The Magic of Direct Drive:

••• What is it that makes the sound quality of direct drive hearing aids so good?

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Speaker & Disclosures

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- Ph.D., Audiology & Biomedical Engineering, Vanderbilt University
- Research interest: Quantification of listener perceived benefit

- Original research presented was funded in part by Earlens corporation

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Learning Objectives

- Identify and define the various approaches to direct drive of the middle ear system.
- Identify advantages and disadvantages of middle ear implants and acoustic hearing aids.

Why bother with Direct Drive?

- Air conduction hearing aids (ACHA) have limitations that adversely impact the listening experience
- Severely limited low frequency response when vented
- Limited audibility and headroom in the high frequencies due to receiver roll off and feedback
- Users of direct drive hearing devices report:
  - Very natural and superior sound quality,
  - Superior performance in challenging listening situations,
  - Superior ability to hear soft sounds
  - Superior comfort for loud sounds

e.g., Kraus et al. 2011, Luetje et al. 2002, Jenkins et al. 2008 , Levy et al. 2016

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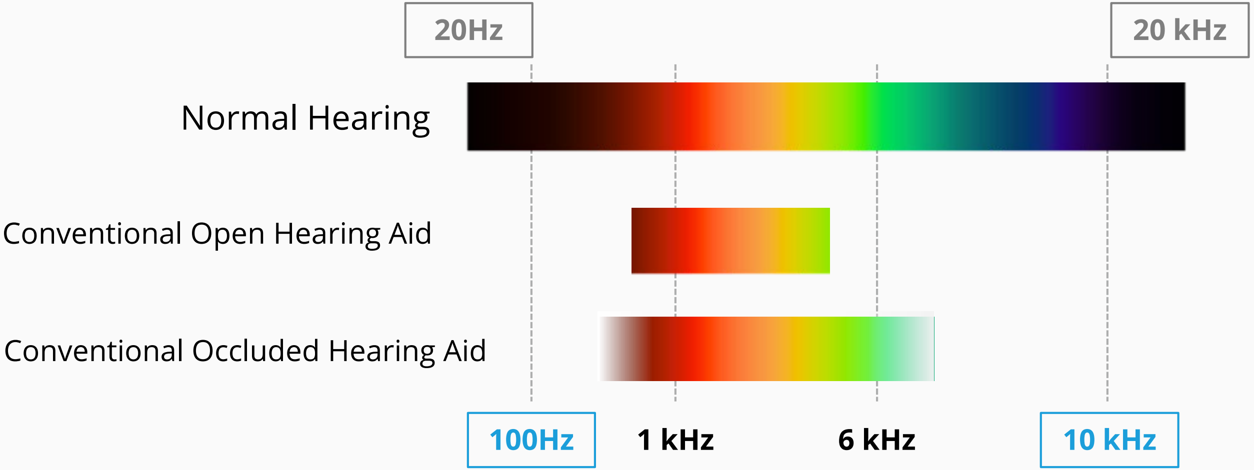
"It doesn't sound natural"

- Air Conduction devices cause distortion in the output signal
  - Harmonic Distortion
  - Intermodulation distortion
  - Comb Filtering
  - Spectral Ripples
  - Signal processing purposely distorts the signal to create audibility of high frequency speech cues
- Limited audible bandwidth and dynamic range
- At high levels, the TM creates distortions in the signal at the stapes due to anisotropic properties

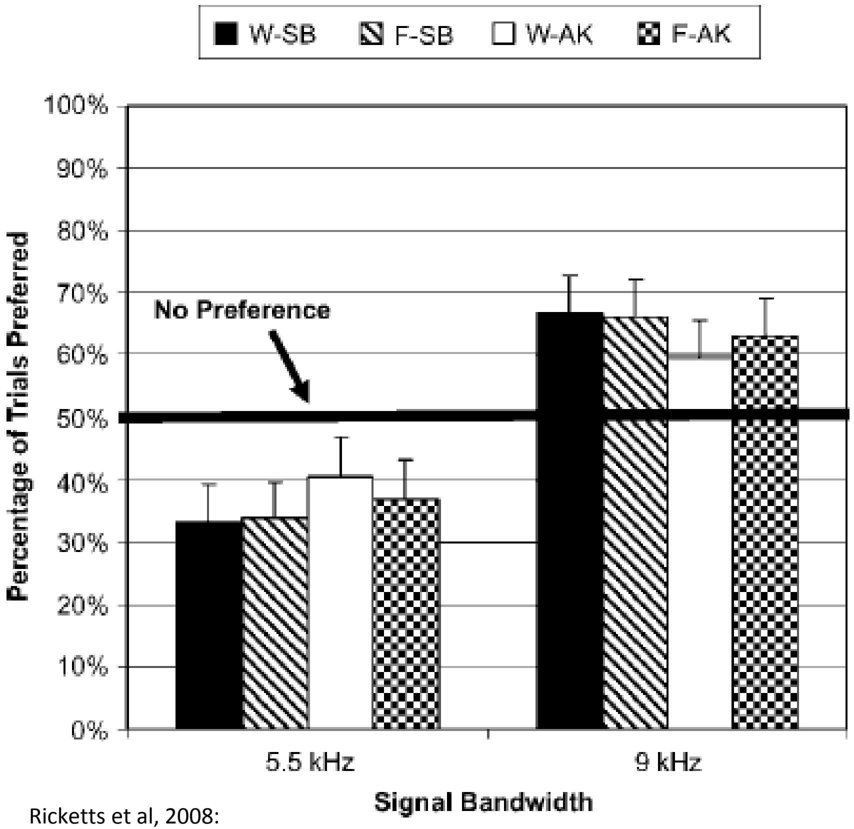
Relative Audible Bandwidth – Mild to Mod SNHL



Increased Bandwidth Enhances Sound Quality

- If tolerable, extended high frequency amplification is beneficial

- Rated ‘Naturalness’
  - Increases with bandwidth
- Rated Preference
  - Increases with bandwidth

