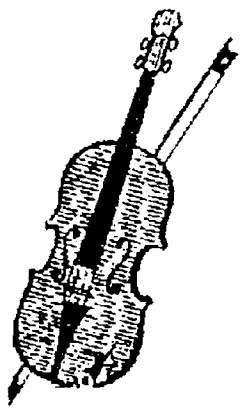
Chapter 2



Physics of Carnatic Music

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Indian Music is based on the Raga system. In Classical Carnatic Music, we have 72 Melakartha Ragas, which are the mother Ragas. Each of these Ragas can generate a number of Janya Ragas. Mathematically, this system has a potential of producing about 35,000 Ragas. But only about 150 to 200 Ragas are extant in actual practice [8]. The reason for the limited number is that only these Ragas have combinations of Notes which are musical in sound and are capable of creating an artistic air.

When we go through the literature related to acoustics and Carnatic Music, very little is available about the physics of Raga. In Acoustics we come across terms like frequency, amplitude, loudness, pitch, velocity, timbre, quality etc. In Carnatic Music we always come across the terms like Sruti, Swara, Gamaka, and Raga etc.

Musical Sound has three identifying characteristics; loudness, pitch and timbre (or quality). Loudness is power, as it depends on the amplitude or the intensity of the corresponding wave, and is measured in decibels. The pitch of a musical sound is determined mainly by its frequency [9] and is a measure of how "high" or "low" a tone is, and is measured in hertz (Hz). The third identifying feature, timbre, stems from the fact that musical sounds are made up of many different sine waves. Each instrument has a characteristic pattern of sine waves. Timbre (quality) essentially depends on the number, intensity and distribution of the harmonic components of a tone. The Notes of the same pitch from a Guitar, Sitar, Violin and a Flute are entirely different in quality and are instantly

recognizable. We have used a program: **Sruti**, developed by us for studying the performance of musical instruments. The details of **Sruti** are available in later chapters.

The eminent scientist Ohm stated that the ear recognises music only in terms of pure tones, and that it resolves any other complex vibrations into its harmonic components, perceiving them as a summation of pure tones [10]. It means that the ear is capable of converting a complex tone into a Fourier harmonic series of simple tones. This is achieved by the complex structure of Cochlea in the ears.

2.1 Cochlea

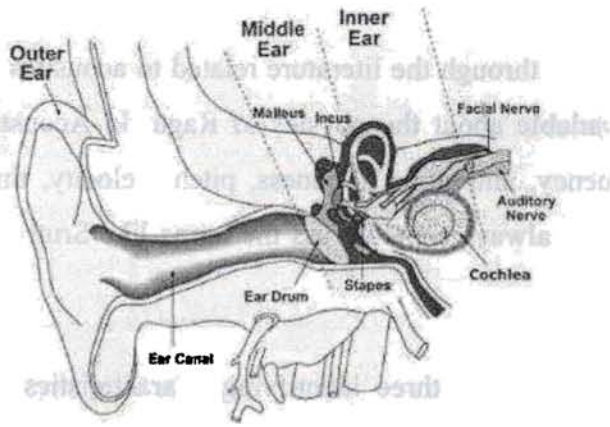

Fig 2.1 Human ear

In our inner ears, the Cochlea enables us to hear subtle differences in the sounds coming to our ears. The Cochlea consists of a spiral of tissue filled with liquid and thousands of tiny hairs which gradually become smaller from the outside of the spiral to the inside. Each hair is connected to a nerve which feeds into the auditory nerve bundle going to the brain. The longer hairs resonate with lower frequency sounds, and the shorter hairs with higher frequencies. Thus the Cochlea serves to

transform the air pressure signal experienced by the ear drum into frequency information which can be interpreted by the brain as tonality and texture.

2.2 Sruti

The frequencies of Notes used in music lie between 30 Hz and 5000 Hz. This frequency range is divided into many octaves. In western music we have the Notes C, C#, D, D#, E, F, F#, G, G#, A, A#, and B [11]. The Frequency of these Notes is fixed. The frequency of the middle octave C4 is 261.63, C#4 is 277.18, etc. The frequency of C5 in the next octave is 2 x 261.63. Sruti ordinarily refers to frequency. It can be said as a group of frequencies with varying amplitudes. But the one with maximum amplitude will represent a Sruti.

