Forgotten Acoustics

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Canadian Academy of Audiology 2018

Order of the talk

1.Standing waves

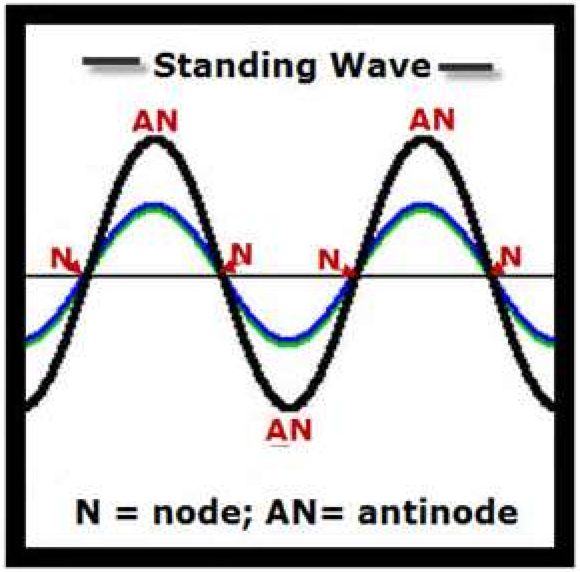
2.Impedance and damping

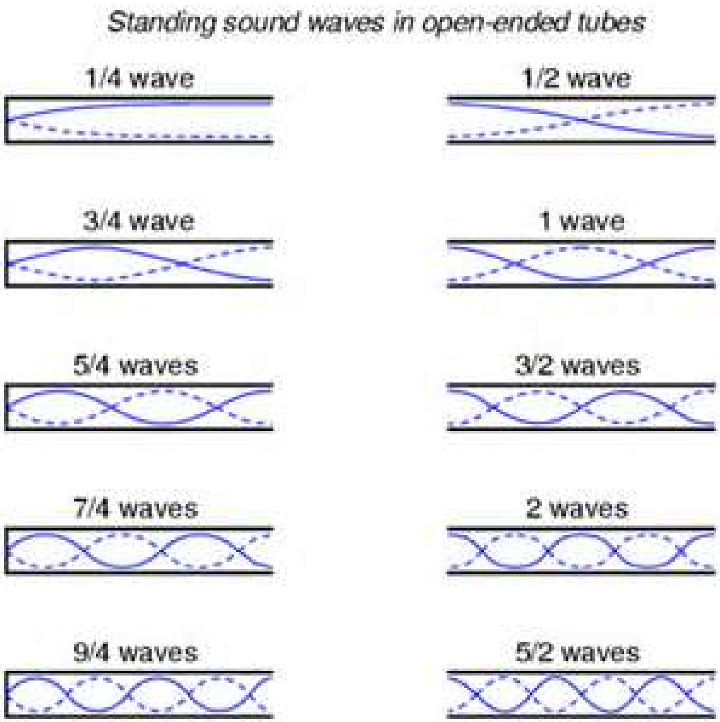
3.Amplification and flaring of a tube

4.Boyle's Law for conventional and deep canal fi

5.Pinna effect and stage setting at a venue

1. All about Standing waves…





A schematic of our vocal tracts

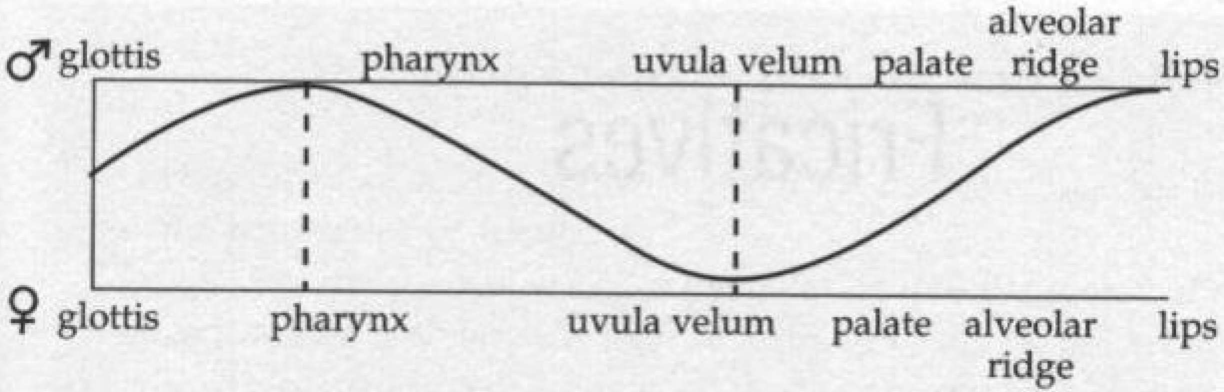


Figure 6.12 Standing wave of the third formant resonance (in a tube that is open at one end and closed at the other), with articulatory landmarks for typical male and female speakers identified. From Hagiwara, 1995, p. 12; reprinted with permission.

Standing waves and resonances

- What are three places we don't have standing waves?

1.sky diving

2.Anechoic chambers

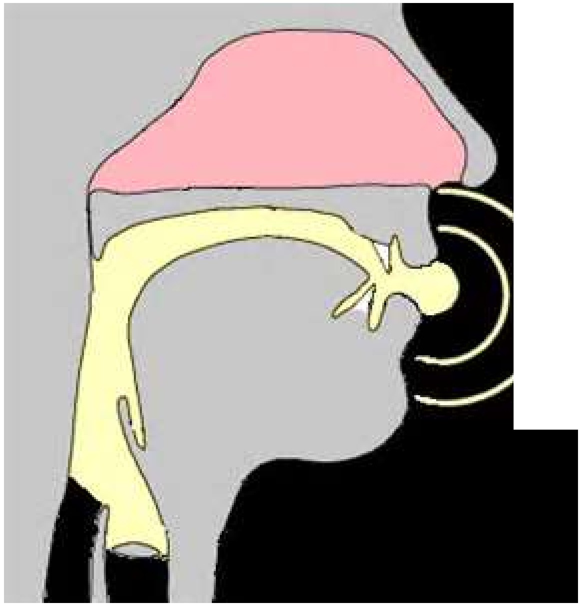
3..... We shall see...

-

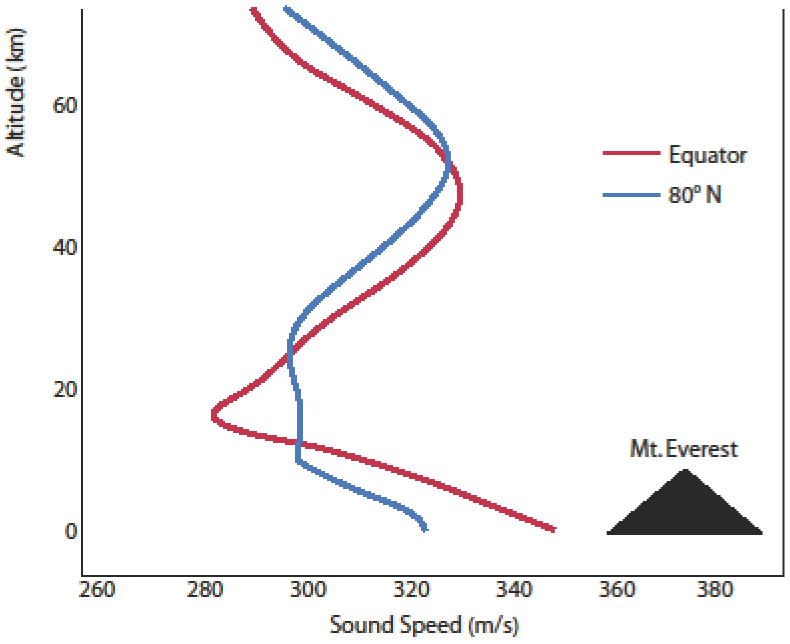
Quarter wavelength resonators

- Related to length only
- $F\ (2k-1)v/4L$

- V is the speed of sound (34,000 cm/sec)
- L is the length of the tube



Speed as a function of altitude



Example #1: F1 for [a]

F=(2(1)-1) x 34,000/4 x 17

F=1 x 34,000/68

F1=500/sec = 500 Hz

Example #2: F2 for [a]