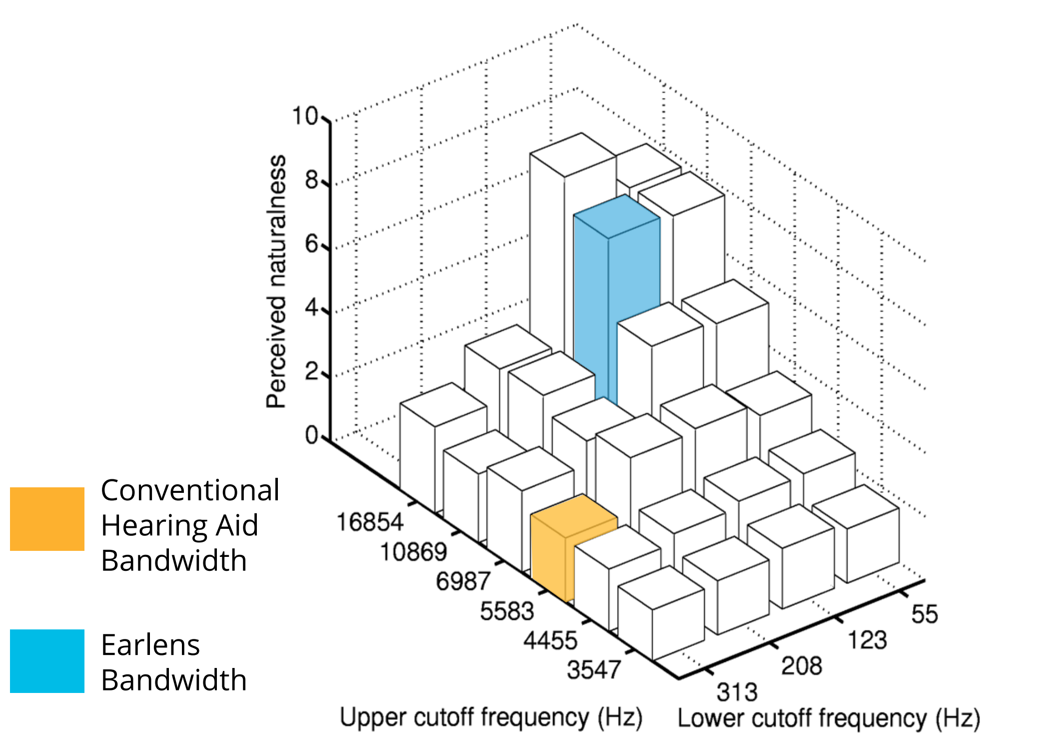


Ricketts et al, 2008:

Moore and Tan, 2003; Ricketts et al, 2008; Brennan et al, 2014

High Frequency Audibility Is Not Enough

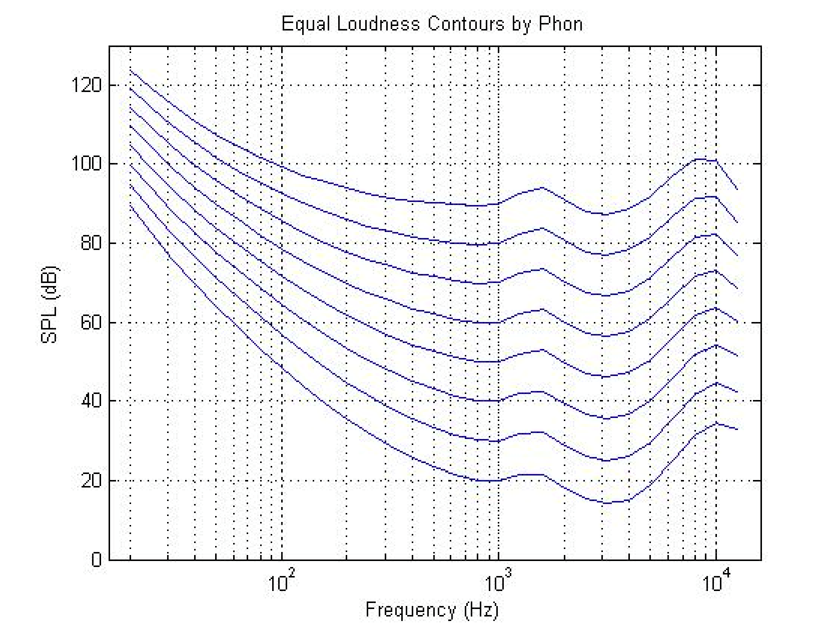
- Merely amplifying a narrow region can sound harsh and tinny
- If balanced with additional lows, providing MORE highs doesn't sound tinny, it sounds more natural[5]



Moore & Tan, 2003

Direct Drive Advantage

- Direct coupling to the ossicular chain overcomes the impedance mismatch that limits energy transfer from the air into the ear



ISO 226 Equal-Loudness-Level Contour

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However…

- Implantable devices have limited audible bandwidth due to gain limitations, transducer drive efficiency (effective mass) and power budget considerations

Retrieved from: https://s3.medel.com/pdf/VSB_relaunch/28477_10_FactsheetVSBSystem_en_.pdf

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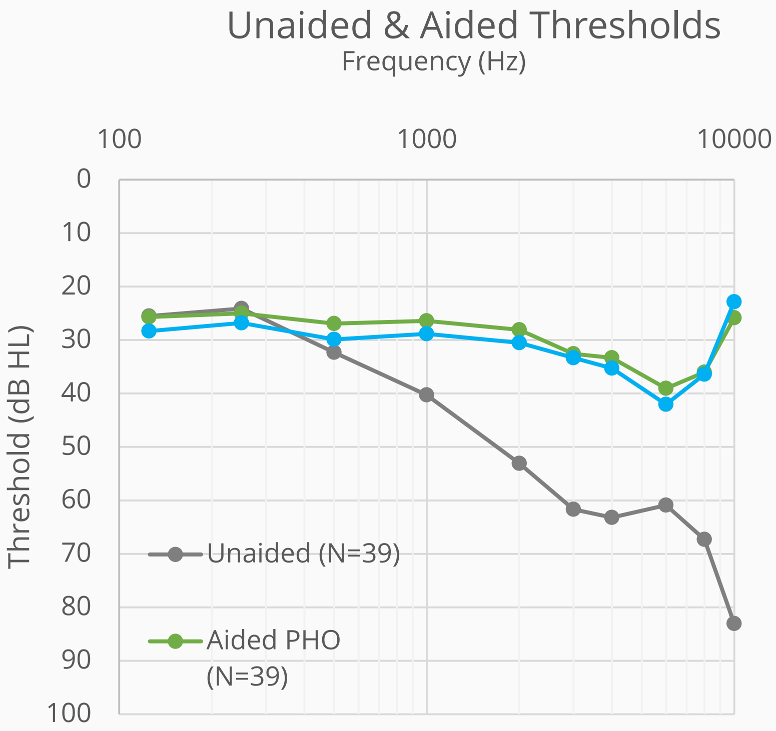
Exception: Earlens

- Consistently produces 100-10,000Hz audible bandwidth
- Maximum output increases smoothly from 500-10KHz, allowing for exceptional audibility even with steeply sloping loss

