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MUSICAL ACOUSTICS

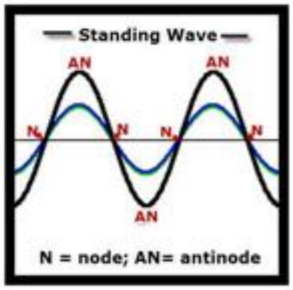
MARSHALL CHASIN, AUD,
MUSICIANS' CLINICS OF CANADA

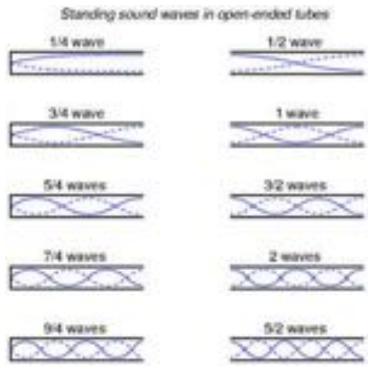
AUDIOLOGYONLINE MAY 15, 2014

ORDER OF THE TALK

1. Standing waves
2. Impedance and damping
3. Amplification and flaring of a tube
4. Pinna effect and stage setting at a venue

1. ALL ABOUT STANDING WAVES…





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A SCHEMATIC OF OUR VOCAL TRACTS

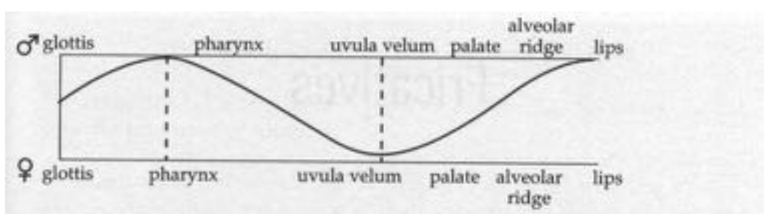

Figure 6.12 Standing wave of the third formant resonance (in a tube that is open at one end and closed at the other), with articulatory landmarks for typical male and female speakers identified. From Hagiwara, 1995, p. 12; reprinted with permission.

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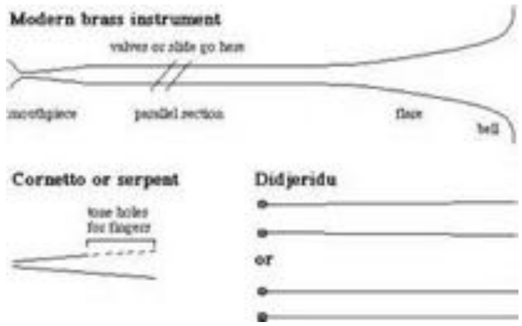
SCHEMATIC OF A TRUMPET



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STANDING WAVES AND RESONANCES

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

1. sky diving
2. Anechoic chambers
3. Custom hearing aids

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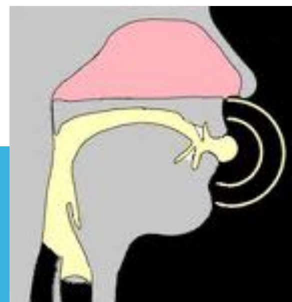
QUARTER WAVELENGTH RESONATORS

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



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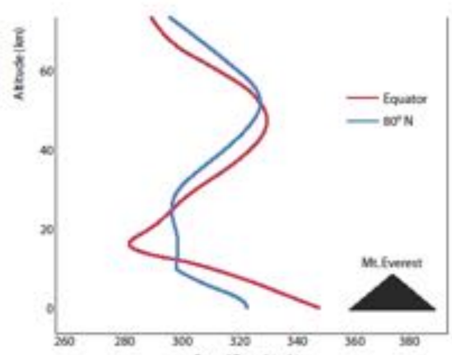
SPEED AS A FUNCTION OF ALTITUDE



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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

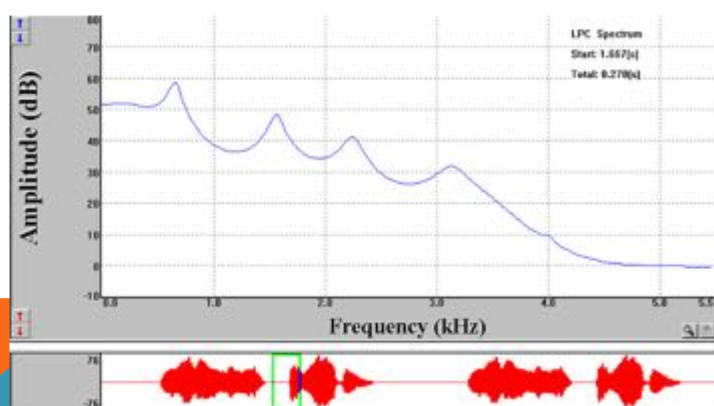
EXAMPLE #3: F3 FOR [A]

