OtoStat 2: In-situ Measurements Using WAI Forward Pressure Level Calibration

Real-Ear calibration: Past & Present

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Abstract

In-situ ear canal measurements are an important calibration tool for removing variability in audiologic measurements caused by the earphone placement in the ear canal. Standard in-situ methods work best at frequencies below 2 kHz. However, for insert-earphone measurements, standing waves (SWs) due to ear-canal and tympanic membrane (TM) delayed reflections can affect measurements at higher frequencies important to speech perception (e.g., up to 7 kHz). Level errors due to SWs can be $>$20 dB in magnitude. Forward pressure level (FPL) calibration is a technique that allows for precise removal of SW artifacts. With FPL calibration, stimuli may be delivered to the middle ear without SW errors.

In this presentation we will describe how ear-canal SWs originate, and how FPL can be used to remove their effects. FPL-calibrations are enabled by wideband acoustic complex immittance (WAI) measurements, specifically, measurement of the middle-ear acoustic reflectance, made using a Thv́enin-calibrated probe. Advances in WAI technology allow for characterization of the TM immittance and more accurate calibration of acoustic stimuli, independent of probe placement in the ear canal.

Mimosa Acoustics' OtoStat 2.1, is now available for research trials. It makes WAI and DPOAE measurements, including FPL-calibrated DPOAE - all available in a handheld unit.

Learner Outcomes: After this presentation, participants will be able to 1. Compare methods of in-situ measurements, including using forward-pressure-level calibration, 2. Identify sources of measurement error, 3. Describe the effect of ear canal SWs on real-ear measurements, 4. Describe advantages of forward pressure level calibration for audiologic measurements.

1. Outline

- Intro + Objectives
  - In-situ receiver calibration for Audiometric thresholds & OAE
  - *In-situ* defined: Probe mic in the canal
- Overview of In-situ calibration methods
  1. RETSPL calibration using "artificial ear"
  2. Real-Ear: test subject's "real" ear + free-field loudspeaker
  3. Wideband Acoustic Immittance WAI ⇒ Thevenin calibration
- Forward Pressure Level (FPL) ⇒ accurate PTA to 10 kHz
- Mimosa System with FPL: PTA, DPOAE, ...
- Summary + Conclusions
  - FPL removes the standing wave ⇒ HF audiometry >10 [kHz]
  - Review utility of Tympanometry vs. WAI

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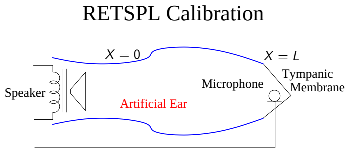
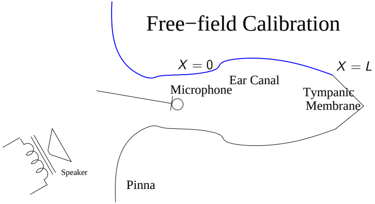
- Ear canal impedance determines the ear canal (In-situ) pressure
  - Traditional Methods:





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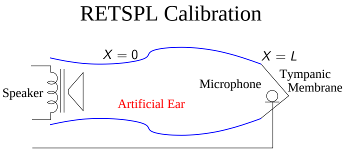

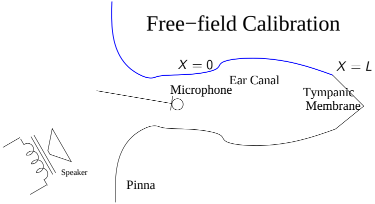

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4. Thevenin calibration & impedance measurement

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   - Left: WAI calibration procedure
   - Measure the pressure for several cavities of known impedance
   - The Thevenin pressure $P_s(f)$ & Impedance $Z_s(f)$ are derived

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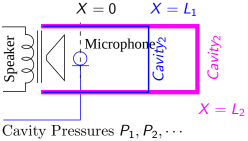

Thevenin $P_s(f)$ and $Z_s(f)$ derived from
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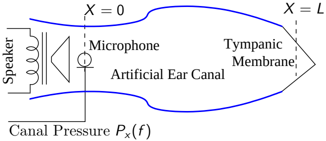

$P_s(f), Z_s(f)$ & $P_x(f) \Rightarrow Z_x(f)$

2. Right: WAI measurement
   - Canal impedance derived from $P_x(f)$ given TPs: $P_s(f)$, $Z_s(f)$
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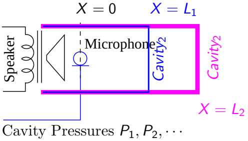

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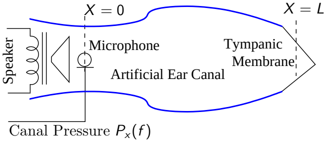

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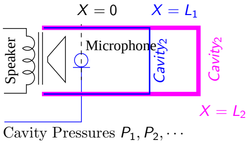

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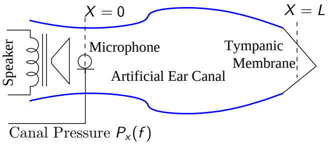

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4. WAI Utility: Forward Pressure Level (FPL)

- In-situ microphone provides sum of two waves:

$$P_{mic} = P_+ + P_- = P_+(1 + P_-/P_+)$$

- WAI separates forward P_+ and reflected P_- pressure waves
  - Complex Reflectance $R(f)$ defined by ratio

$$R(f) = P_-(f)/P_+(f).$$

  - Reflected sound cannot enter the cochlea
- WAI factors out the Forward pressure Level (FPL)