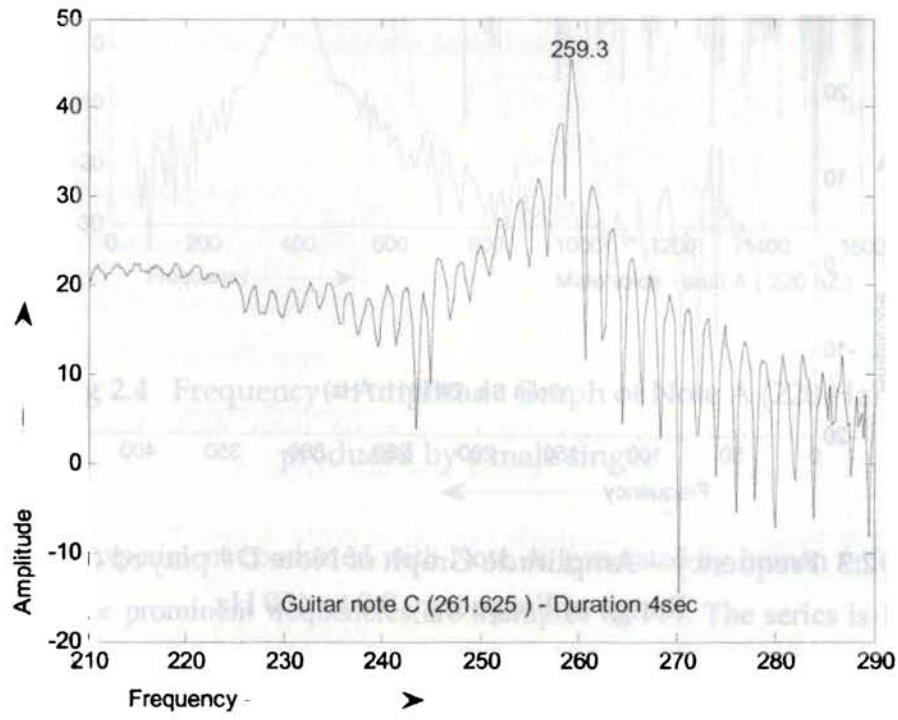

Fig 2.2 Frequency - Amplitude graph of Guitar Note C

The experiments conducted using Guitar and Violin, explain how we can find out the frequency of a Swara with the help of **Sruti**.

Fig 2.2 refers to the C Note produced by the second string of a Guitar. The frequencies generated were found out using the program **Sruti** and a graph was plotted with frequency on the x-axis and amplitude on the y-axis. The frequency corresponding to maximum amplitude was found to be 260, which is the frequency of the C Note (261.625). The error accounts for the lack of fine tuning of the strings of the guitar used. The program is capable of detecting frequency at any level of accuracy, with the appropriate hardware. However, fractions of frequency can be neglected for the purpose of this study.

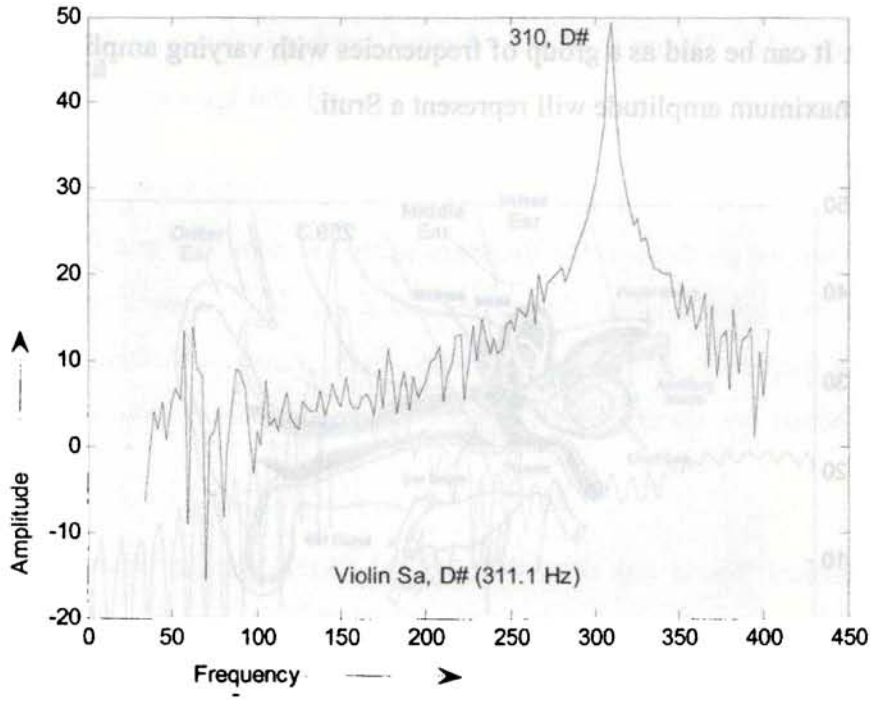

Fig 2.3 Frequency - Amplitude Graph of Note D# played on Violin Range of Frequency 0.0 to 450 Hz

Fig 2.3 shows the D# Note played with Violin was identified almost correctly by the program **Sruti**. The detected value is 310 Hz and the standard value of D# is 311.1 Hz.

2.3 Fundamental frequency and overtones

When a string fixed at both ends is plucked or bowed at the centre, it generates a fundamental frequency and its overtones, which are integral multiples of the fundamental frequency.