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

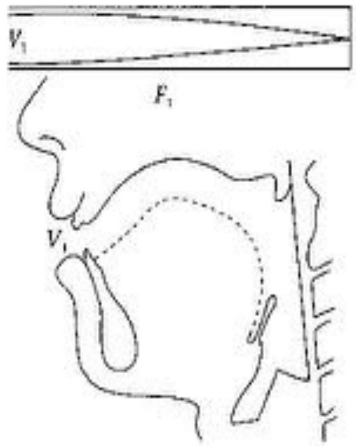
F=5 x 34,000/68

F3=2500/sec = 2500 Hz

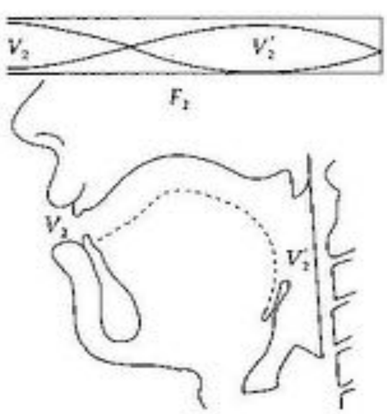
VOWEL [A] AS IN 'FATHER'



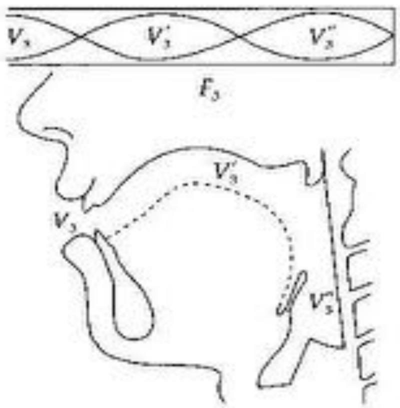
F1 OF [A]



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 at the other.

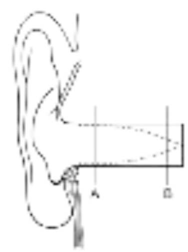
EXAMPLES OF A QUARTER WAVELENGTH RESONATOR

1. Trumpets and all brass
2. Clarinet in lower register
3. Human vocal tract during articulation of vowels and nasals.

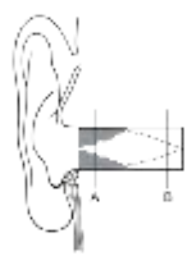
FRENCH HORNS AND HANDS

Placing one's hand in the bell of a French horn (or equivalently, using a mute on a brass instrument, serves to reduce mid and high frequency sound transmission.

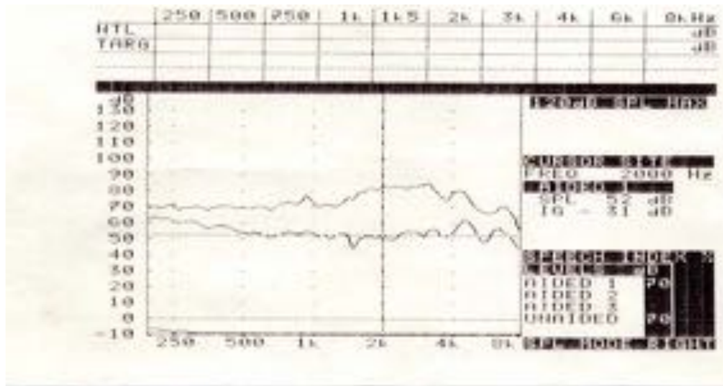
REUR UNOBSTRUCTED EAR CANAL



REUR DUE TO OBSTRUCTED EAR CANAL



CHANGE IN REUR DUE TO OBSTRUCTED EAR CANAL



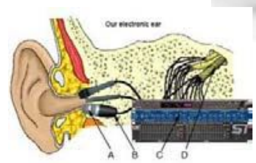
REAL LENGTH AND "ACOUSTIC LENGTH"

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



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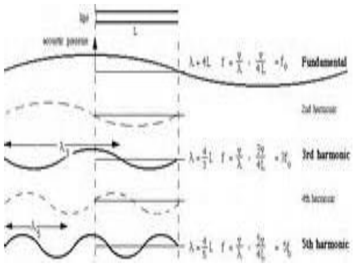
TRUMPET LENGTH

134 cm (C) - 147 (B flat) cm, but it actually behaves as if it is shorter.



