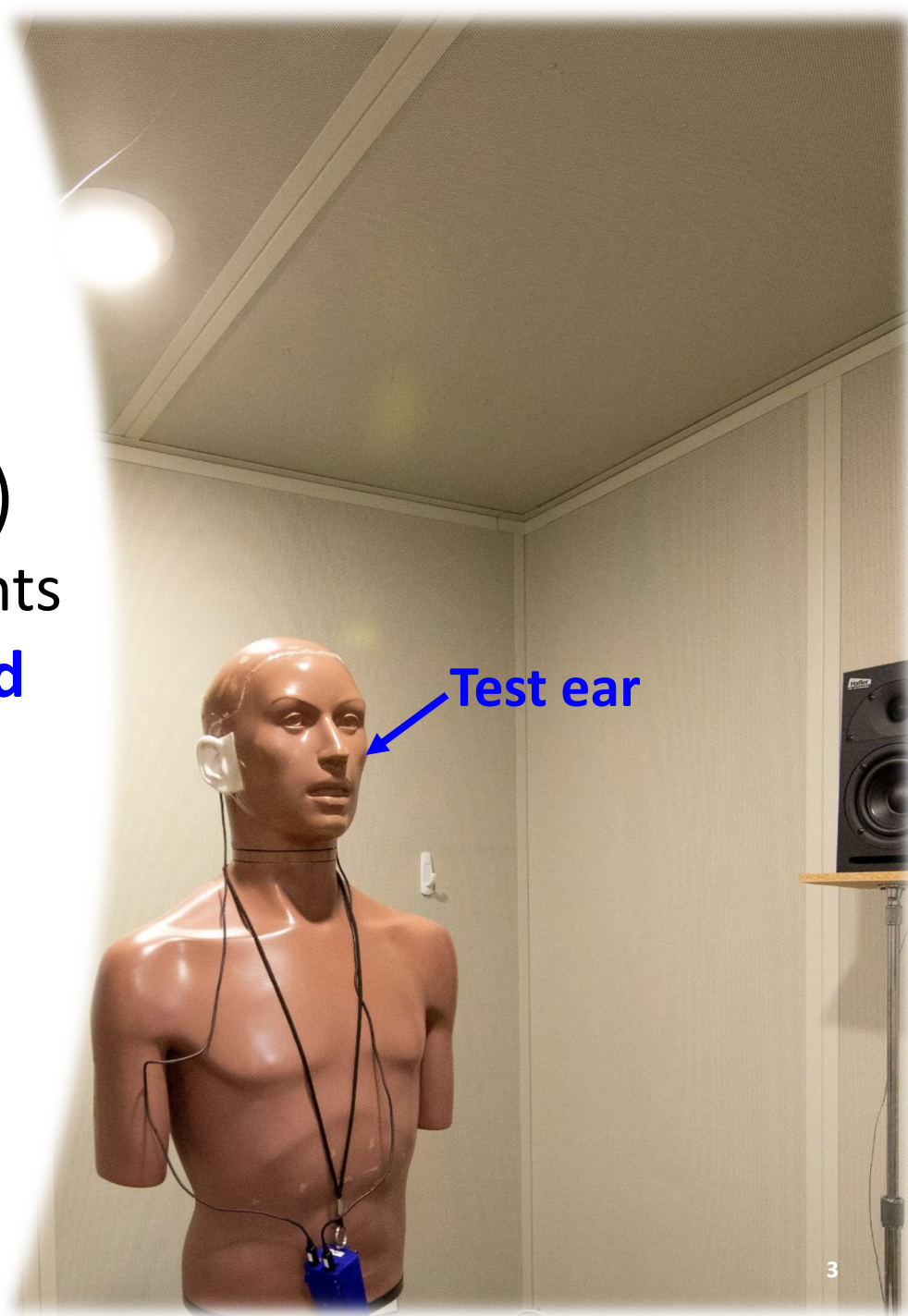
Earpieces

- 9.5-mm mic spacing (d)
  - $c \approx 343$ m/s
  - Travel time (d/c): 27.7 μs

- Sampling rate set to 36.1 kHz → 1-sample delay = d/c = 27.7 μs
  - Cardioid directivity

Microphone Matching

- Critical for optimal cancellation
  - **Rear mic output** was ≈ 5 dB lower than the **front mic**
    - 5 dB of gain was added to **match the two mics**

