

# Using WBR in the Clinic

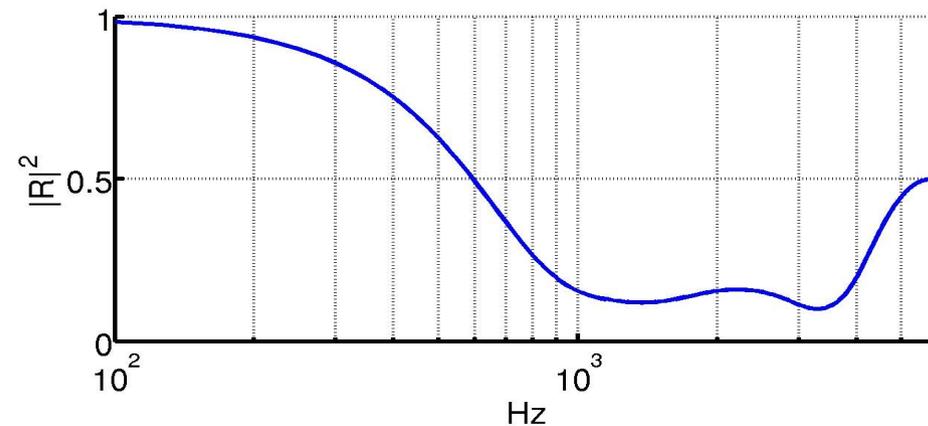
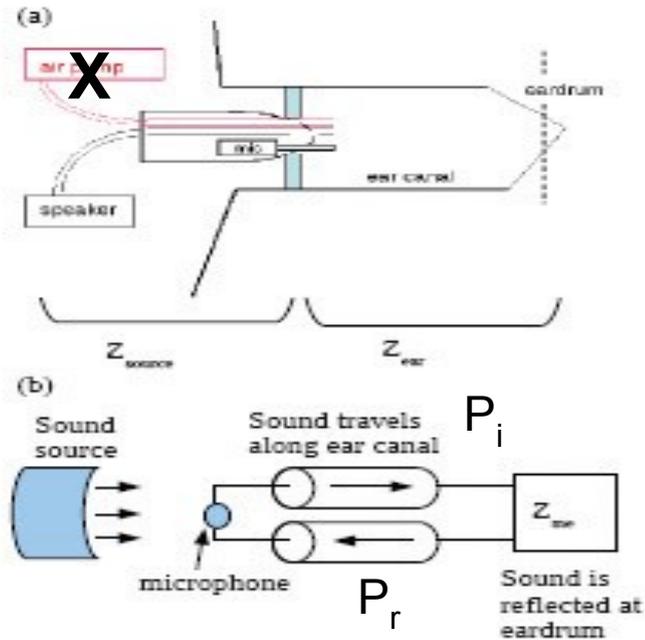
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Champaign, IL.

# ABSTRACT

Wideband power reflectance (WBR) provides a broad spectrum measure of the acoustic input impedance of the ear. Research has established the utility of WBR to assess the status of the middle ear. With clinical WBR systems now available, this presentation will focus on the technical aspects of using WBR in the clinic, including calibration, proper insertion of the eartip in the ear canal, recognizing an acoustic leak and/or inadequate depth of insertion of the eartip in the ear canal, and interpreting the magnitude and phase of the reflectance in normal and disordered ears. WBR has the virtue that the status of the middle ear can be assessed without the need for static pressure changes in the ear canal. The magnitude of the reflectance is an expression of how the middle ear filters sound; it is not confounded by the acoustic impedance of the ear canal. The phase of the reflectance is dominated by the acoustic delay due to the enclosed length of the ear canal.

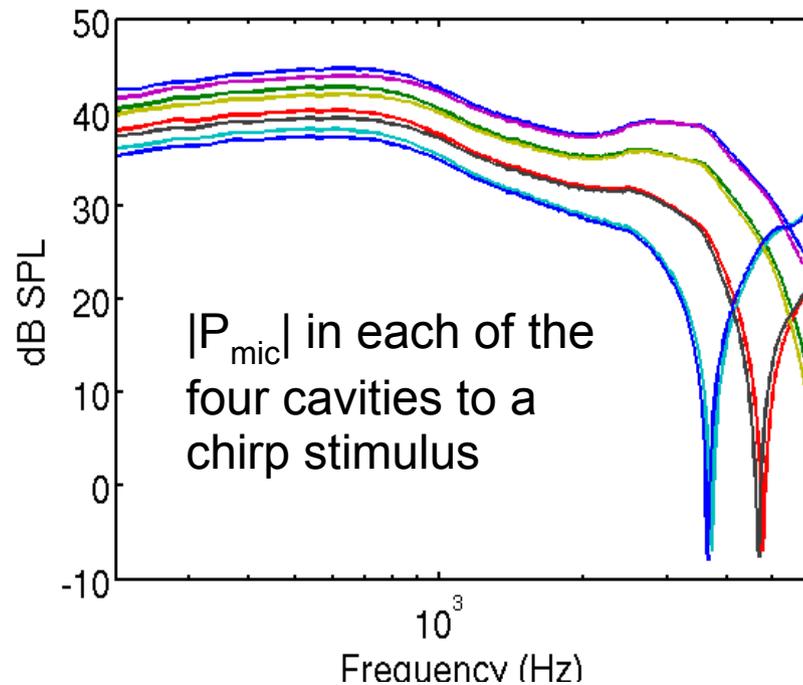
# Wideband Reflectance



- $R = P_r/P_i$
- A measure of the impedance mis-match between the ear canal and middle ear
  - i.e., how the ear filters the sound it receives

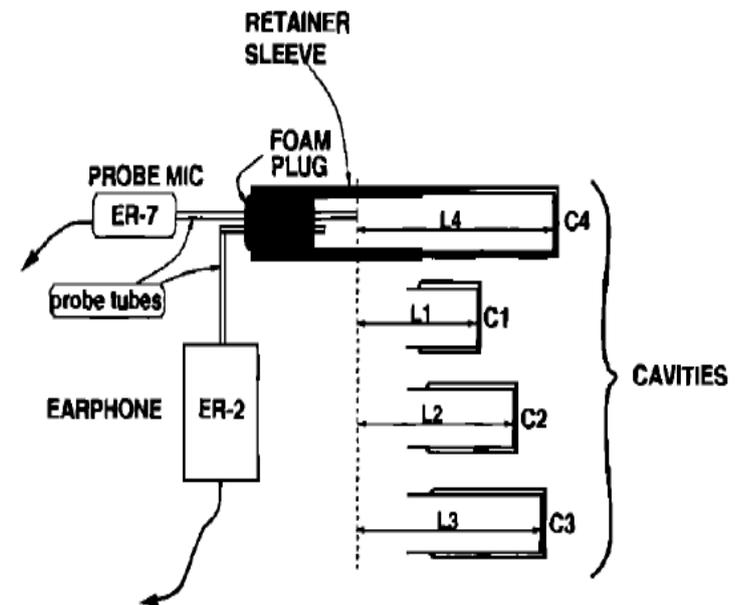
Withnell et al (2009)