F=(2(2)-1) x 34,000/4 x 17

F=3 x 34,000/68

F2=1500/sec = 1500 Hz

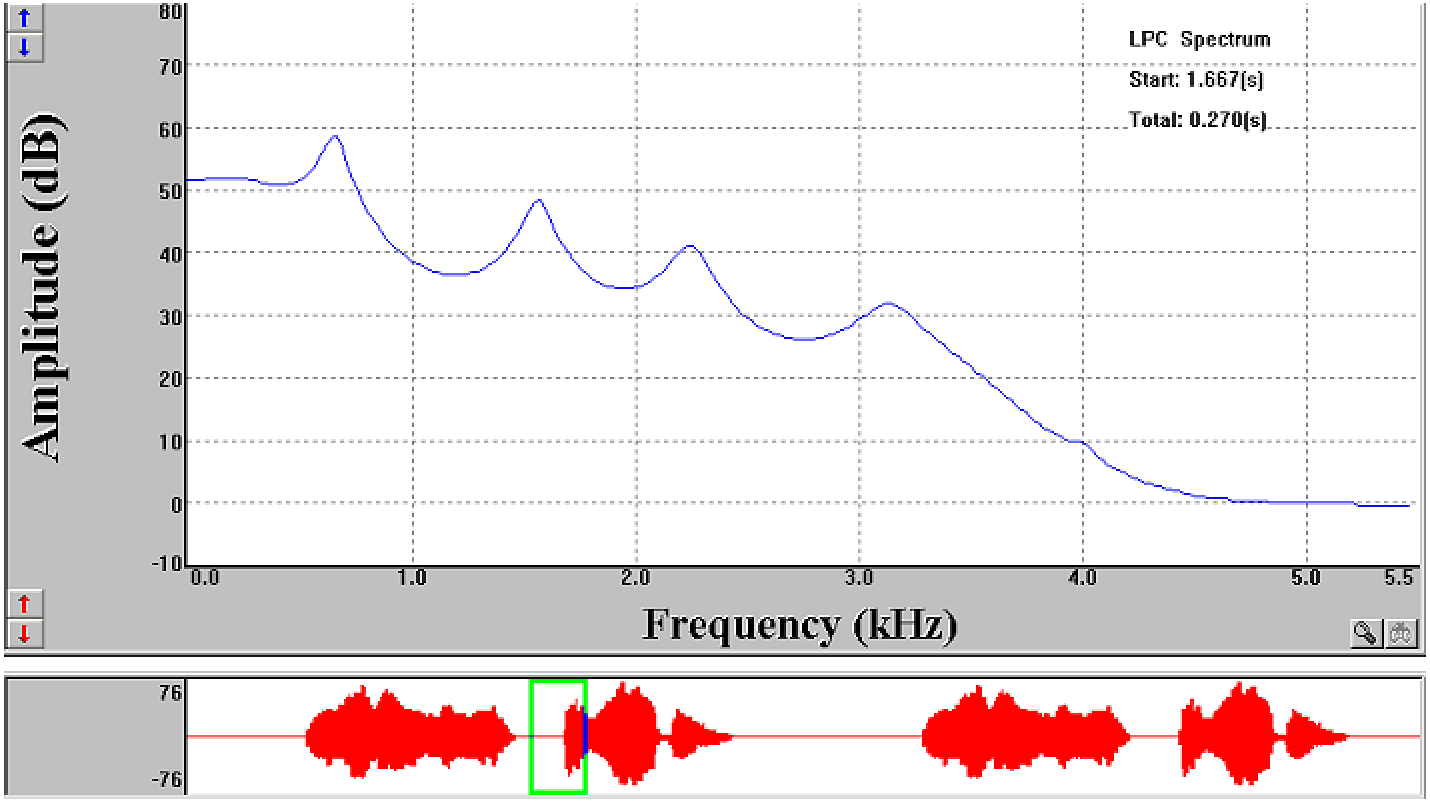
Example #3: F3 for [a]

F=(2(3)-1) x 34,000/4 x 17

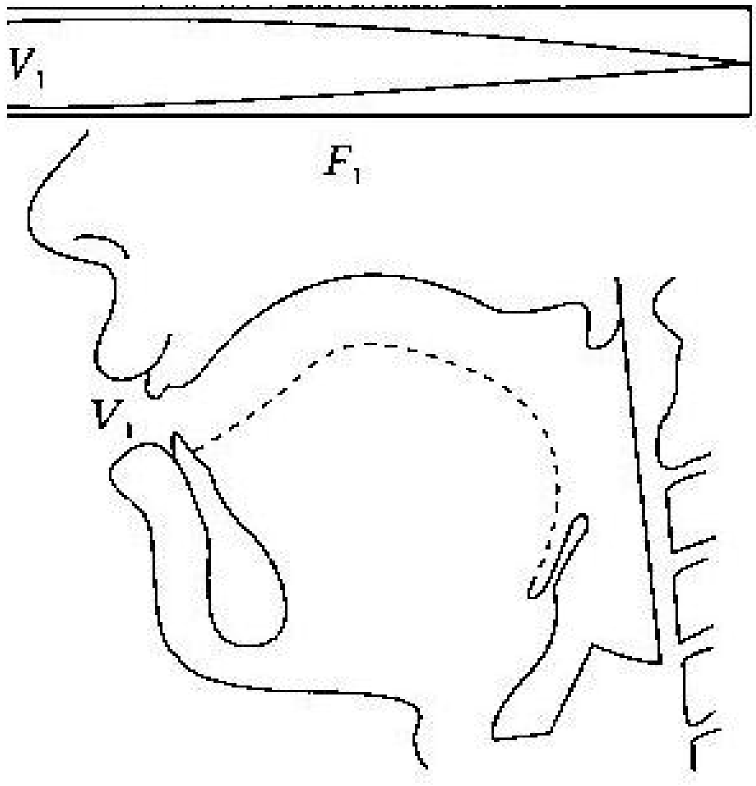
F=5 x 34,000/68

F3=2500/sec = 2500 Hz

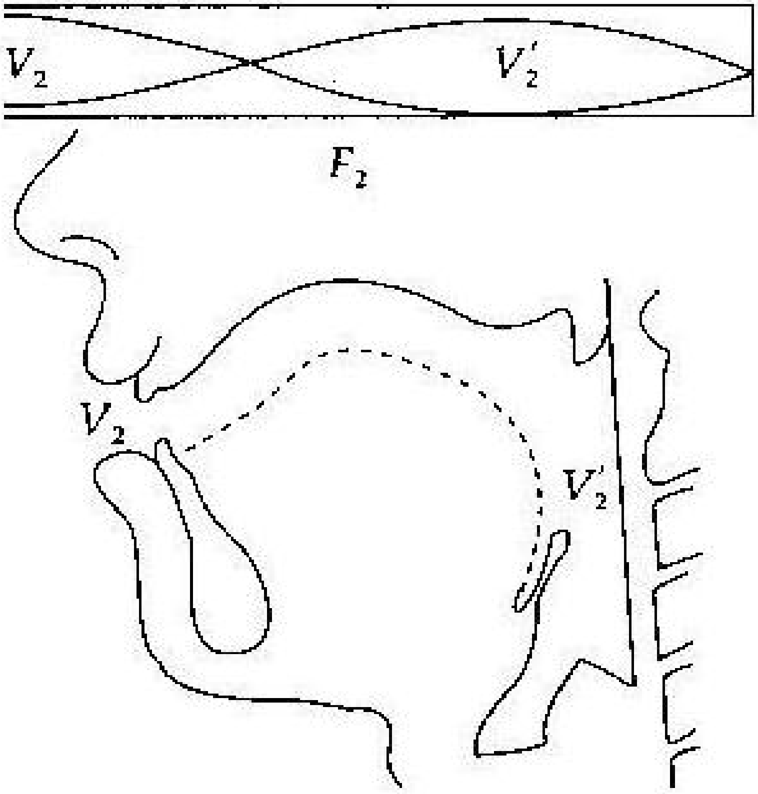
Vowel [a] as in 'father'



