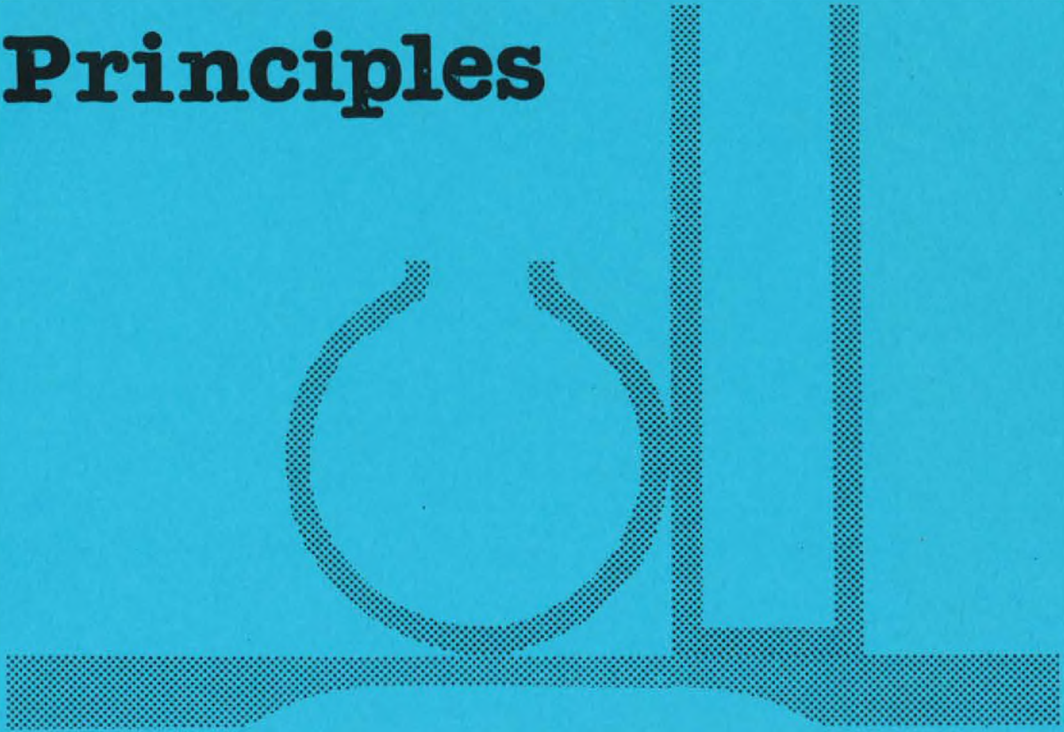
Basic
MARIMBA BAR
Mechanics and
RESONATOR
Principles



Christopher C. Banta

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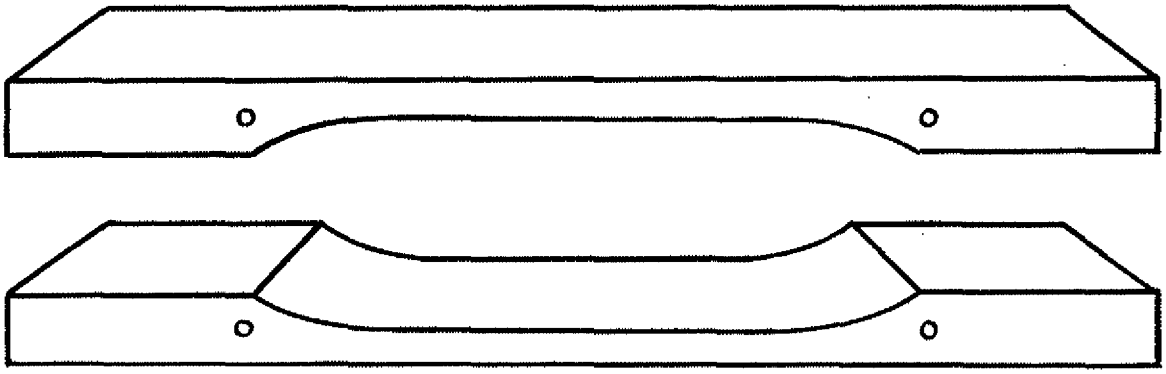
Compiled and illustrated by:

Christopher C. Banta

CCB-1015

Contents

MARIMBA BAR Mechanics



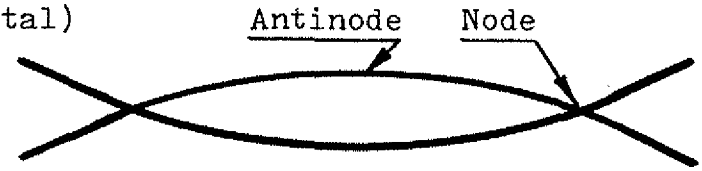
Chapter 1

Marimba Bar Mechanics

All percussion bars vibrate in various modes or sections when played. Each one of the movements contribute to the overall timbre or sound quality of the bar.

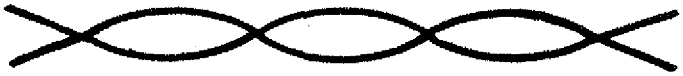
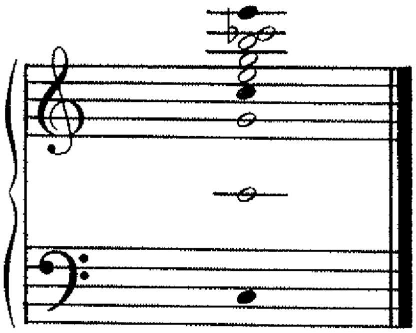
Modes of Vibration

1st mode (fundamental)



2nd mode (2nd harmonic)

3rd mode (3rd harmonic)



Note: White notes (o) indicate the natural overtone series.

Definitions

FUNDAMENTAL - The lowest natural frequency of a vibrating system. Considered the primary or first mode of vibration.

HARMONIC - An integral multiple of the fundamental frequency.

NODES - The point of minimum movement. All vibrating bodies have nodal points.

Size/Pitch Relationships

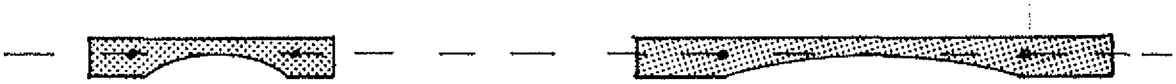
Physically, shorter bars have higher pitches than longer bars. If wood is removed from the underside of the bar, the whole moving system becomes weaker. This causes the overall structure to vibrate slower because it cannot recover from the inertia as quickly.