# Calibration



Note the coincidence of the two sound pressure measurements for each cavity

$$Z_{source} = \frac{Z_{cavity} * (P_{source} - P_{mic})}{P_{mic}}$$



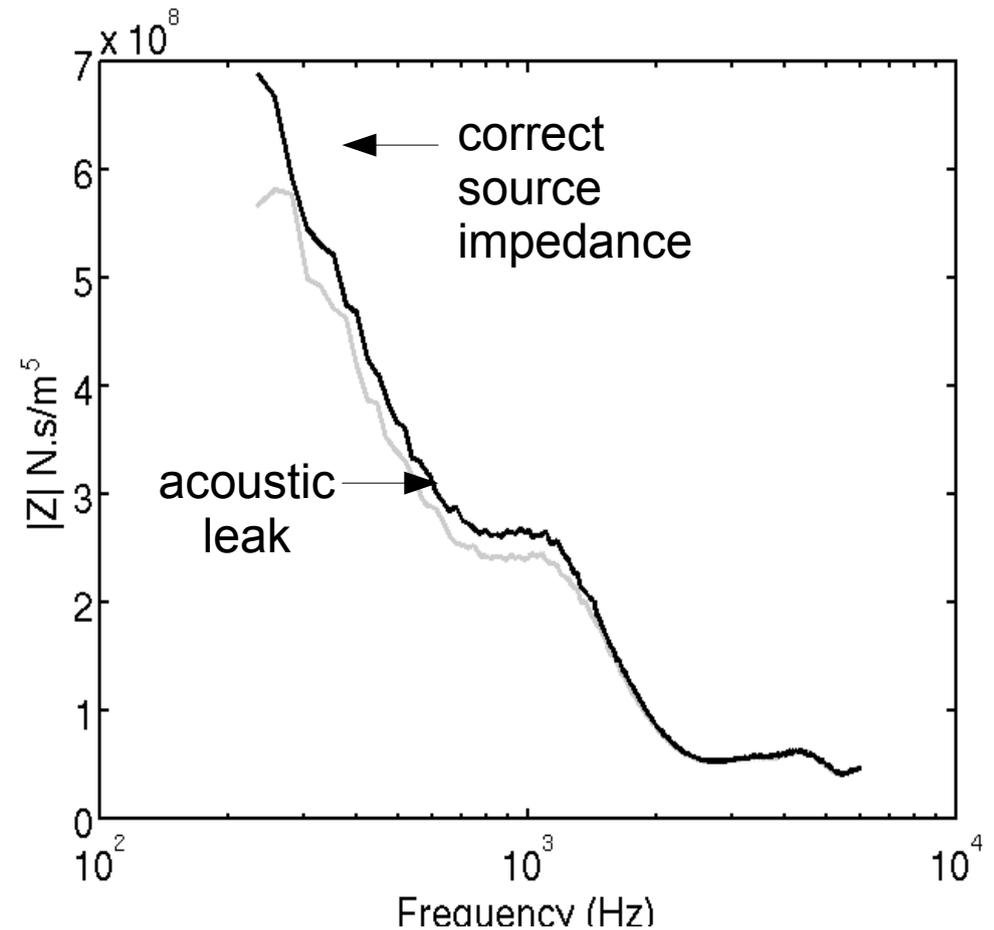
Voss & Allen (1994)

- Solve four simultaneous equations with two unknowns,  $Z_{source}$  and  $P_{source}$

# Calibration

## -Acoustic Leak-

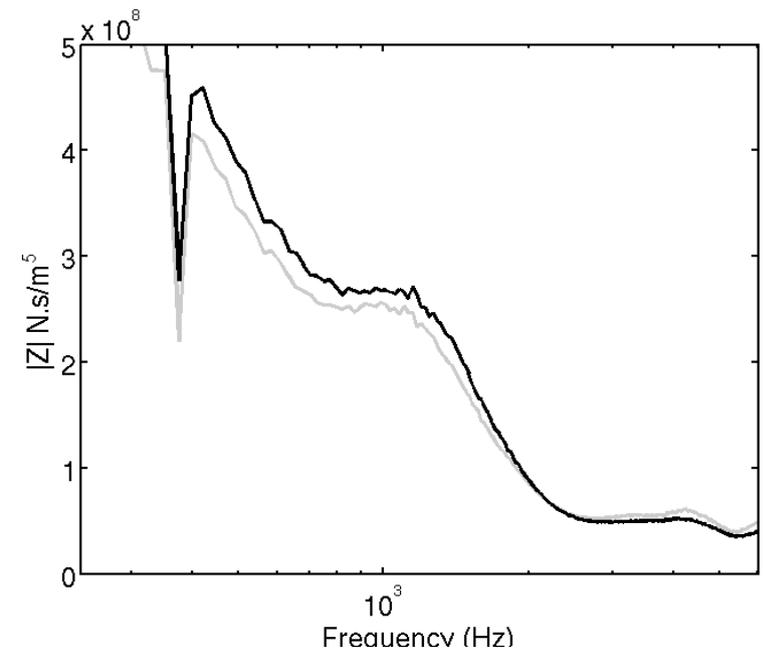
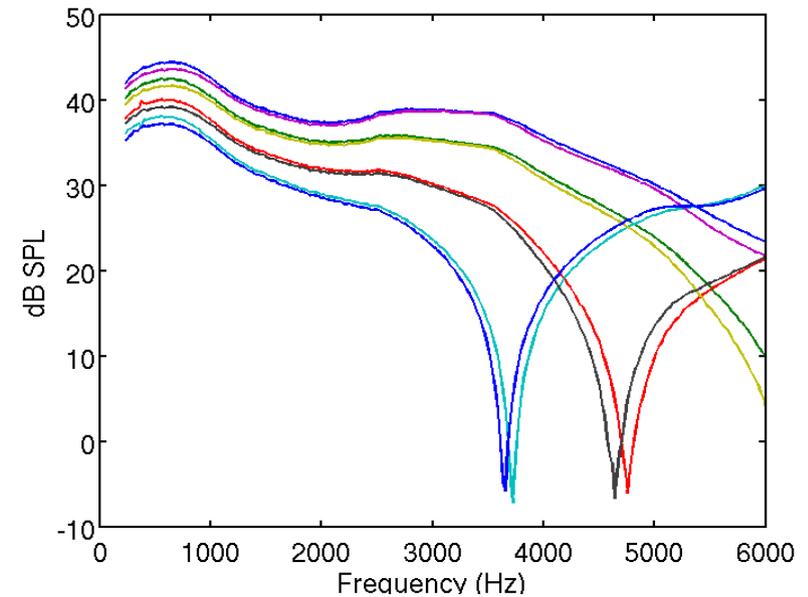
- Eartip not allowed to expand before performing calibration
  - Acoustic leak
- Acoustic impedance of Source in error for frequencies  $< 2$  kHz