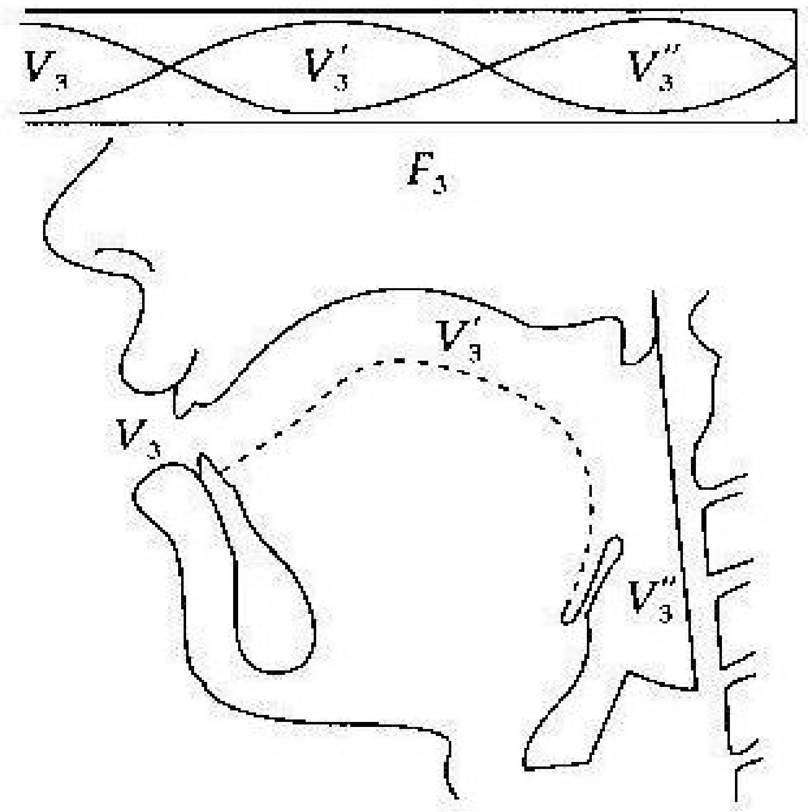
F1 of [a]



F2 of [a]



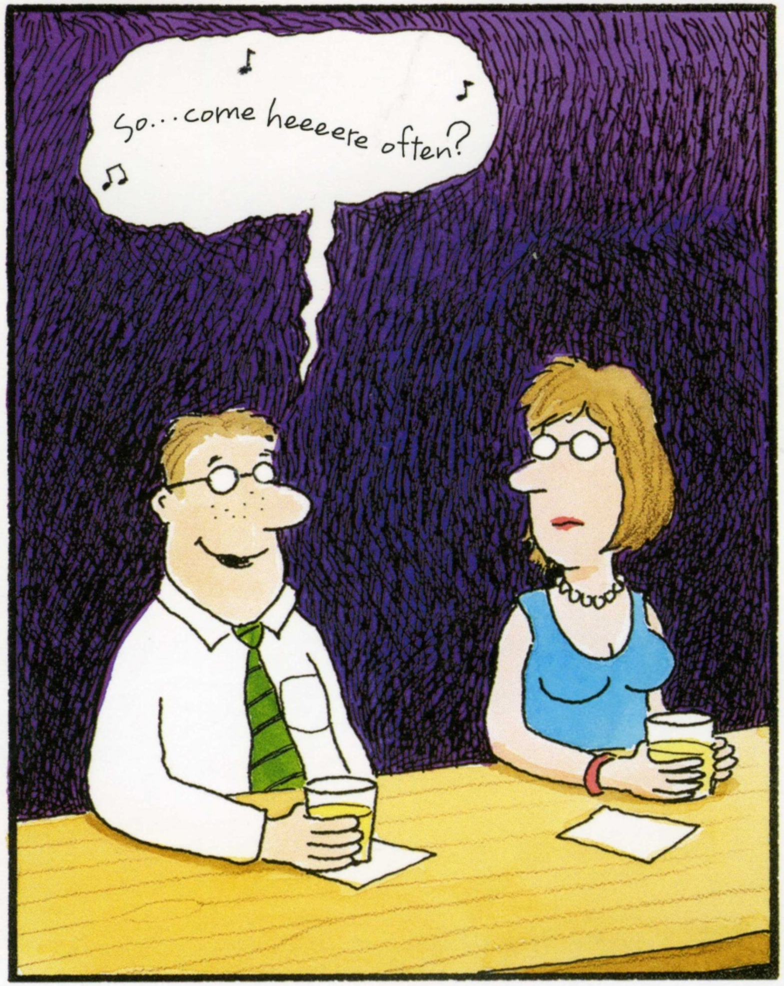
F3 of [a]



Example #H: (F1 in Helium)

F=(2(1)-1) x 100,000/4 x 17

F=1470.5 Hz (~ 1500 Hz)

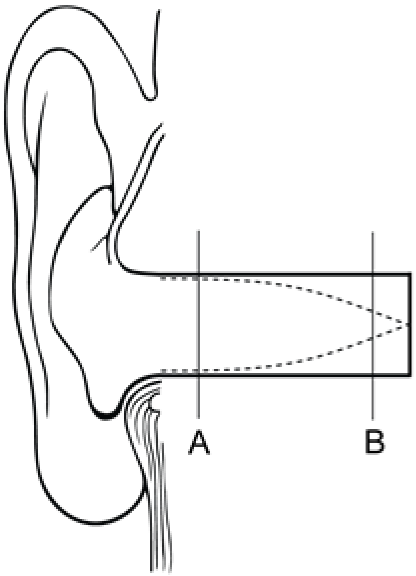


Even though his job at the helium plant paid well, Ernie found it hard to socialize after work.

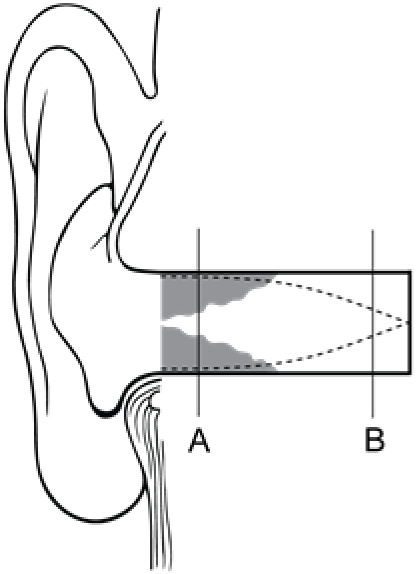
SO… Quarter Wavelength Resonators

- Odd multiples of the first resonance
- No information on amplitude of formants
- Only found in a tube that is open at one end and closed