Lengths equal

Shallow undercut
-higher pitch

Deep undercut
-lower pitch

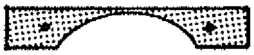
Undercuts equal



Short length
-higher pitch

Long length
-lower pitch

Pitches equal

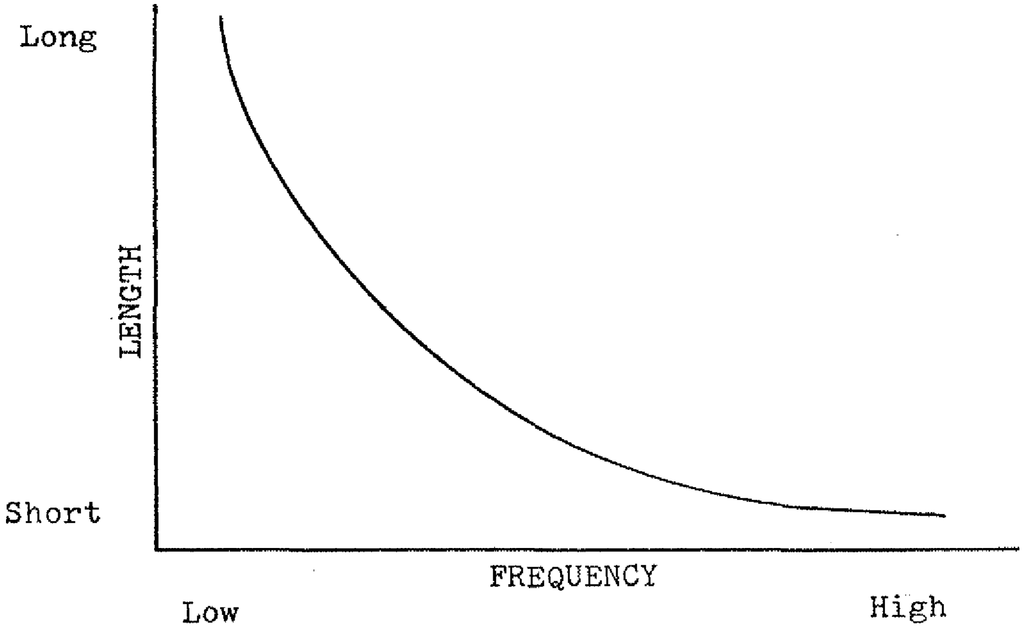


Short length
Deep undercut

Long length
Shallow undercut

Relative Bar Lengths

The undercut arch should not be so deep that there is a possibility of breakage. Low pitches will require proportionally longer pieces of wood. High pitches will require shorter pieces.

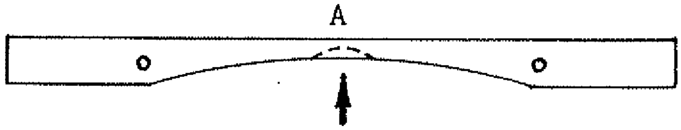


Tuning Control

The first three modes of vibration can be controlled during the tuning process. But, it is necessary to start with a piece of wood that is sharp of the desired pitch.

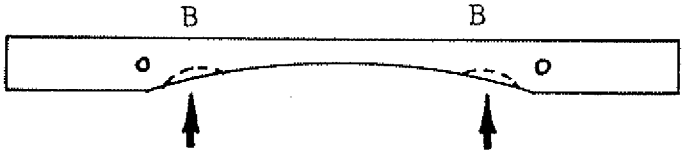
To flatten pitch

Fundamental



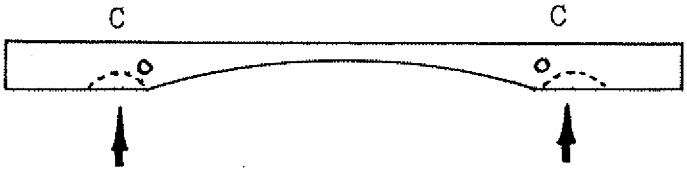
Remove wood from arch center.

2nd harmonic



Remove wood from points B.

3rd harmonic



Remove wood from points C.

Tuning the fundamental

1. Bandsaw undercut arch.
2. Check pitch with tuning device (Strobe Tuner).
3. Remove wood from arch center until desired pitch is reached.

Note: The depth of wood removal is responsible for the flattening of specific harmonics. Not the width.

Tuning the fundamental and 2nd harmonic

1. Bandsaw undercut arch.
2. Locate harmonic pitch with tuning device.
3. Locate fundamental pitch with tuning device.
4. Remove wood from center of arch to lower fundamental until it becomes a unison to the harmonic pitch.
5. Flatten both fundamental and harmonic in equal amounts until desired pitch is reached.

Corrective Actions

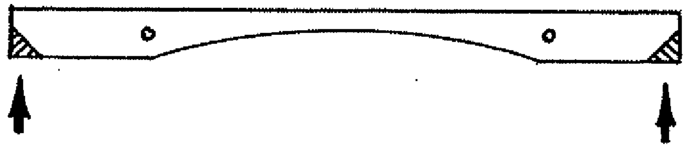
What happens if you go too flat?

If too much wood is removed at one time, it is possible to go below the desired pitch. However, a certain amount of tuning control can be regained, but this depends on the degree of flatness.

To raise pitch

1. For pitches that range from 10 to 40 cents* flat.

Method A



Remove wood from underside corner(s).

One corner at a time. If further pitch raising is necessary, remove additional wood or remove wood from other corner.

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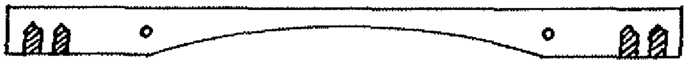
*Note: A cent is a small sub-division. There are 100 cents between half-steps and 1200 cents to the octave.

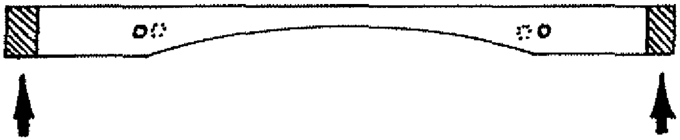
Method B



Drill shallow holes to remove wood (mass) from underneath side end(s). Always start with one or two holes and add if necessary.

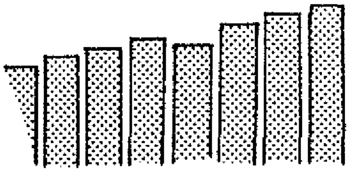
Note: This method will not affect the external appearance of the bar.

2. For pitches that range from 50 cents to a half-step (100 cents) flat.



Remove additional mass from ends.

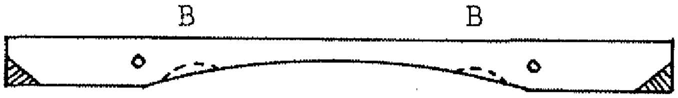
Note: This method destroys the visual continuity with the surrounding notes and will also shift the node points to new nodal centers.



3. For pitches that become a step and a half and more below the desired note, it may be very difficult to remove enough wood to retrieve the pitch. However, it is possible to use this bar as a lower note in the scale providing the dimensions and node points are not too far off. If none of this works, the bar will have to be scrapped.

When an additional harmonic is involved and the pitch of both fundamental and harmonic is flat, the overall pitch of the bar will have to be raised. It is impossible to raise the pitch of one and not affect the other.

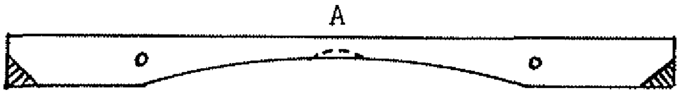
Fundamental FLAT/2nd harmonic CORRECT



1. Remove wood from underside corner(s). This will raise the fundamental to pitch and sharpen the harmonic.

2. Remove wood from points B to lower harmonic.

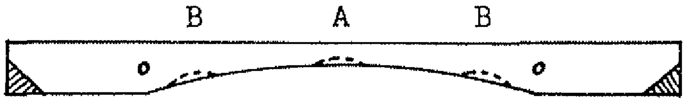
Fundamental CORRECT/2nd harmonic FLAT



1. Remove wood from underside corner(s). This will raise the harmonic to pitch and sharpen the fundamental.

2. Remove wood from point A to lower fundamental.

Fundamental FLAT/2nd harmonic FLAT



1. Remove wood from underside corner(s) to raise pitch of both fundamental and harmonic.

2. Remove wood from point A and points B to lower both pitches.

CAUTION!

When tuning percussion bars, always remove material in small amounts - especially when approaching the tuning pitches. It is easier to remove wood than to replace it or raise pitch.