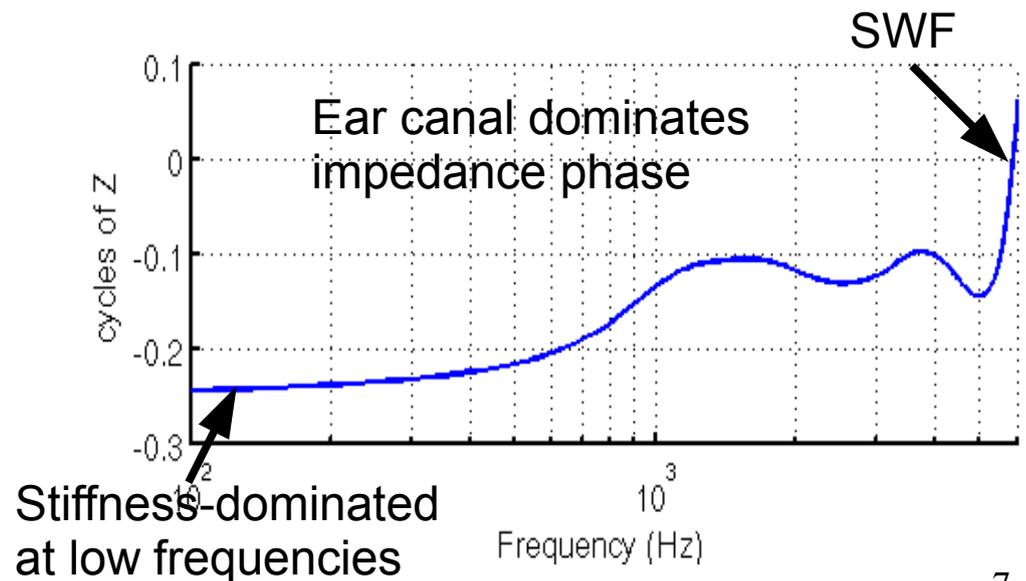
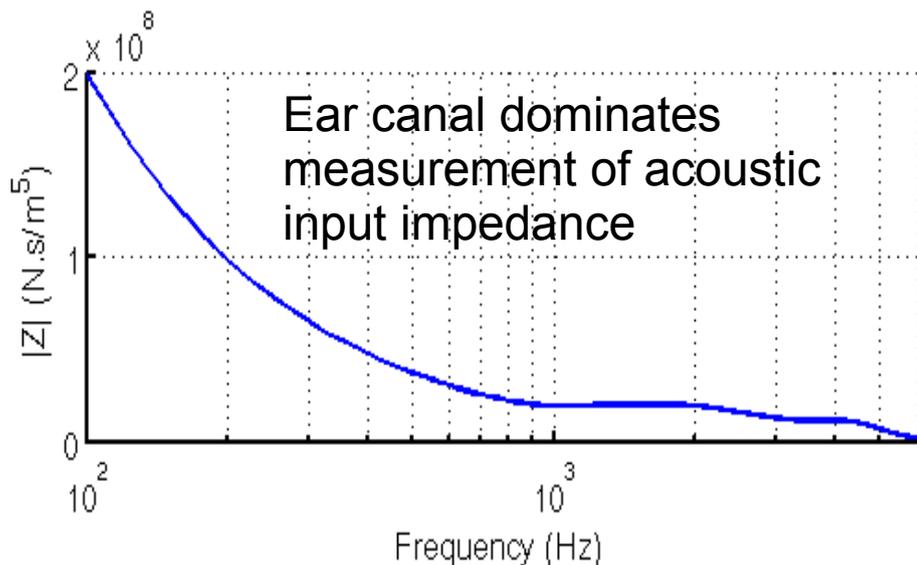
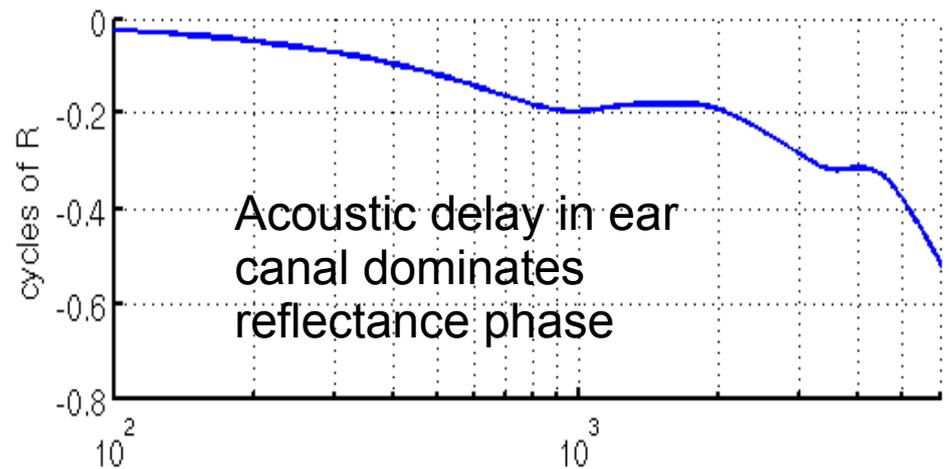
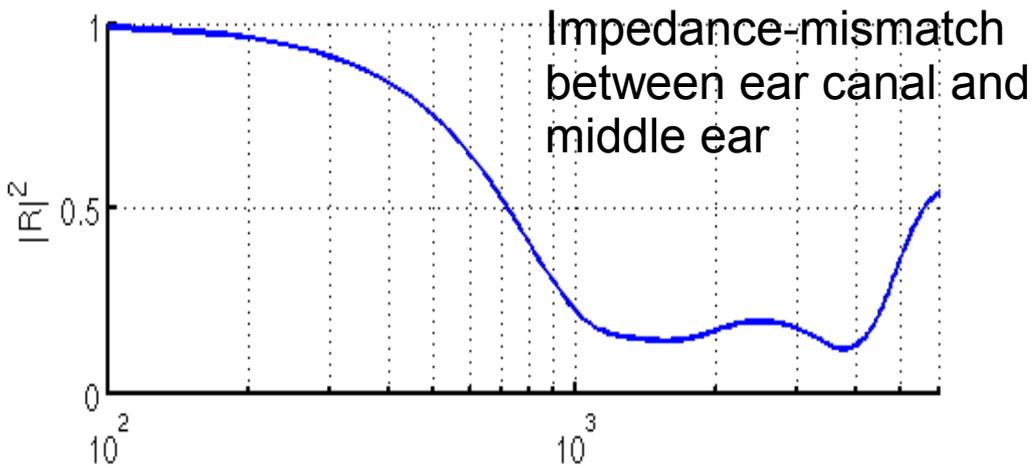
# Calibration

## -Improper (angled) Placement-

- Weight of cord pulls down on eartip
  - Alters shape of foam eartip sound delivery tubes
- Sound pressure responses differs for speaker 1 vs speaker 2 providing stimulus
  - Acoustic path differs for two stimuli
    - SWF magnitude minima differ
- Acoustic impedance calculation differs for speaker 1 vs speaker 2 providing stimulus