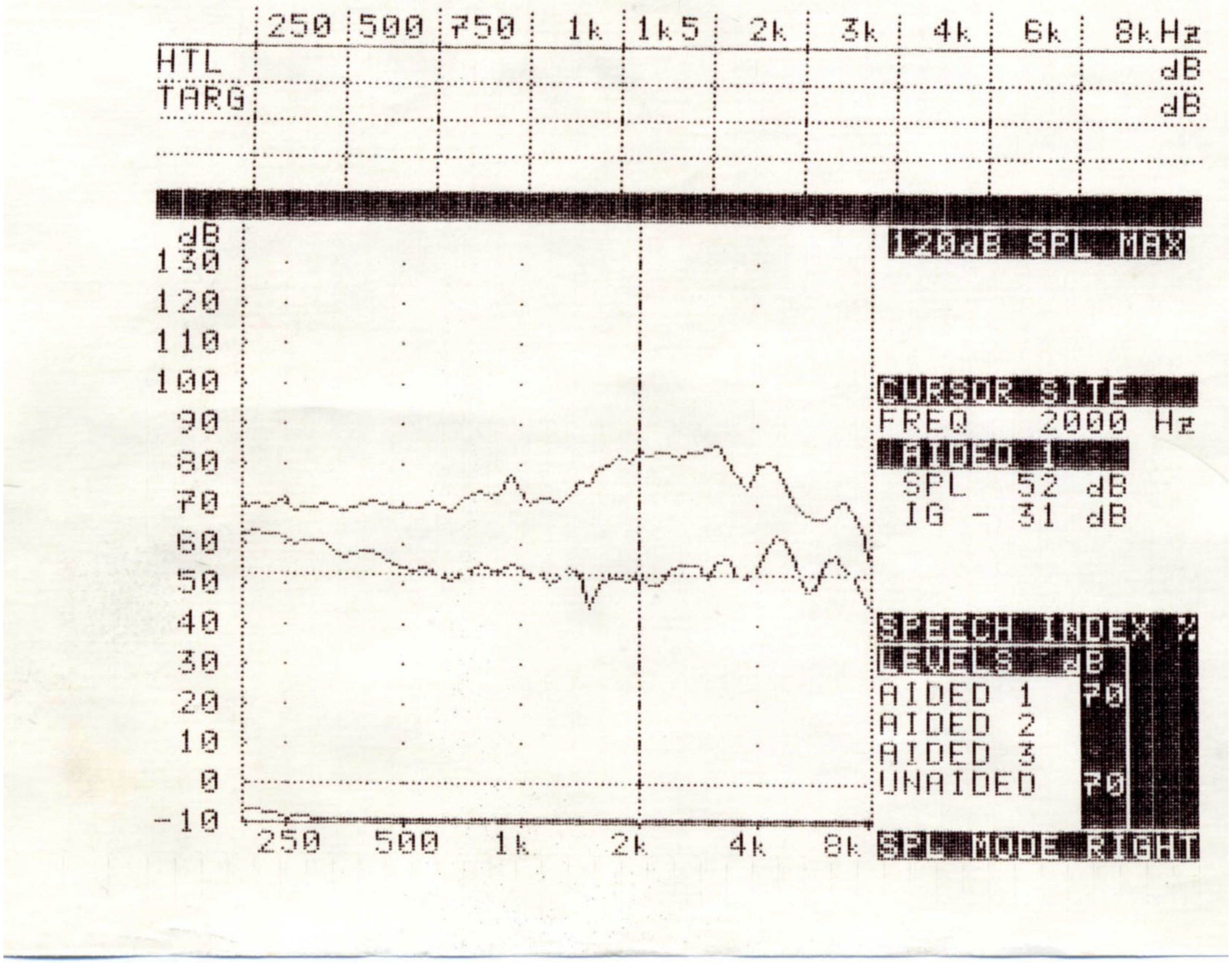
REUR unobstructed ear canal



REUR due to obstructed ear canal

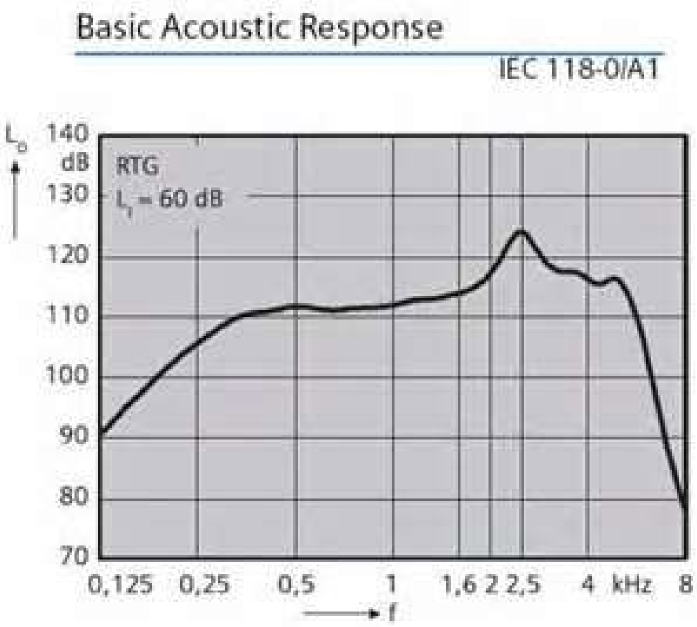


Change in REUR due to obstructed ear canal



No quarter wavelength resonances in custom products… no standing waves…

- F = v/4L
- If L = 1 cm
- Then F = 8500 Hz

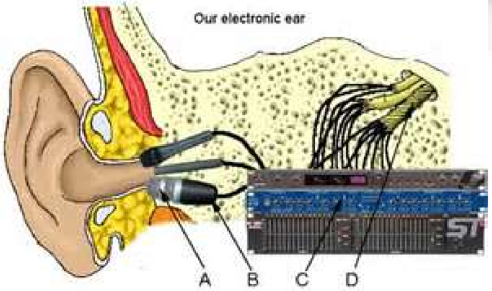


Real Length and "acoustic length"

- KEMAR's ear canal length is 21.5 mm
- Adult ear canal length is 28 mm

- F = v/4L

- 1. Compliance of TM
- 2. Inertance (mass of air) at open end



Quarter wavelength resonances…

- Odd numbered multiples of the first mode
- Found only in tubes closed at one end and open at the other
- Both the open end and the closed end can provide some additional length
- No information on the resulting amplitude… damping

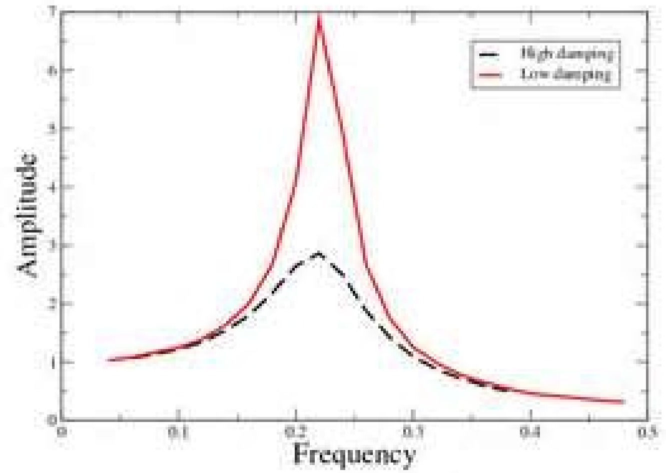
2. All about damping…

Reactance and resistance

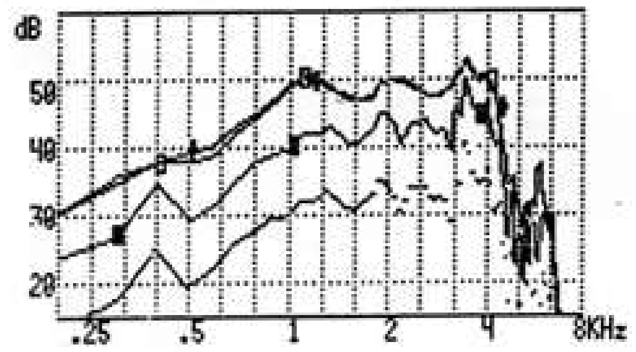
- Reactance is a function of frequency and is made up of both stiffness and mass components
- Resistance is independent of frequency and is a characteristic of the system.
- At resonance, reactance = 0

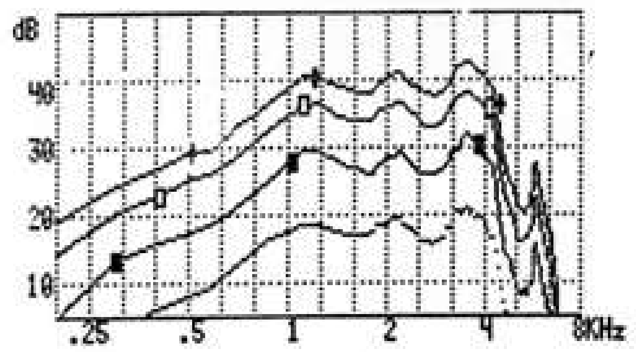
Impedance at resonance

- Z=$\sqrt{\boldsymbol{reactance}^{\mathbf{2}} + \boldsymbol{resistance}^{2}}$
- At resonance, reactance = 0 (mass = stiffne
- Z = resistance (independent of frequency)
- At resonance…
-         Z = pure resistive damping



All resonant peaks of similar amplitude





Specific Impedance

- Z= ρv/area (cgs)
- Z= density of air x speed of sound / cross sectional area of tube (cgs)
- Z= 0.0012gr/cm^3 x 34,000 cm/sec / 0.0314 cm^2

- Z=1300 Ω

- So…. A tube that has an inner diameter of 2 mm (0.2 cm) such as #13 tubing has a specific impedance of Z=1300 Ω.
- It takes Z=1300 Ω to get rid of all tubing related resonances. (we use 1500 Ω)
- It would take Z >> 1300 Ω for a thin tube. Independent of frequency

(Knowles) acoustic resistors (dampers)

A schematic of our vocal tracts (F3)