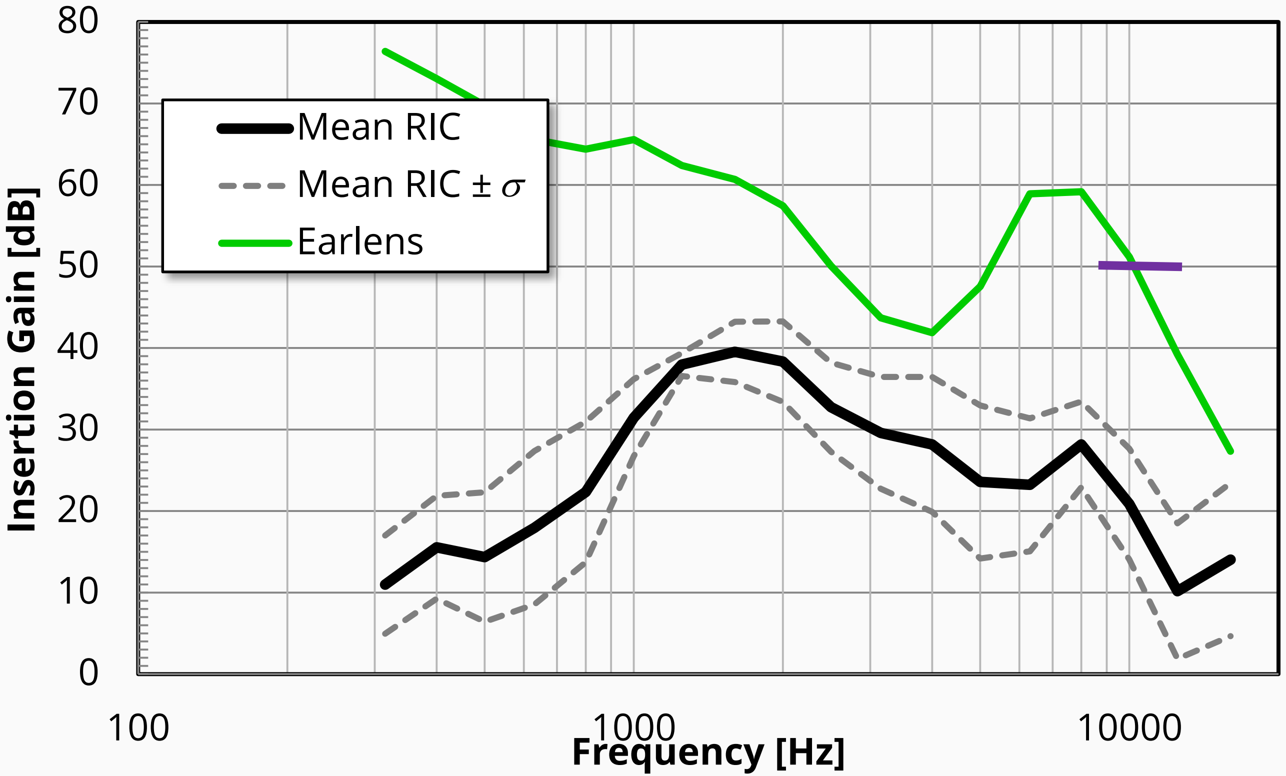


*data on file at Earlens

High Gain Margin ***without Trade-offs***

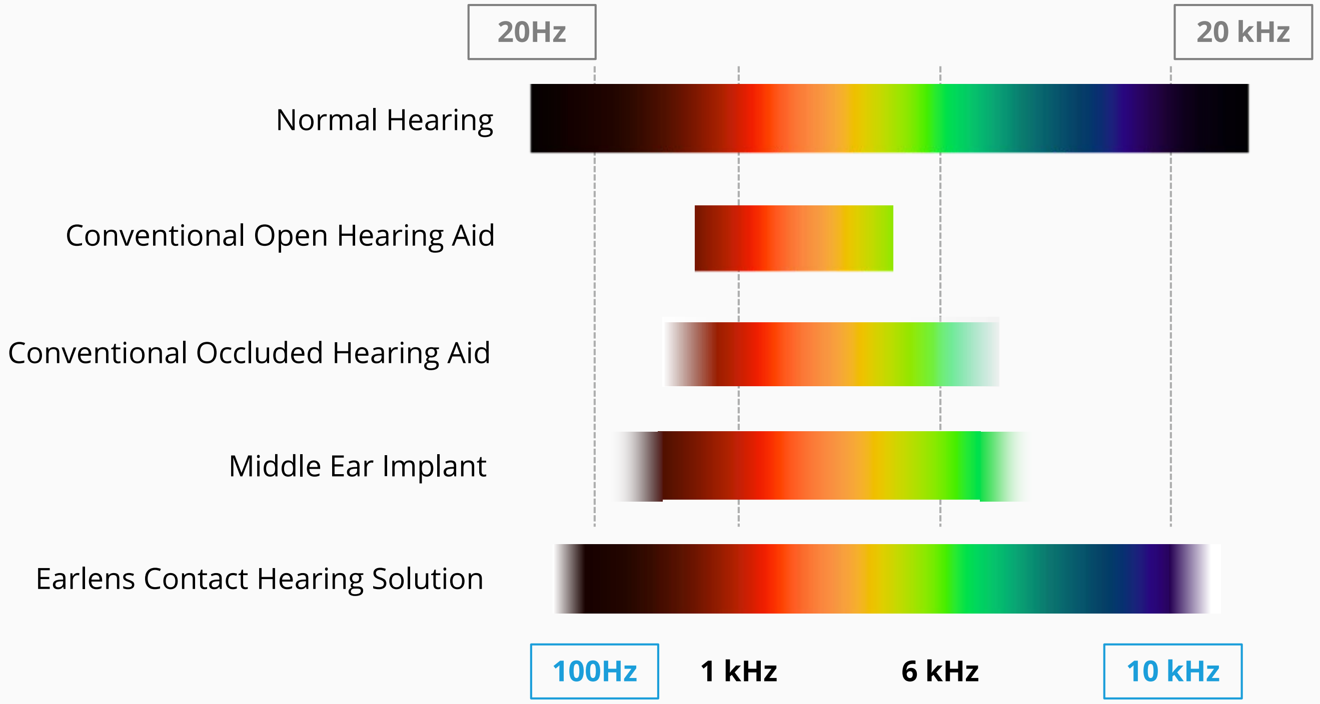
With direct vibration instead of acoustic transmission:

- High gain margin with open fit
- Sound quality preserved without use of feedback cancellation at all in some cases
- Broad spectrum audibility without the annoyance of feedback



Struck & Prusick 2017

Relative Audible Bandwidth – Mild to Mod SNHL



Treatment of SNHL

ACHA vs. Direct Drive Approaches

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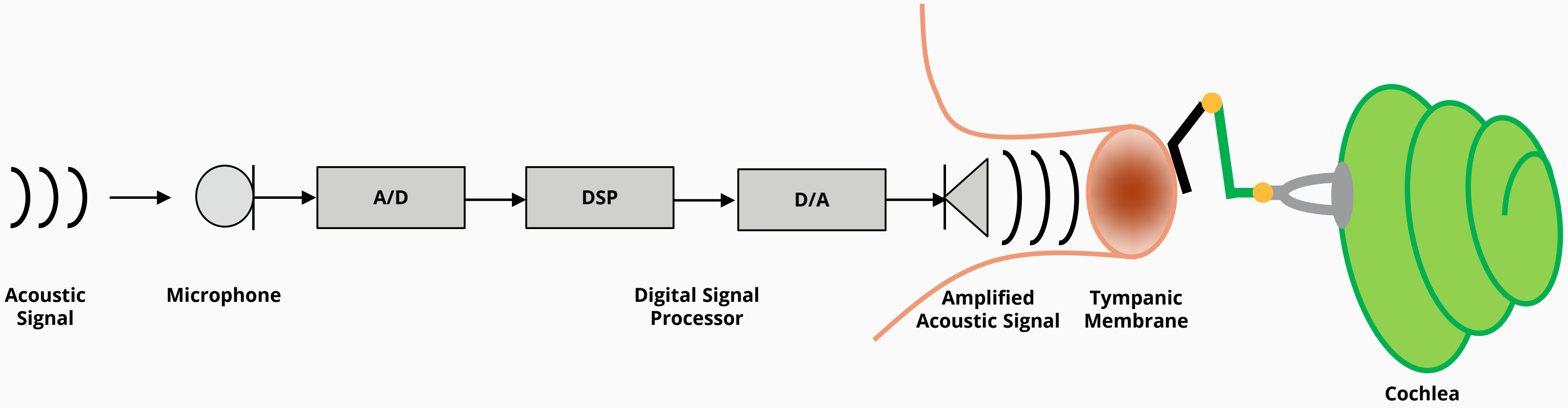
Approaches

More Invasive

Less Invasive

- Fully Implantable
  - e.g., Esteem (Med El)
- Partially Implantable
  - e.g., Soundbridge (Med el)
  - e.g., Maxum (Ototronics)
- Non-implantable
  - e.g., Earlens
- Conventional Acoustic Hearing Aids

How it works - Conventional HA



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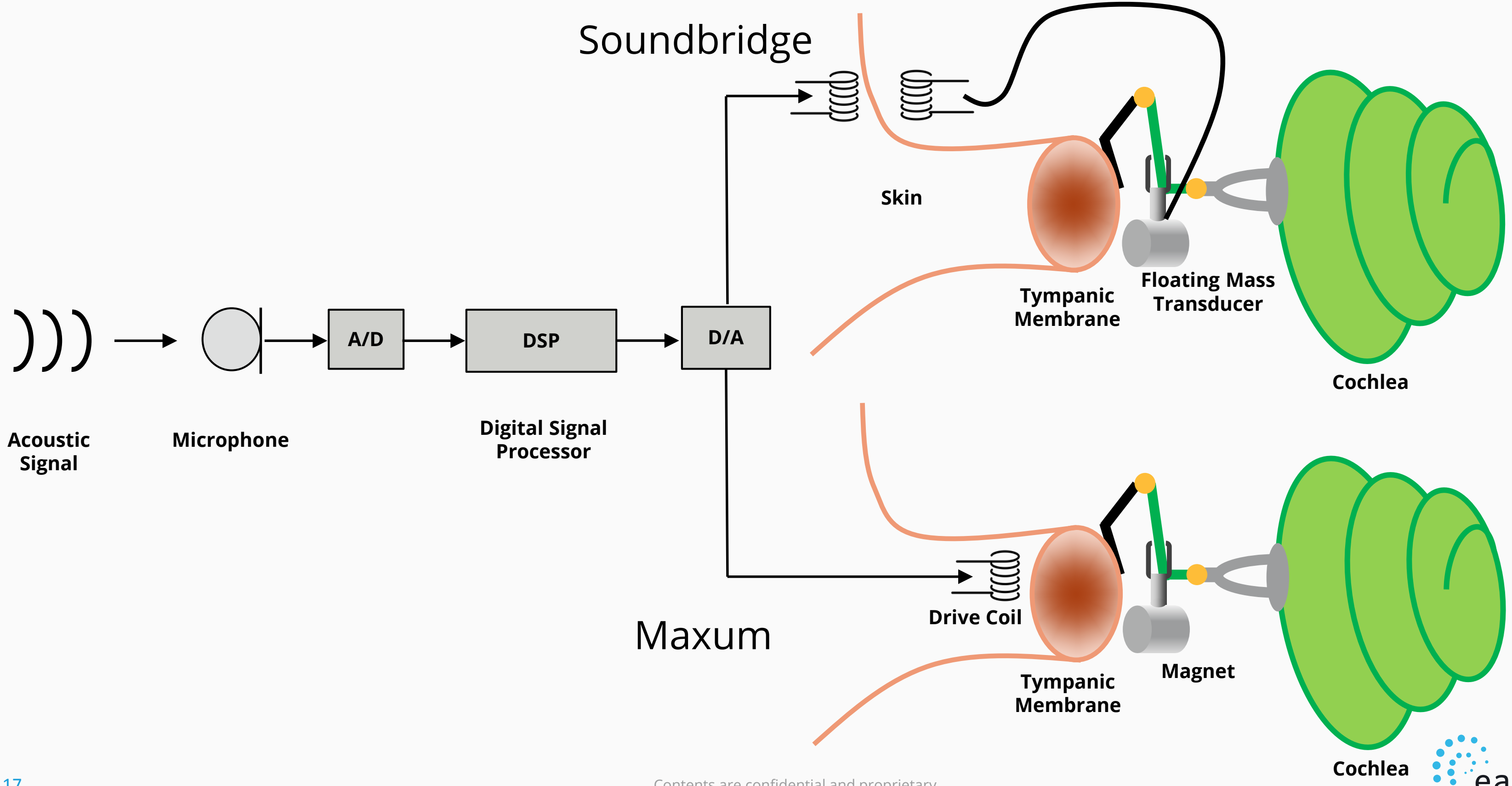
How it works – Partially Implantable