General Rules

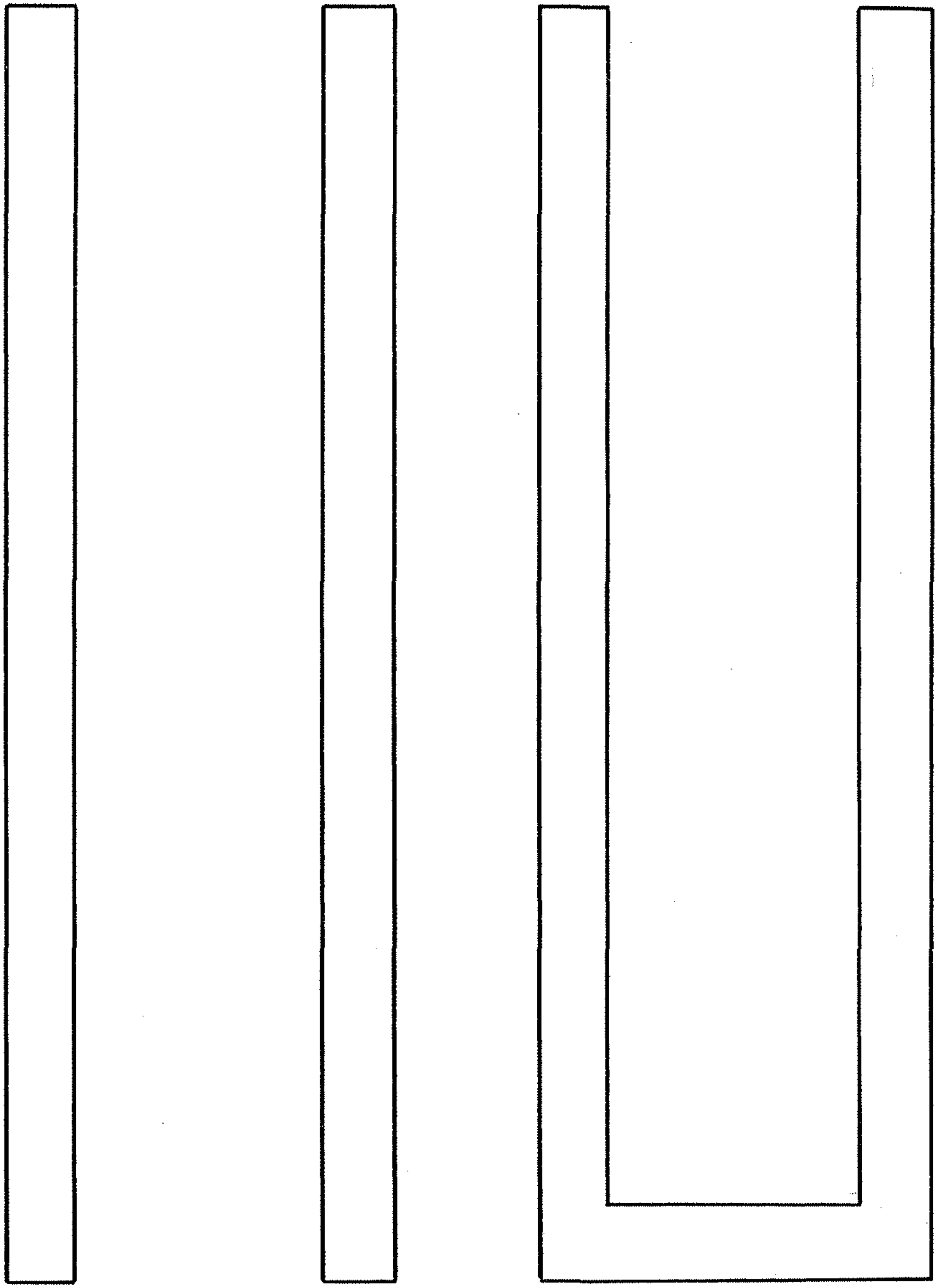
1. Warm wood reads FLAT. Caused by sanding friction or by a warm day.

   Note: When sanding out undercut arch, allow the wood to cool before checking on the tuning device.

2. Cold wood reads SHARP. Caused by the cold temperature.

Tune in temperatures of approximately 70 degrees F for most consistent results.

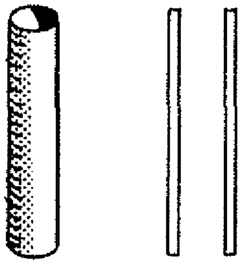
RESONATOR Principles



Chapter 2

Column Resonators

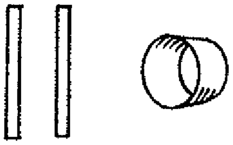
What is a Column?



A column is a physical component, like a tube, whose inside diameter is consistent throughout its length.

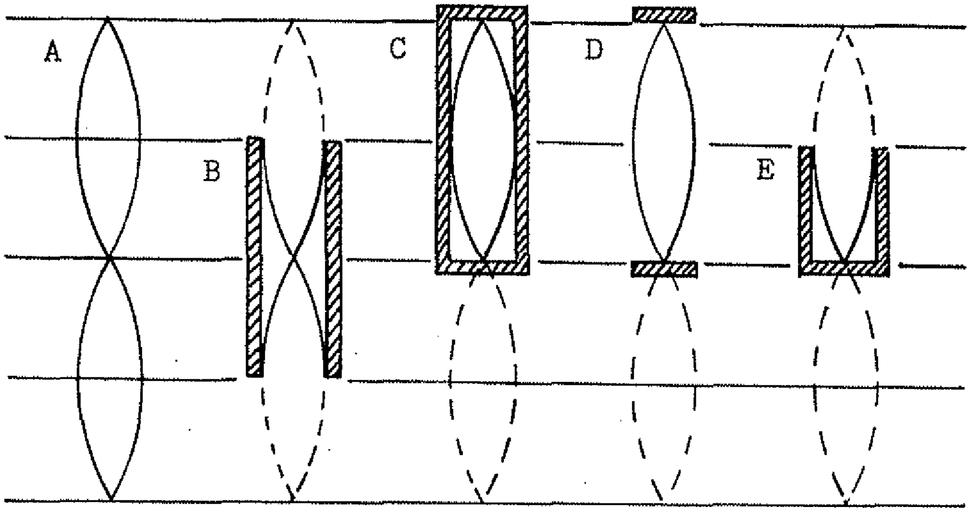
The column resonator represents an acoustical system whose length is a proportional segment of its wavelength.

Types of Columns



A tube that is open at both ends is a Half-wavelength resonator.

A tube that is open at one end but closed at the other end is a Quarter-wavelength resonator.



A - Full wavelength of a frequency.*

B - Half-wavelength resonator of the same frequency.

C - Theoretical half-wavelength inside a tube that is closed at both ends.

D - Half-wavelength of the frequency as it is reflected between two parallel surfaces. (Standing wave)

E - Quarter-wavelength resonator of the same frequency.

Rules

1. The shorter the wavelength, the higher the pitch. Therefore, higher pitches will require shorter resonators.

   The longer the wavelength, the lower the pitch. Therefore, lower pitches will require longer resonators.

   Note: This applies to both quarter and half-wavelength resonators.

2. A Node always exists at a closed end.

   An Antinode always exists at an open end.

Definitions

NODE - An area or zone with the least amount of movement or maximum amount of pressure.

ANTINODE - The area or zone with the greatest degree of movement or least amount of pressure. Sometimes called a "loop".

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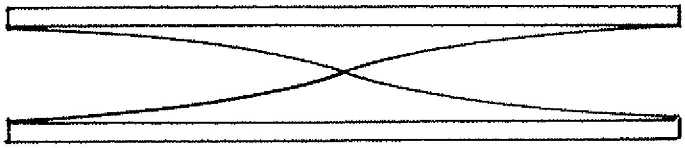
*Note: A full wavelength cannot exist within the confines of a physical environment. This is a free-space phenomenon.