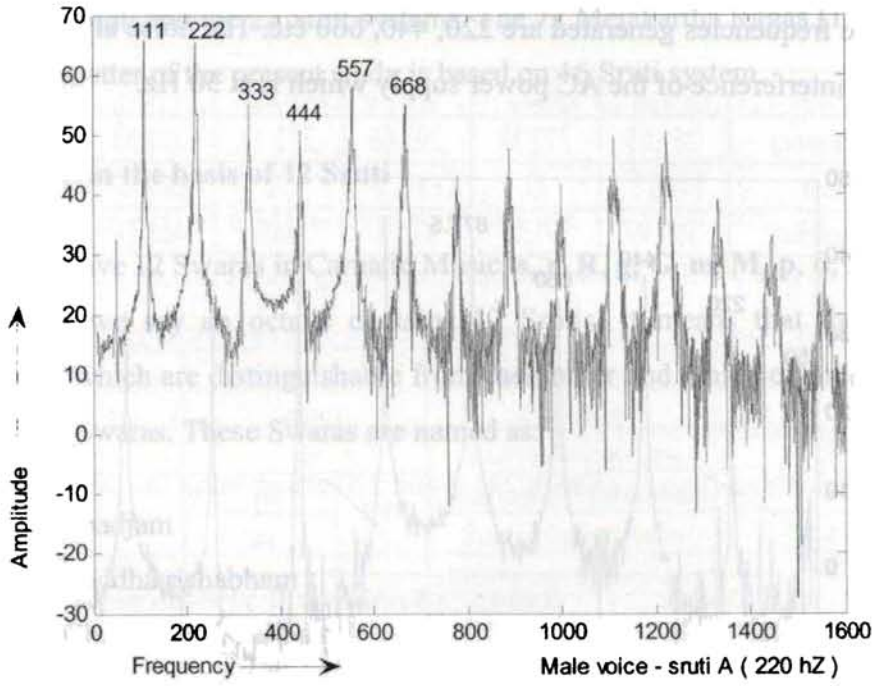

Fig 2.4 Frequency - Amplitude Graph of Note A (220 Hz) produced by a male singer

The experiment conducted with Note **A,** generated by human voice (male) found that the prominent frequencies are multiples of 111. The series is 111, 222, 333, 444 etc. as seen in Fig 2.4. Practically this may not be exactly as estimated. For example the next frequency observed is 557 instead of 555. The slight variation may be because of the limitation of the sample rate. It is also noted that it contains not only the above frequencies, but many other frequencies as well, with less amplitude. The frequency allotted to Note **A**3 is 220. The difference of 2 Hz (222-

220) is only an error in the singing. But when **A** (here 222Hz) is sounded, another lower frequency 111 Hz is also generated, which is the fundamental frequency. But when the same Note **A** is played with Violin on the 2nd string, it doesn't generate a lower frequency of 111 Hz, Fig 2.5. In other words, there is a mismatch in the fundamental frequencies generated by a male vocalist and a Violin in a music concert, even though they are using the same base Sruti **A.** In the case of the Violin, the frequencies generated are 220, 440, 660 etc. The noise at 50 Hz may be due to the interference of the AC power supply which is at 50 Hz.

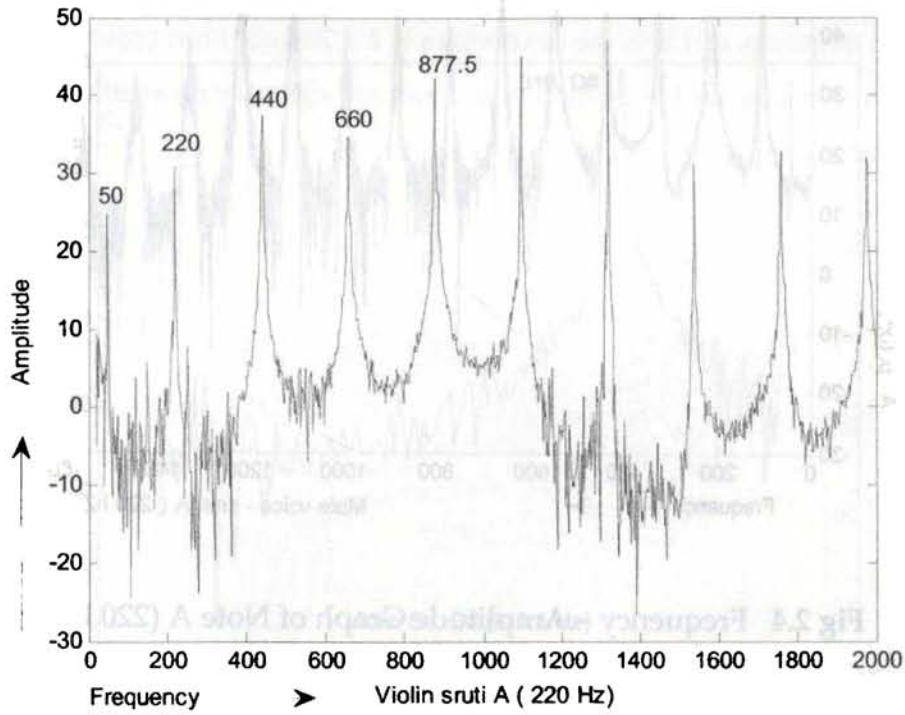

Fig.2.5 Frequency- Amplitude Graph of Note **A** generated by Violin

Now consider the octave starting from 220 to 440. Since Note A is the Sruti, when the vocalist sings **sa**, frequencies 220, 330 and 440 will be present, where 220 is **sa**, 330 is **pa** and 440 is the top **Sa** (thara shadjam). For each Swara sung by the vocalist, its **pa** is automatically generated. For **sa, pa** is generated, for **ri, da** and for **ga, ni** etc. But Violin generates only **sa** (220) and top **Sa** (440) in this

octave. Notes played by Violin don't generate **pa, da, ni** etc. corresponding to **sa, ri, ga** in this range.

2.4 Sruti systems

In Carnatic Music, three types of Sruti systems are discussed. They are the 12 Sruti, 16 Sruti and the 22 Sruti systems. The 72 Melakartha Ragas [12] which is the subject matter of the present study is based on 16 Sruti system.