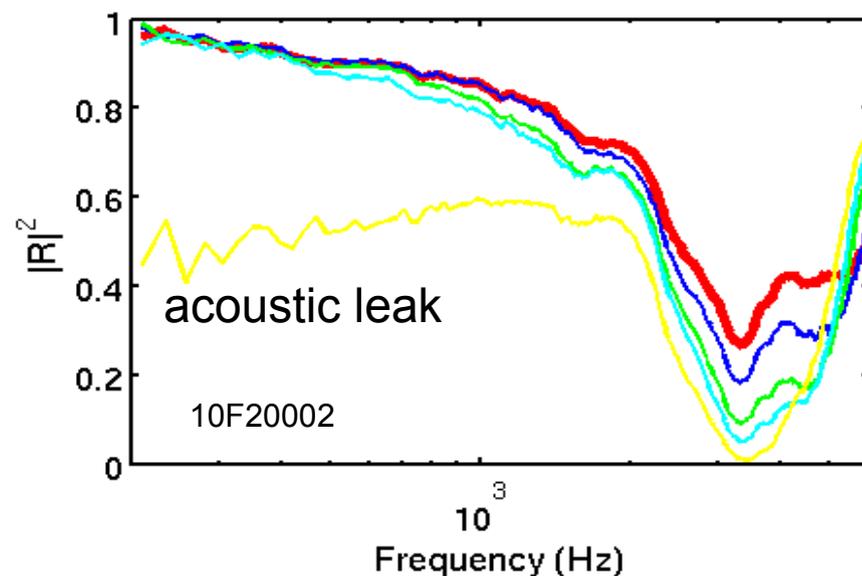
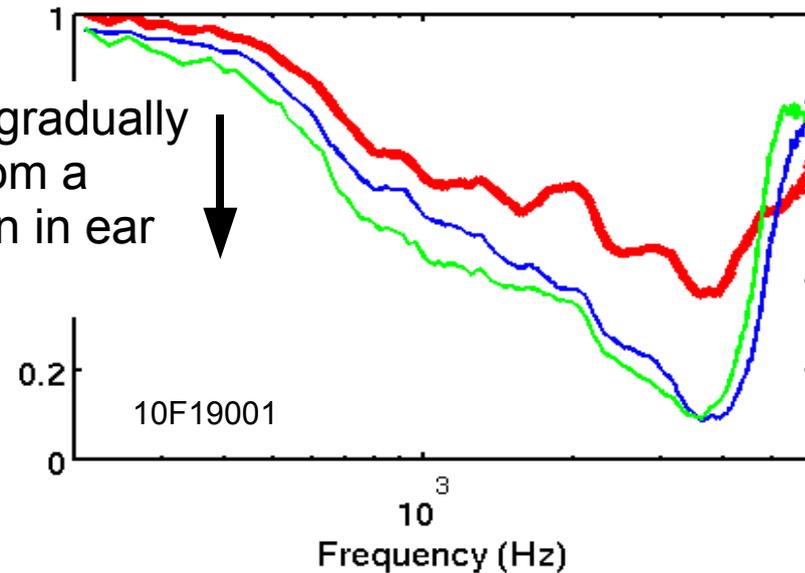
# Reflectance and Impedance of the Ear



# Eartip Insertion

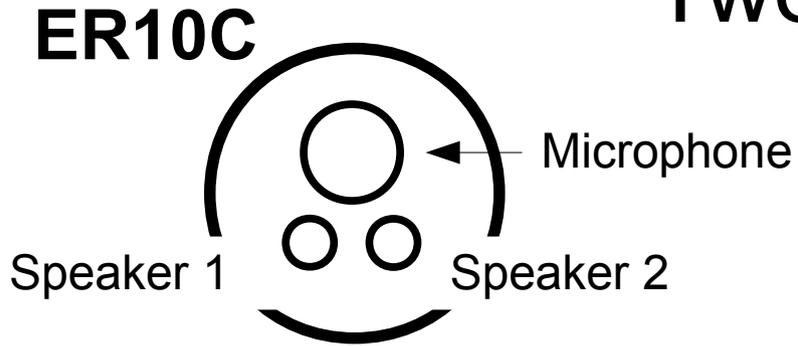
- The foam eartip should be inserted so that the distal end is flush with the ear canal entrance
  - This places the proximal end near the isthmus