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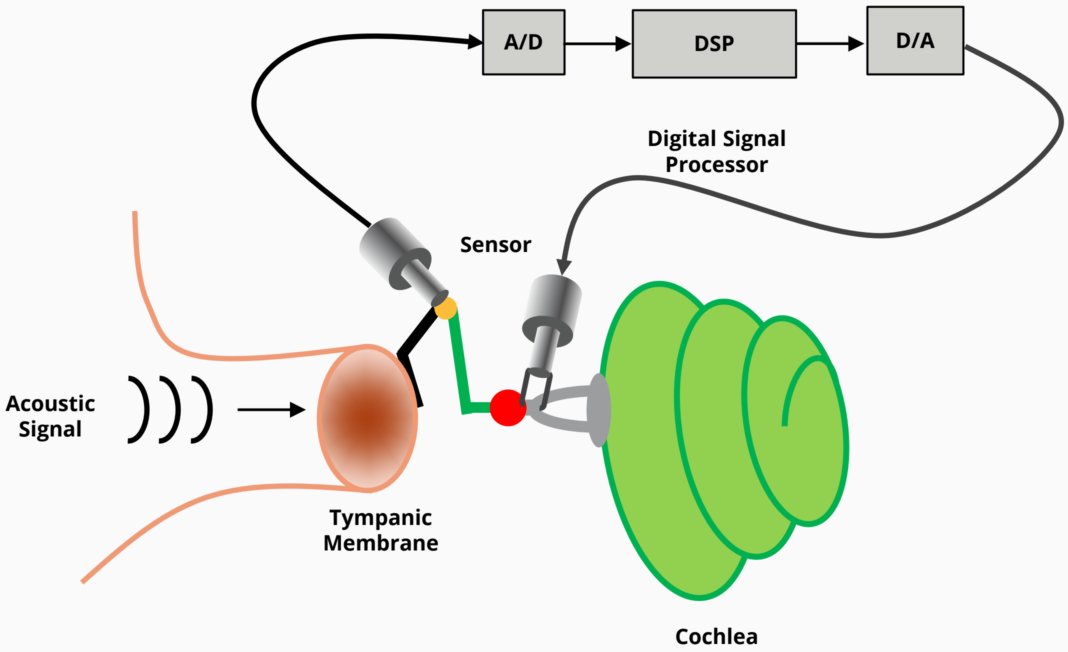
How it works – Fully Implantable



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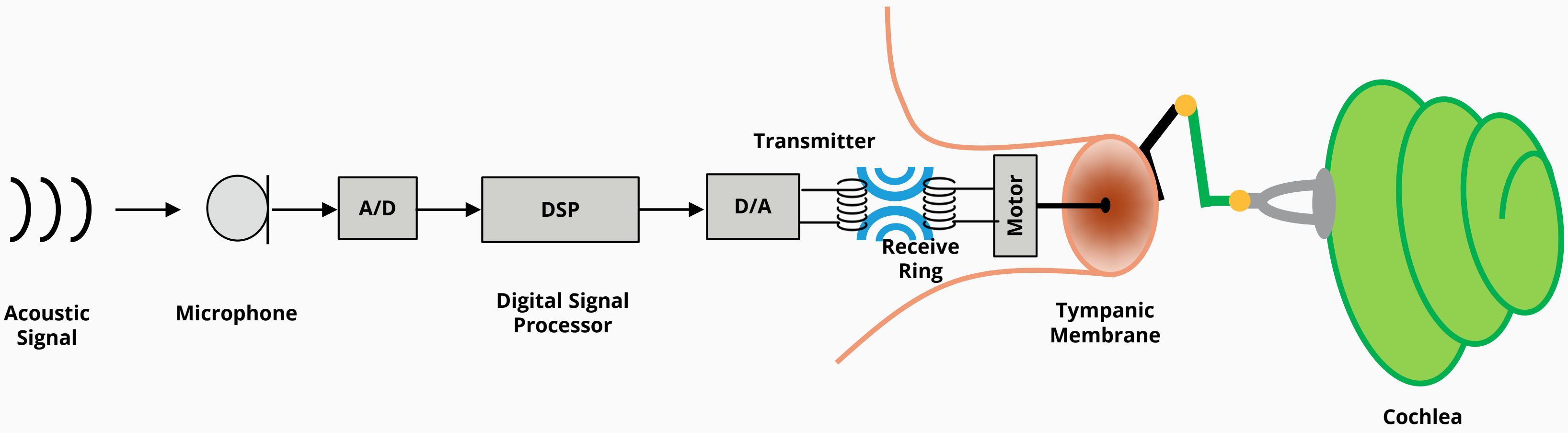
How it works – Contact Drive