2.4.1 Ragas on the basis of 12 Sruti

We have 12 Swaras in Carnatic Music, **s**, **r**, **R**, **g**, **G**, **m**, **M**, **p**, **d**, **D**, **n** and **N** [13]. When we say an octave contains 12 Srutis, it means that there are 12 frequencies which are distinguishable from each other and which can represent the 12 Srutis or Swaras. These Swaras are named as:

1. Shadjam
2. Suddha rishabham
3. Chatusruti rishabham
4. Sadharana gandharam
5. Anthara gandharam
6. Suddha madhyamam
7. Prathi madhyamam
8. Panchamam
9. Suddha dhaivatham
10. Chathusruti dhaivatham
11. Kaishiki nishadam
12. Kakali nishadam

Here the frequency assigned to each Swara is not fixed, but is relative. The frequency of all Swaras depends on the frequency of the basic Swara **sa**, and other

Swaras have a fixed ratio with **sa**. That is, we have 12 Swaras having 12 different frequencies depending on the frequency of **sa**. In Western Music we have 12 Notes C Db D Eb E F F# G Ab A Bb B . The notation 'b' is spelled as 'flat'. frequencies of the western Notes are fixed. They are equally divided in an octave [14]. The middle octave frequencies are shown in table 2.1. The frequency of C is 261.63 and that of other Notes are given by C * $2^{\wedge (n/12)}$, n=1,2,3,...11.

Note	C	C#/D b	D	D #/E b	E	F
Frequency	261.63	277.18	293.66	311.13	329.63	349.23
Note	F#/G b	G	G #/A b	A	A#/B b	B
Frequency	369.99	391.99	415.3	440	466.16	493.88

Table 2.1 Western Music Notes and their corresponding frequencies

The frequency ratio of 12 Swaras in Carnatic Music [15] and the frequencies of Swaras corresponding to **sa** with 261.6 and 220 are given in the table 2.2 below:

Swara	Ratio	Frequency1	Frequency2
s	1	220	261.6
r	16/15	234.70	279.1
R	9/8	247.5	294.3
g	6/5	264	314.0
G	5/4	275	327.0
m	4/3	293.3	348.8
M	45/32	312.9	372.1
p	3/2	330	392.5
d	8/5	352	418.6
D	27/16	371.3	441.5
n	9/5	396	470.9
N	15/8	412.5	490.1

Table 2.2 Carnatic Music Swaras, their frequency ratios & frequency

We can see that there are two **ri** (**r** and **R**), two **ga** (**g** and **G**), two **ma** (**m** and **M**), two **dha** (**d** and **D**) and two **ni** (**n** and **N**). To form a Raga, we take only one Swara each from the pair. That is from the 12 Srutis we choose 7 Swaras (saptha Swaras) and we name it **sa, ri, ga, ma, pa, dha, ni**. From the above we get 32 combinations and 32 Ragas.

2.4.2 Ragas on the basis of 16 Sruti

Venkatamakhin classified Ragas according to the Melakartha scheme. In this scheme there are 72 Melakartha Ragas. Each Melakartha Raga is given a Melakartha number. In a Melakartha Raga we use 7 Swaras from the available16 Swara positions, **sa, ra, ri, ru, ga, gi, gu, ma, mi, pa, da, di, du, na, ni, nu** [16].

Semitone step	Swara name		Technical name	Swara positions
1	sa		Shadjam	1
2	ra		Sudha Rishabham	2
3	ri	OR	Chathusruti Rishabham	3
	ga		Sudha Gandharam	4
4	ru	OR	Shadsruti Rishabham	5
	gi		Sadharana Gandharam	6
5	gu		Anthara Gandharam	7
6	ma		Sudha Madhyamam	8
7	mi		Prathi Madhyamam	9
8	pa		Panchamam	10
9	dha		Sudha Dhaivatam	11
10	dhi	OR	Chathusruti Dhaivatam	12
	na		Sudha Nishadam	13
11	dhu		Shadsruti Dhaivatam	14
	ni	OR	Kaisiki Nishadam	15
12	nu		Kakali Nishadam	16

Table 2.3 16 Srutis of Carnatic Music and their Swara names

Here Swaras **sa** and **pa** are one each only. Swara **Ma** has two positions, **ma** and **mi**. But **Ri**, **Ga**, **Dha** and **Ni** have three positions each. The frequency of **ri**

and **ga** are the same. Frequency of **ru** and **gi** are the same. Frequency of **di** and **na** are the same. Similarly frequency of **du** and **ni** are the same. Considering the above fact, we have only 12 frequencies available for 16 Swara positions. We name these 12 frequencies as **s**, **r**, **R** (ri or ga), **g**,**G** (ru or gi), **m**, **M**, **p**, **d**, **D** (di or na), **n** (du or ni), and **N**. The frequency of **s** can be chosen according to the convenience of the singer. The other frequencies depend on **s**. The different Swara names and their technical names on the basis of sixteen Srutis are given in Table 2.3