Foam eartip gradually withdrawn from a flush insertion in ear canal

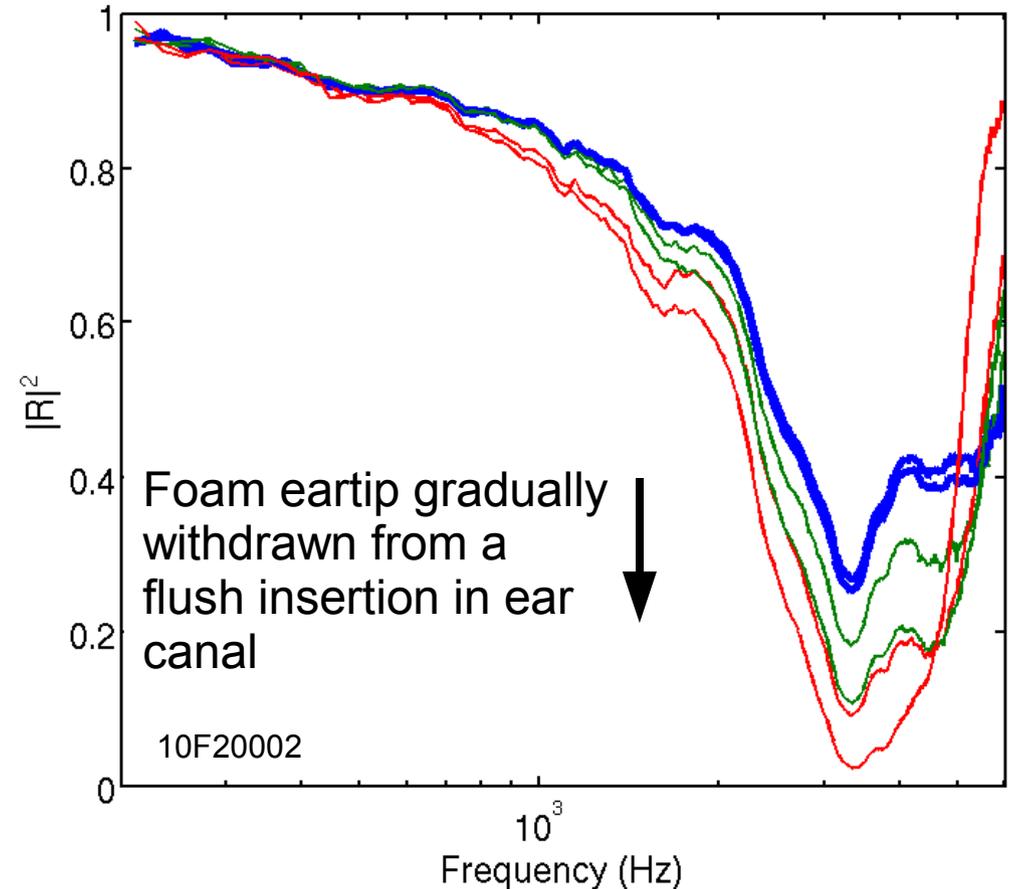


# Eartip Insertion

## -Two Speaker Test-



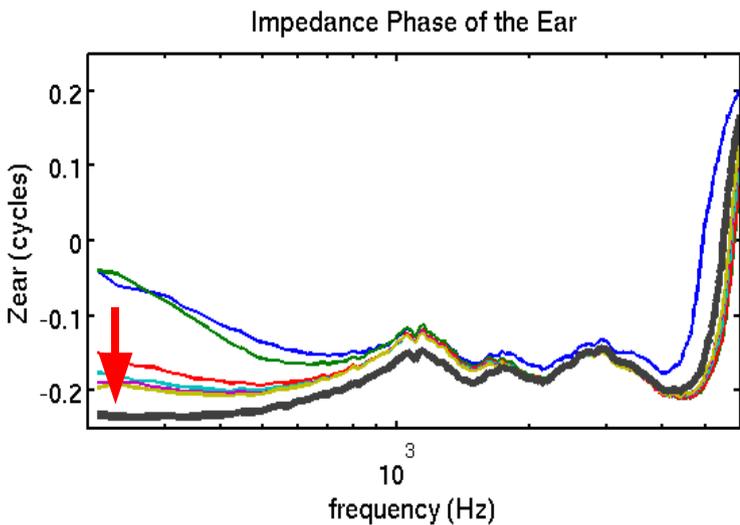
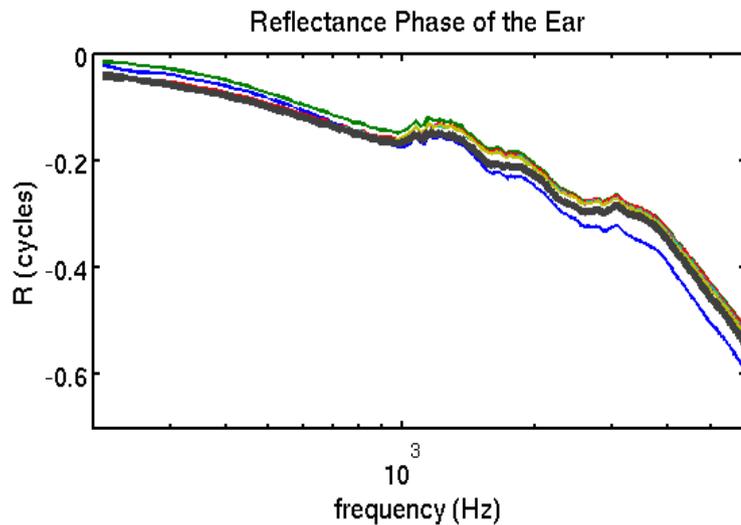
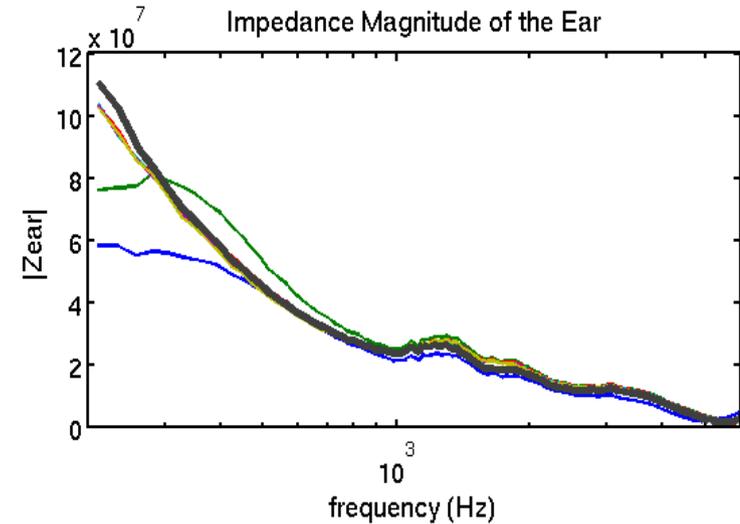
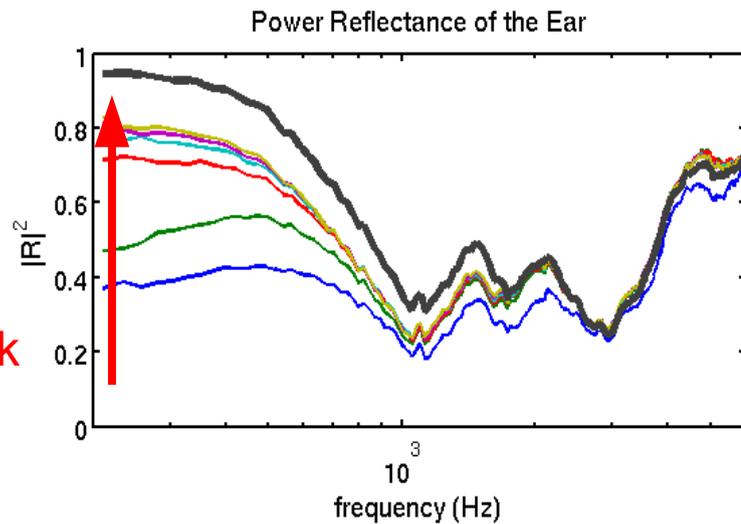
- Stimulus delivered to ear through each of two speakers
- Correct probe placement produces reflectance curves that overlap
  - Sound from both speakers propagates, unimpeded, as a plane wave



# Acoustic Leak

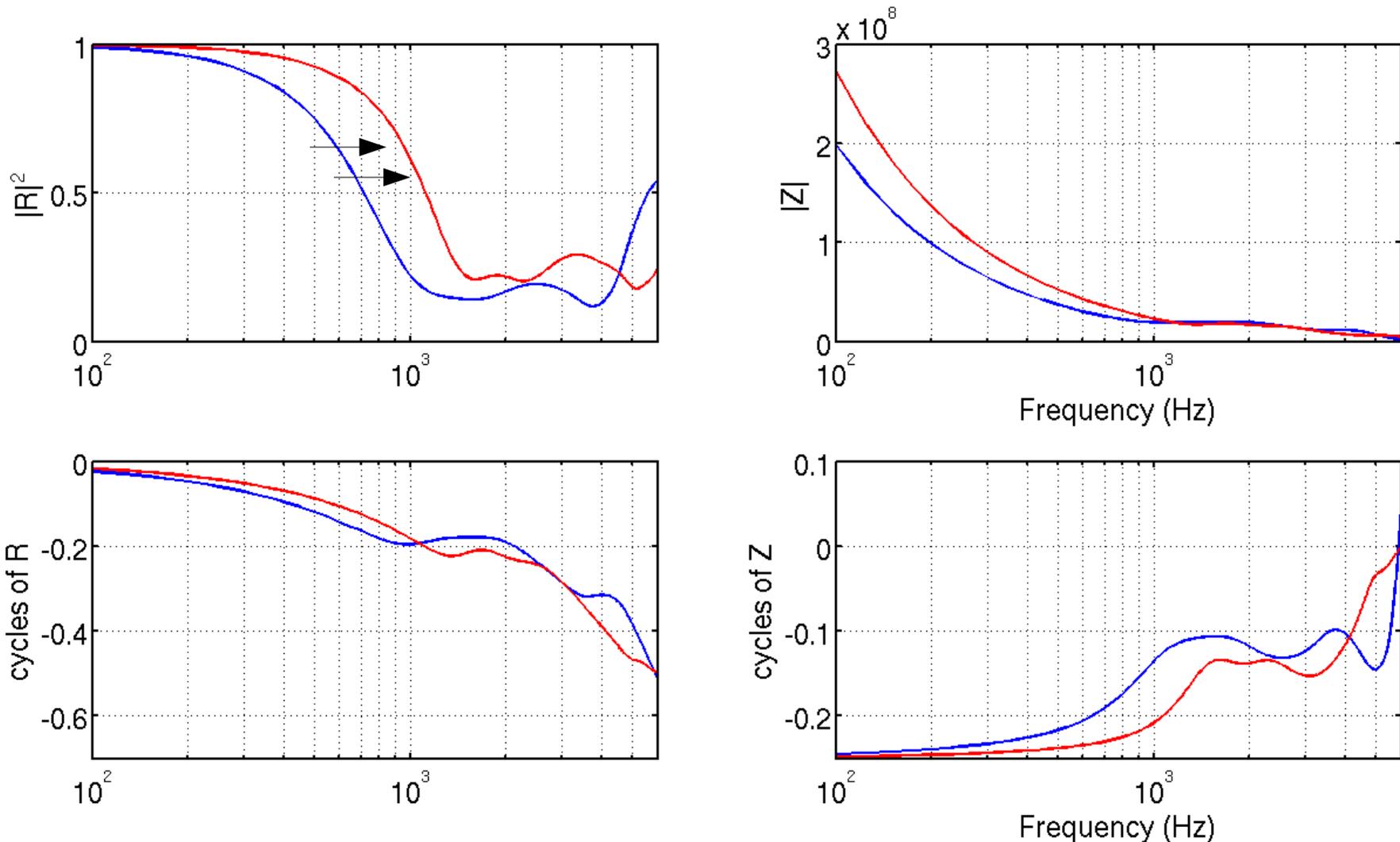
Measurements made in a sound-treated booth