Comparison of Front and Rear Mic Output at 0 deg Azimuth
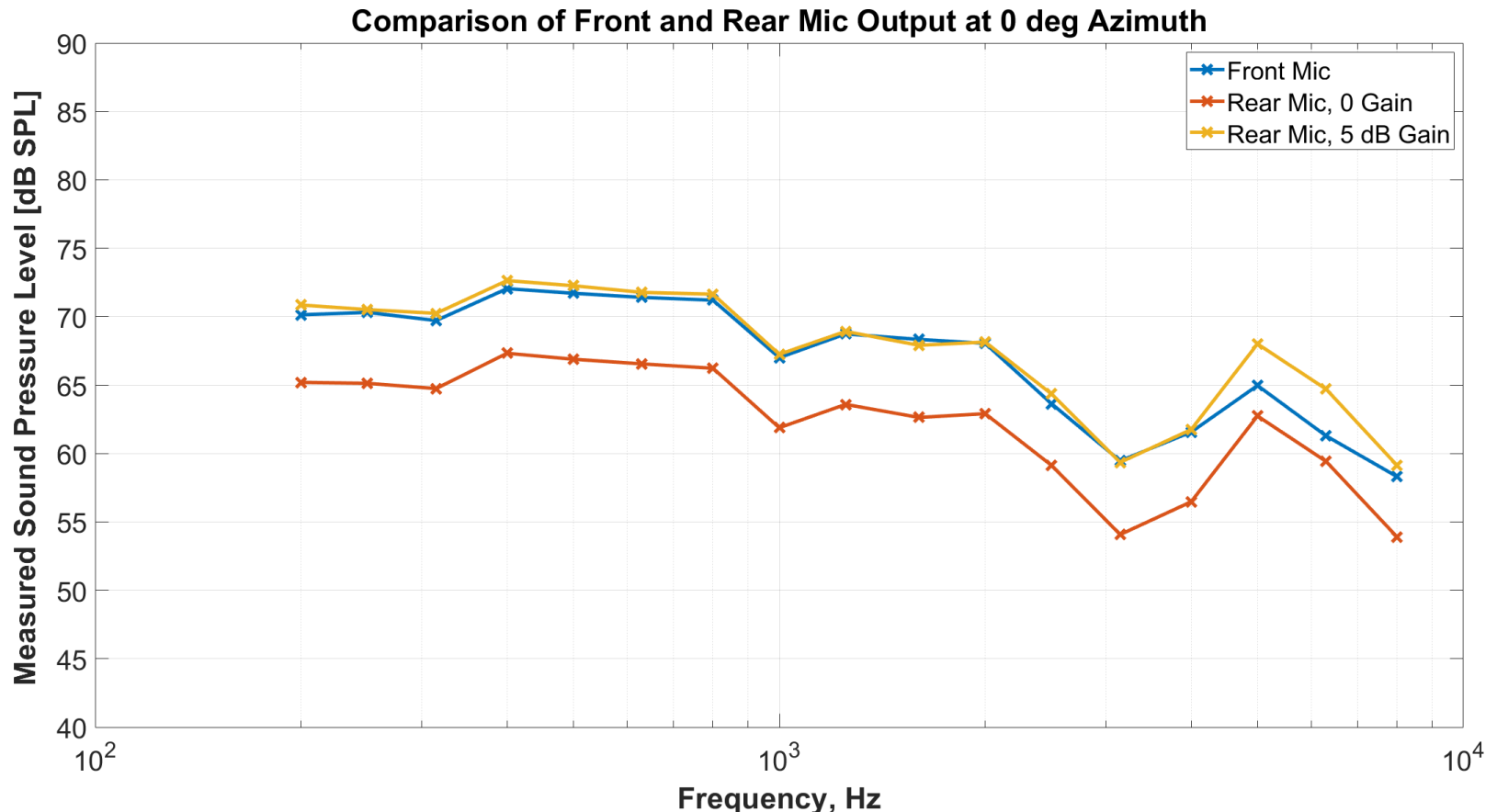
Omni-Directional Responses

