

## **Kala – Science behind Indian musical instruments**

This report gives a brief account of the Indian musical instruments and Science behind their working.

### 1. Sangitha from Bharatiya perspective

#### a. **Concept of Shruti and Swaras**

Shruthi is that which does the function of listening. There are two types of Sruthi. Swara Sruthi and Antharasruthi...: Dwani itself is shruti since it is grasped with ears. It is one but due to swara anthara (difference in swara) it appears as two. In Geethi (music/songs) depending upon the 7 positions of shruthi from which they originate there are 7 swara. The shruti which is heard in the interspace or intervals between swara is called antara shruthi. The importance of anthara shruthi depends on the kriya (function) gramam (a srEni or series) and their differences.

*From Brihaddeshi of Matangamuni.*

#### • **Shruti:**

In the human chest reside sounds of twenty-two kinds [termed] mandra ; the same [range of sounds when sounded] in the throat is called madhya [and] in the head, tara. Thus we obtain a successively higher pitch as we move up (uttarottara - tarastu). Conversely, on the veena a successively higher pitch [is obtained on] successively lower [strings]. These specific sounds are termed Srutis for they are audible.

#### **Swara :**

Of these [Srutis] some are selected and sung in all the gitis. Among these [Srutis] those that attain the state of a swara (svaratva) are esteemed as the s. Some argued that Srutis were identical with svaras (swaraSrutyostu tadatmyam) : both swara and Sruti, they reasoned, are grasped through the same organ of hearing and our perceptive 'feeling' or experience (sparSa) of Sruti and swara does not cognise any thing which distinguishes them. Sruti and swara are thus identical, just as a 'class' (jati) is indistinguishable from the individual objects of that class even svaras beginning with sadja.

*From Dattilam of Dattila*

b. Definitions and descriptions of various aspects of music

- **Jatis** are basically patterns of swara. The use of notes in the raga forms, born of the jatis, the takkaragas and malavakaisikas both use the same sadja with the same number of srutis but still the note sounds different in the two ragas.

*From Dattilam of Dattila*

- Sound that can be reproduced musically (vocally or on instrument) is called **Naada**.

*From Brihaddeshi of Matangamuni.*

- **TANA**

The aforementioned murchanas [when formed] with five notes and with six notes, have, indeed, been declared by the wise as the tanas; eighty-four [in all].

*From Dattilam of Dattila*

- **STHANA**

the sthanas (or the registers), [each of] which, as has been described, contains twenty two distinct sounds. To obtain the mandra and other (octave, i.e. the tara) these [twenty-two sounds] should be known to extend to sixty-six.

*From Dattilam of Dattila*

c. Classification of musical instruments/sangeeta vadyas

- Thatha Vadya - string instruments
- Sushira vadya – wind instruments
- Avanadha vadya – membrane instruments
- Ghana vadya – Percussion instruments made of metal/mud/stone

*From Natya shastra of Bharata muni.*

*Example - ● That in which the svaras (i.e. frets ) relating to each individual raga are set separately in the upper and middle registers is called Ekaragamela Veena.*

- The Veena which has all the svaras in the middle and upper registers is said to be Sarvaraga mela.
- There is Ekatantri Veena.

*From Chaturdandi Prakashika of Venkatamakhin.*

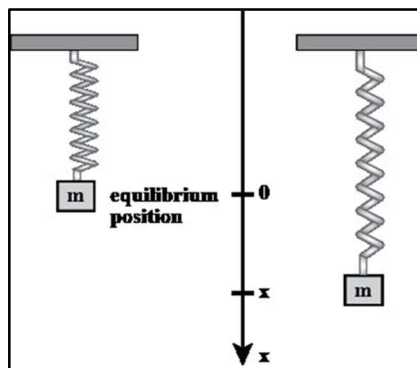
## 2. Basics of sound from modern scientific perspective

### ❖ Vibration:

- To and fro motion of the object around its equilibrium position
- Oscillations are either periodic or random
- Types of vibrations- Free vibration, Forced Vibration, Damped vibration
- Desired vibrations - speaking, listening
- Undesired vibrations -engines, motors
- Vibration produces sound

### ❖ Understanding the phenomena of vibration

- Simple harmonic motion - It is defined as a motion in which the restoring force is directly proportional to the displacement of the body from its mean position. Spring mass system is a good example of the SHM.
- Restoring Force - Depends upon the elasticity or compressibility of the material; System tends to return to its equilibrium position due to restoring force;
- Hooke's law – Restoring force  $\propto$  Change in length ;  $F = -Kx$ , Where K is the stiffness constant
- Ordinary differential equation  $m\ddot{x} + Kx = 0$  ; where,  $m$  = mass ;  $\ddot{x}$  = acceleration;  $K$  = spring constant or stiffness;  $x$  = displacement