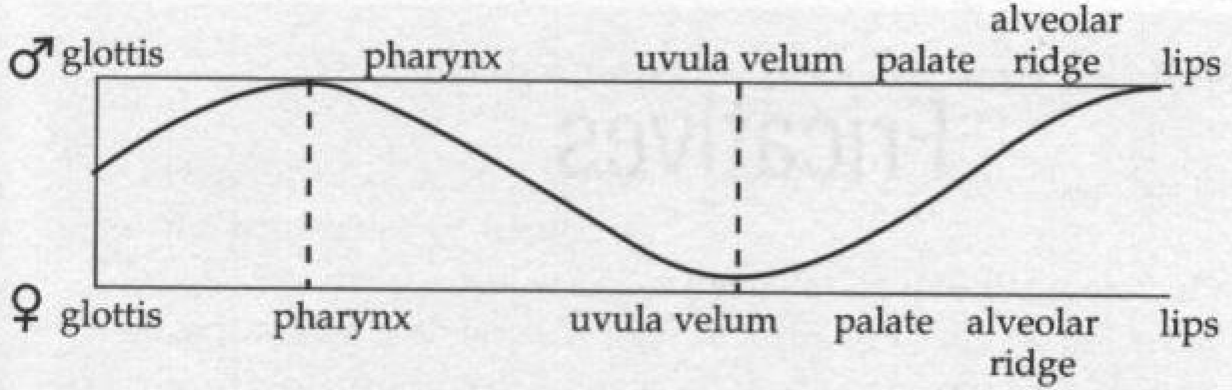
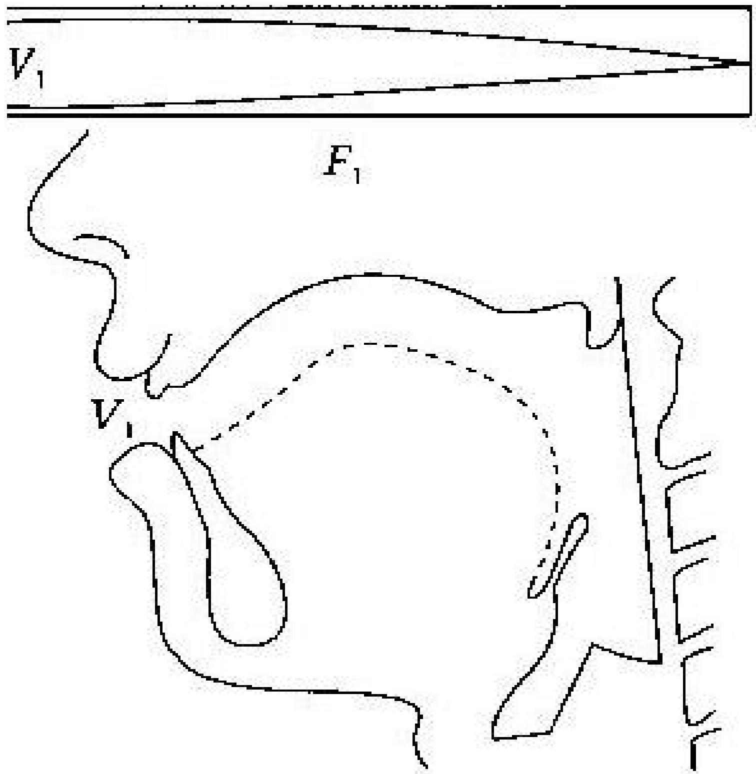
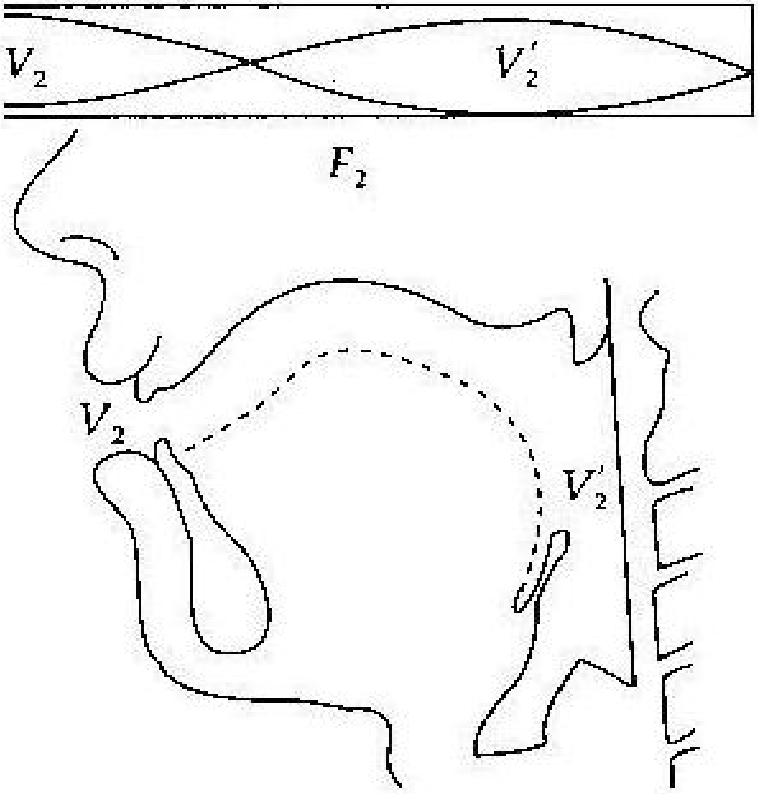


Figure 6.12 Standing wave of the third formant resonance (in a tube that is open at one end and closed at the other), with articulatory landmarks for typical male and female speakers identified. From Hagiwara, 1995, p. 12; reprinted with permission.

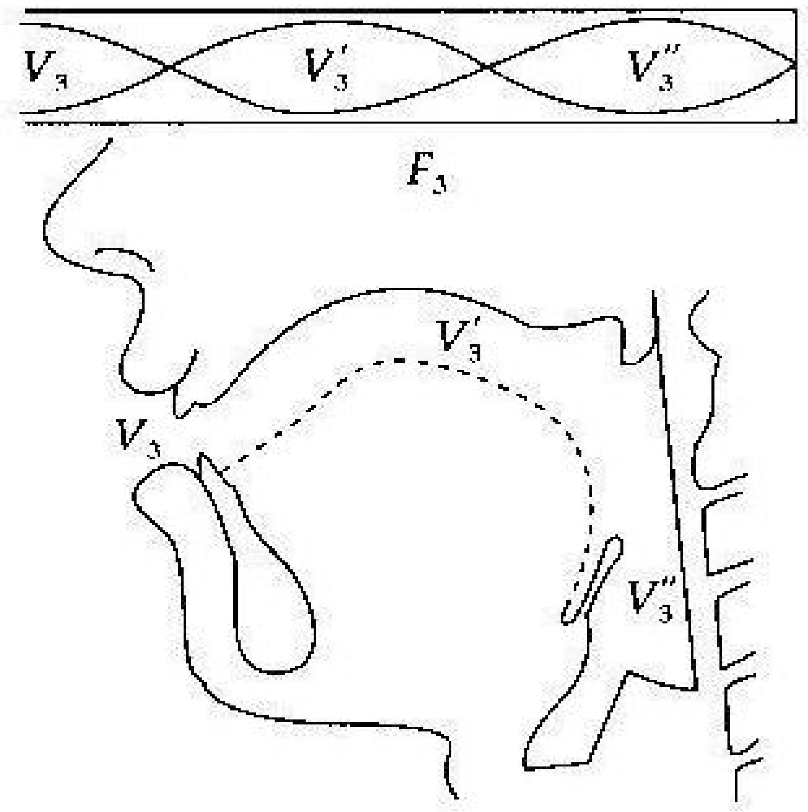
F1 of [a]. Also 1000 Hz tubing resonance



F2 of [a]. Also second resonance (3kHz)



F3 of [a]. Also third resonance (5kHz)

