ACOUSTIC PROPERTIES OF THE SOUTH INDIAN MRUDANGA

by

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Abstract: This article deals with some of the theoretical and experimental aspects of the acoustic properties of the South Indian Mrudanga. First, an overview of the acoustic properties of percussion instruments belonging to the category of Membranophones is presented. Next, the construction and general characteristics of the Mrudanga is presented in some detail. We focus only on the pitched sounds of the right drum head. We examine the modes of vibration of the Mrudanga head, both from the theoretical and experimental perspective. Measured waveforms and the spectra of the various pitched sounds of the Mrudanga are then presented. These studies provide a deep understanding of the acoustic and psychoacoustic properties of the Mrudanga sounds relating them to the ingenious construction of the instrument.

I. INTRODUCTION

Percussion instruments provide rhythmic accompaniment to instrumental or vocal music. They are also employed in percussion ensembles and as solo instruments in percussion concerts. They constitute one of the most important classes of musical instruments. Of the various types of percussion instruments, Membranophones assume a very prominent place. As the name suggests, Membranophones are those instruments that produce sound via a thin vibrating membrane held under tension.

There are two important sub categories of Membranophones. 1. Instruments that produce inharmonic overtones and 2. Instruments that produce harmonic overtones. Before we proceed any further, we need to understand the concept of overtones and harmonics.

In general, sound consists of a fundamental frequency and a number of distinct higher frequencies known as overtones. A harmonic is an overtone that is an integral multiple of the fundamental. For example, let us say an instrument produces a set of frequencies – 100 Hz, 120 Hz, 149 Hz, 200 Hz, 245 Hz, and 300 Hz. Here the fundamental is 100 Hz, where 120 Hz is the first overtone, 149 Hz is the second overtone, 200 Hz is the third overtone and also the second harmonic (note that 200 is an integral multiple of 100 and the factor of multiplication is 2). The frequency 245 Hz is the fourth overtone, and 300 Hz is the fifth overtone and also the third harmonic (note that 300 is an integral multiple of 100 and the multiplication factor is 3). Thus harmonics bear an integral ratio to the fundamental. However, there is a slight difference in the way overtones and harmonics are designated. Let us consider a sample sound that has harmonic overtones only. The first harmonic is the fundamental itself. The second harmonic is designated as the first overtone, third harmonic is designated as the second overtone etc. This distinction must be borne in mind when we discuss overtones and harmonics.

Figure 1: Tympani

A vast majority of Membranophones produce inharmonic overtones. Examples are several of the of the western percussion instruments such as Tom Tom, Snare drum, Kick drum, and instruments of the world percussion such as Conga, Djambe, Darbuka, and Bongo (not Banjo). All these percussion instruments essentially have a circular piece of a vibrating membrane that is pulled over the opening of a hollow shell. (Sometimes multiple sheets are stacked to form a thicker sheet, enhancing the durability of the drum head.)

Among the Membranophones that produce harmonic overtones are the kettle drum (also called the Timpani or Tympani) and an array of Indian instruments such as the South Indian Mrudanga, Pakhwaj, Tabla, Khol, and so on. The Tympani produces nearly harmonic overtones due to its unique bowl shape and the air pressure variations within the bowl when the membrane vibrates. Barring the Tympani, there is no other percussion instrument of the harmonic category in the world other than those that originated from India.

Indian percussion instruments such as the Mrudanga and Tabla produce near harmonic overtones based on the principle of symmetric loading which is quite a unique technique. It was Sir C.V. Raman who first observed that these instruments produce harmonic overtones due to the process of loading the central part of the membrane with a material of higher density. This loaded portion in the Mrudanga is called the *Karane* (*Sadham* or *Soru* in Tamil) and *Syahi* in the case of the Tabla.

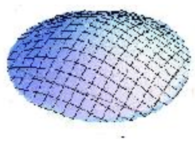
In turns out that Raman's observations regarding the harmonicity of these drums need some corrections. While the higher overtones up to the fourth form a near harmonic series, the fundamental is actually a bit higher and sounds at the note *Rishabha*. We shall discuss this aspect later in this article.