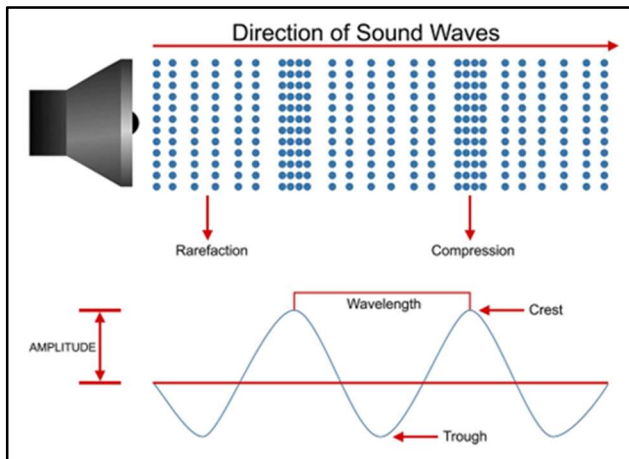
### ❖ Acoustics

- Science of sound
- Sound helps us to communicate
- Sound is a form of energy; it gets transmitted in the form of wave
- Needs a medium to propagate

- How do we hear the sound? → Object vibrates - particles displace i.e., disturbance in medium - reaches ear

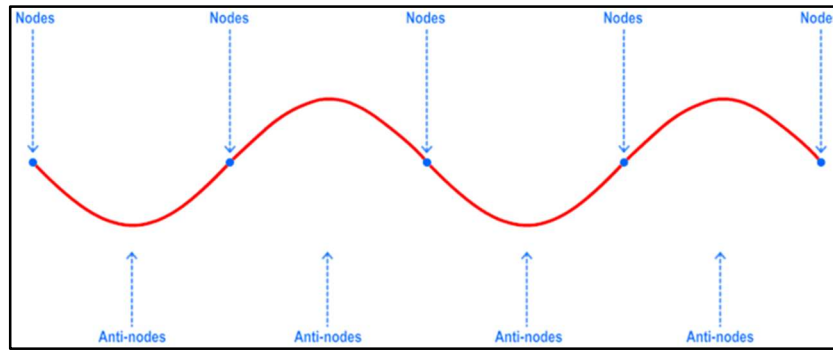
#### ❖ Sound Wave

- Particles oscillate in the medium
- Vibration energy propagates in terms of waves
- Types of waves -
  - 1. Transverse wave- A transverse wave is a wave in which particles of the medium move in a direction perpendicular to the direction that the wave moves
  - 2. Longitudinal wave - A longitudinal wave is a wave in which particles of the medium move in a direction parallel to the direction that the wave moves.
- Sound wave is a Longitudinal wave or also called as a Pressure wave
- Molecules in the medium undergo compression and rarefaction
- Sound waves – series of compression and rarefaction



#### ❖ Standing Wave

- A vibration of a system in which some particular points remain fixed while others between them vibrate with the maximum amplitude.
- Structure of standing wave –
  - Nodes – points that don't oscillate
  - Antinodes – points oscillates are at maximum height of the peak
- Standing wave is a result of reflection and interference
- Standing wave does not travel anywhere; amplitude of the wave changes
- String, Wind instruments etc. use standing waves
- Standing waves with different frequencies correspond to different musical notes