2.4.3 Ragas on the basis of 22 Sruti

No	Name of the sruti	Sym-bol	Sruti ratio	Raga which uses the sruti
1	Shadjam	sa	1	All
2	Ekasruti Rishabham	r1	256/243	Gaula
3	Dvisruti Rishabham	r2	16/15	Mayamalava Gaula
4	Trisruti Rishabham	r3	10/9	Bhairavi
5	Chatusruti Rishabham	r4	9/8	Sankarabharana
6	Sudda Gandharam	g1	32/27	Bhairavi
7	Sadharana Gandharam	g2	6/5	Kharaharapriya
8	Antara Gandharam	g3	5/4	Sankarabharana
9	Chyuta Madhyama Gandharam	g4	81/64	Devagandhari
10	Suddha Madhyama	m1	4/3	Kunthalavarali
11	Tivra suddha Madhyamam	m2	27/20	Begada, Gaulipanthu
12	Prati Madhyamam	m3	45/32	Kalyani
13	Chyuta Panchama Madhyama	m4	64/45	Varaali
14	Panchamam	pa	3/2	All
15	Ekasruti Dhaivatam	d1	128/81	Saaveri
16	Dvisruti Dhaivatam	d2	8/5	Mayamalavagaula
17	Trisruti Dhaivatam	d3	5/3	Kamboji
18	Chatusruti Dhaivatam	d4	27/16	Kalyani
19	Suddha Nishadam	n1	16/9	Bhairavi
20	Kaishiki Nishadam	n2	9/5	Kharaharapriya
21	Kakali Nishadam	n3	15/8	Sankarabharana
22	Chyuta Shadja Nishadam	n4	243/128	Kuranji

Table 2.4 Names of the 22 Srutis of the Carnatic Music & freq. ratios

Carnatic Music uses micro tones. It is the use of micro tones that give a peculiar charm to the Ragas. In the 22 Sruti system, each Swara ri, **ga, ma, dha** and **ni** has four Srutis. **sa** and **pa** has only one Sruti, to a total of 22. We can arrive at these Srutis, by taking the cycles of fourth and fifths in progression. In the cycle of fifths, the frequency of **sa** is multiplied with 3/2 giving **pa**. Again when **pa** is multiplied with 3/2 we get **ri** (chathur sruti rishabham) of the next octave. In the cycle of fourths, the frequency of **sa** is multiplied with 4/3 giving sudha madhyama ma. When ma is multiplied with 4/3, we get suddha nishada. We can repeat this cyclic operation to get the other Swaras in the 22 Sruti. The names of the 22 Sruti and their frequency ratio are given in the table 2.4. This method of finding the 22 Srutis was put forward by Bharatha [17].

Another method of generating 22 Srutis and its frequencies are explained in The mystic citadel of 22 Srutis music [18]. But the present day teachings are based on Bharatha's theory.

2.5 Gamaka

Gamaka shakes the Notes (Swaras) resulting in a musical effect. The individual shade and colour of a Raga becomes clear only with the proper usage of the Gamakas. Gamaka plays a vital part in Indian Music, and they determine the melodic part of a Raga. It has been classified mainly into ten [19].

Dr. P.T. Chelladurai, speaks about Dasavidha (ten) Gamakas in his book, "The Splendour of South Indian Music" [20], as follows:

1. Arohana Gamaka: This is employed when we sing or play a Raga in the ascending order properly. Eg. **s r g m p d n S**.
2. Avarohana Gamaka: This occurs when we sing in the descending order. Eg. **S n d p m g r s**

3. Ahatha Gamaka: This is noticed when we sing the musical phrases like **sr rg gm mp pd dn nS**.
4. Pratyahatha Gamaka: The same as the above, but in the descending order. Eg **Sn nd dp pm mg gr rs**
5. Sphuritha Gamaka: This occurs when we sing Janta varisa like **ss rr gg mm pp dd nn SS**.
6. Tripucha Gamaka: This is obtained when we sing the Swaras in triplets. Eg. **sss rrr ggg mmm** etc.
7. Dhalu Gamaka: This is produced when a person starting on a basic Swara reaches the higher Swara in conformity with the Raga bhavam. Eg. **ss sg sm sp** etc.
8. Andolitha Gamaka: When played Swaras in the following manner – **srs dd, srs pp, srs mm**
9. Kampitha Gamaka: This is produced when we lengthen the duration of the Swaras and sing them with stress like in **s r g m** in Hanumathodi Raga.
10. Murchchanai Gamaka: Start on shadjam, proceed regularly in the Arohana Kramam and finish on the Dirgha Nishadam; then start on Rishabham and finish on Dirgha Nishadam and so on. Eg. **s r g m p d n – r g m p d n S.**

By applying Gamaka to a Swara, the Sruti position of the Swara changes momentarily. The frequency may go up or down. It depends on what type of Gamaka has been used. But whatever be the type of Gamaka, the actual frequency of the Swara will be the one having maximum amplitude within a range. It is found that after applying Gamaka, the identified Swara using the program **Sruti** is the same as the original Swara in almost all the cases except in the case of Kampitha Gamaka. This can be seen from the figures - Fig 2.6 to 2.15 given below. The various Gamakas were played on a Violin and was tested using **Sruti.m**

Figure 2.6 given below shows the frequency detected when Arohana Gamaka is played. Swaras **sa**, **ri**, **ga**, **ma**, **pa**, **da** and **ni** of Sankarabharana Raga, with base Sruti C# (280 Hz) are played in the ascending order with Gamaka. The frequency of Swara **ga** was measured using the program. The measured frequency is 352 Hz. The calculated value of **ga** is 350 Hz. and will be identified as **ga**.

Fig 2.7 shows the frequency detected when avarohana Gamaka is played. Swara tested is tara shadjam **Sa**. The calculated frequency is 560 Hz and the measured frequency is 564 Hz. Swara detected will be **Sa**.

For testing Ahata Gamaka, phrases like **sr rg gm mp pd dn nS** in Sankarabharana Raga were tested. The Swara detected was any one in the Sankarabharana Raga. In the test it is **Ri**, Fig 2.8. In Pratyahata Gamaka also a Swara of Sankarabharana was detected.