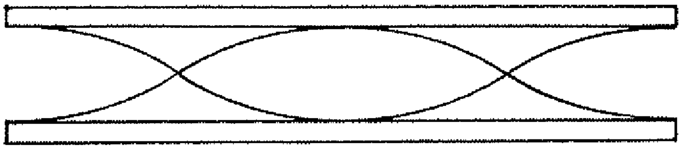
Overtones

Half-wavelength resonators contain a full series of overtones.

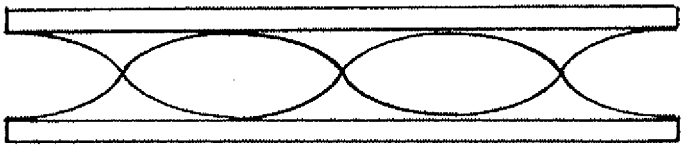
Fundamental (100Hz)



1st overtone (200Hz)

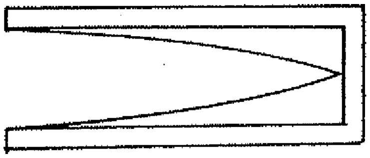


2nd overtone (300Hz)

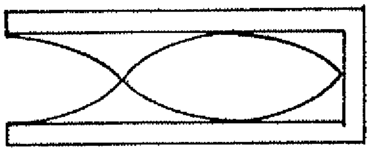


Quarter-wavelength resonators contain only the odd numbered overtones.

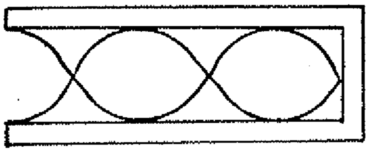
Fundamental (100Hz)



3rd overtone (300Hz)

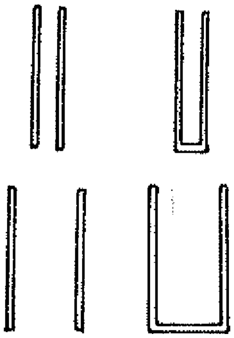


5th overtone (500Hz)



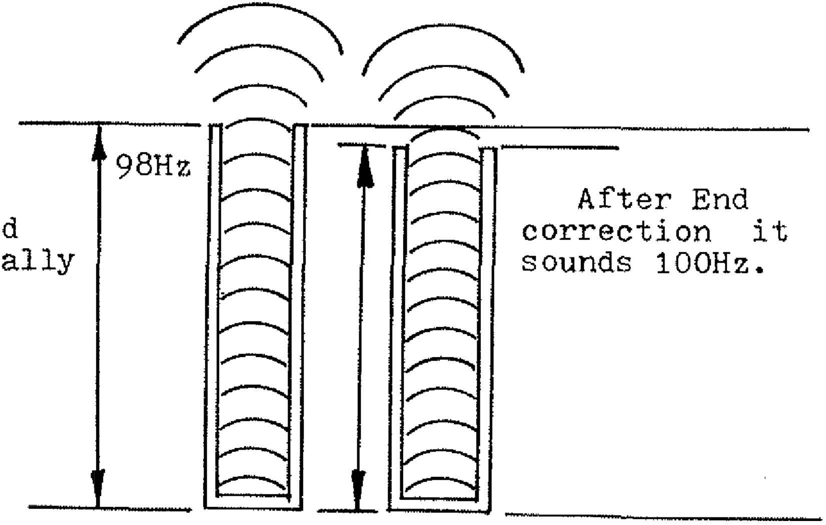
Column Proportions

Thin scaled resonators (small width to overall length) have louder harmonic content with an attenuated fundamental. Wide scaled resonators, on the other hand, have mostly fundamental with attenuated overtones.



End Correction

As the internal wave approaches the opening, the wave shape characteristics change from longitudinal to spherical. This is caused by inertia and radiational losses from within and occurs a short distance beyond the opening. If this change took place exactly where the tube ended, no sound would be heard. Because of this phenomenon, a resonator will sound flatter or lower in pitch than its theoretical wavelength. End correction is therefore necessary to raise the pitch of the resonator. (See formulas on page 25.)



Theoretically this length should sound 100Hz. Actually it sounds 98Hz

After End correction it sounds 100Hz.

Tuning the Column

To raise pitch - 1. shorten length
2. flare opening

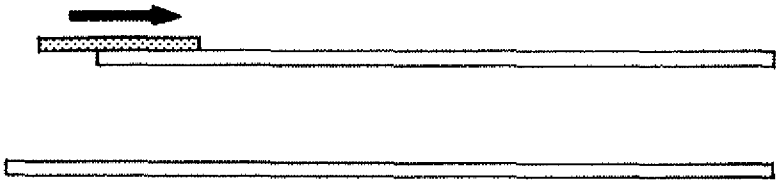
To lower pitch - 1. lengthen length
2. close off opening

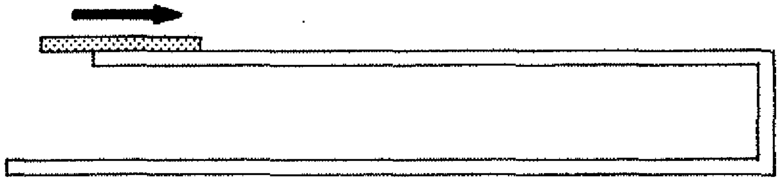
Methods of Tuning

To raise pitch

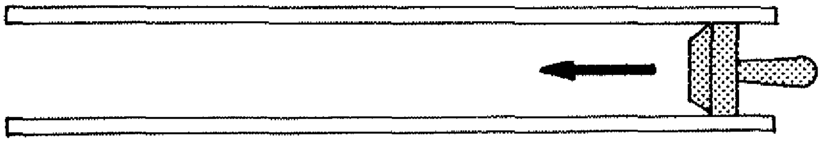
Method A

Adjustable slider



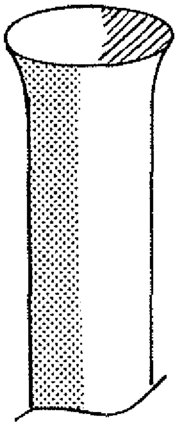


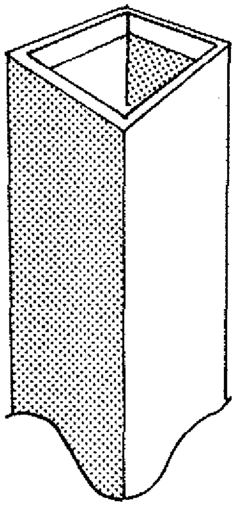
Adjustable stopper

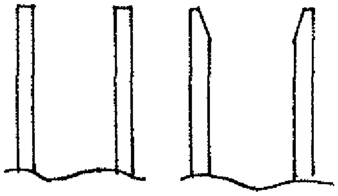


Method B

Flare opening





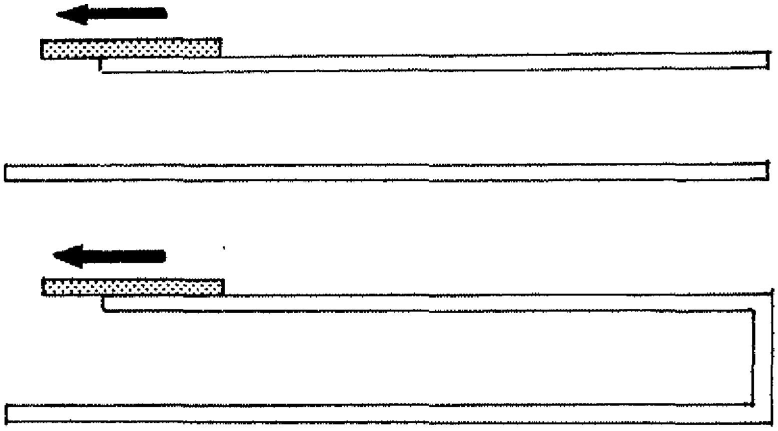


This method works on both
$\frac{1}{4}$ and $\frac{1}{2}$ wavelength resonators.