II. MODES OF VIBRATION OF UNLOADED DRUMS

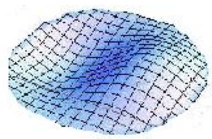
Figure 2: A Tom Tom drum

In drums such as the Tom Tom, a thin synthetic material is stretched uniformly over a wooden shell using tension rods that are attached to the lugs on the outside of the shell wall. These drums are played using a drum stick. The modes of vibration of these drum heads have been studied extensively.

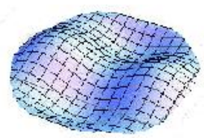
A mode of vibration is indicated by a pair of indices (**m,n**). The integer **m** represents variation along the angular direction while the integers **m** and **n** together represent variation with respect to the radial direction. A node represents a point where the vibration is zero. A nodal line represents a straight line over which the vibration is zero. Likewise, a nodal circle denotes a circle over which the vibration is zero. Some of the vibrational modes of unloaded drums are sketched below (with the vibrational amplitudes exaggerated for the sake of illustration).



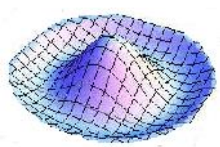
1. **The fundamental mode**: In this mode, the entire drum head vibrates such that there are no nodal lines or circles. This mode is designated as the (0,1) mode. This is the mode with the lowest frequency f.



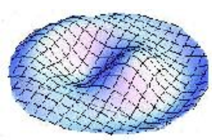
2. **The first overtone mode:** In this mode, the drum head vibrates such that there is one nodal line due to variations in the angular direction. This mode is designated as the (1,1) mode. The frequency of this mode is 1.593f.



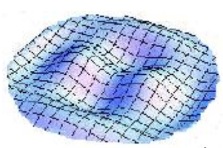
3. **The second overtone mode:** In this mode, the drum head vibrates such that there are two nodal lines due to variation in the angular direction. This mode is designated as the (2,1) mode. The frequency of this mode is 2.135f.



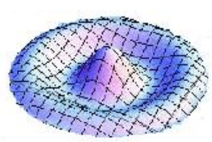
4. **The third overtone mode:** This mode is designated as (0,2). There is no variation in the angular direction but there is a nodal circle formed due to variation in the radial direction. The frequency of this mode is 2.29f.



5. **The fourth overtone mode:** This mode is designated as (1,2). The drum head vibrates in such a way that there is one nodal line and one nodal circle. The frequency of this mode 2.917f.



6. **The fifth overtone mode:** This mode is designated as (2,2). The drum head vibrates in such a way that there are two nodal lines and one nodal circle. The frequency of this mode 3.5f.



7. **The sixth overtone mode:** This mode is designated as (0,3). There is no variation in the angular direction but there are two nodal circles formed due to variations in the radial direction. The frequency of this mode is 3.598f.

If we now look at the frequency ratios of the first six overtones with respect to the fundamental, we find that they are of values 1.593, 2.135, 2.295, 2.917, 3.5, and 3.598. **Thus, none of these overtones are harmonics of the fundamental.** Even the higher order modes exhibit a similar inharmonic behavior. When such a drum head is sounded, although there is a perception of pitch due to the presence of the fundamental, the sound appears tinny and rather unmusical. Thus drummers who play these instruments often use muffling rings or patches to reduce the intensity of these inharmonic overtones.

It is possible that several modes of vibration get generated at the same time when a drum head is struck. The number and intensities of these modes depend on the point at which the drum head is struck, intensity of the strike, contact time of the stick with the drum head, and construction of the drum head and stick. It is also possible to generate single modes of vibration using a loud speaker by directing a sound wave of frequency equal to that of the mode under consideration. When sand particles are sprinkled over a vibrating drum head, they settle down along the nodal lines and circles giving a visual display of the vibrational modes. Such displays are called *Chladni* patterns. Animations of modes of vibration based on theoretical calculations and actual vibrations of circular membranes captured on a video using a stroboscope, are available on the Internet. However, it must be mentioned here that the vibrations of real world drums are noticeably different than those based on the theoretical model, which assumes ideal conditions such as zero stiffness and zero damping for the vibrating membrane.