In Sphuritha Gamaka phrases like **ss rr gg mm pp dd nn SS** were tested. When frequency of **rr** was measured, it was found to be 314 Hz, while the calculated value was 315 Hz.. See Fig 2.9.

In Tripucha Gamaka, phrases like **sss rrr ggg mmm ppp ddd nnn SSS** were used. Gamaka in **Ni** was tested and the experimental value found was 530 Hz which was identified as **Ni** of Sankarabharana Raga. See Fig 2.10.

In Dhalu Gamaka, phrases like **sS**, **sg**, **sm** and **sp** were tested. When **sp** was tested for detection, frequency measured was 420 Hz which is **pa** while the calculated frequency is 418 Hz. See Fig 2.11.

Andolitha Gamaka uses phrases like **srsmm**, **srspp** and **srsdd**. When the phrase **srsmm** was tested, the detected frequency was 374Hz, while the calculated was 373 Hz, which is **ma** of Sankarabharana Raga. See Fig 2.12.

Kampitha Gamaka uses phrases like **s r g m** played as in Hanumathodi (Thodi) Raga. For testing, Thodi Raga in popular form was played on a Violin. This Gamaka is seen in **ga** and **ni** of Thodi Raga. First the Gamaka in **ga** was tested. The expected frequency was 336 Hz (**ga**), but the detected was 294 Hz (**ri**), fig 2.13. Similarly the Kampitha Gamaka was tested for Swara **ni**. The expected frequency was 504 Hz (**ni**), but the detected was 440 Hz (**da**), fig 2.14.

In Murchchanai Gamaka, phrases like **s r g m p d n – r g m p d n S** etc. are used. When s **r g m p d n** phrase of Sankarabharana Raga was used for testing, and for five repetitions, frequencies 416 Hz, 538 Hz, 416 Hz, 278 Hz and 314 Hz were obtained. These are the Swaras **pa**, **ni**, **pa**, **sa** and **ri** of Sankarabharana Raga. That is in all cases the Swara detected was one of the Swaras of Sankarabharana Raga. Figure 2.15 shows the result of the last testing, where **ri** was obtained.

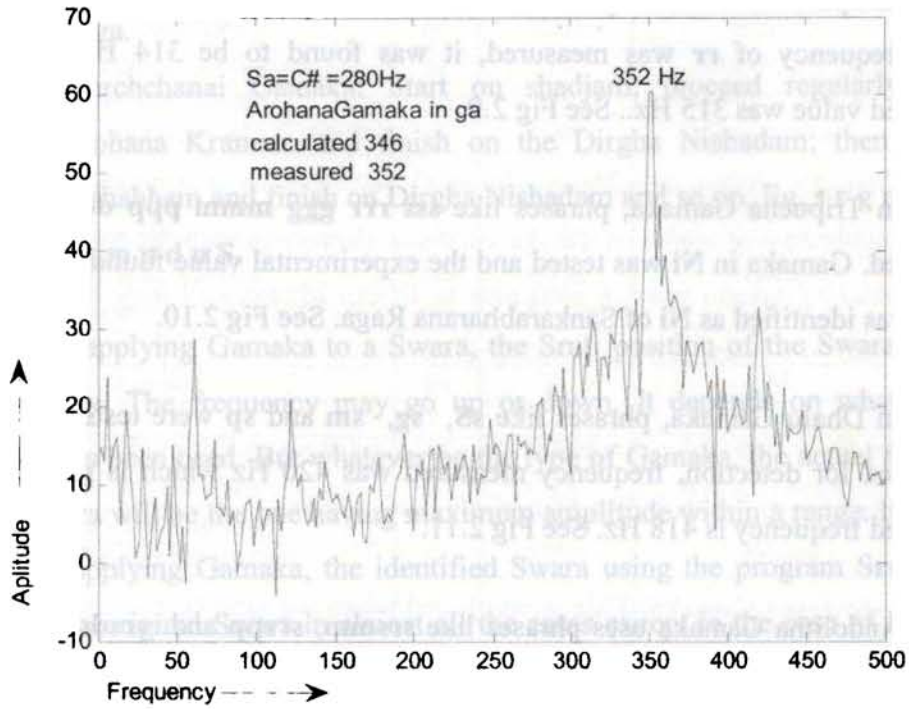

Fig 2.6 Frequency – Amplitude Graph of Swara **ga** after applying Arohana Gamaka