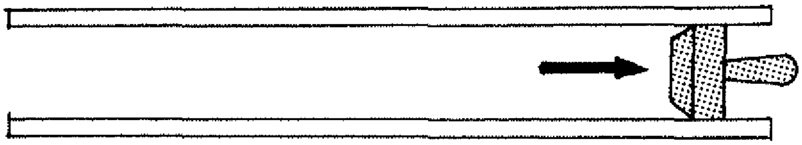
To lower pitch

Method A

Adjustable slider

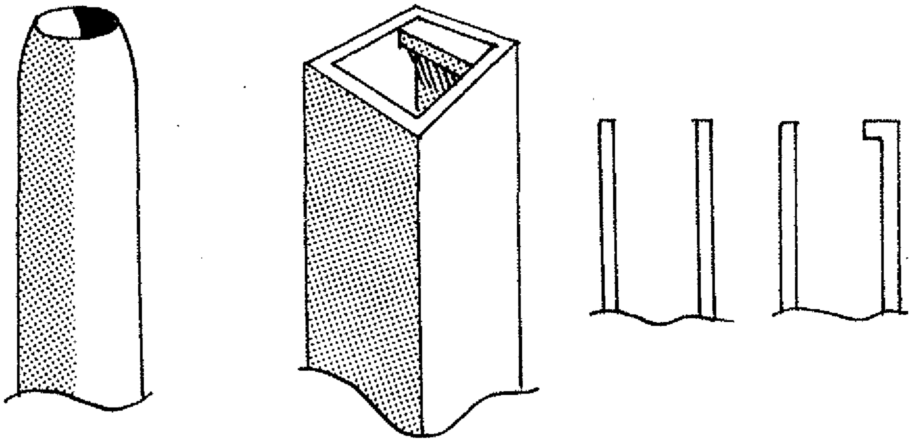


Adjustable stopper



Method B

Close off opening



This method works on both
$\frac{1}{4}$ and $\frac{1}{2}$ wavelength resonators.

Test Equipment

Audio Oscillator - A device that produces a continuously variable sine wave test tone.

Frequency Counter - A device that counts the number of cycles in a given time period. Has better resolution than the oscillator dial frequency.

AC Voltmeter - A sensitive analog device that is capable of displaying the peaks and dips in voltage.

Strobe Tuner - An accurate pitch measuring device that has one cent resolution.

Amplifier - A voltage boosting device.

Loudspeaker - An electromechanical transducer that converts electrical energy into mechanical movement (sound).

Microphone - An electromechanical transducer that converts mechanical movements into electrical energy.

Testing Procedure

A test tone from the Audio Oscillator is fed into the Amplifier which drives the Loudspeaker. A small Microphone is inserted into the resonator and is connected to the AC Voltmeter. The Oscillator is swept until the primary resonant frequency of the resonator is located. This is displayed by a peak (not pegged) on the AC Voltmeter. It is at this point the Strobe Tuner will give a pitch reading while the Frequency Counter gives a precise frequency reading.

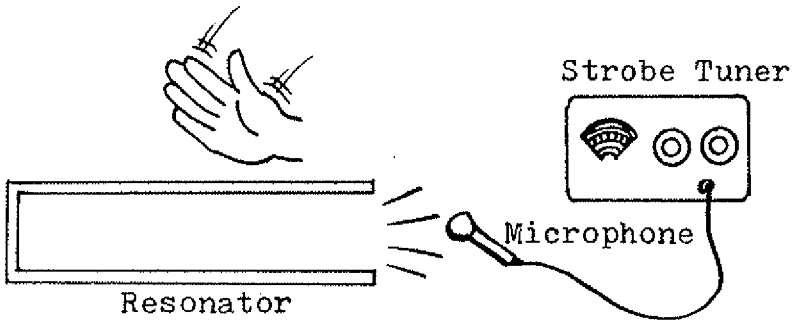
CAUTION!

Keep the volume of the Loudspeaker very low. When the test tone approaches the resonant frequency, the sound within the resonator will be very powerful and can damage a small microphone.