If L = 134 cm, then F = 34,000/536 = 63.5 Hz, and second mode is 3 x 63.5 Hz

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QUARTER WAVELENGTH RESONANCES…

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

F = (2k-1) v/4L

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continued™

HALF WAVELENGTH RESONANCES…

1. Integer multiples of the first mode
2. Found only in "tubes" or strings closed or open at both ends
3. No information on the resulting amplitude… damping

$F = kv/2L$

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EXAMPLES OF HALF WAVELENGTH RESONATORS

1. All stringed instruments (violin, piano, guitar,…)
2. Flute
3. Saxophone
4. Oboe, bassoon

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2. ALL ABOUT DAMPING…

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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

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IMPEDANCE AT RESONANCE

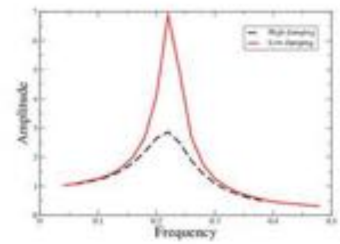
Z=$\sqrt{reactance^2 + resistance^2}$

At resonance, reactance = 0 (mass = stiffness components)

Z = resistance (independent of frequency)

At resonance…

Z = pure resistive damping



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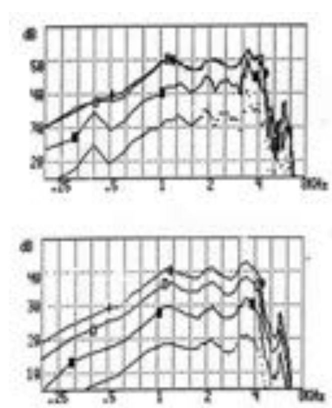
ALL RESONANT PEAKS OF SIMILAR AMPLITUDE



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SPECIFIC IMPEDANCE

Z= ρv/area (cgs)

Z= density of air x speed of sound / cross sectional area of tube (cgs)

Z= 0.0112gr/cm^3 x 34,000 cm/sec / 0.314 cm^2

Z=1212 Ω

Specific impedance of a horn is much lower which is why mutes and hand obstructions (e.g. French horn) work

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(KNOWLES) ACOUSTIC RESISTORS (DAMPERS)

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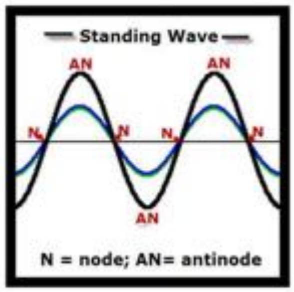
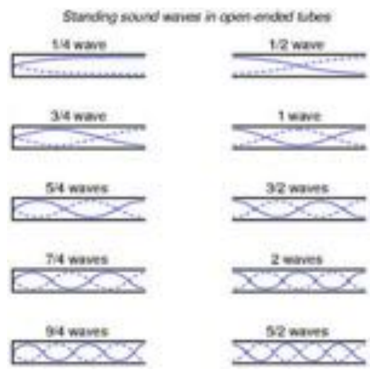
RECALL STANDING WAVES…





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RESISTANCE AT END OF SPEAKING TUBE

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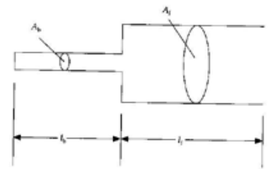
3. ACOUSTIC TRANSFORMER EFFECT