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5. Functional Utility

WAI allows one to:

- Remove the residual ear canal delay
- Measure complex TM admittance to >8 kHz
- Interpret ME pathologies, providing detailed information on:
  - OME, disarticulations, perforations, otosclerosis,
  - Middle ear parameters: TM compliance, canal delay (i.e., FPL)
- Advantages over Tymp: 0.2-10 [kHz], reliable, non-invasive,

+ Corrects >3 kHz frequency ≈20 dB SWs
+ FPL calibration precisely measure: $< \pm 6$ dB) HL to 10 kHz
+ Removes 20 dB random effects of SWs (predictable results) for:

- Reliability (i.e., a predictable outcome) is the key to health care

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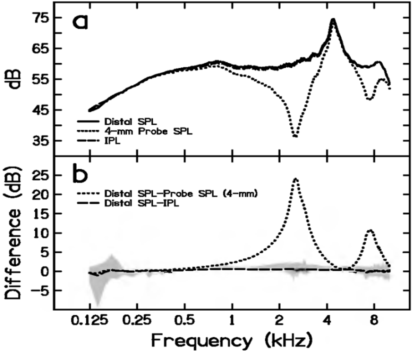
6. Example of canal standing waves Lewis et al 2009

- The complex reflectance $R(f)$ quantifies the standing wave



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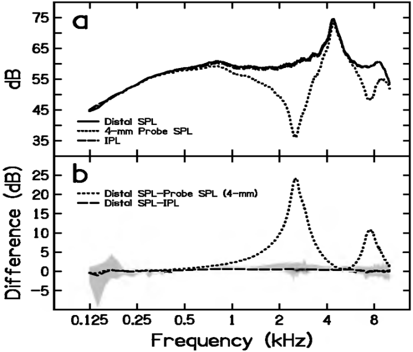

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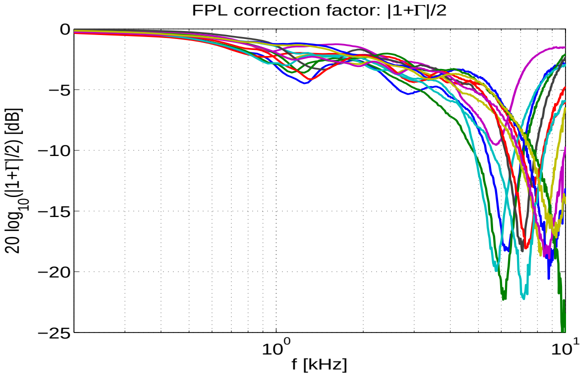
7. Are Standing Waves common?

- For frequencies > 5 kHz
  - Standing waves from 10 ears (Voss and Allen, 1994):
  - 2 ears: SW >20 dB; 9 ears: >17 dB; 1 ear 9 dB



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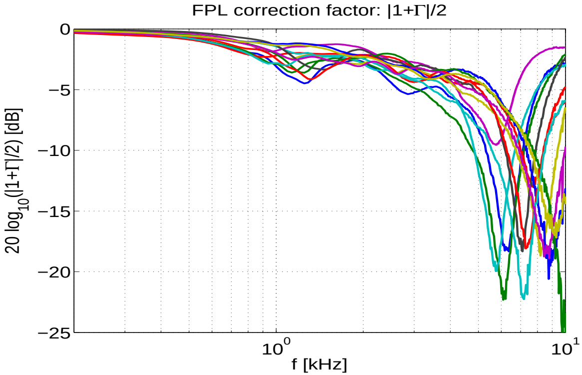

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8: Tympanometry vs. WAI: Functional comparison

- Tympanometry: Invalid Assumptions
  - \- Residual canal: Ignores delay & $Y_{TM} \neq 0$ at -300 dPa
  - \- TM is a compliance (ignores cochlear loss)
  - \- Bandwidth: one or a few frequencies
  - \- Infants: Canal wall compliance not rigid
  - \- TPP: Middle ear pressure utility
  - \+ Clinicians understand the technology
- WAI: Valid Assumptions
  - \+ Residual canal directly estimated
  - \+ Complex Y_{TM} directly estimated
  - \+ Bandwidth: All speech frequency
  - \+ Works with infants
  - \+ Middle ear pressure effect directly measured
  - \+ TM impedance includes cochlear resistance
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- TM Pressure correction using FPL to remove Standing Waves
  - Audiometric thresholds:
    - SW distorts Thresholds at null frequency
    - Introduces randomness in the thresholds
  - DPOAE levels with standing waves: Assume $\Delta L = 10$ dB
    - As f_1 and f_2 fall on null frequency, ΔL rises and falls round target
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    - SW distorts Thresholds at null frequency
    - Introduces randomness in the thresholds
  - DPOAE levels with standing waves: Assume $\Delta L = 10$ dB
    - As f_1 and f_2 fall on null frequency, ΔL rises and falls round target
    - Result: ΔL swings randomly from -10 to $+30$ dB at null frequency

Mimosa Acoustics' OtoStat & OtoStation

OtoStat

OtoStation

WAI (in-situ calibration)

- PTA + FPL
- DP + FPL
- TE