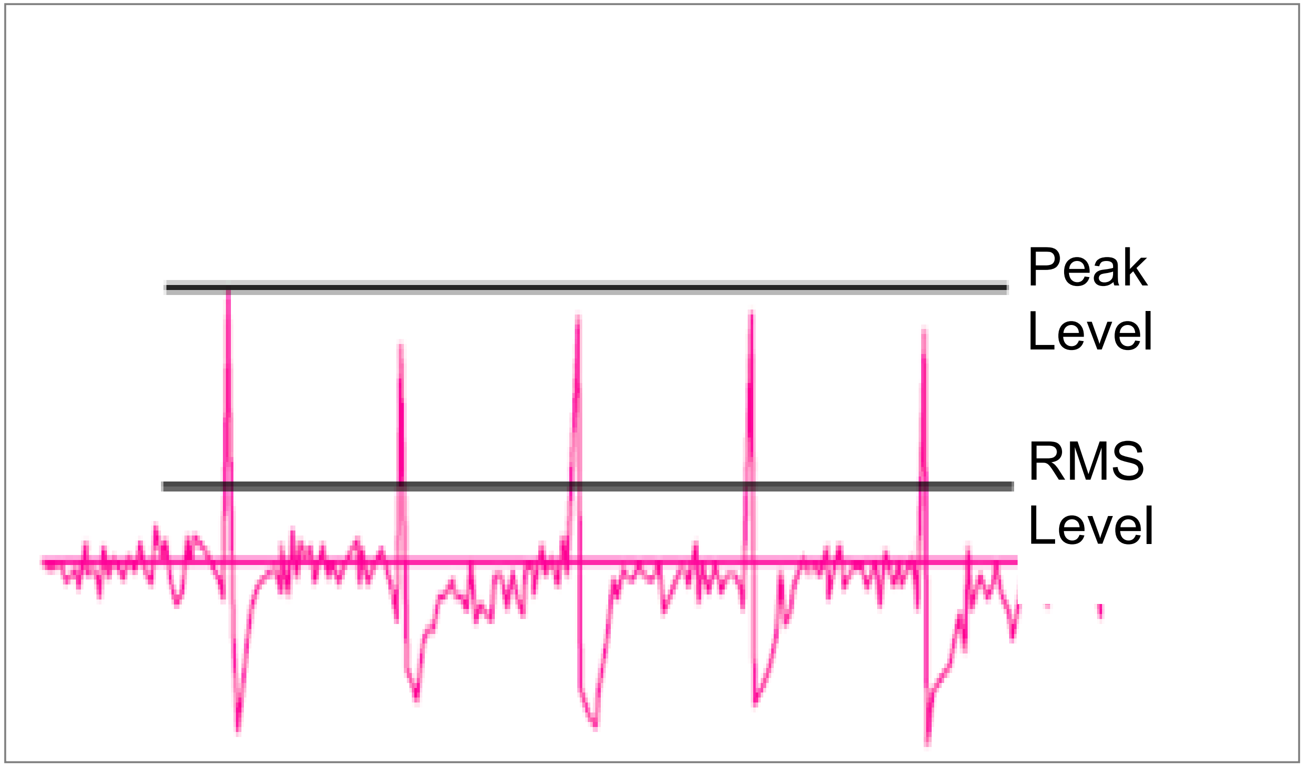


Resistance at end of speaking tube

Damping and crest factor

- Crest factor: (peak – RMS)
  - *Speech has a crest factor of 12 dB*
  - *Music has a crest factor -up to 18 dB*
    - Less damping.

Crest factor



Let’s re-examine the crest factor for speech …

Analysis window (msec)	500	400	300	200	125	100	50	25
Crest factor (dB)	12.46	12.48	12.46	12.45	12.46	13.22	16.68	16.68

Let’s re-examine the crest factor for speech …

- Sivian and White (1933)

  and Cox et al. (1988)

  -assumed the analyzing window should be 125 msec.

  … but we are not talking about our auditory systems, only the front end.

What the crest factor can tell us about speech…

- If the crest factor is actually a function of the window of analysis, then a hard of hearing person's own voice can overdrive their own hearing aid!

- 84 dB input + 16 dB crest factor > 96 dB

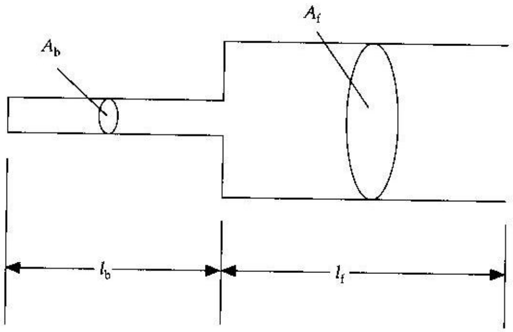
3. Acoustic transformer effect

- The advantages of flaring the tubing

- 1. F = v/2L
- 2. Flare needs to be >1/3 of the L for any effect

- The intensity of all frequencies whose one half the total length of the tubing are enhanced by having a flare or horn….

- …. High frequencies are enhanced



Examples of flares…

But not....

- FLARE < 1/3L

Amplification factor

- Amplification for higher frequencies up to…. X dB
- 10log(area of wider end of flare/area of narrower end of flare)
- Function of the ratio and not the absolute values
- Useful for anything that is flared

Acoustic transformer effect

Amplification factor

- 4 mm Libby horn
- From 2 mm (ID of #13 tubing) to 4 mm
- 10log (πr^2 of wider / πr^2 of narrower portion)
- = 10log (2^2) = 2 x 10log (2) = 6dB
- …. Also 6 dB from 1 mm ID to 2 mm ID (for thin tube)

Advantages of using an acoustic horn

- Not as much of an advantage as in the 1980s for hearing aids
- (class A amplifiers)

- Maintenance of headroom
- - for frequency response and OSPL90 curves

- Better battery life

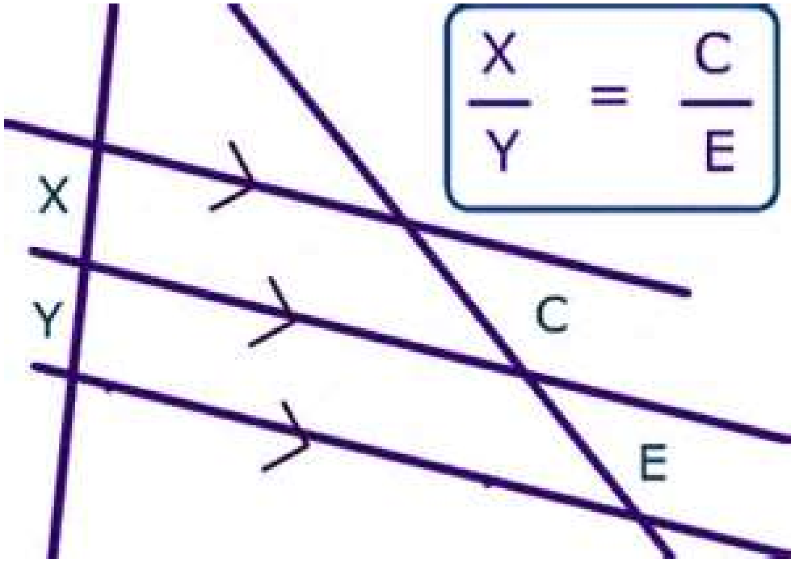
4. Boyle’s Law

- first published 1660

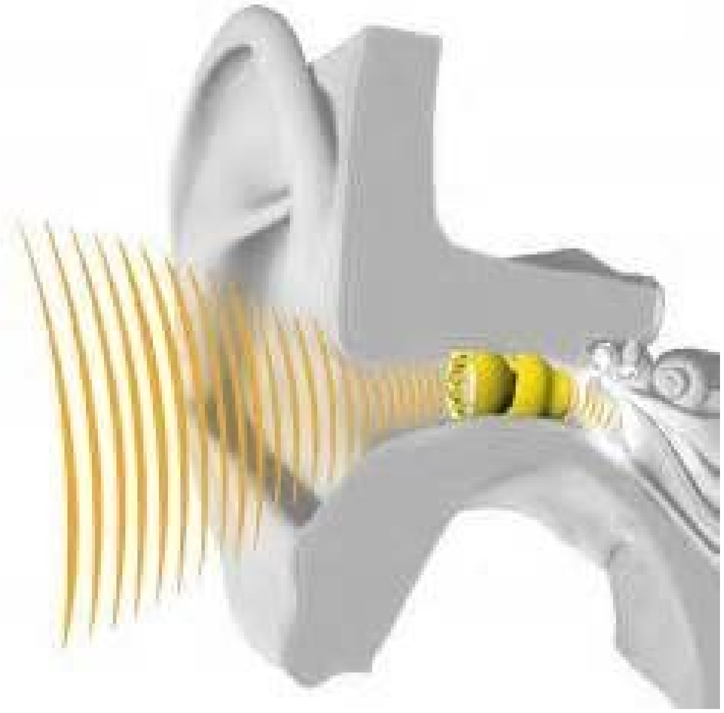
- residual volume α 1/ pressure
- long canals, lower residual volume, higher SPL
- independent of frequency (like damping)
- AND residual volume α 1/ impedance