- It is well-known that putting mics on the head will shift the response to the side due to head shadow
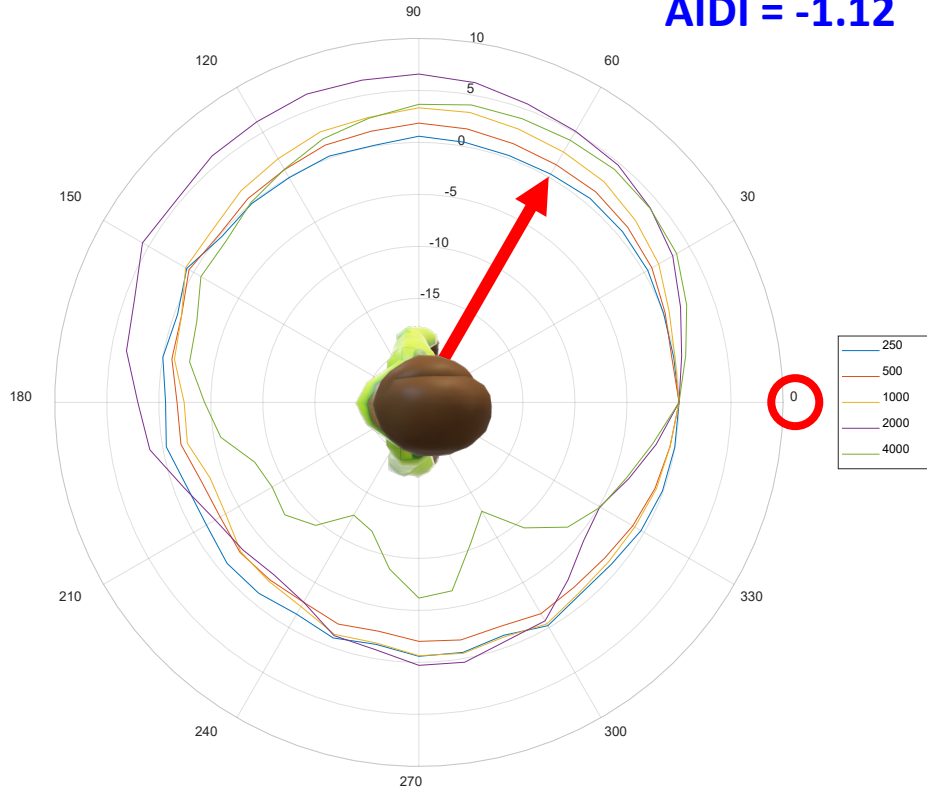
Front Mic (re 0°)

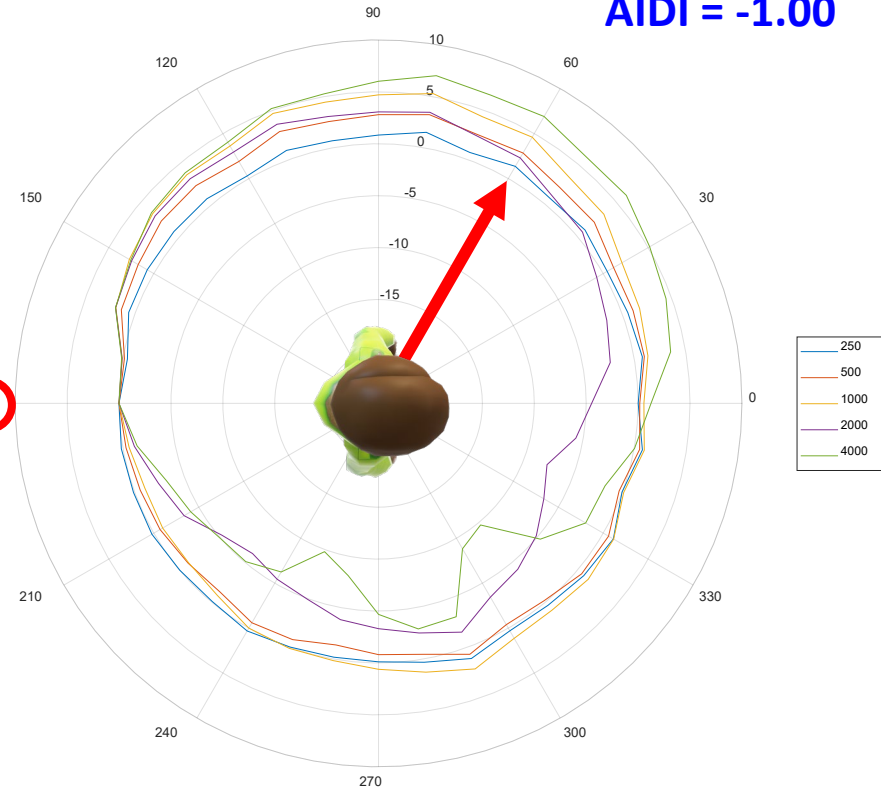Tympan Directionality - Left Side

Front Mic

0 dB Gain

AIDI = -1.12

Rear Mic (re 180°)