Foam tip gradually expanding, reducing acoustic leak



# Power Reflectance

- increase in stiffness of middle ear -



# WBR

- Calibration and measurement requires
  - Correct depth of insertion of eartip
  - Cord not pulling on probe
  - Eartip fully expanded (for foam-type eartip)
- Reflectance curves should overlap for a valid measurement
- $|R|$  is an expression of how the middle ear filters sound
- Phase of  $R$  dominated by acoustic delay due to enclosed length of ear canal

# Using WBR in the Clinic

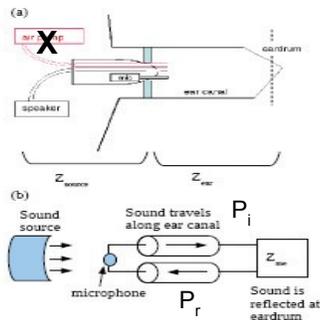
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## ABSTRACT

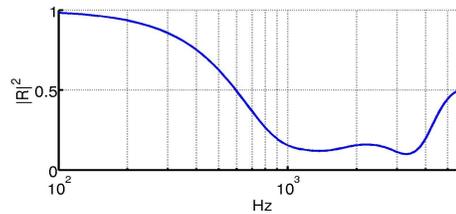
Wideband power reflectance (WBR) provides a broad spectrum measure of the acoustic input impedance of the ear. Research has established the utility of WBR to assess the status of the middle ear. With clinical WBR systems now available, this presentation will focus on the technical aspects of using WBR in the clinic, including calibration, proper insertion of the eartip in the ear canal, recognizing an acoustic leak and/or inadequate depth of insertion of the eartip in the ear canal, and interpreting the magnitude and phase of the reflectance in normal and disordered ears. WBR has the virtue that the status of the middle ear can be assessed without the need for static pressure changes in the ear canal. The magnitude of the reflectance is an expression of how the middle ear filters sound; it is not confounded by the acoustic impedance of the ear canal. The phase of the reflectance is dominated by the acoustic delay due to the enclosed length of the ear canal.

# Wideband Reflectance



Withnell et al (2009)

AAS 2010



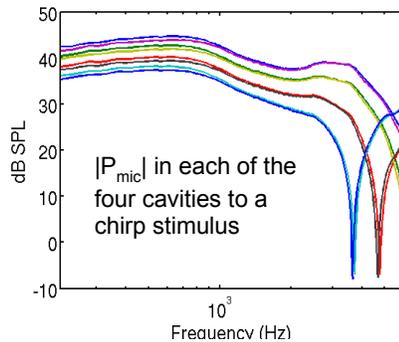
- $R = P_r / P_i$
- A measure of the impedance mis-match between the ear canal and middle ear
  - i.e., how the ear filters the sound it receives

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The acoustic input impedance of the ear can be measured using wideband power reflectance (WBR) or tympanometry. In both cases, the microphone in the ear canal measures the sound pressure, it being a sum of the incident and reflected sound waves. The source acoustic impedance and source pressure are not known for tympanometry, and so static pressure changes in the ear canal are used to generate an estimate of the impedance of the middle ear. WBR uses a calibrated probe source and so static pressure changes in the ear canal are not required (hence the air pump is crossed out in the probe schematics).

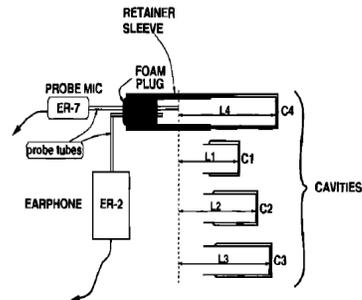
Reflectance is the ratio of the amount of sound reflected from the ear ( $P_r$ ) versus the sound delivered to the ear ( $P_i$ ). Wherever there is an impedance mismatch as sound propagates from the speaker to the cochlea (the sub-tectorial space), sound is reflected. Reflectance is a measure of how the ear filters sound, as illustrated in the figure showing the magnitude of the reflectance as a function of frequency. At low frequencies the middle ear is stiffness-dominated and so much of the sound incident on the eardrum is reflected. At higher frequencies, the impedance match between the ear canal and middle ear is better and much of the sound is transmitted rather than reflected and so the reflectance has a lower value.

# Calibration



Note the coincidence of the two sound pressure measurements for each cavity

$$Z_{source} = \frac{Z_{cavity} * (P_{source} - P_{mic})}{P_{mic}}$$



Voss & Allen (1994)

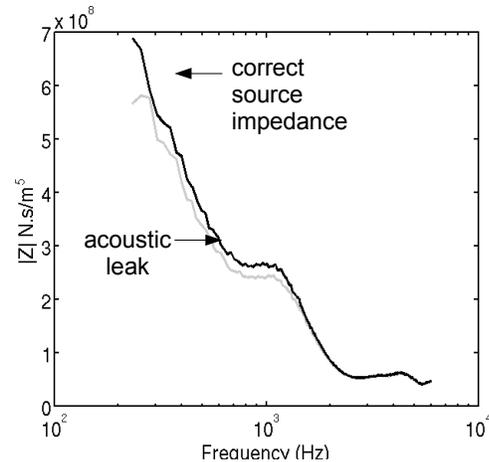
- Solve four simultaneous equations with two unknowns,  $Z_{source}$  and  $P_{source}$

Calibration of the probe for WBR requires placing the probe in two or more cavities and measuring the sound pressure to a broad-band stimulus (in this case, a chirp). The magnitude spectrum plot shows the sound pressure measured in each of four cavities. The amplitude minima in the figure represent standing waves in the cavities. The Mimosa system uses a four-cavity calibration, as illustrated, the acoustic impedance of each cavity being known.