III. ACOUSTICAL PROPERTIES OF THE MRUDANGA

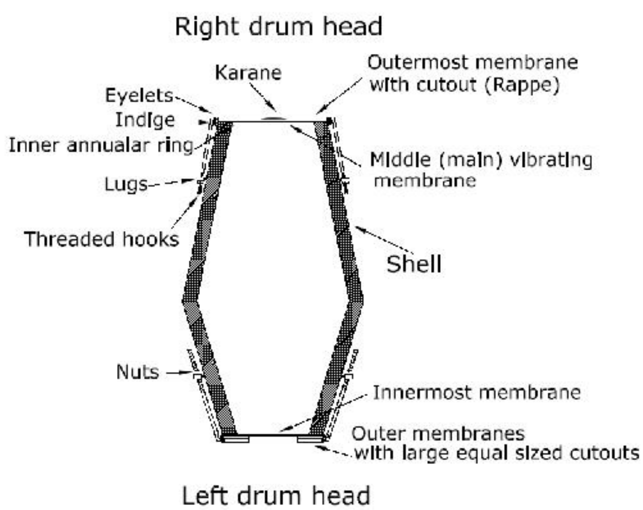


Figure 3: Cross sectional view of the Mrudanga

In its present form, the Mrudanga is constructed using a hollow shell carved out of a single piece of Jack or any other suitable wood. The right head consists of three membranous coverings as shown in figure 3. The innermost one is in the form an annual ring with its inner edge slightly projecting into the opening. Made of goat skin, this layer serves to protect the main membrane from wear and tear due to friction with the bearing edge of the drum. The middle membrane is the main vibrating membrane, also made of goat skin. Both of these are approximately 350 microns (0.35 mm) to 400 microns (0.4 mm) thick. To the central portion of this layer, a permanent black paste made of a dense material is applied, which is known as the *Karane*. The Karane’s constitution has been proprietary, with different makers using different formulations. Broadly speaking, the paste consists of boiled rice mixed with heavy particles such as iron oxide or manganese used to increase the density. After it is applied, each layer is allowed to dry and is then rubbed with a smooth stone until tiny cracks appear on the surface. The patch ends up with a slightly convex surface. Although the paste appears hard and dry, it remains considerably flexible over the vibrational amplitude range of the drum membrane. Heavy metal particles suspended in a flexible matrix of starch and tiny cracks within the body of the Karane hold the clue to its flexibility. Since the bonding of the paste to the skin is mainly through the starch acting as glue, the particles of the Karane wither away over time and reapplication of the paste is required every now and then.

The outermost membrane made of cow skin has a circular cutout larger than the Karane. The diameter of the cutout is about 6-10 mm larger than that of the Karane. This layer is much thicker, typically about 1200 microns (1.2 mm). All the layers are braided together at their outer edges and fastened to a leather hoop known as the *Indige* made of buffalo skin. Small pieces of broom stick (Kannada: *Hanchi Kaddi*) are placed around the inner edge between the outer and middle head. Tension is applied to the head by means of a long leather thong made of buffalo skin that weaves back and forth (normally 16 times) between the top and bottom of the drum holding the two heads together. More recent versions include threaded hooks attached to the Indige through its eyelets and tightened at the other end using nuts that press against permanently attached metal lugs, creating the required tension.

The left head consists of usually three membranes. The innermost membrane is made of goat skin. Two thick layers of buffalo skin about 1400 microns (1.4 mm) in thickness, each having large equi-diameter cutouts, constitute the outer layers. All the layers are braided together at their outer edges and fastened to a circular leather hoop that in turn attaches to the leather thongs (or hooks). The innermost layer is the vibrating membrane to which semolina paste is applied just before playing to bring down the overall pitch. It may be noted that the left head does not produce pitched sounds. In fact, the two outer skins press against the innermost skin preventing it from producing pitched sounds, referred to as ringing. The tension of the left head (the innermost vibrating membrane) cannot be varied and the pitch can only be lowered by applying the semolina paste. The outer layers offer rigidity to the left side and the Mrudanga can be stored upright with the left head placed on the ground. The head produces un-pitched bass sounds and facilitates playing of the Glissando type of sounds known as *Gumkie-s*.

Un-pitched sounds such as Tha and Thom are produced by the left head while sounds such as Ta, and Dhi are produced by the right side. Some people have called the un-pitched sounds, “non vibrating” modes. This is incorrect because without vibration, there is no sound at all.

There are five pitched sounds that are produced by the right head. These are listed below:

Sr.No.	**Name of the stroke***	**Method of playing***
1	Meetu (Nam)	Striking the rim at the edge of the drumhead with the forefinger while holding the Karane at rest at its outer edge with the ring finger. This is generally known as the Rim Stroke.