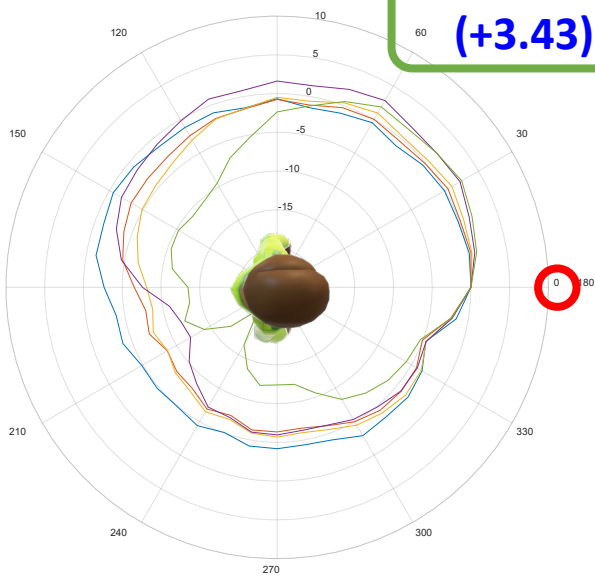Tympan Directionality - Left Side

Rear Mic

0 dB Gain

AIDI = -1.00

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Rear Mic Delay

0° reference

-3 dB Rear Gain

Tympan Directionality - Left Side
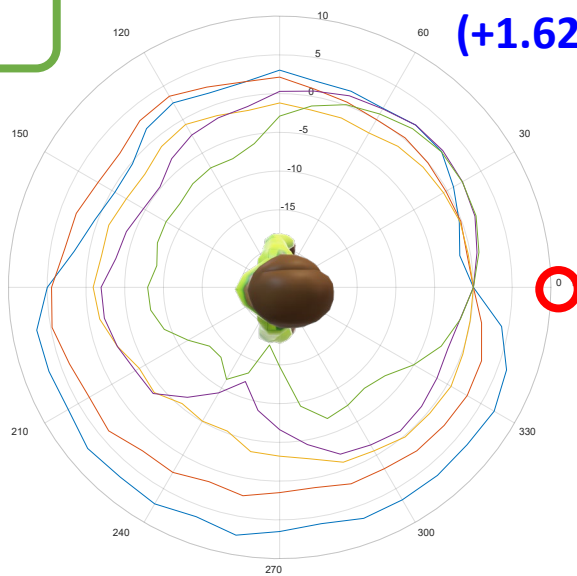1 sample Rear Delay
-3dB Rear Gain

AIDI = +2.31
(+3.43)

0 dB Rear Gain

Tympan Directionality - Left Side
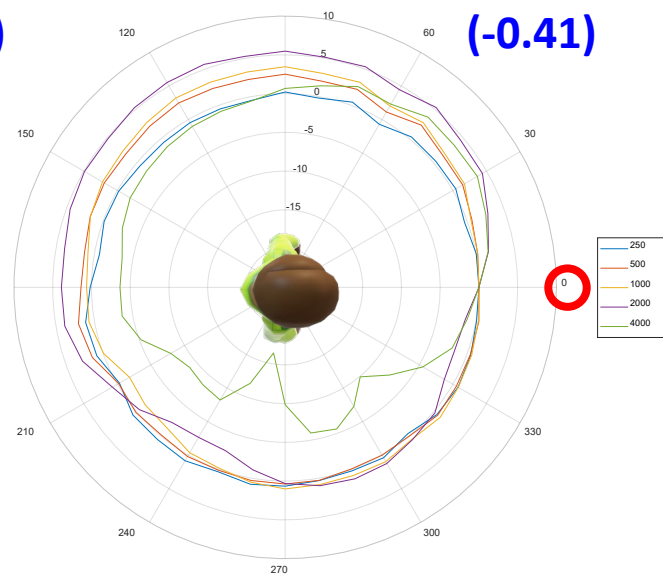1 sample Rear Delay
0dB Rear Gain

AIDI = +0.50
(+1.62)

+3 dB Rear Gain

Tympan Directionality - Left Side
1 sample Rear Delay
+3dB Rear Gain

AIDI = -1.53
(-0.41)