From the calibration, the acoustic impedance ( $Z_{source}$ ) and pressure ( $P_{source}$ ) are obtained. The calibration procedure may not always be successful (as denoted by the software giving an error message), this being a product typically of one of two errors: i. an acoustic leak, ii. the cord attached to the probe loading the probe and altering the angle of placement. These two issues are addressed in the following slides. Taking care to ensure these two errors do not occur should result in successful calibrations.

# Calibration -Acoustic Leak-

- Eartip not allowed to expand before performing calibration
  - Acoustic leak
- Acoustic impedance of Source in error for frequencies < 2 kHz



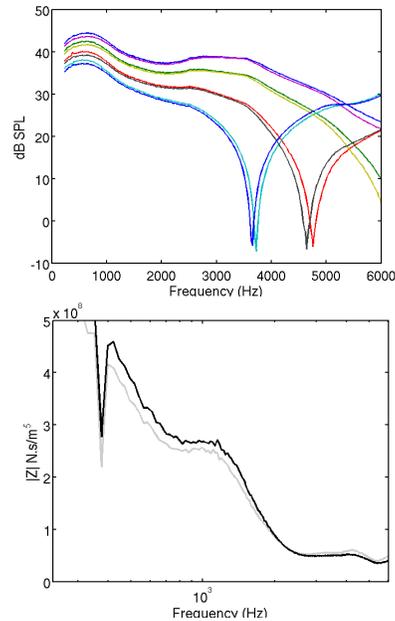
The foam eartip must be compressed before placement in the calibration cavity aperture. The foam subsequently takes a small amount of time to expand and create an acoustic seal. The figure above illustrates what happens if the calibration procedure is commenced before allowing the foam to fully expand. The acoustic impedance calculated for the probe shows an acoustic leak, the acoustic impedance of the probe being in error for frequencies less than 2 kHz.

It is recommended that 60-90 seconds be allowed to elapse following eartip insertion in the cavity aperture before beginning the calibration procedure.

# Calibration

## -Improper (angled) Placement-

- Weight of cord pulls down on eartip
  - Alters shape of foam eartip sound delivery tubes
- Sound pressure responses differs for speaker 1 vs speaker 2 providing stimulus
  - Acoustic path differs for two stimuli
    - SWF magnitude minima differ
- Acoustic impedance calculation differs for speaker 1 vs speaker 2 providing stimulus



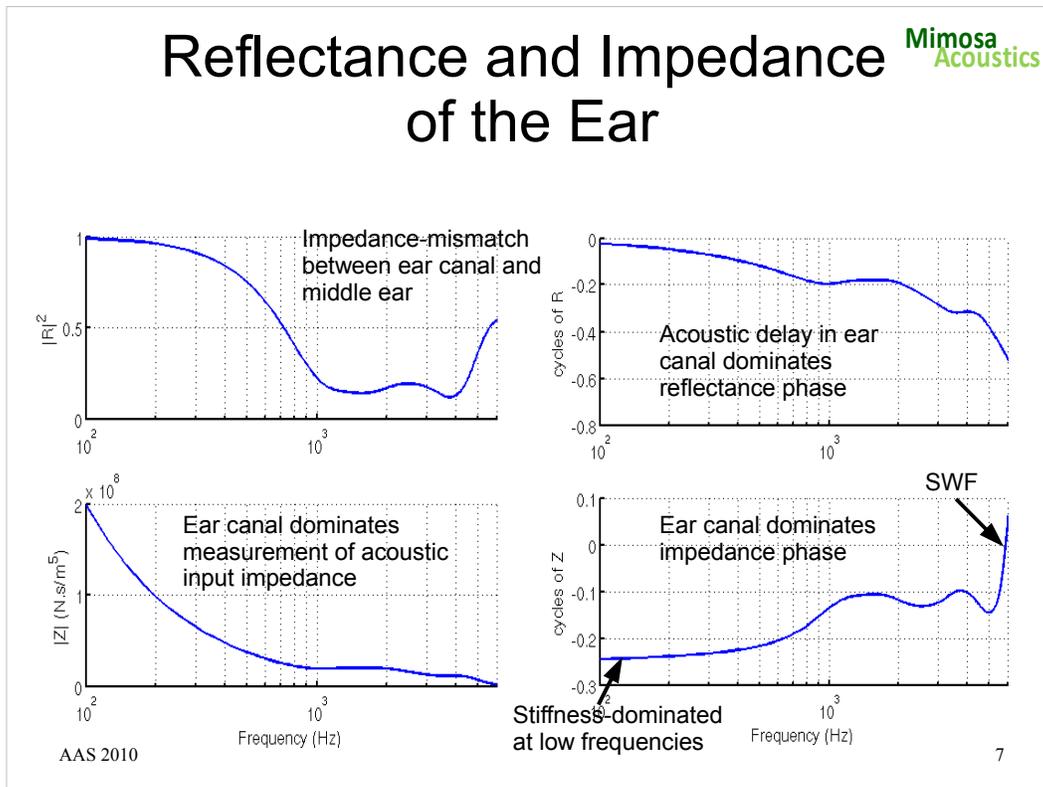
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The weight of the cord attached to the probe can load the probe, pulling down on the eartip, altering the shape of the foam eartip sound delivery tubes. This is illustrated in the top figure where the amplitude spectrum for measurement in each of the four cavities shows the frequency responses to differ for speaker 1 versus speaker 2. In particular, the standing wave frequency minimum differs for sound delivered through speaker 1 versus speaker 2, showing that the acoustic paths for the sound stimuli differ.

The lower figure shows the acoustic impedance calculation, neither being the correct acoustic impedance.

With a valid calibration of the probe one can then measure the acoustic input impedance of the ear. This is illustrated in the next slide, with errors in measurement related to eartip location and adequate expansion of the foam eartip considered in subsequent slides.

# Reflectance and Impedance of the Ear

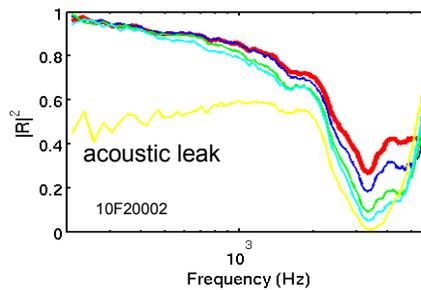
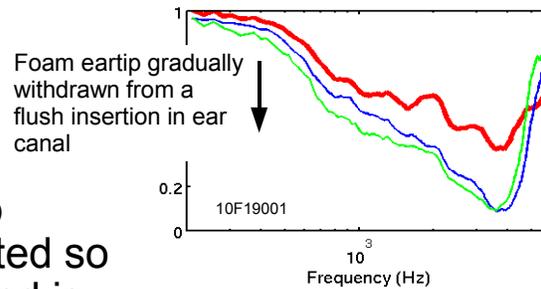


“Reflectance is equivalent to impedance but easier to understand” (Withnell et al., 2009). This slide illustrates reflectance and impedance of the ear. The magnitude of the reflectance represents the impedance mismatch between the characteristic impedance of the ear canal and the impedance of the middle ear... it is a measure of the filtering of sound by the middle ear and cochlea. It is not influenced by the acoustic impedance of the ear canal. In contrast, the acoustic input impedance of the ear, magnitude and phase, is dominated by the acoustic impedance of the ear canal.