Boyle's Law….. 2 corollaries

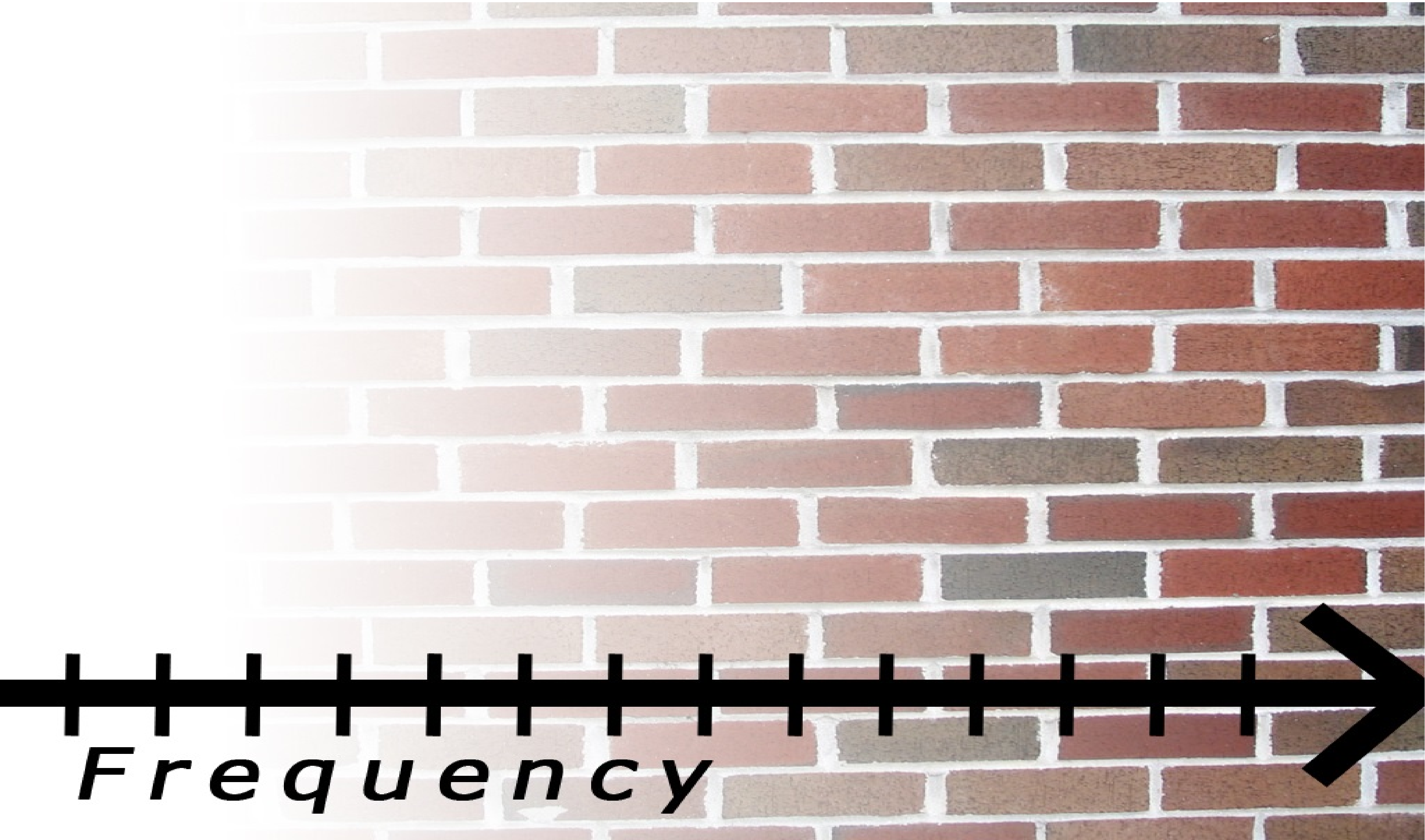
1. Sound pressure is inversely related to residual volume
2. For small residual volumes, TM and middle ear structures become important… RECD implications



Deep canal hearing aid and SPL



High frequencies see a brick wall



High frequencies see a brick wall

- Low frequencies see a much larger volume (1.4 cc) than higher frequencies do (0.4 cc)
- Boyle's Law predicts a lower SPL for lower frequencies than for higher frequencies.
- Its as if Boyle's Law moves ahead with a hand break on for low frequencies.

From Staab, Seminars on Auditon, 1996

(personal communication from Mead Killion, 1993)

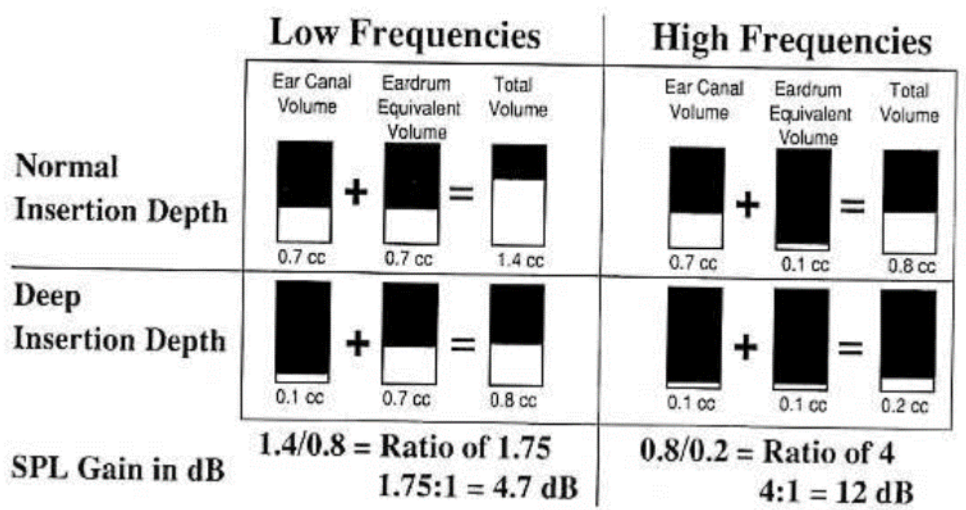
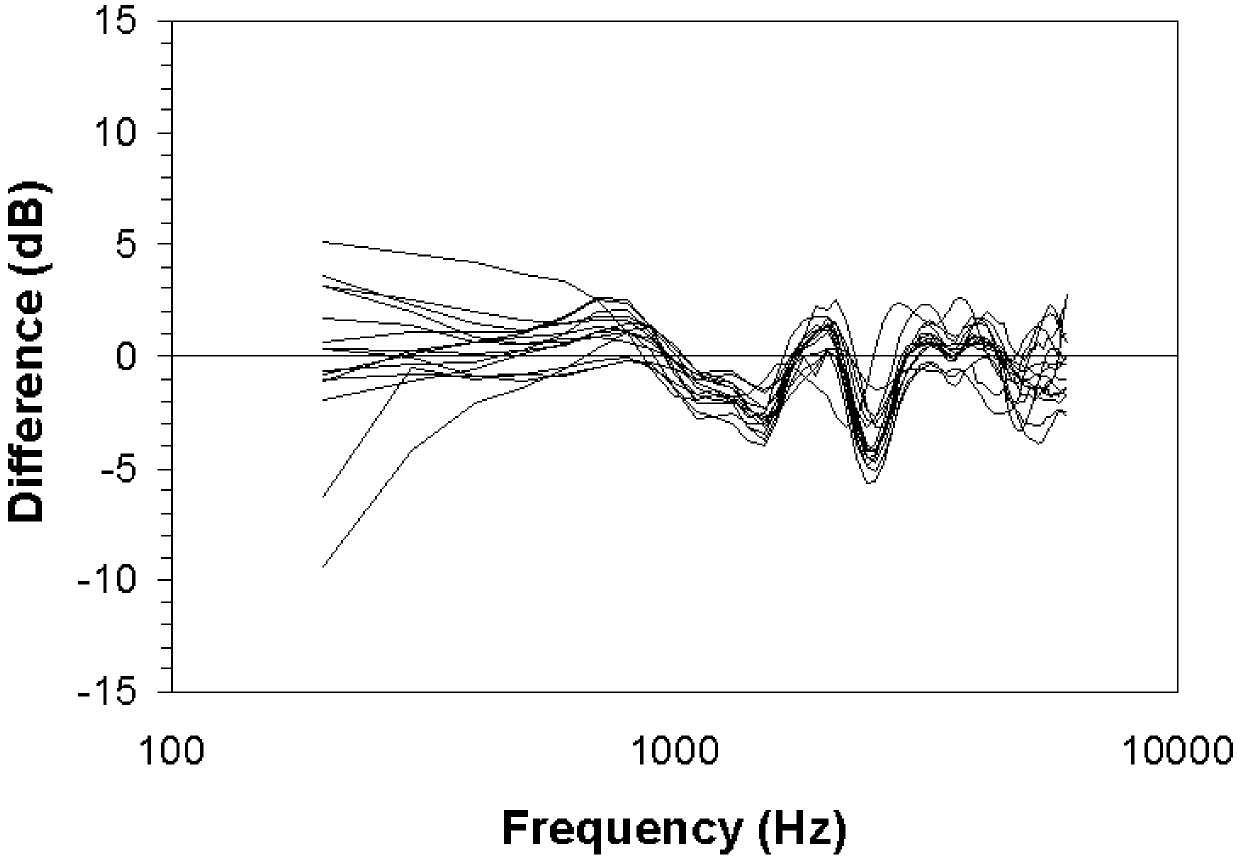
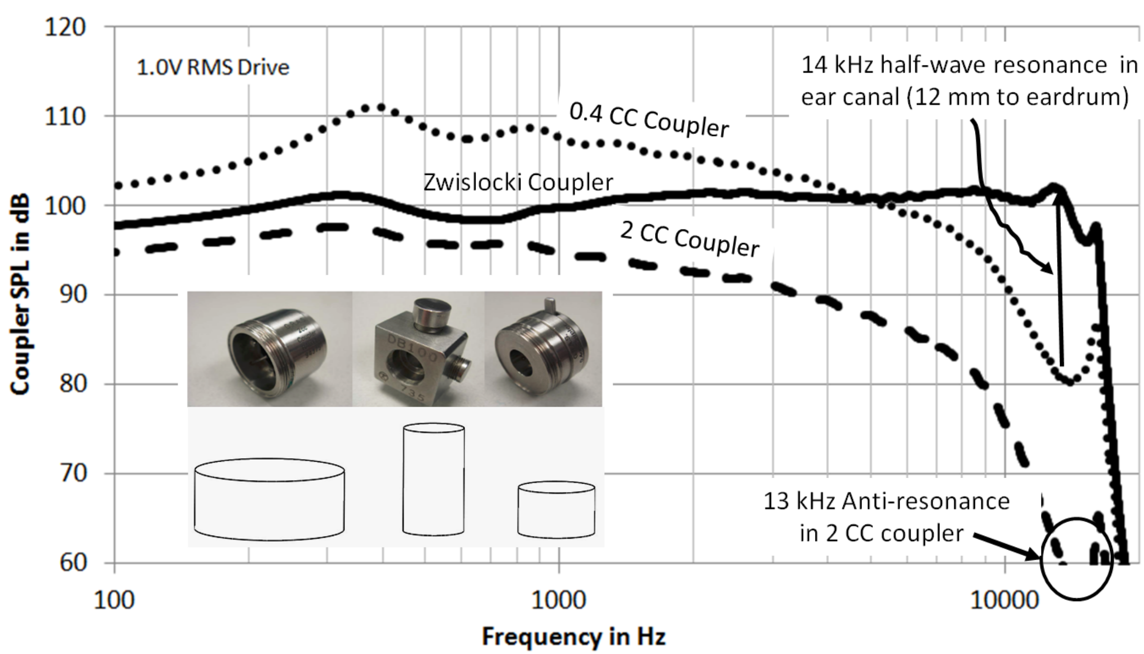