Legend: 250, 500, 1000, 2000, 4000

*Gain values after mic matching

AIDI was lowest with -6 dB and +6 dB rear mic gain

AIDI = Articulation Index weighted Directivity Index
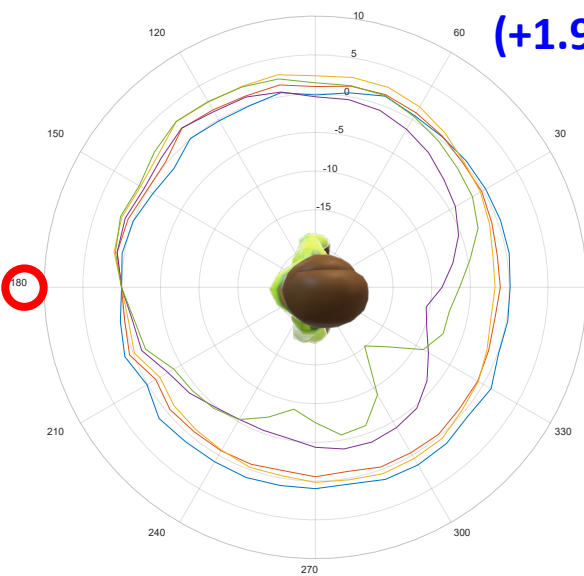values in () = **Improvement** re: front mic only

Front Mic Delay

← **180° reference**

-3 dB Front Gain

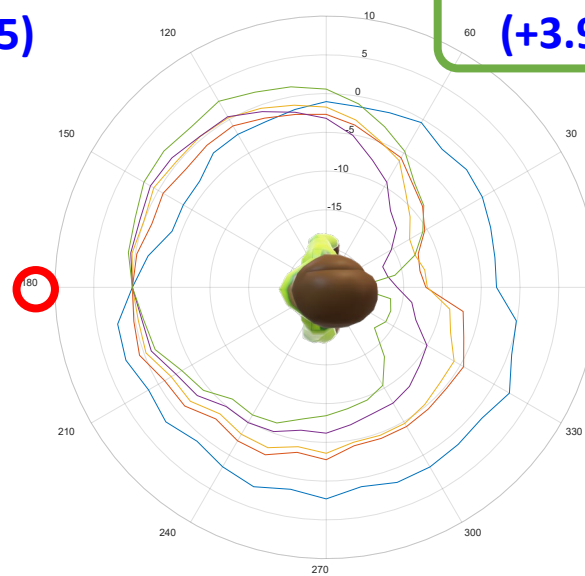Tympan Directionality - Left Side
1 sample Front Delay
-3dB Front Gain

AIDI = +0.95
(+1.95)

0 dB Front Gain

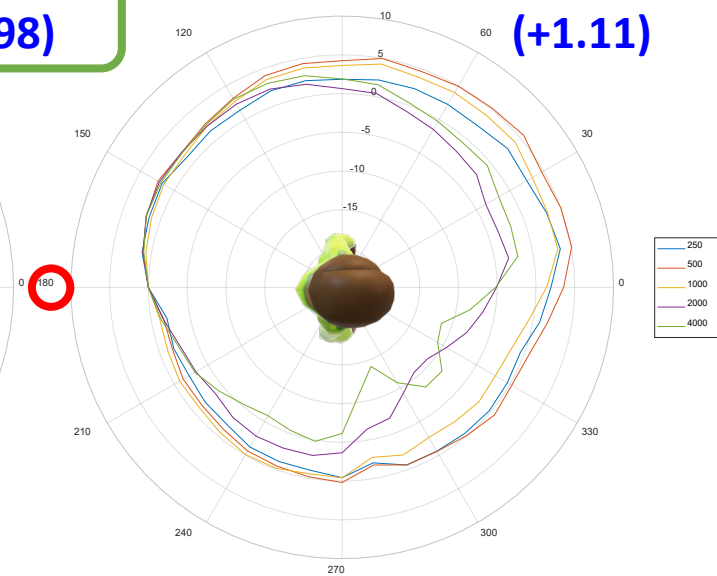Tympan Directionality - Left Side
1 sample Front Delay
0dB Front Gain

AIDI = +2.98
(+3.98)

+3 dB Front Gain

Tympan Directionality - Left Side
1 sample Front Delay
+3dB Front Gain

AIDI = -0.11
(+1.11)