2.	Chapu	Striking the Karane forcefully with the little finger. The playing position is such that the little finger is placed to extend from the outer edge of the Karane towards the centre.
3.	Arachapu	Played forcefully using the little finger, supported by other fingers along the diameter of the Karane towards the far end. This stroke elicits the Tarasthayi Shadja quite strongly.
4.	Dhim (or Dhin)	Played using the forefinger extending a little inwards from the outer edge of the Karane, while holding the ring finger pressed down at a point at the outer edge of the Karane about 60 degrees away.
5.	Dheem	Played by striking the Karane at the centre with the forefinger and recoiling immediately. This stoke elicits the Rishabha above the tonic.

***** The names of these sounds and the exact playing technique may vary from school to school.

As mentioned, the Mrudanga produces near harmonic overtones due to the Karane which modifies the inharmonic overtones to harmonic ones. This was first observed by Sir C.V. Raman who conducted a series of experiments in this regard. However, several studies have shown that Raman's observations need a correction. While the higher order overtones form a nearly harmonic series, the fundamental is actually out of tune, which is in contrast with Ramans's observations. The ratio of the actual fundamental is about 1.07 times the required fundamental frequency and this corresponds to the Suddha Rishabha Ri_1. The Dheem stroke corresponds to the mode (0,1), where the entire membrane vibrates as a single entity and its frequency is higher than the required fundamental, as suggested by the harmonic overtones.

Several theoretical studies have been conducted by modeling the Mrudanga as a loaded circular membrane. In this context, Prof. B.S. Ramakrishna's work assumes considerable significance. His theoretical model of the Mrudanga as a "composite membrane" proves clearly the harmonicity of the overtones, with the exception of the fundamental, which is a bit high. There are several other studies as well, both theoretical and experimental, which clearly point to this non ideal behavior of the Mrudanga overtones. Rossing has presented several experimental studies on the Mrudanga and has demonstrated how the inharmonic overtones of the Mrudanga gradually move towards their harmonic slots as the Karane is built up layer by layer.

Nevertheless, we do not hear this out of tune fundamental when the Mrudanga strokes (other than the Dheem stroke) are played. We seem to hear the correct fundamental which is actually non-existent. How is this possible?

We DO hear the correct fundamental due to the psychoacoustic effect of missing the fundamental.

A sound is said to have a **missing fundamental**, **suppressed fundamental**, or **phantom fundamental** when its overtones suggest a fundamental frequency but the sound lacks a component at the fundamental frequency itself. The brain perceives the pitch of a tone not only by its fundamental frequency, but also by the periodicity implied by the relationship between the higher harmonics. Therefore, we may perceive the same pitch even if the fundamental frequency is missing from a tone.

When pitched sounds (other than Dheem) are produced, the fundamental corresponding the (0,1) mode is substantially suppressed. What we hear as the tonic Sa is actually a non existing component that is perceived by the brain due to the presence of harmonic overtones. It is purely a psychoacoustic effect. For example, when the Meetu is played, the Karane is held at rest at its outer edge. This suppresses the fundamental mode (0,1) as it requires this point to move up and down for this vibrational mode.

Modal degeneracies in the Mrudanga

If we look at the first nine modes, we find that many of them are degenerate. Two modes are said to be degenerate if they produce the same frequency. In the case of the Mrudanga, the following are first nine modes:

1. Mode (0,1) corresponding to the lowest mode of vibration that produces a slightly out of tune fundamental at Ri_1, the Dheem sound.

2. Mode (1,1) with one nodal diameter that produces the second harmonic (Tarasthayi Sa) with a ratio of 2:1 to the perceived fundamental and is elicited strongly by the Arachapu stroke.

3. Mode (0,2) with one nodal circle and mode (2,1) with two nodal diameters produce the third harmonic with respect to the perceived fundamental.

4. Mode (1,2) with one nodal circle and one nodal diameter, and mode (3,1) with three nodal diameters are all degenerate and they produce the forth harmonic.