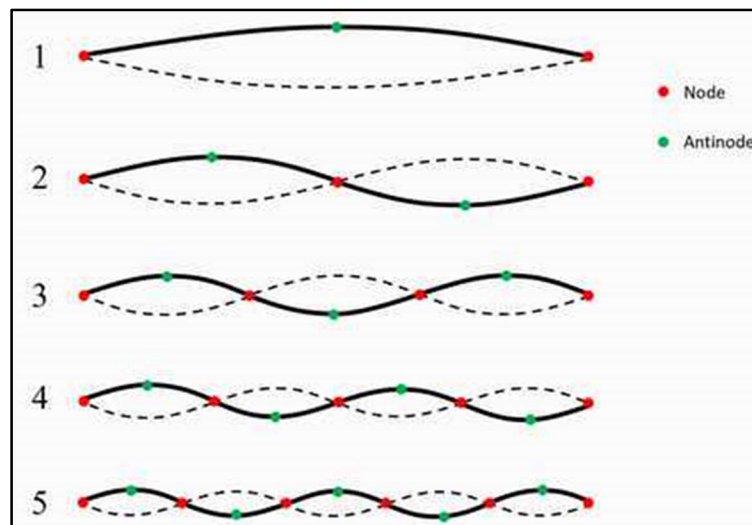
#### ❖ Properties of Sound Wave

- Frequency - Number of oscillations per unit time.
  - $f =$  ; SI unit- Hz;
  - Decides the pitch of the sound.
- Pitch - Perceptual property of sound
  - Identifies high and low sounds
  - More the frequency - higher the pitch; Lower the frequency - lower pitch
- Amplitude - Maximum distance covered by a body from its mean position when set into a vibratory motion.
  - Decides the loudness of the sound.
  - More amplitude – louder sound; Less amplitude – feeble sound
- Wavelength – Distance between the peak value of two consecutive compressions or rarefactions (crests or troughs).
  - $\lambda =$  ; SI unit – meter
- Time Period - Time taken by an object to complete one oscillation i.e., two consecutive compressions or rarefactions.
  - $T =$  ; SI unit – seconds

#### ❖ Harmonics and Overtones

- Harmonics – fundamental and overtones together become harmonics

First Harmonic	<ul style="list-style-type: none"> <li>• First harmonic is also called as fundamental</li> <li>• Basic kind of standing wave, which has 2 nodes and 1 antinode</li> </ul>	<ul style="list-style-type: none"> <li>• <math>L = \frac{1}{2} \lambda_1</math></li> <li>• <math>f_1 = \frac{v}{2L}</math></li> </ul>
Second Harmonic	<ul style="list-style-type: none"> <li>• String holds exactly one wavelength</li> <li>• 3 nodes, 2 antinodes</li> </ul>	<ul style="list-style-type: none"> <li>• <math>L = \frac{2}{2} \lambda_1</math></li> <li>• <math>f_2 = 2 f_1</math></li> </ul>
Third Harmonic	<ul style="list-style-type: none"> <li>• 4 nodes, 3 antinodes</li> </ul>	<ul style="list-style-type: none"> <li>• <math>L = \frac{3}{2} \lambda_1</math></li> <li>• <math>f_3 = 3 f_1</math></li> </ul>
Fourth Harmonic	<ul style="list-style-type: none"> <li>• 5 nodes, 4 antinodes</li> </ul>	<ul style="list-style-type: none"> <li>• <math>L = \frac{4}{2} \lambda_1</math></li> <li>• <math>f_4 = 4 f_1</math></li> </ul>



❖ Equation –

1.  $L = \frac{n}{2} \times \lambda_n$

Where, L= length of the string

n = harmonic number

$\lambda_n$  = wavelength

2.  $f_n = n \times f_1$

$f_n$  = Frequency of the standing wave

n = harmonic number

$f_1$  = fundamental frequency

3. Tata vadya, the stringed instrument

- Vibration of strings produces sound
- Pitch of the sound- Pitch depends on thickness, length and tightness of the string
  - Thickness - Thick strings- low pitch ; Thin strings- high pitch
  - Length – short string – high pitch; long string – low pitch
  - Tightness - Tighter string – high pitch; Slacker string – low pitch

Considering Veena as an instance of string instruments from Indian classical music

❖ Structure of Veena

**The Resonator (Kudam)** : Consists of a top plate which has a bridge.

**Bridge** : Curved metal strip. Strings are passed tangentially on it.

**Fretboard**: Connecting part between the resonator to the other end. Consists of 24 frets

**Support Resonator** : Hollow, small. Supporting purpose.

**Strings**: 7 strings. 4 passes over the fret board. 3 are on the other side



❖ Musical notes of Veena

- Covers the fundamental frequency range of 99 to 1056 Hz and considering the harmonics it covers the overall range from 90 to 6000 Hz.
- Each note has a unique relation with the length and diameter of the string.
- Twelve Shruti frequencies are used to tune this string instrument.

❖ Working of Veena

As string is plucked it vibrates with the particular frequency. It gets transferred to bridge, top plate and resonator causing vibration of much greater surface area. This generates much amplified sound by moving the significant amount of air. Musical notes are produced by plucking the string near the bridge by maintaining the distance by pressing the string on the corresponding fret.

❖ Mentions in Natyashastra about the Quality of musical notes, produced by string instruments

**एतेषां स्वराणां न्यूनत्वमधिकत्वं वा तन्म्युपवादनदण्डेन्द्रय वैगुण्यादुपजायते।**(Natyashastra 28.31)

Meaning – In the production of the notes, the rise or fall of pitch is caused by various defects of the strings or of the pegs where the strings are tied, or by the defects in the body of a vīṇā, or by defects or the lack of training of fingers or voice of these notes. This shows that the ancient innovators had clearly identified the factors that distinguish the build quality of musical instruments based on various scientific concepts.