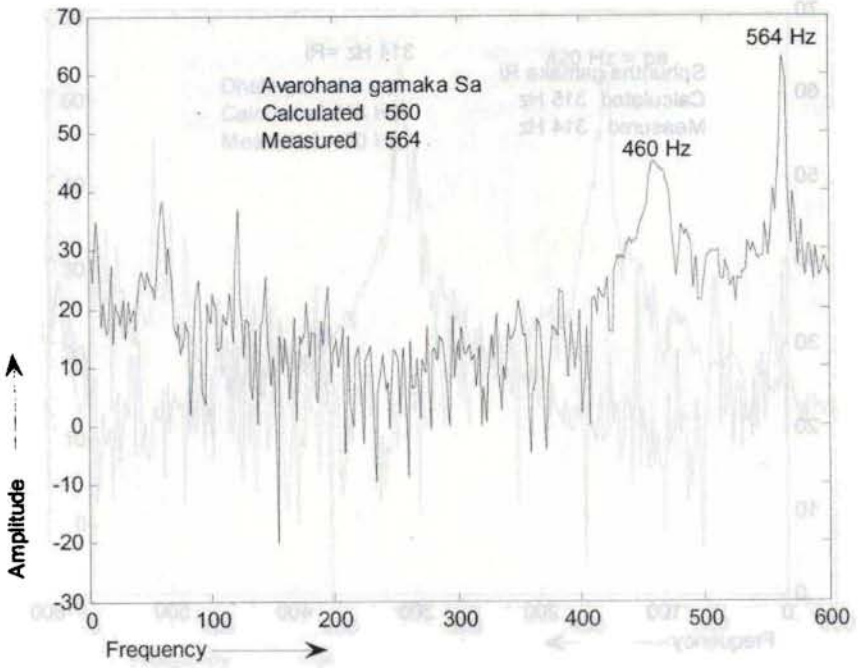

Fig 2.7 Graph shows Avarohana Gamaka

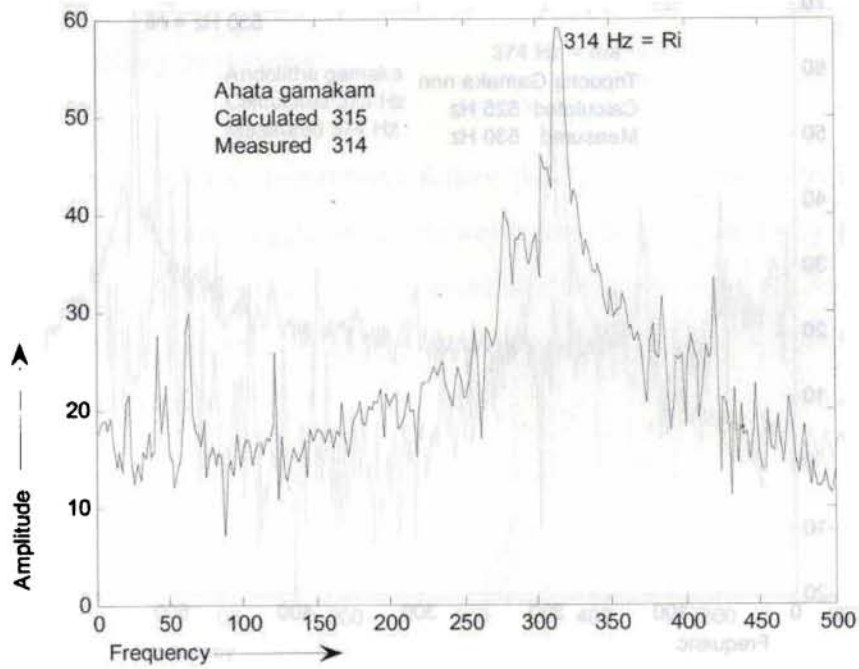

Fig 2.8 Graph shows Ahata Gamaka

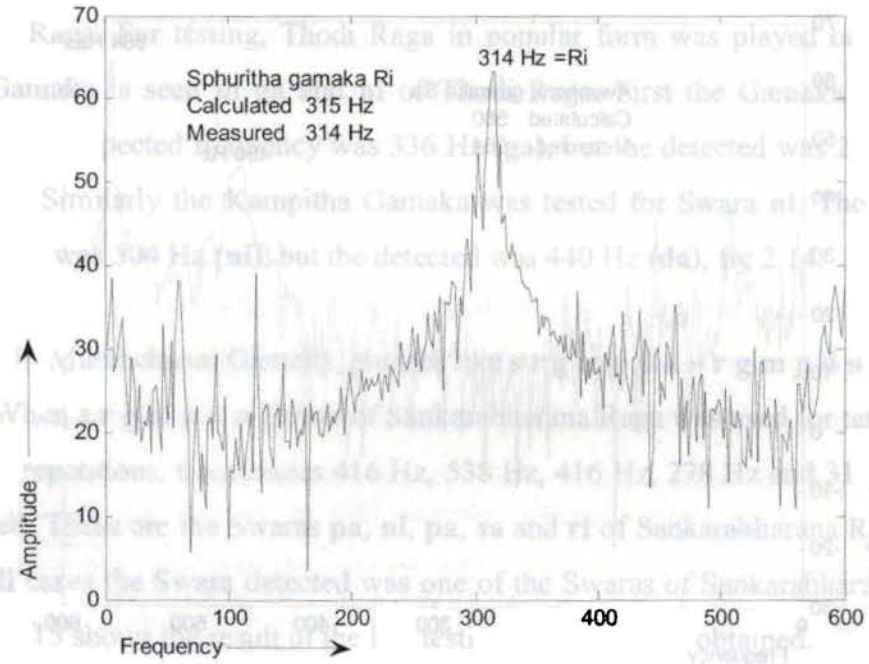

Fig 2.9 Graph shows Sphuritha Gamaka