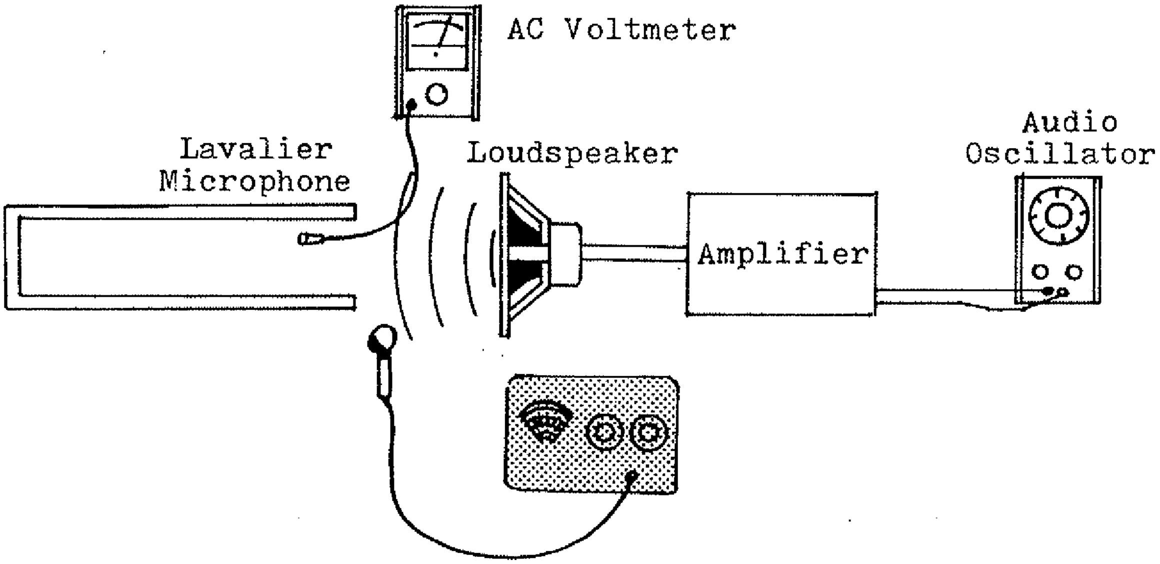
Methods of Measurement

Measuring Pitch

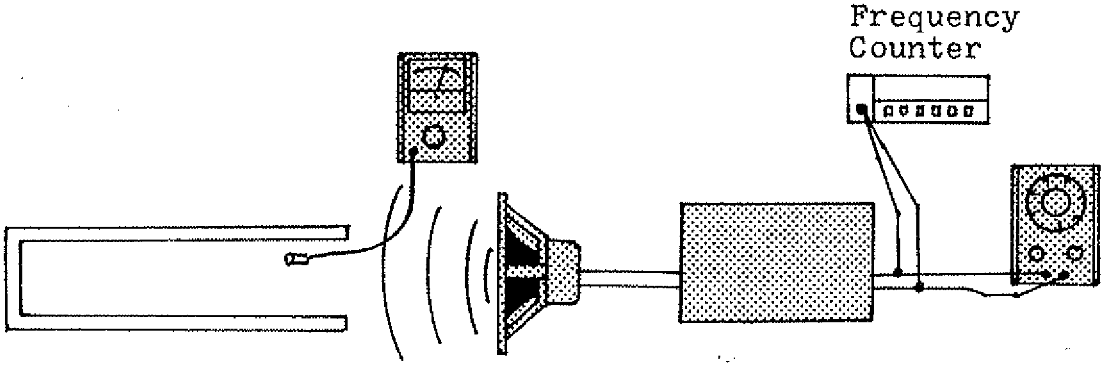
Standard



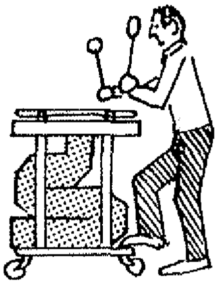
Optimum



Measuring Frequency



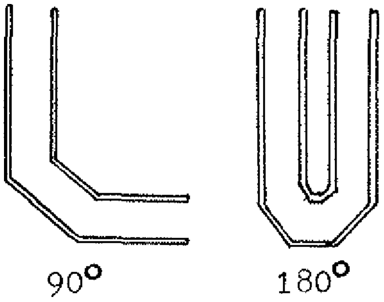
Mitering



Mitering long resonators may be necessary so that they will fit into tight spaces. It is important that the mitered joint be a gradual bend. This minimizes the internal resistance thus allowing the wave to propagate.

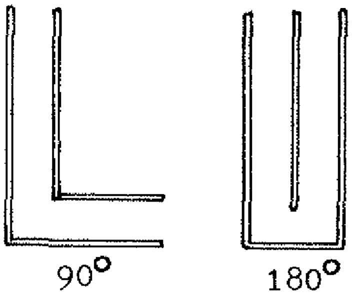
Correct

Gradual bends



Incorrect

Abrupt bends



Formulas

Half-wavelength resonator

$$L = \frac{s/f}{2}$$

Quarter-wavelength resoantor

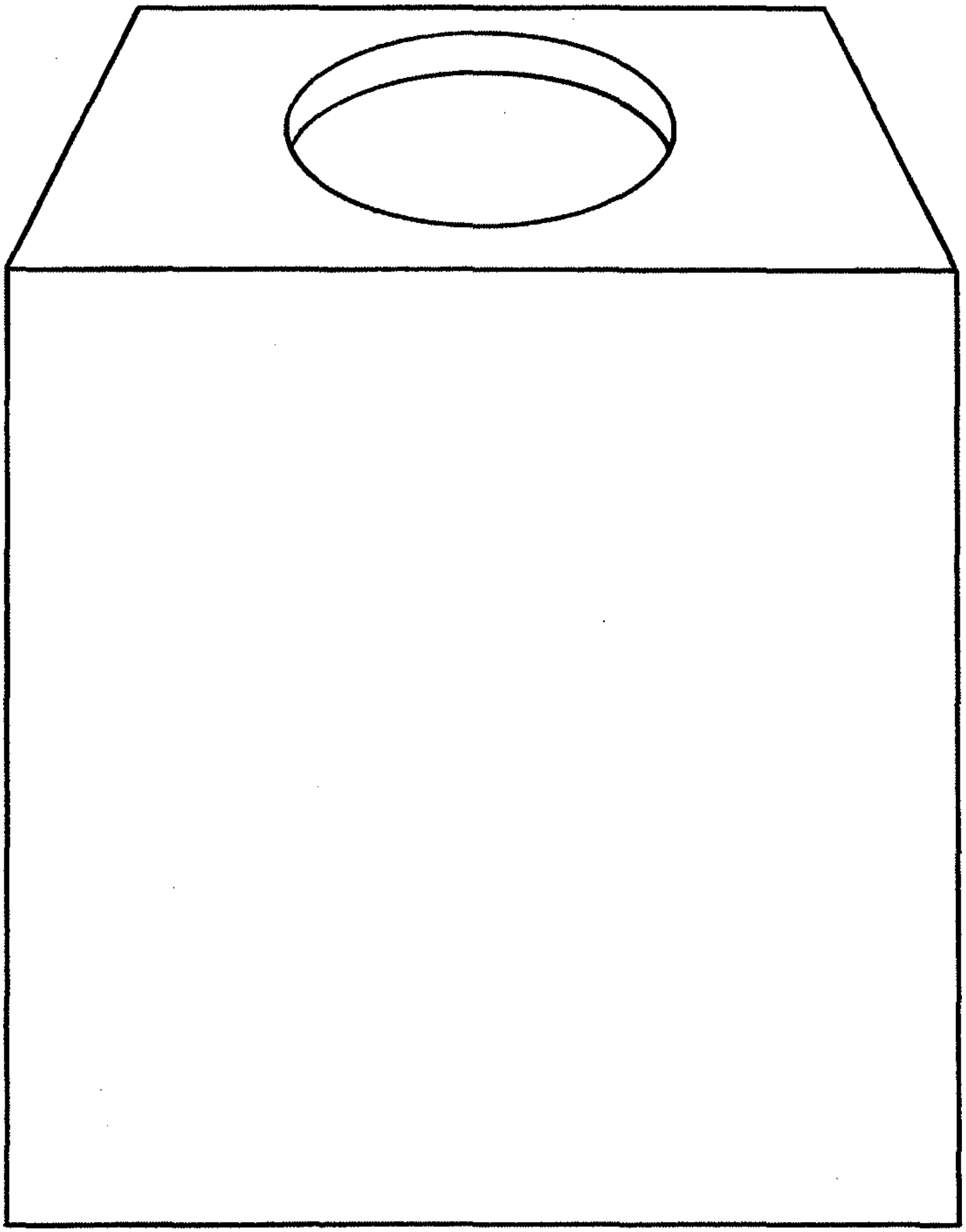
$$L = \frac{s/f}{4}$$

Where: L = length in feet
f = frequency in Hertz
s = speed of sound in ft. per second
(approximately 1129 ft/sec @ 70° F)

End Correction

End Correction = L - (I.D. X 0.29)

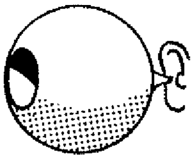
Where: L = length of tube in inches
I.D. = inside diameter

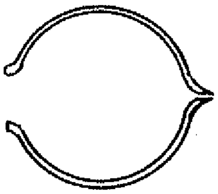


Chapter 3

Helmholtz Resonators

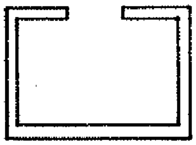
Hermann Ludwig Ferdinand von Helmholtz (1821-1894) devised spherical vessels or cavities that were used to analyze frequencies. They had two openings; a large opening opposite a small opening. The small opening was on top of a taper that could easily fit into the ear. A single unit could efficiently absorb one specific frequency thus allowing the listener to tell if a pitch was sharp or flat. This type of vessel will reject all other frequencies except its resonating frequency.





What is a Helmholtz Resonator?

The Helmholtz resonator represents an acoustical system that is small in comparison to its wavelength. It is defined as a physical component whose interior is connected to the exterior by means of an opening.



How does it work?

The enclosed volume of air compresses and expands as a unit. Its rate of compression and expansion or frequency is regulated by two primary factors:

1. Opening area

2. Volume displacement

General Rules

1. A small opening per given volume will have a lower resonating frequency than a large opening per same volume.

   A large volume per given opening area will have a lower resonating frequency than a small volume per same opening area.