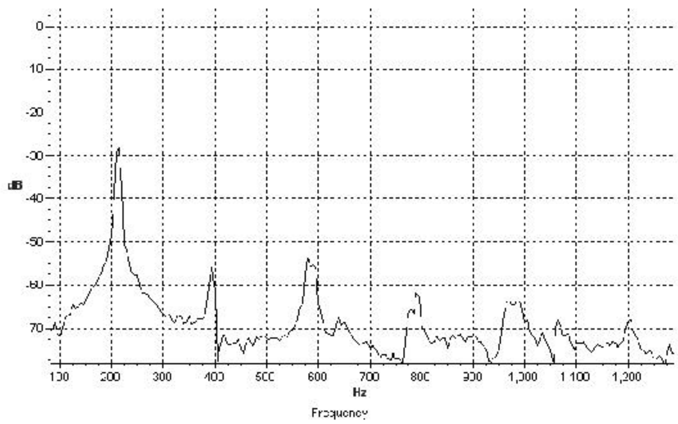
5. Mode (0,3) with two nodal circles, mode (2,2) with two nodal circles, and one nodal diameter and mode (4,1) with four modal diameters produce the fifth harmonic.

In general, the higher order modes are smaller in amplitude and may not contribute perceptibly to the sound of the Mrudanga. Further, it is possible that several modes of vibration get generated at the same time when the drum head is struck. The number and intensities of these modes depend on the type of the strike, intensity of the strike, contact time of the hand with the drum head, and overall construction of the drum head. When multiple modes are generated on the drum head, they produce complex Chladni patterns due to the combination of nodal lines and nodal circles. Some of these patterns may be seen in the original research papers of Sir C.V. Raman as well.

IV. EXPERIMENTAL RESULTS

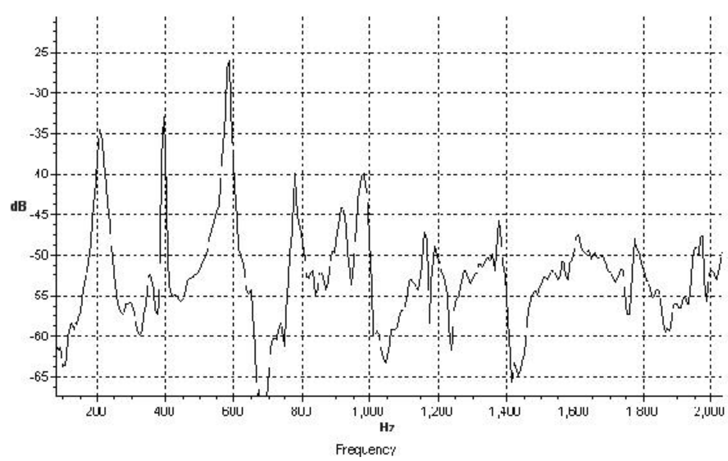
A standard G-pitch Mrudanga is chosen for the experiment. This is a good quality concert Mrudanga made of Jack wood shell. The instrument was tuned to pitch G and the acoustic spectrum is observed on the computer using the Visual Analyzer 2011 software (Visual Analyzer is a free downloadable software by Sillanum Software). This software uses the sound card in the computer and converts it into a powerful oscilloscope/spectrum analyzer, thus saving lakhs of rupees required to buy a hardware spectrum analyzer.)

Spectrum of Dheem:



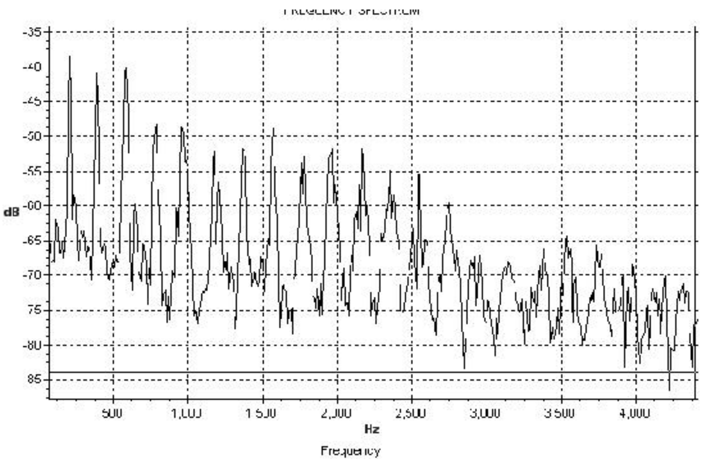
This spectrum clearly shows a prominent fundamental at 214.7 Hz. The second harmonic is at 395 Hz. In the case of sounds like Meetu, the perceived fundamental is taken to be half of this at 197.5 Hz. (Notice that this is close to the standard, G pitch equal to 196 Hz.) Thus the actual fundamental is about 214.7/197.5=1.07 times the perceived fundamental. The other frequencies in the spectrum are the second harmonic at 395 Hz (overtone ratio 2:1), two-third harmonic peaks at 579.6 Hz (overtone ratio 2.93:1) and 590 Hz (overtone ratio 2.99:1), fourth harmonic peak at 791 Hz (overtone ratio 4:1), two-fifth harmonic peaks at 970.2 Hz (overtone ratio 4.91:1) and 990 Hz (overtone ratio 5.01:1). The double peaks at the third and fifth harmonic may be due to generate modes. Note that the overtone ratios are all nearly integers and thus represent harmonics. The spectrum also indicates that the actual fundamental is very prominent with the other harmonics, at least 200 times smaller than this.