❖ Energy of vibrating string

When a string vibrates in one of its normal modes, the kinetic and potential energies alternately take on their maximum value, which is equal to the total energy.

The maximum kinetic energy of a segment vibrating in its nth mode is

$$dE_n = \frac{\omega_n^2 \mu}{2} (A_n^2 + B_n^2) \sin^2 \frac{n\pi x}{L} dx.$$

Integrating over the entire length gives

$$E_n = \frac{\omega_n^2 \mu L}{4} (A_n^2 + B_n^2) = \frac{\omega_n^2 \mu L}{4} C_n^2.$$

The total energy of the string can be found by summing up the energy in each normal mode:

$$E = \sum_n E_n.$$

#### 4. Avanaddha vadya, the drums

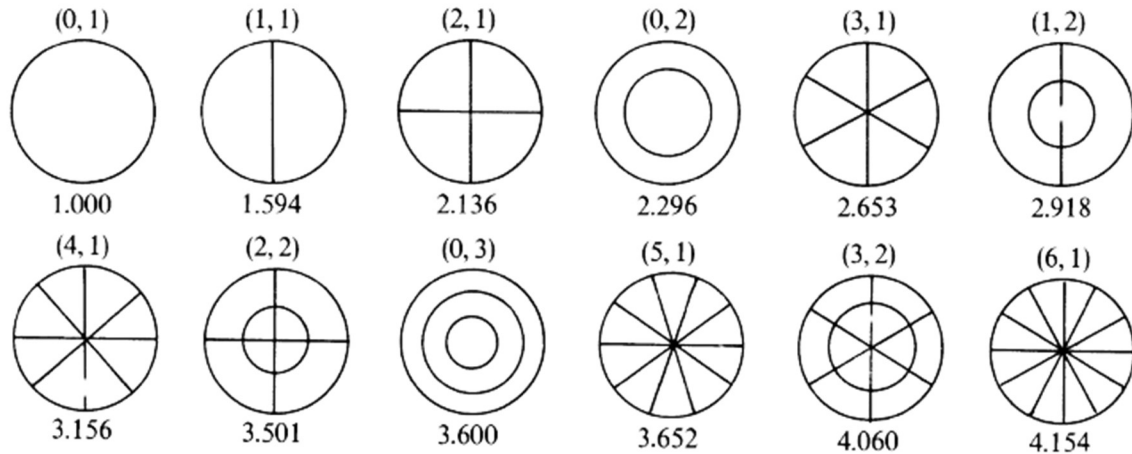
Vibration of membranes produces sound

- Pitch of the sound
  - Less air inside the drum - less air to vibrate - high pitch sound is produced
  - More air inside the drum – more air to vibrate – low pitch sound is produced
- Striking the membrane produce loud and feeble sound
  - Hard strike – large vibrations – loud sound
  - Light strike – less vibrations – feeble sound

#### Two dimensional systems

Unlike a string instrument where we deal with 1-D systems, here for membraned instruments we have to study 2-D systems. So first we will look at how the wave equation is, in 2-D systems, mainly for circular membranes as our focus is on understanding the sound production in mridangam

An ideal membrane has no stiffness of its own. So while analyzing the mathematics of the wave equation, we only take the restoring force to account.



The  $n$ th zero of  $J_m(kr)$  gives the frequency of the  $(m,n)$  mode. Which has  $m$  nodal diameters and  $n$  nodal circles (including one at the boundary). In the fundamental  $(0,1)$  mode, the entire membrane moves in phase.

### Construction of mridangam

The Mridangam is a traditional Indian percussion instrument that holds a significant place in the world of classical music, particularly in the Carnatic music tradition of South India. It is a double-headed drum with a distinctive shape and sound that adds rhythmic depth and complexity to various musical compositions. The construction of the Mridangam is a meticulous and intricate process, with specific materials and techniques employed to create this unique instrument.

The Mridangam consists of two main parts: the drumheads and the drum shell.

**DRUM SHELL:** The body of the mridangam is scooped out of a single block of wood. Jack wood or redwood is the ideal choice of mridangam makers, but the wood of morgosa tree or the core of the coconut tree and the palm tree is also used for this purpose. It is shaped like a barrel whose right head is a little smaller than the left. The instrument is one-and-a-half or two feet in length and its diameter is twenty-five to thirty centimeters.