*Gain values after mic matching

AIDI was lowest with -6 dB and +6 dB front mic gain

AIDI = Articulation Index weighted Directivity Index
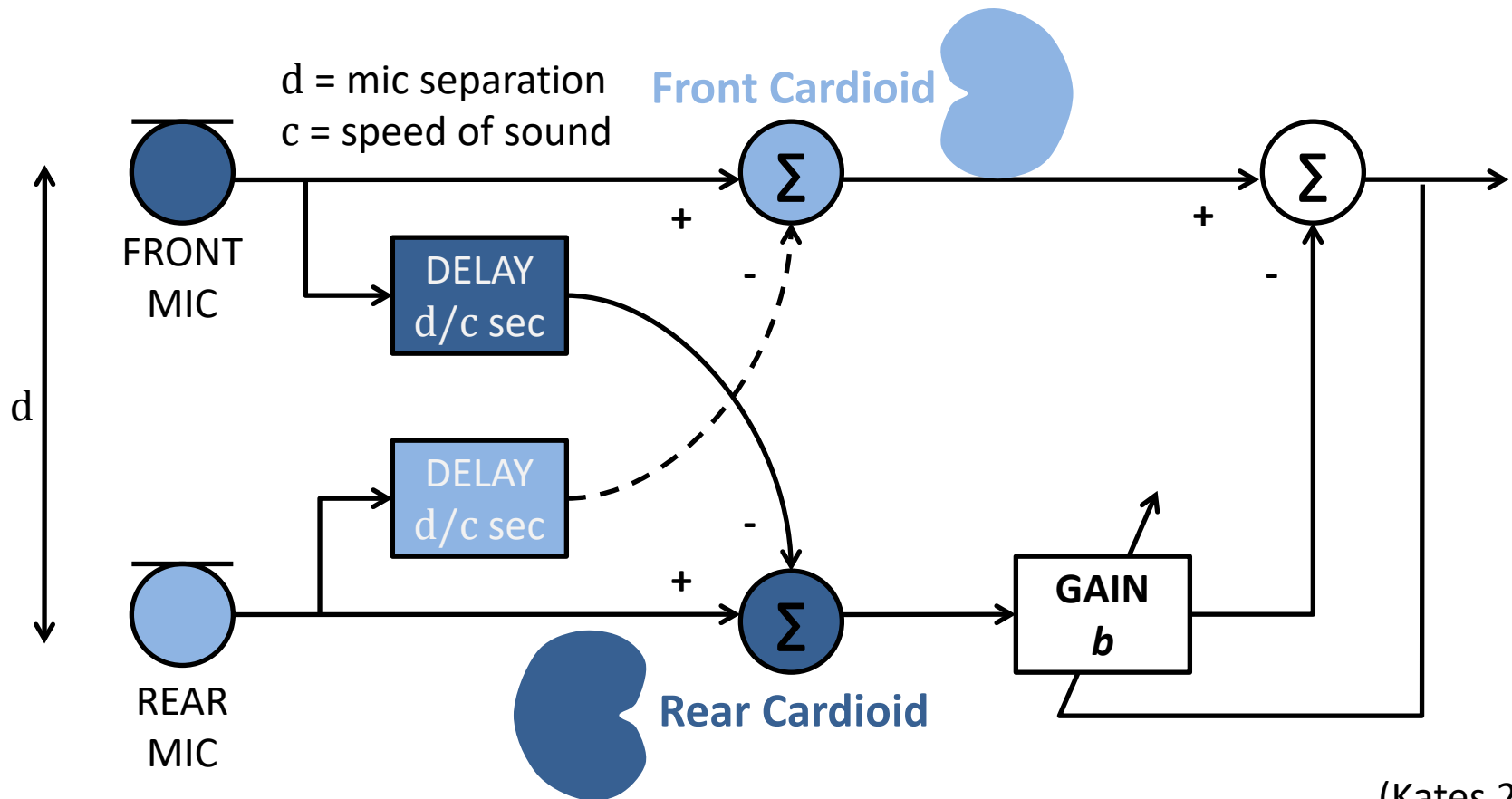values in () = **Improvement** re: rear mic only

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AIDI Improvement

- Front mic with rear mic delay and gain = -3 compared to front mic only (0° reference)