Spectrum of Meetu:



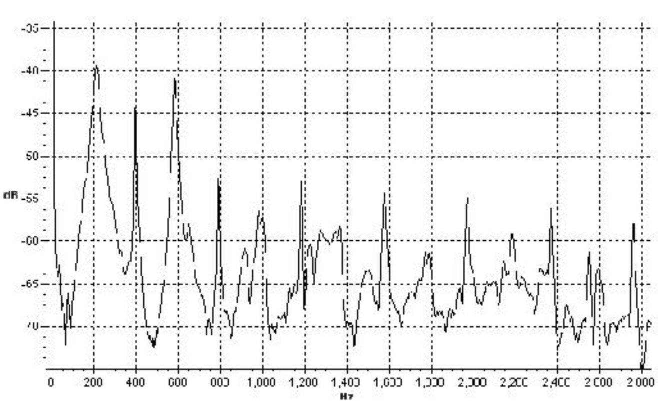
The striking feature of this spectrum is the strong third harmonic. The fundamental is suppressed quite substantially (it is about 8 times smaller than the third harmonic). The second harmonic is also fairly strong and even the higher harmonics are stronger as compared to the Dheem case. The strong presence of the second and third harmonic enables us to hear the missing fundamental at around 197.5 Hz. The out of tune fundamental is thus over shadowed by the perceived fundamental. The measured frequencies are as follows: Fundamental at 209.6 Hz (1.06 times the perceived fundamental), the second harmonic is at 395.2 Hz. (overtone ratio 2:1), third harmonic peak at 585.8 Hz (overtone ratio 2.96:1). fourth harmonic peak at 779 Hz (overtone ratio 3.94:1), and fifth harmonic peak at 980.3 Hz (overtone ratio 4.96:1). Note again that the overtone ratios are all nearly integers and thus represent harmonics.

Spectrum of Arachapu:



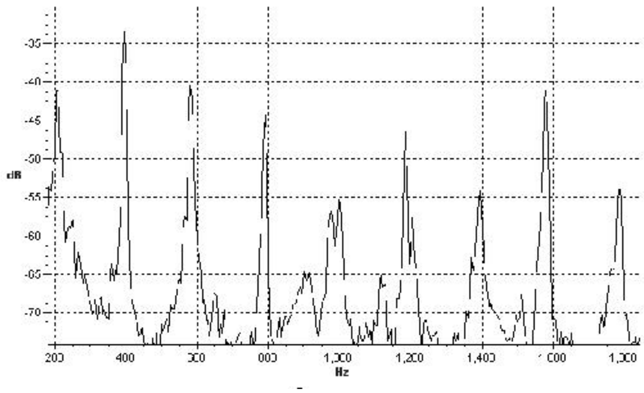
The Arachapu is a very powerful stroke and elicits a very large number of harmonic overtones. Note that the near harmonic overtones are all strong and comparable in strength. Further, the second harmonic is almost equal in strength to the third harmonic. The placement of the edge of the hand along the diameter during the strike forms a nodal diameter and thus the second harmonic is excited more strongly, leading to a clear perception of the Tarasthayi Shadja. Note that the fundamental is quite strong unlike the case of Meetu. The actual fundamental is at 210.4 Hz which is about 1.08 times the perceived tonic frequency. The other frequencies in this spectrum are the second harmonic at 390.4 Hz (overtone ratio 2:1), third harmonic peak at 590.1 Hz (overtone ratio 3.02:1), fourth harmonic peak at 788.9 Hz (overtone ratio 4.04:1), fifth harmonic peak at 969.4 Hz (overtone ratio 4.97:1), sixth harmonic at 1186.9 Hz (overtone ratio 6.08:1), and seventh harmonic at 1381.2 Hz (overtone ratio 7.08:1). Note that the overtone ratios are all nearly integers and thus represent harmonics. It is also seen that the hamonicity extends even to many of the higher overtones as seen in the figure.