The advantages of flaring the tubing



1. F = v/2L (v is velocity, L is length)
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

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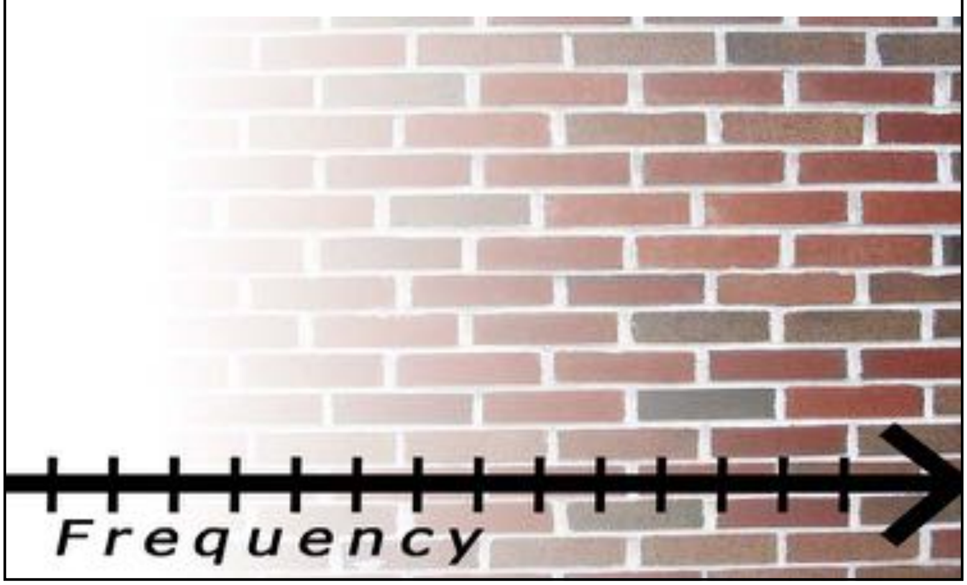
HIGH FREQUENCIES SEE A BRICK WALL



ACOUSTIC TRANSFORMER CALCULATIONS

Our vocal tract is 17 cm long

F = v/2L

F = 34,000 cm/sec/ (2 x 17 cm) = 1000 Hz

All sounds above 1000 Hz will be amplified by having our mouths open.

A trumpet is 134 cm long

F=v/2L

F = 34,000 cm/sec/ (2 x 134 cm) = 127 Hz

All sounds above 127 Hz will be amplified by the flare of the trumpet.

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EXAMPLES OF FLARES...

BUT NOT….

FLARE < 1/3L

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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

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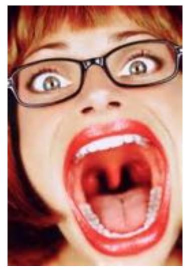
ACOUSTIC TRANSFORMER EFFECT



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AMPLIFICATION FACTOR CALCULATION

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)

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ANOTHER AMPLIFICATION FACTOR CALCULATION

Trumpet flares from 1 cm to 16 cm

$$2x\ 10 \log (16/1) = 20 \log 2^4 = 80 \log 2 = 24 \text{ dB}$$

24 dB is the maximum increase in amplitude that can be obtained with this trumpet and if it is 134 cm long, then this enhancement will be only for sounds above 127 Hz.

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4. PINNA EFFECT AND HIGH FREQUENCIES

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

.... High frequencies hate obstructions

... they reflect...

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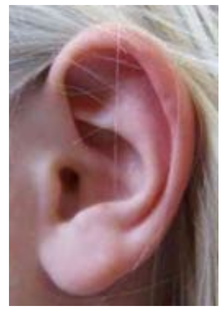
PINNA EFFECT

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



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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.

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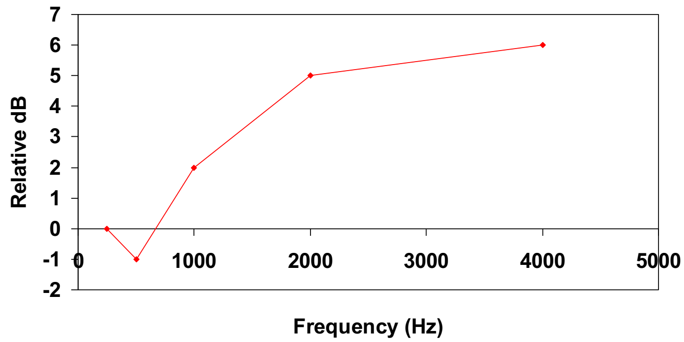
NET BOOST CAUSED BY HAVING 2 METERS OF FLOOR "MIRROR" IN FRONT OF ORCHESTRA



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ORDER OF THE TALK

1. Standing waves
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FORGOTTEN ACOUSTICS

Marshall.Chasin@rogers.com

Hearing Review May 2013 Part 1 (acoustics)

Hearing Review June 2013 Part 2 (deep canal acoustics)

www.HearingHealthMatters.org/HearTheMusic

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