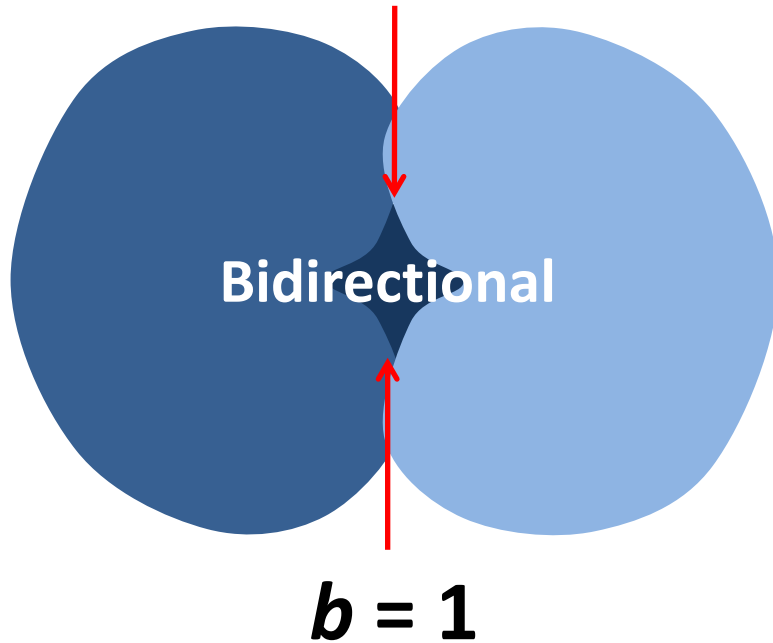- Rear mic with front mic delay and gain = 0 compared to rear mic only (180° reference)
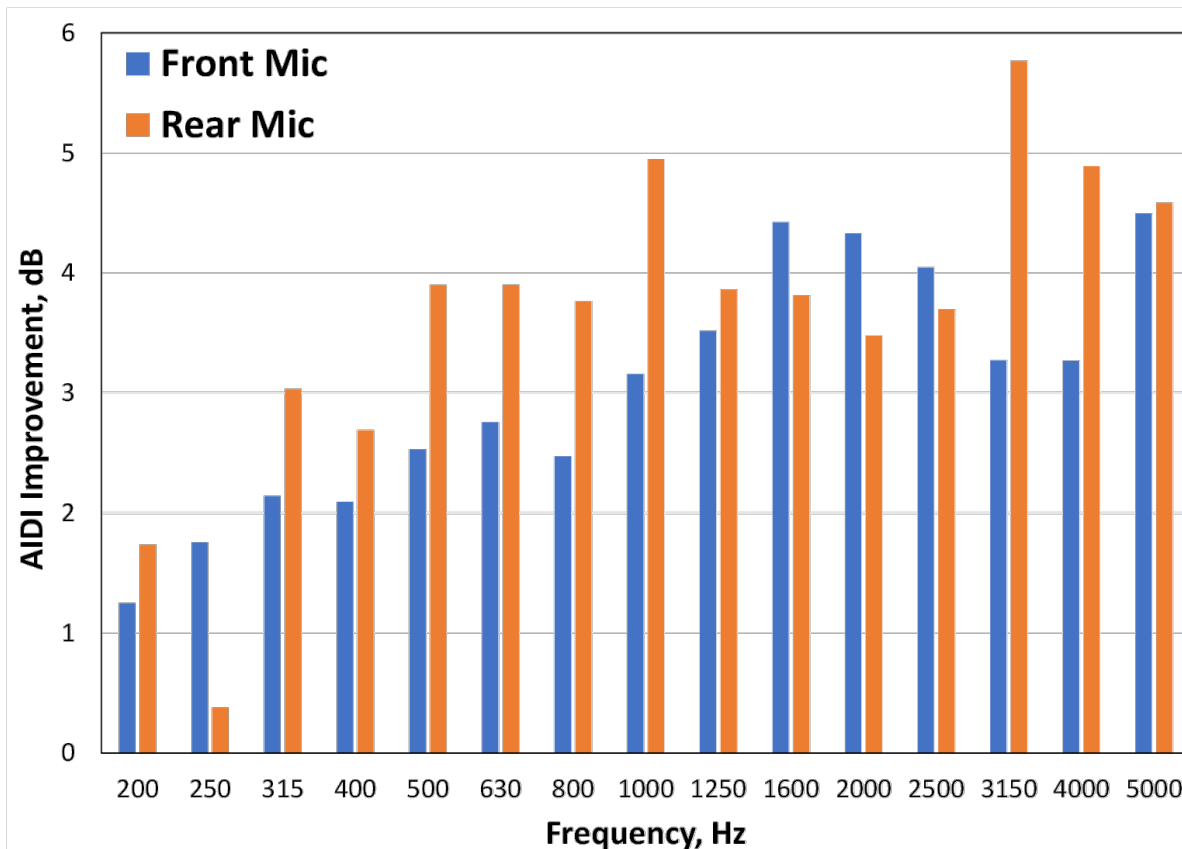
Future Directions: Variable Directionality