Spectrum of Dhim:



During the Dhim stroke, the Karane is hit at its edge using the index finger. In the Mrudanga, most of the vibrational energy is confined to the Karane area and striking this will produce a number of overtones. The fundamental, second, and third harmonic are all strongly excited and this gives a rich tonal texture to this stroke. The fundamental is at 211.7 Hz, which is about 1.08 times the tonic frequency. The other frequencies in the spectrum are the second harmonic at 393 Hz (overtone ratio 2:1), third harmonic at 581.8 Hz (overtone ratio 2.96:1), fourth harmonic at 788.9 Hz (overtone ratio 4.04:1), fifth harmonic peak at 979.2 Hz (overtone ratio 4.98:1), and sixth harmonic at 1181.7 Hz (overtone ratio 6.01:1) The overtone ratios are all nearly integers and thus represent harmonics.

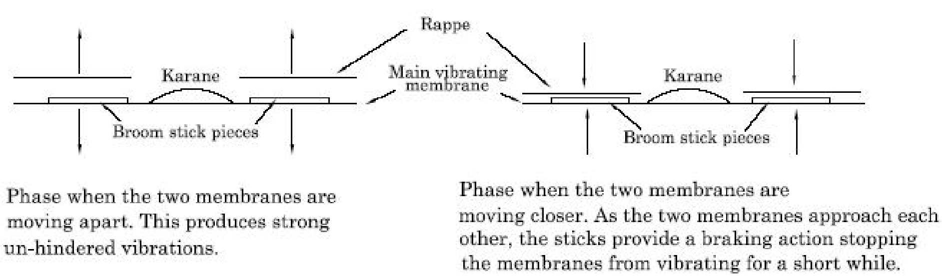
Spectrum of Chapu:



The Chapu is yet another powerful stroke that elicits a very large number of harmonic overtones. Note that all the near harmonic overtones are strong and comparable in strength. The second harmonic is very strong and the fundamental is about 16 times smaller than this. The actual fundamental is at 209.6 Hz, which is about 1.06 times the perceived tonic frequency. The other frequencies in the spectrum are the second harmonic at 394.6 Hz (overtone ratio 2:1), third harmonic peak at 582.5 Hz (overtone ratio 2.95:1), fourth harmonic peak at 787.8 Hz (overtone ratio 3.99:1), two-fifth harmonic peak around 987.2 Hz (overtone ratio 4.00:1), and sixth harmonic at 1192.4 Hz (overtone ratio 6.04:1). The hamonicity extends even to many of the higher overtones, as seen in the figure.

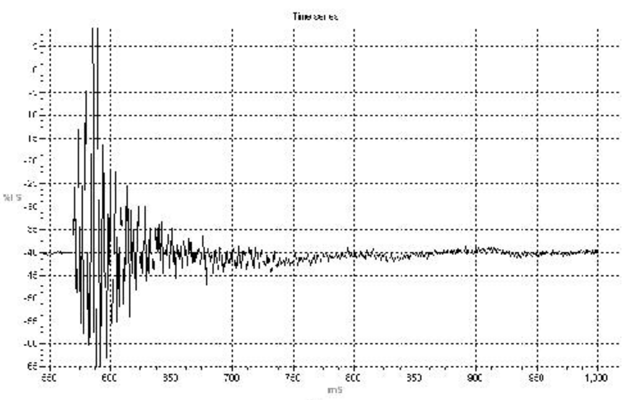
The Chapu is one of the most important sounds of the Mrudanga and gives it a very distinct "crackling" sound. How is this cracking sound produced?