2. To halve an existing frequency in a given resonator, you can either:

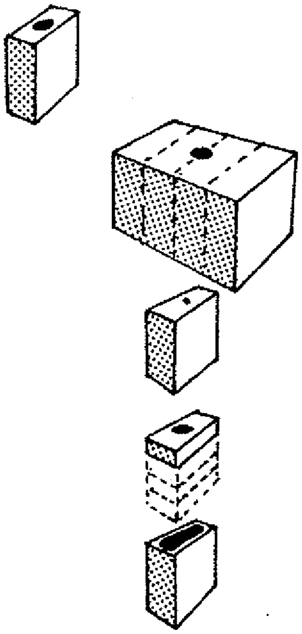
   A - increase its internal volume four times (or)

   B - decrease the opening area to one-fourth its original size.

   To double an existing frequency in a given resonator, you can either:

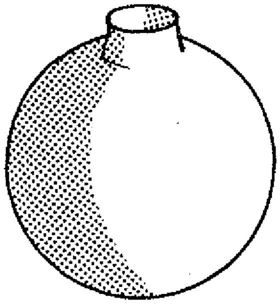
   A - decrease its internal volume to one-fourth its original size (or)

   B - increase its opening area by four times.

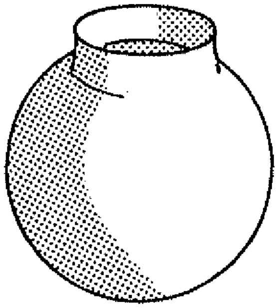


Basic Relationships

Volumes equal

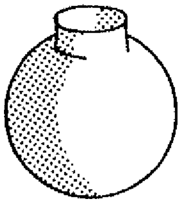


Small opening
-Lower resonance

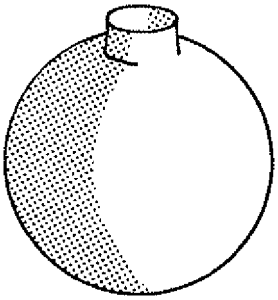


Large opening
-Higher resonance

Openings equal

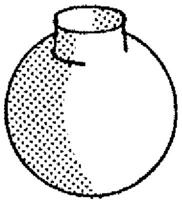


Small volume
-Higher resonance

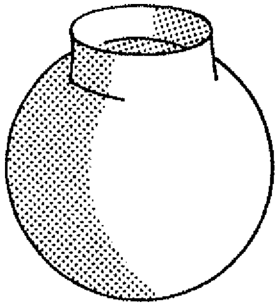


Large volume
-Lower resonance

Resonance equal



Small opening
Small volume



Large opening
Large volume

Bottle and Water Analogy

A large bottle with a small opening would take a very long time to fill and empty its capacity. This condition is considered to be low frequency. Now, if the large bottle had a large opening, it could accept water much faster thus decreasing its fill and empty time. This is a raise in frequency.

A small bottle with a large opening would be able to fill and empty its capacity very quickly. This condition is considered to be high frequency. Now, if the small bottle had a small opening, it would not be able to accept the water as fast thus slowing down its filling and emptying time. This is a lowering in frequency.

Tuning the Resonator

To raise pitch - 1. increase opening area (and/or)
2. decrease volume displacement.

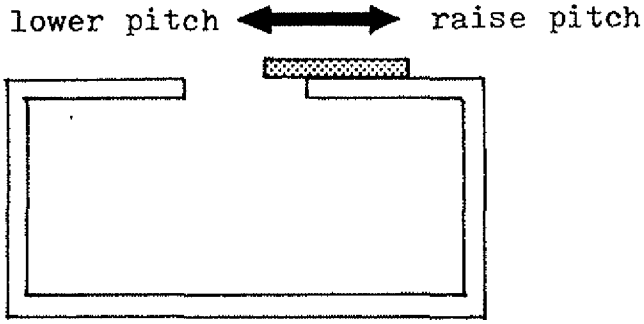
To lower pitch - 1. decrease opening area (and/or)
2. increase volume displacement.

Methods of Tuning

Opening Area

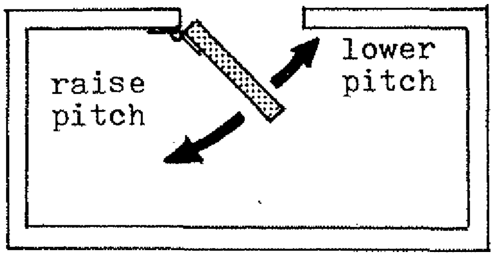
Method A

Adjustable slide



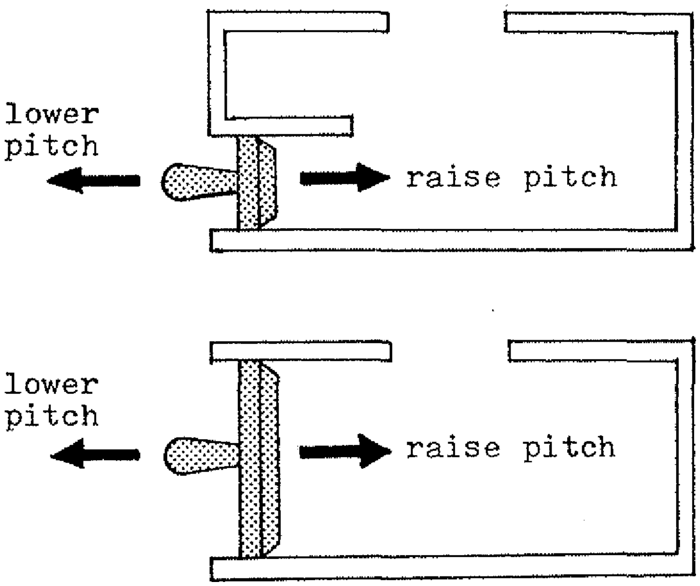
Method B

Adjustable louvre (internal)



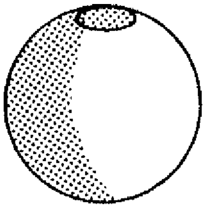
Volume Displacement

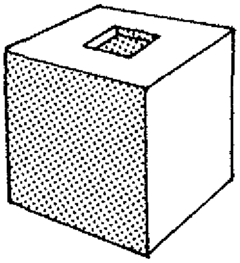
Adjustable stopper

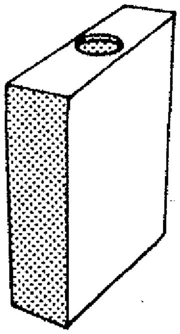


Physical Relationships

Shape	advantages	disadvantages
sphere	optimum shape -all inner dimensions are equi-distant.	takes up too much space -not practical for laying out musical instruments.
cube	next best shape	same
rectangular	can fit several notes within a playable proximity to each other.	contains certain non-related resonances that correspond to the internal dimensions.







Wall Thickness

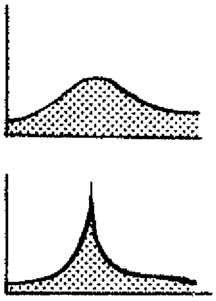
Thin walls tend to absorb energy and breath with frequency thus lowering the overall resonance.

Thick walls support the energy thus reinforcing the output along with raising the overall resonance.

Wall Porosity

Porous wall material will broaden, attenuate and cause the resonance to die out out faster. (Low "Q").

Dense highly polished wall surfaces will cause maximum reflection and maintain resonance for a longer period of time at a specific frequency. (High "Q").