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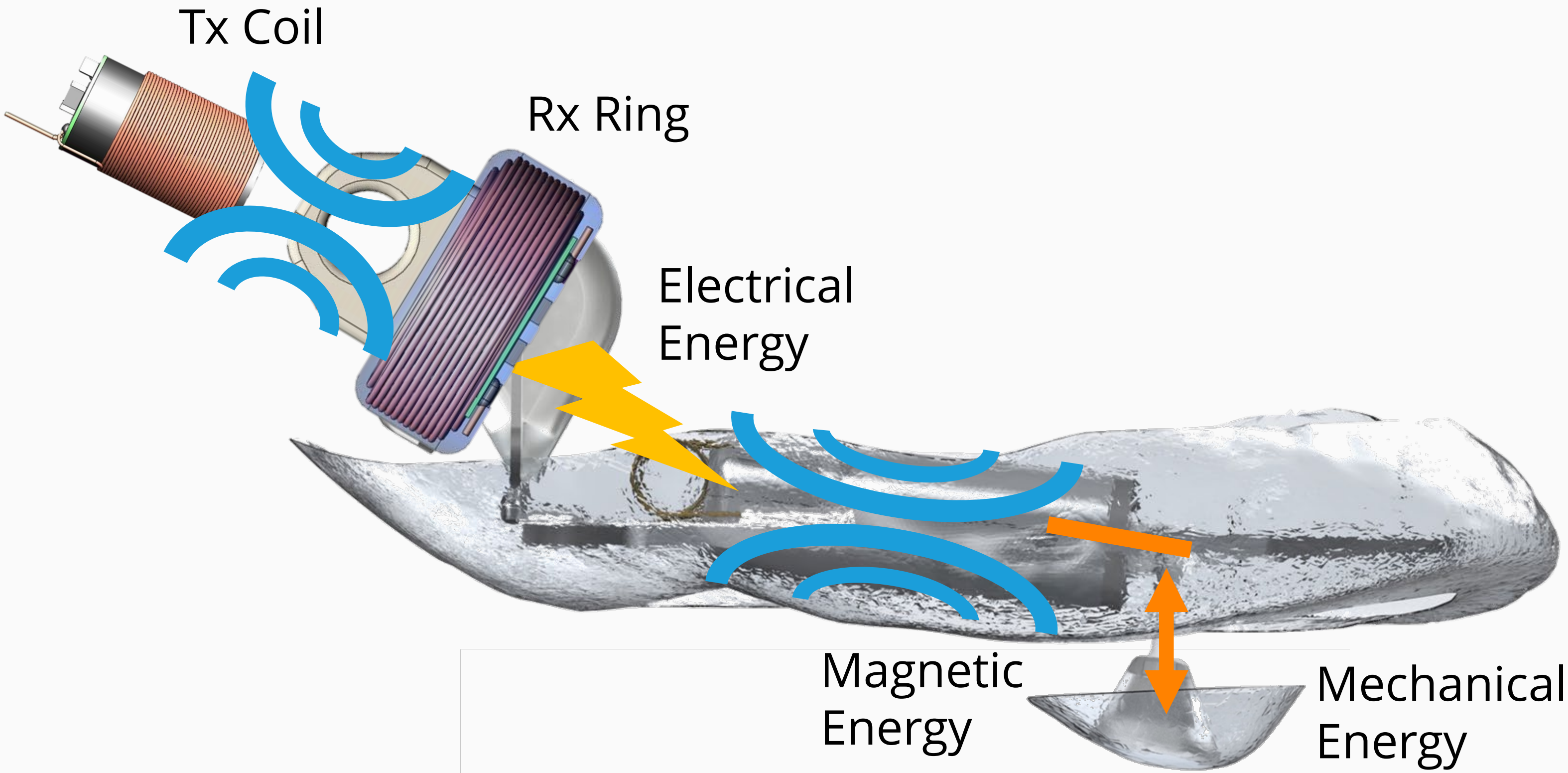
Earlens Contact Hearing Solution



Research Question

- Relative to acoustic stimulation, what is different about the signal transmitted to the stapes footplate via direct drive?

Experiment

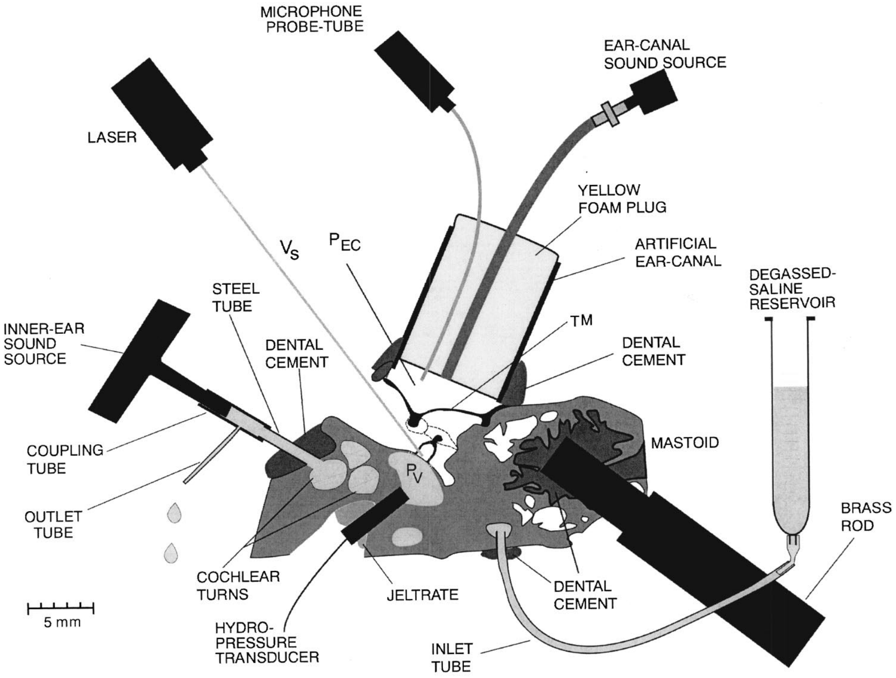
Hypotheses

- Direct Drive of the ossicular chain generates a signal at the stapes footplate that is free of distortions to the input signal
- The calibration gain/damping effect of the direct drive mechanism prevents comb filtering