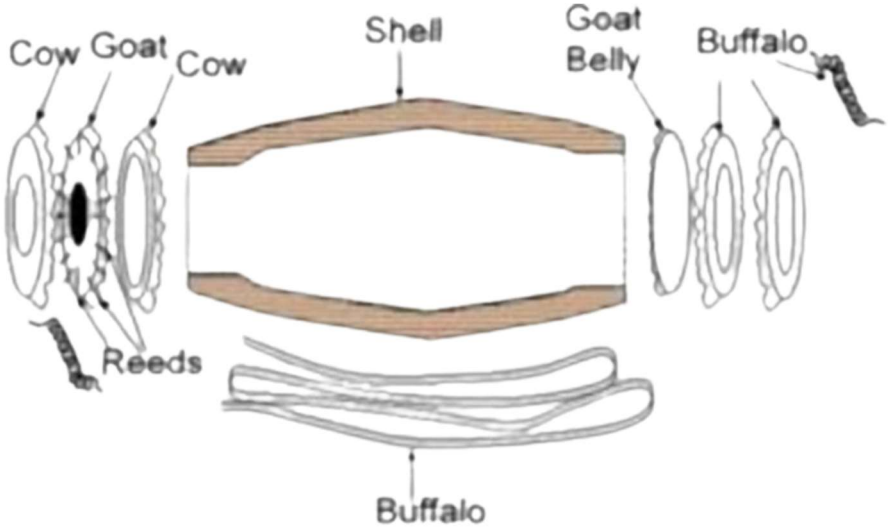


**DRUM HEAD:** The making of the parchment is a highly developed skill. The right head of the drum consists of three concentric layers of the skin, the innermost being concealed from view, which is a complete skin, and two layers at the periphery. Out of these three the complete one is made of cow-hide with calf-skin used for the outer ring and sheep skin for the inner ring.





There is another version of the arrangement of the skin, i.e. the interior is made of calf skin, the middle layer is of goat skin and the outer thick layer is made from cow skin. The left head consists of only two rings. The outer one is made of buffalo skin and the inner one is of sheep/goat skin. Both the parchments are stretched and kept intact by means of a plait called chattai or pinnal made of twisted leather straps. These two plaits are connected with the leather braces of buffalo/cow skin. These can be tightened or loosened to keep the instrument in tune. At times small pieces of wood are also put in between these braces, in order to switch over to the desired pitch of the instrument.



KARNAI: The right head of the drum is loaded with a permanent fixture of black paste. The circular layer, called 'soru', is a composition of manganese dust, boiled rice and tamarind juice or a composition of fine iron fillings and boiled rice. A stone called kittan is powdered and mixed with rice in proper proportion. This black paste is applied on the inner skin in small grains and finely rubbed over for hardening with the polished surface of a hard stone. The paste is thickest in the center and thins out towards the edges. It is this black paste which gives the fine characteristic tone to the mridangam. The left face is not loaded with black paste like the right face, but at the commencement of a concert, a paste of soojee (fine flour) and boiled rice mixed with water and ashes is temporarily fixed on to the center of right head. The quantity of this paste is so adjusted that the note given by the left head is exactly an octave or a fourth below the note tuned at the right side.



## 5. Sushira vadya, the wind instrument

Instruments such as flute, nadaswara produce sound by a jet of air blown from the player's mouth. Different swaras (notes) can be played by selectively closing certain tone holes which in turn change the resonance frequency of the vibrating air column within the instrument, which is basically a pipe with constant (flute) or varying (nadaswara) inner diameter. Though there are similarities in the mechanics of sound production and acoustics of western and Indian wind instruments, there has not been much formal study in the Indian woodwind instruments.

## 6. Ghana vadya- solid bodied instruments

- Generally, these instruments are used maintain the Tala or the rhythmic cycle of the music

• ततं तन्त्रीकृतं ज्ञेयमवनद्धं तु पौष्करम् ।

घनं तालस्तु विज्ञेयः सुषिरो वंश उच्यते ॥

- From Natyashastra, we can get the reference which says that Ghana vadya are the instruments which mark the rhythm or the time.

### Talam :



- One of the oldest musical instruments
- Generally made up of bronze

Modes of vibration of Cymbals:

- Low frequency mode - When the cymbal is supported at its center, the first five or six modes have radial nodes extending from the cup to the edge. These may be thought of as being due to bending waves propagating around the cymbal in both directions.
- High frequency mode - At higher frequencies, the modes of vibration often mix with one another, and mode identification becomes somewhat difficult.

### Ghatam (clay pot):



The ghatam is one of the most ancient percussion instruments of India. It is a clay pot with a narrow mouth. From the mouth, it slants outwards to form a ridge. Made mainly of clay baked with brass or copper filings with a small amount of iron filings, the pitch of the ghatam varies according to its size. The pitch can be slightly altered by the application of plasticine clay or water.

## 7. References

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