Acoustical Relationships

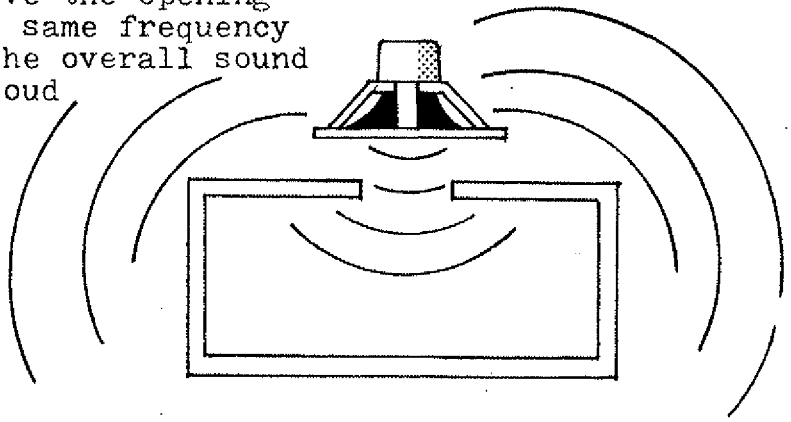
Large resonators can couple more energy to the air thus making them sound louder.

Small resonators do not have the ability to excite the surrounding air with as much force, therefore their sound will be quite attenuated when compared to the larger type.

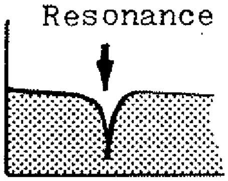
Helmholtz resonators actually "suck" frequency into them while resonating. This is because the resonator will not allow any frequency that approaches its own resonating frequency to exist near it.

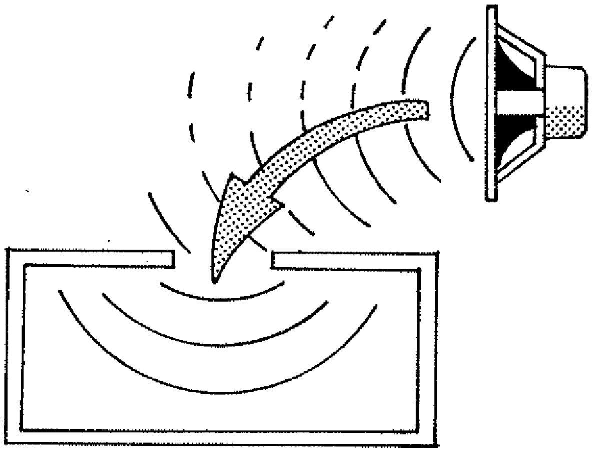
This phenomenon is entirely dependent on the placement of the primary sound source.

A. If the primary sound source is placed directly above the opening and is tuned to the same frequency as the resonator, the overall sound will become quite loud using a momentary tone burst.

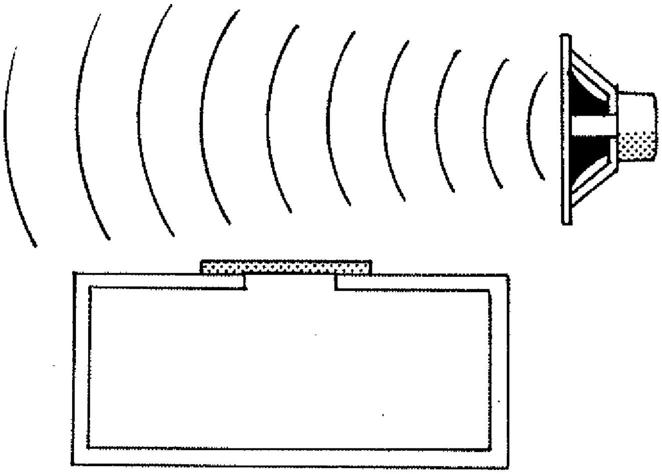


B. If the sound source is moved a short distance away from the opening, the resonator will draw the sound into it. This now becomes a type of acoustic dip filter.

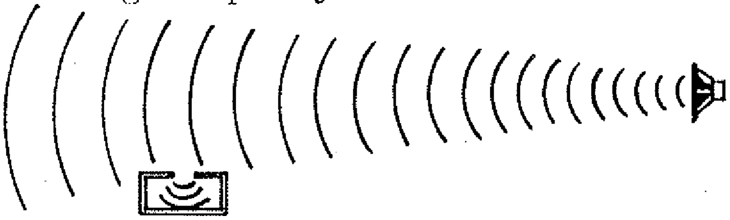




C. By covering the opening, the primary sound will be restored.

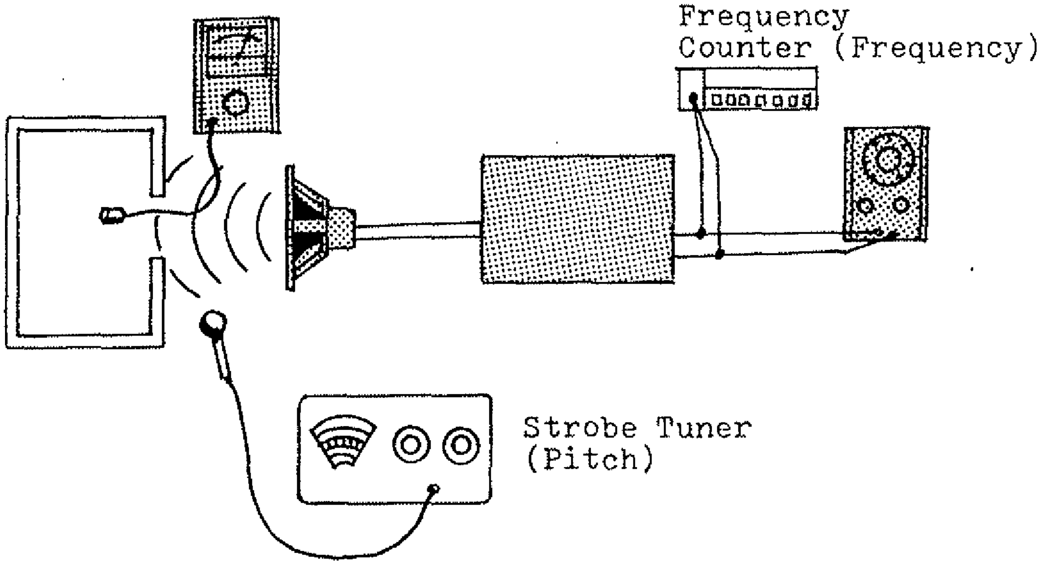


D. If the primary sound source is far enough away from the resonator opening, there will be little or no affect on the sound source although the resonator still picks up the sounding frequency.



Method of Measurement

The methods used for the Column resonator can be applied to the Helmholtz resonator as well.



Formulas

Frequency

$$f = 1856.1\sqrt[4]{\frac{A}{V^2}}$$

Opening Area

$$A = \left(\frac{f}{1856.1}\right)^4 V^2$$

Internal Volume

$$V = \sqrt{A}\left(\frac{1856.1}{f}\right)^2$$

Where: f = Resonant frequency in Hertz
A = Area of opening in sq. in.
V = Total internal volume in cu. in.
1856.1 = A constant

The Author

Christopher C. Banta has been working with the musical acoustics phenomena since 1968. His work consisted of loudspeaker systems design and pipe organ maintenance. While in the Navy, he worked with and studied radio communications. In 1973, he studied music theory at Pasadena City College, then transferred to California Institute of the Arts where he was granted a new category "Music - Special Studies". This was due to undertakings such as the constructions of Bass and Contra-Bass Marimbas and a Pipe Organ. From Cal-Arts he went to James B. Lansing Sound, Inc. as a Quality Assurance Inspector. In 1976, he started a small loudspeaker business which eventually developed into C.C. BANTA Creative Percussion Company.

To this day, C.C. BANTA has provided bass marimbas and services to percussionists like: Emil Richards (Mr. World of Percussion), Carl Rigoli, Joe Porcaro, Steve Traugh (Supercussion), John Bergamo (Cal-Arts Percussion Ensemble), and to Paramount Studios for the recordings of "SHO-GUN", "The Equals", and "Poltergeist". Instruments have even gone to Japan.