The Mimosa system provides the option of viewing the data in each of these formats.

# Eartip Insertion

- The foam eartip should be inserted so that the distal end is flush with the ear canal entrance
  - This places the proximal end near the isthmus

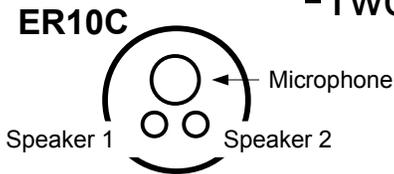


Note how the magnitude of the reflectance decreases up to about 4 kHz as the eartip is withdrawn from a flush insertion in the ear canal, and then increases sharply relative to a flush insertion.

A flush insertion presumably optimizes the placement of the sound and microphones ports with respect to the bony portion of the ear canal.

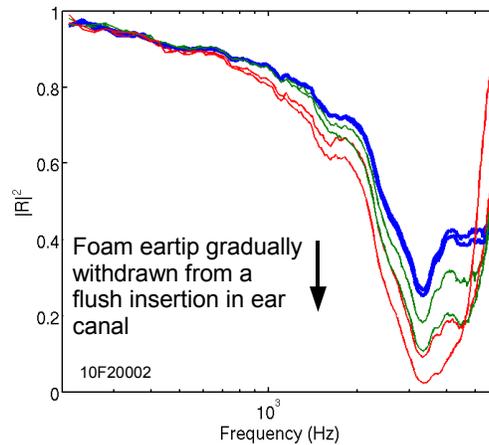
# Eartip Insertion

## -Two Speaker Test-



- Stimulus delivered to ear through each of two speakers
- Correct probe placement produces reflectance curves that overlap
  - Sound from both speakers propagates, unimpeded, as a plane wave

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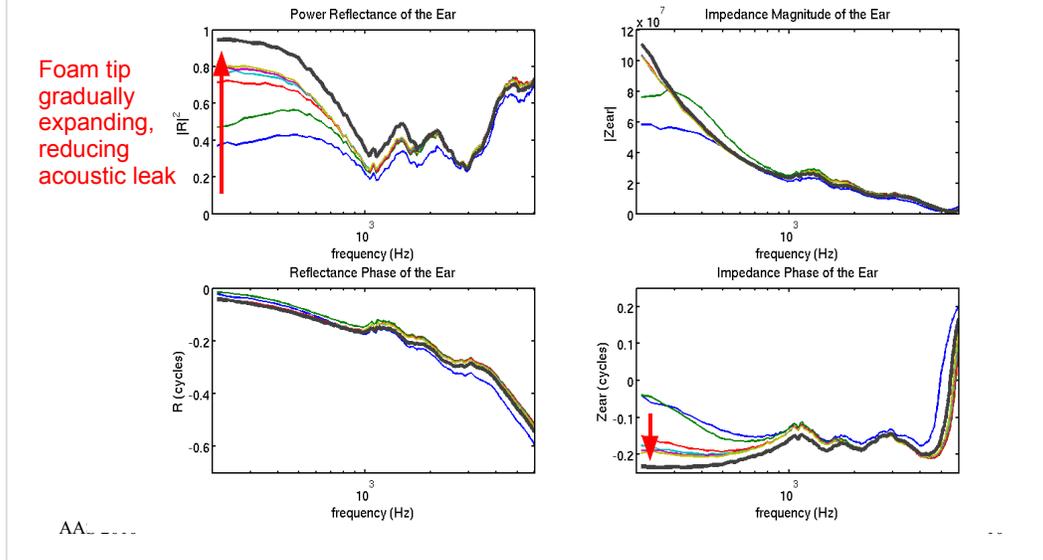


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The two speakers with separate outlet ports (see schematic) provide a test of eartip placement. Insertion of the eartip so that the distal end is flush with the ear canal entrance will place the proximal end of the eartip near the isthmus and so close to the bony portion of the ear canal, presumably centrally locating the sound and microphones ports with respect to the ear canal. A common acoustic path for sound delivered from both speakers will produce similar sound pressure measurements at the microphone and generate reflectance curves that overlap. Reflectance curves that do not overlap are consistent with incorrect eartip placement. Correct eartip placement with the distal end of the eartip flush with the ear canal entrance is illustrated with the blue reflectance curves in the figure. Two subsequent measurements with the eartip withdrawn from a flush insertion show reflectance curves that do not overlap (two green curves and two red curves).

# Acoustic Leak

Measurements made in a sound-treated booth

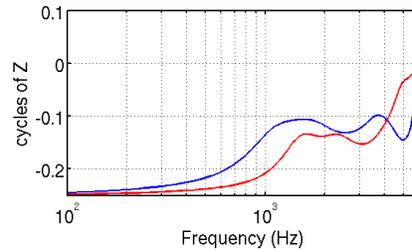
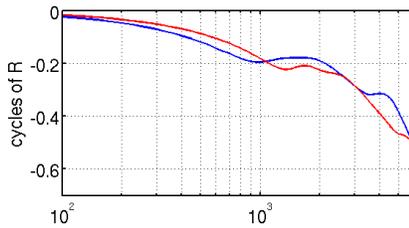
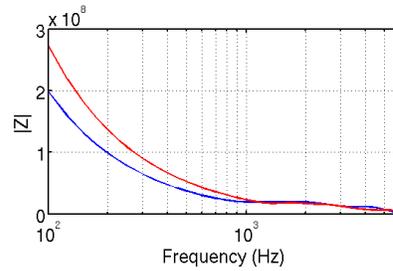
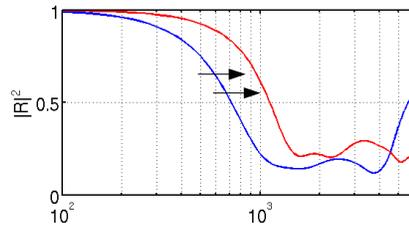


If the foam eartip, once inserted in the ear, is not given sufficient time to expand, then an acoustic leak can result, the effect of which is illustrated in the figures in the slide. As with calibration, adequate time must be given for the eartip to expand in the ear canal before beginning measurements in the ear.

With a valid calibration and measurement of the acoustic input impedance of the ear, WBR can then be used to assess the status of the middle ear. The following slide provides an example of the change in reflectance due to an increase in stiffness in the middle ear. See Withnell et al. (2009) in *Hearing Journal*, volume 62, number 10, pp. 36-39, for more details.

# Power Reflectance

- increase in stiffness of middle ear -



An increase in stiffness in the middle ear will shift the reflectance magnitude curve to the right (red curve, top left panel).

# WBR

- Calibration and measurement requires
  - Correct depth of insertion of eartip
  - Cord not pulling on probe
  - Eartip fully expanded (for foam-type eartip)
- Reflectance curves should overlap for a valid measurement
- $|R|$  is an expression of how the middle ear filters sound
- Phase of R dominated by acoustic delay due to enclosed length of ear canal