- **Step 1:** create opposing cardioid patterns
  - **Front facing**
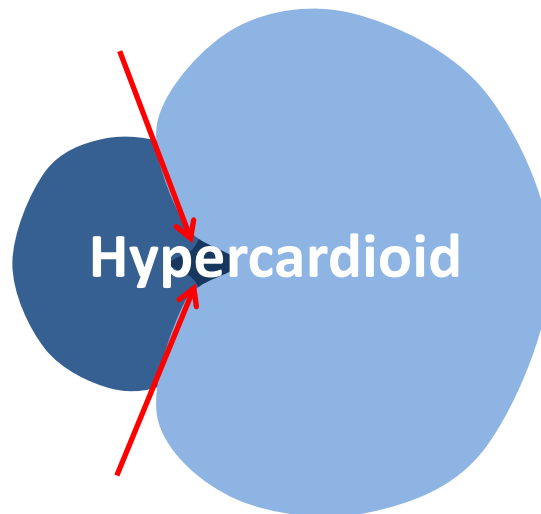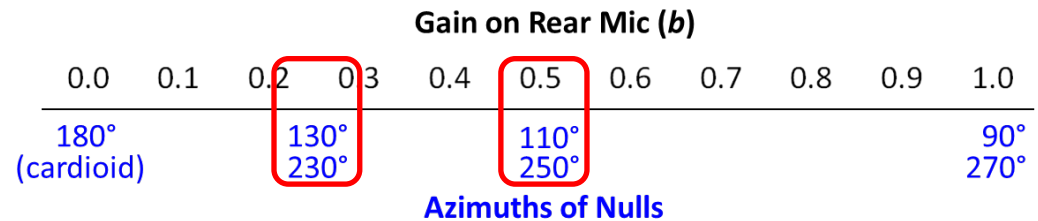 - **Rear facing: inverted phase and variable gain, *b***

d = mic separation
c = speed of sound

Front Cardioid

FRONT MIC

DELAY d/c sec

REAR MIC

DELAY d/c sec

Rear Cardioid

GAIN *b*

(Kates 2008)

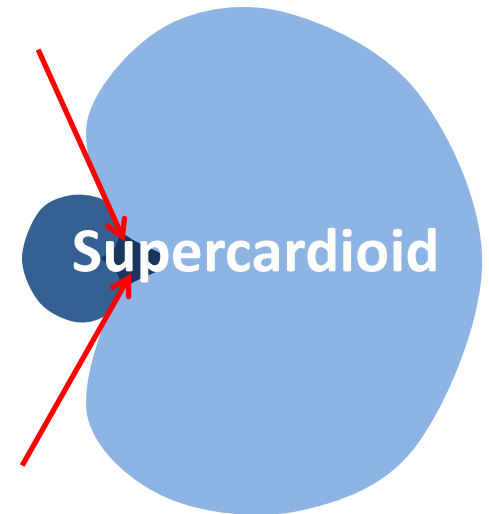# **Future Directions**: Variable Directionality

Bidirectional

b = 1

The **front** and **rear** responses **add with opposite sign**, thereby creating nulls where they intersect

- **Step 2:** vary relative gain *b* on rear cardioid to create different polar patterns with a continuous range of nulls

Gain on Rear Mic (*b*)

0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0

180°
(cardioid)

130°
230°

110°
250°

90°
270°

Azimuths of Nulls

Hypercardioid

b = 0.5

Supercardioid

b = 0.25

Conclusions

1. Optimized directionality requires **precise timing** (sampling rate) and **microphone matching**

2. Directional patterns and relative AIDI improvements (≈3-4 dB) are **consistent with published research**

3. **Optimal directivity**
   - Front cardioid obtained with -3 dB gain on the rear mic
   - Rear cardioid obtained with matched mic gain

4. **Future directions:** use optimized front and rear cardioids with opposite phase to **vary null with fixed and adaptive directionality**