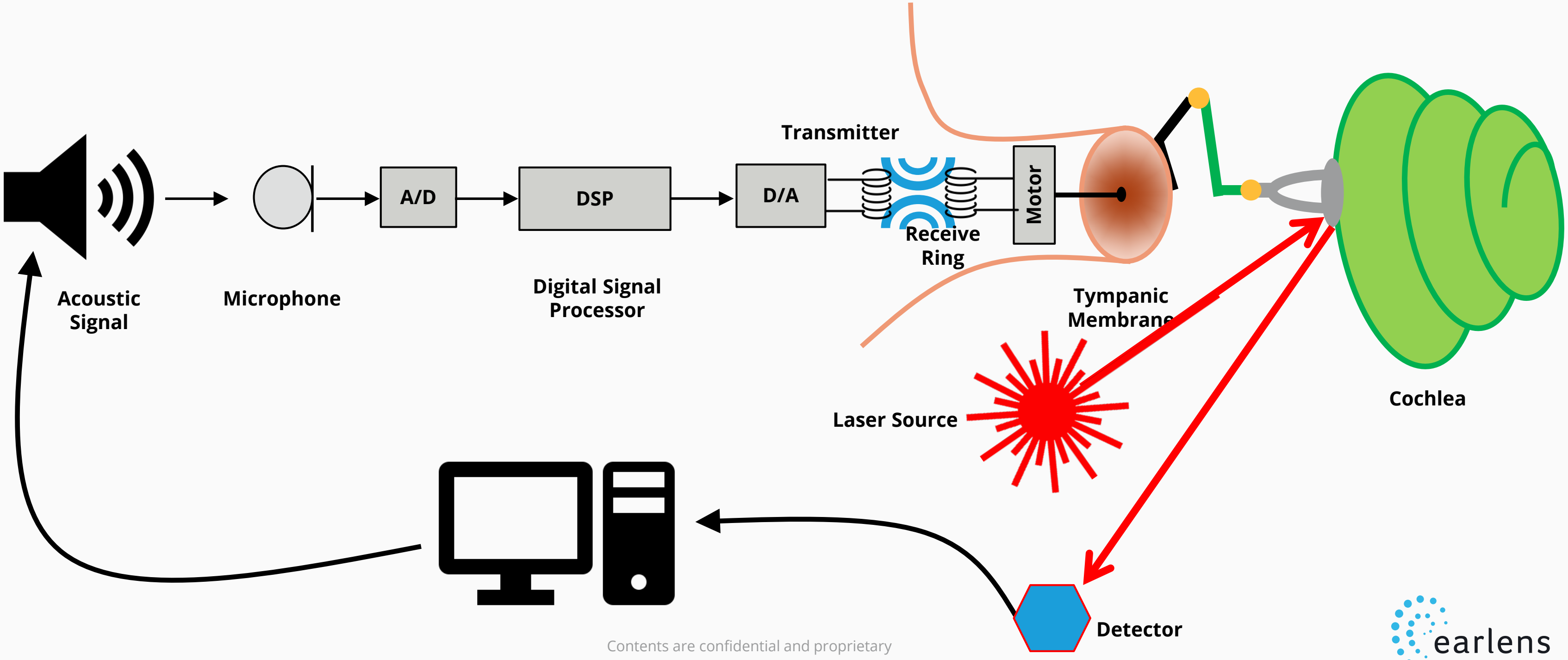
Methods

- In donated cadaver temporal bones:
- Compared stapes footplate responses achieved via:
  - Acoustic stimulation
  - Direct drive with Earlens Contact Hearing Solution
- Measured acceleration of stapes footplate using laser doppler vibrometry
- Derived frequency & phase responses to high level chirp signal

Experimental Setup



Experimental setup – Block Diagram



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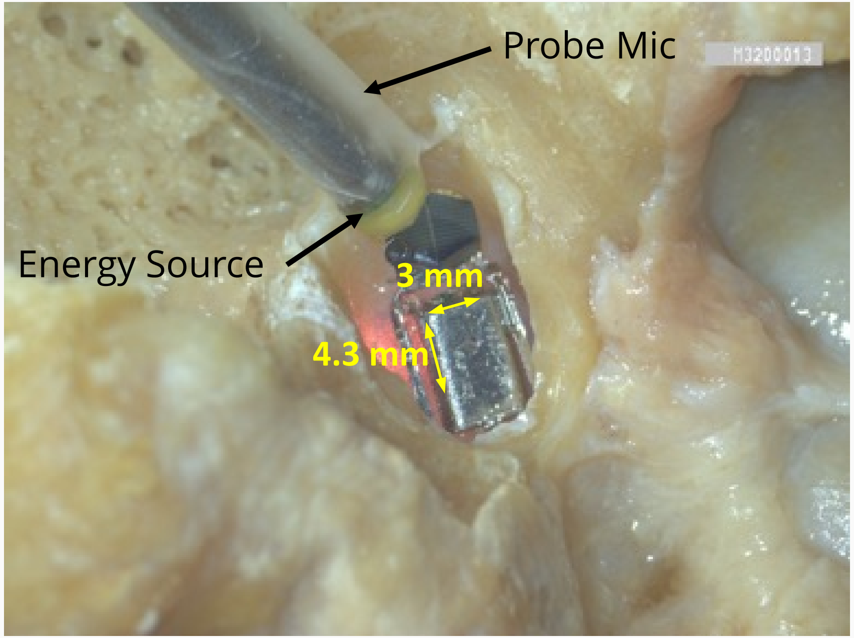
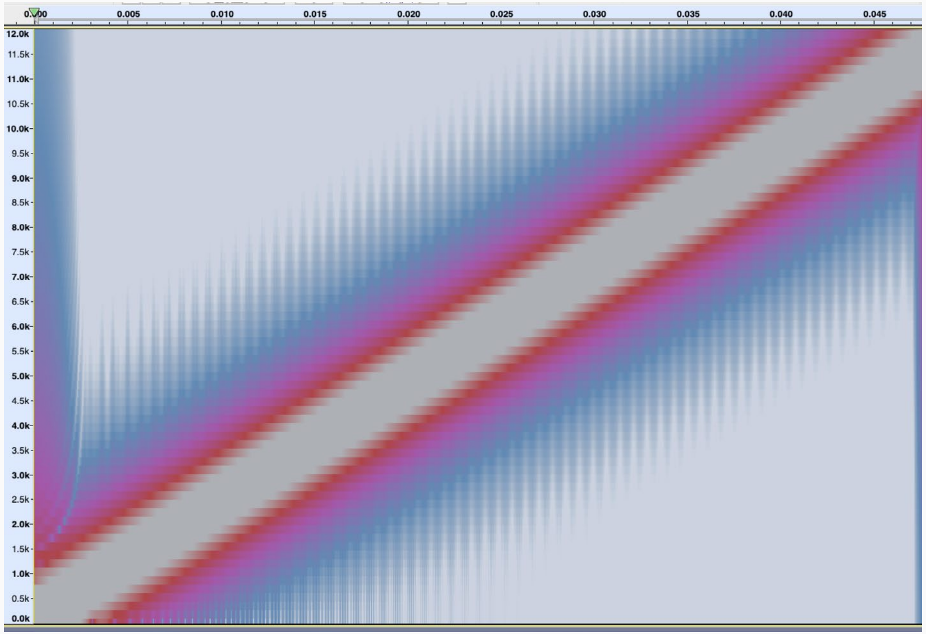
Measurement Setup