The pieces of broom stick play a very important role in the production of this sound. When the main membrane and Rappe are appropriately tensioned and struck, and if the conditions are favorable, the two membranes start vibrating together. During a certain phase of the vibration, they come together and move apart in another phase. The broom stick pieces play the role of spacers and facilitate these vibrations. During the phase the two membranes move apart, they vibrate freely and produce maximum sound. During the phase they come close, they collide with each other, with the sticks acting like brakes to stop the sound. This reduces the sound intensity considerably. However, the vibrations do not stop completely because of the momentum of the membranes. In the next instant, they again move apart producing sounds of higher intensity. This concept is illustrated below:



The process repeats itself until the sound damps completely and becomes inaudible. The production of Chapu depends on many factors and is properly produced only when conditions are favorable. If the Rappe is too thin, the braking action will be too weak and if it is too thick the braking action will be too strong, thereby altogether stopping the vibrations. The number of sticks and the thickness of the sticks also matter a lot. Strips that are too thin produce a “fine grain” Chapu sound while too thick sticks produce a harsh Chapu sound with reduced sustain. In a good Mrudanga, all these factors must be optimally balanced.

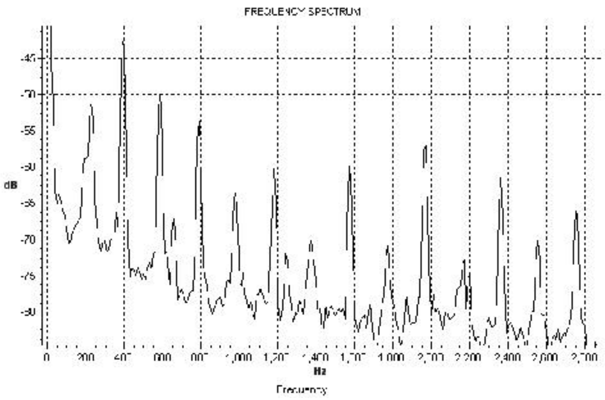
It must be mentioned here that the Chapu is a result of the “make and break” process of the vibrating membranes, similar to what happens in a *Tamboora* due to the *Jivala* thread. Dr. B.C. Deva in his book, ‘Psychoacoustics of Music and Speech’ notes that in the Tamboora, the vibrating string hits the bridge and momentarily stops during such times. This gives rise to a number of overtones, many of them being harmonic. That is the reason for the rich tone of the Tamboora. It may be noted that even here the Jivala thread needs to be carefully adjusted to produce the desired effect.



The adjoining figure represents the waveform of the Mrudanga Chapu. (Note that this is an oscilloscope pattern and not a spectrum plot.) It can be clearly seen that after the *Attack phase*, the amplitude of vibration varies in a cyclical fashion while generally decreasing in an exponential pattern. This amplitude modulated sound gives us the perception of the distinct “chapu” sound of the Mrudanga. Some people have called this the “snare” sound. This is incorrect because the snare used in Western drums are metal wires attached to the resonant head which produce unpitched rattling sounds, whereas the Chapu is an amplitude modulated sound having a strong sense of pitch.

If we carefully examine the spectra of Dhim and Arachapu, we find that the out of tune fundamental is still very strong. How then do we hear the correct fundamental in these cases?

The answer lies in the dynamic nature of the spectral components. After the drum head is struck, each spectral component gradually decreases in strength but some components decrease more rapidly than the others. In the case of Dhim for example, the spectrum taken after a **small time delay** shows the following components as seen in the figure.



It can be clearly seen that the out of tune fundamental has decreased 10 times at this point in time. This difference will get further accentuated with the passage of time until all components decrease to un-audible levels. A similar behavior is observed in the case of other pitched sounds as well. Thus we perceive the correct fundamental in each case except in case of Dheem where the fundamental is very much stronger than the other components.

V. CONCLUSION

The fundamental mode in the Mrudanga is slightly “out of tune” with the rest of the nearly harmonic overtones. The Dheem sound of the Mrudanga is due to this fundamental mode corresponding to the *swara*, Suddha Rishabha. The perceived fundamental is due to the psychoacoustic effect of the suppressed fundamental. The actual fundamental present in many of the pitched sounds like Dhim and Arachapu, however, is not perceived because this component rapidly decreases in intensity with time when compared to the other components, thus remaining unnoticeable by the human ear.