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
Earpieces

- 9.5-mm mic spacing \((d)\)
  - \(c \approx 343 \text{ m/s}\)
  - Travel time \((d/c)\): 27.7 \(\mu\text{s}\)

- Sampling rate set to 36.1 kHz → 1-sample delay = \(d/c = 27.7 \mu\text{s}\)
  - 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
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°)

Rear Mic (re 180°)

AIDI = -1.12

AIDI = -1.00
Rear Mic Delay

0° reference

-3 dB Rear Gain

AIDI = +2.31
(+3.43)

0 dB Rear Gain

AIDI = +0.50
(+1.62)

+3 dB Rear Gain

AIDI = -1.53
(-0.41)

*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
AIDI = +0.95 (+1.95)

0 dB Front Gain
AIDI = +2.98 (+3.98)

+3 dB 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
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, $b$

\[ \sum \]

- **Front Cardioid**
  - $d = \text{mic separation}$
  - $c = \text{speed of sound}$

- **Rear Cardioid**

(Kates 2008)
Future Directions: Variable Directionality

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

### Gain on Rear Mic ($b$)

<table>
<thead>
<tr>
<th>$b$</th>
<th>0.0</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azimuths of Nulls</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>180° (cardioid)</td>
<td>130° 230°</td>
<td>110° 250°</td>
<td>90° 270°</td>
<td></td>
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</tbody>
</table>

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

- $b = 1$
- $b = 0.5$
- $b = 0.25$
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.