Stimulus

- 50ms Chirp
- 24.4 - 25,000Hz

- Repeated and averaged 160-180x



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Signal Capture and Analysis

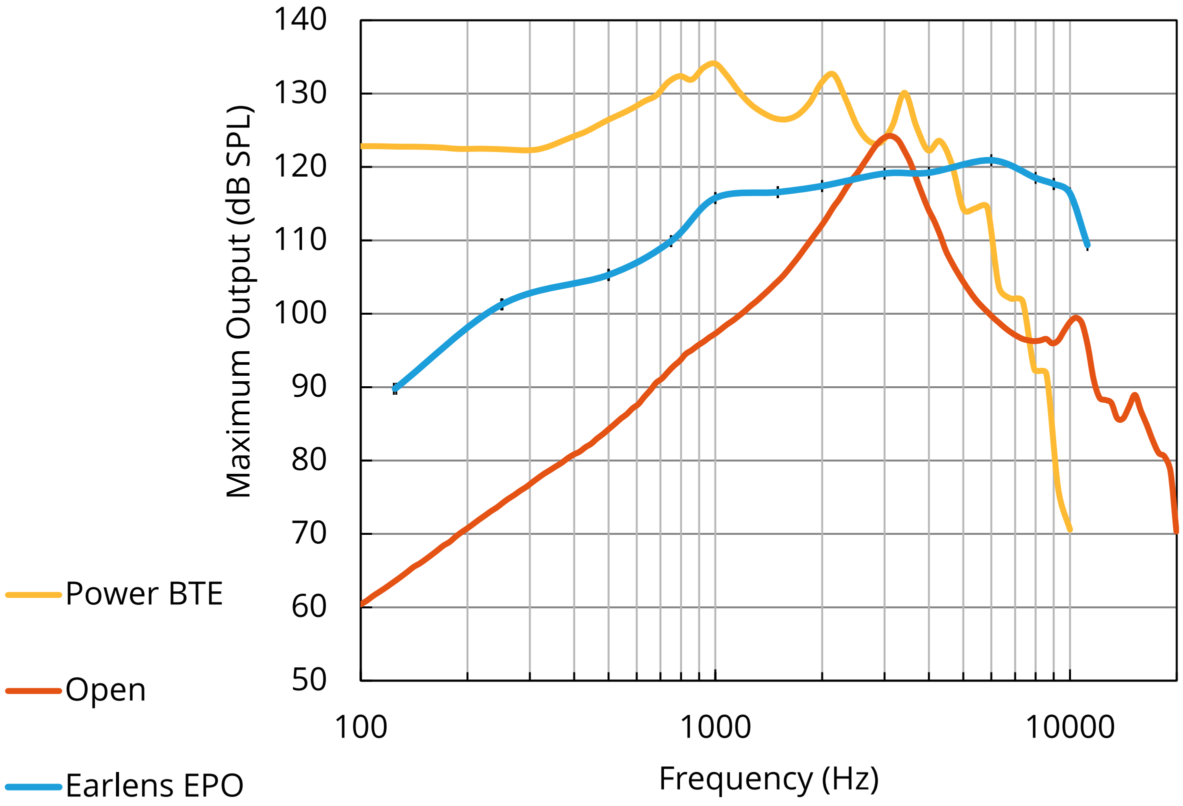
- Hardware: NI USB-4431 data-acquisition module (National Instruments, Austin, TX) with a maximum sampling rate of 96 KHz.
- Software: LabVIEW based synchronous-averaging measurement software (Gottlieb et al., 2016).
  - Sampling rate: 48KHz,
  - Fast Fourier Transform (FFT) length: 4096
  - Runs averaged/temporal bone: 10
- From the measurements of stapes velocity (VST) and ear canal pressure (PEC), the following quantities are calculated:
  - The baseline sound-driven stapes transfer function without the Tympanic Lens on the TM.
  - The equivalent pressure output of the direct drive system

Results

- At the stapes footplate,
  - Acoustic drive condition demonstrated:
    - Minor comb filtering
    - Spectral Ripples
    - Phase shift with frequency
  - Contact direct drive demonstrated:
    - Smooth, flat spectral response
    - Consistent phase relationship

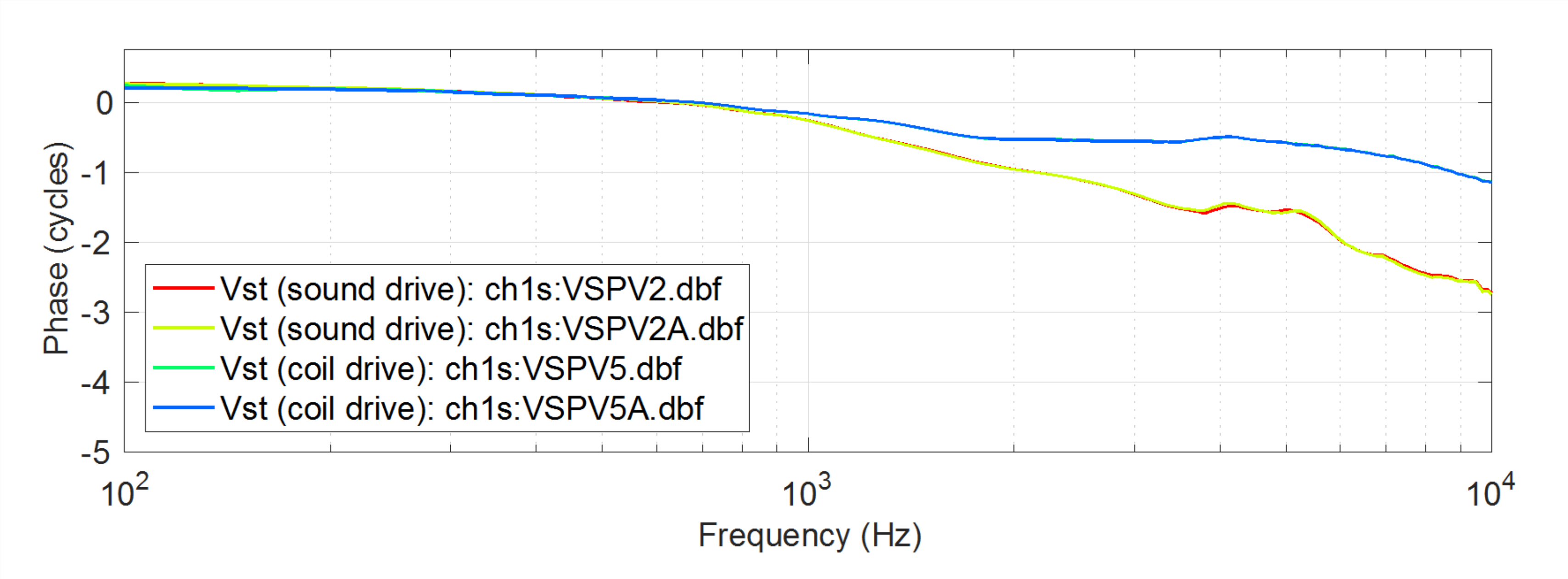
Results

- Spectral ripples minimized with direct drive
- Superior audible bandwidth to both low and high frequencies



Results

- Phase relationship preserved with direct drive



Conclusions

- Substantial differences in transmitted signal quality are observed between acoustic and direct drive modalities
- Direct drive exhibits:
  - Superior effective bandwidth to both low and high frequencies
  - Smooth spectral shape and no induced ripples
  - Preserved phase relationship between input and output signals
  - Minimal group delay
  - Superior stable gain margin

Next Steps

- Investigation of direct/amplified path interaction effects on stapes signal with open fittings
  - Output SNR
  - Comb filtering effects

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