Figure 3. Theoretical explanation for differences in sound pressure increase between low and high frequencies. This representation ignores the complex impedance of the ear but shows a distinct advantage for the high frequencies. (Adapted from M.C. Killion, personal communication, 1993, with permission.) 7

Bagatto et al. (2005)
Trends in Amplification



0.4 cc vs. 2.0 cc couplers (killion, 2015)



Boyle's Law for deep canal fittings.

- Not only is the middle ear system impedance now a factor
- BUT also, because the real ear canal is more flexible than a hard walled coupler, there is an additional high frequency transmission in the real ear…. An added component to the RECD
- Because the ear drum and middle ear system has a low impedance relative to a hard walled coupler, the transmission is dependent on frequency with more net high frequency energy being transmitted than in a hard walled coupler.

5. Pinna effect and high frequencies

- The acoustic impedance of the acoustic inertance is proportional to frequency….

…. High frequencies hate obstructions

… they reflect…

Pinna effect

- Net high frequency boost in sound level
  depends on width and mass of obstruction

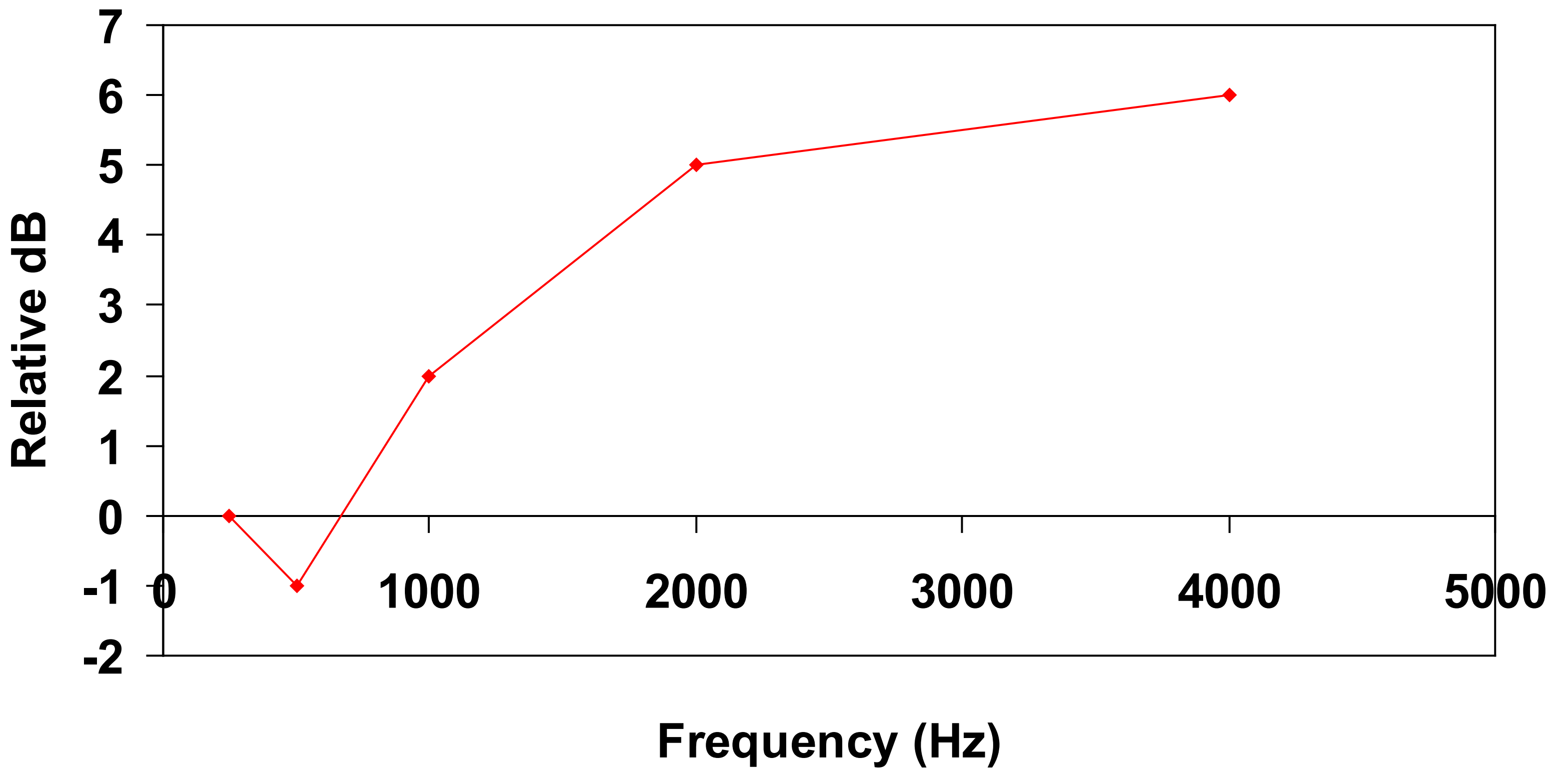
- Human pinnae tend to obstruct (and reflect)
  sounds in excess of 1500 Hz

Pinna effect and performance stages

- Backing an orchestra off 2 meters from the lip of the stage
-
- Acts as an acoustic mirror

- Net high frequency boost "after" the musician.

Net boost caused by having 2 meters of floor “mirror” in front of orchestra



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Hearing Review May 2013 Part 1 (acoustics)

Hearing Review June 2013 Part 2 (deep canal acoustics)