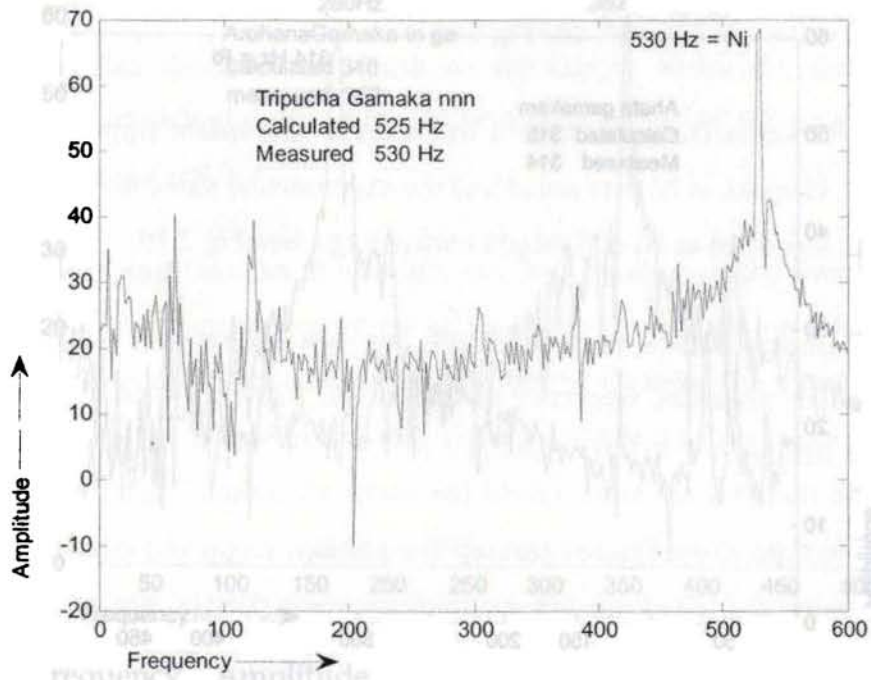

Fig 2.10 Graph showing Tripucha Gamaka

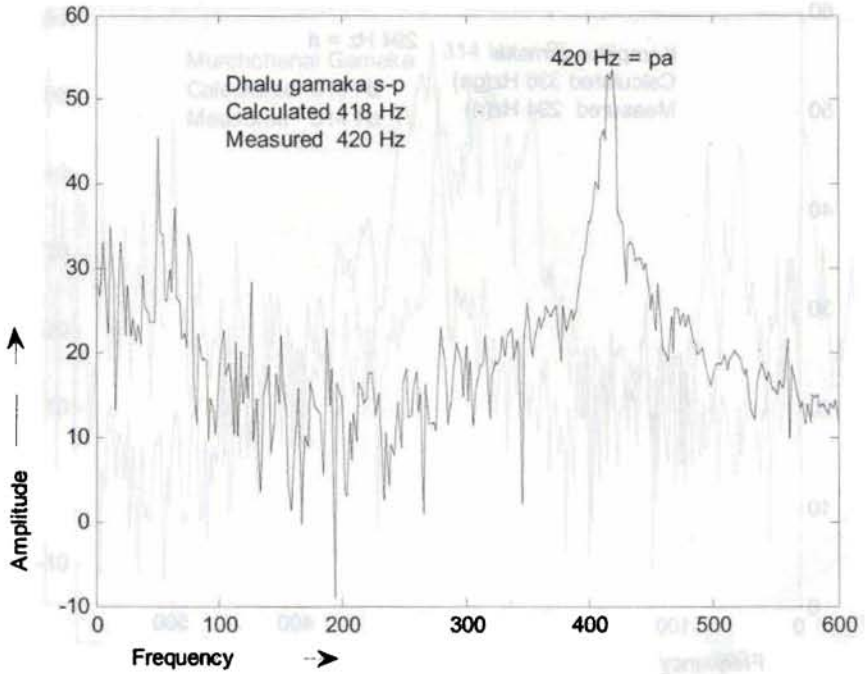

Fig 2.11 Graph showing Dhalu Gamaka

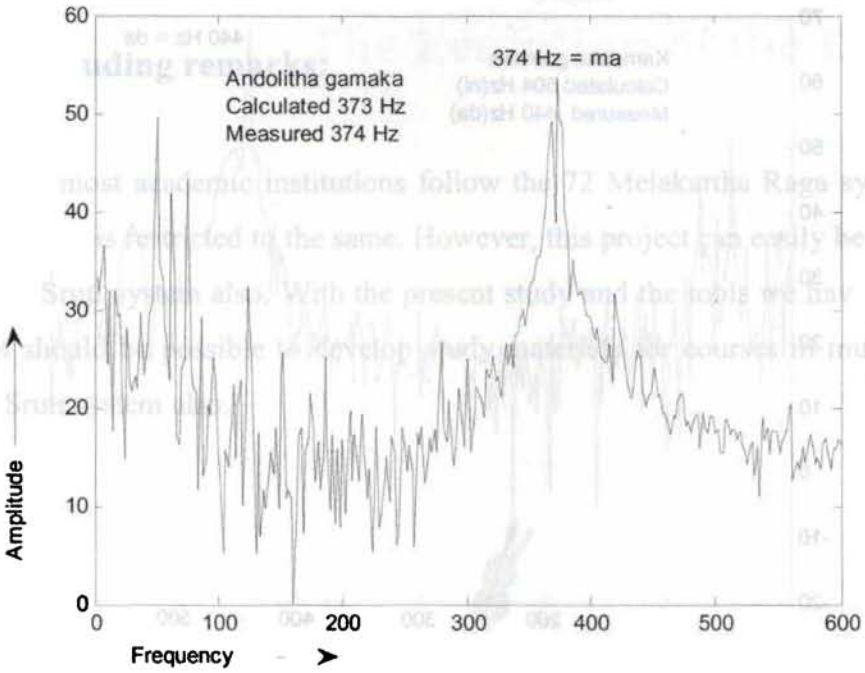

Fig 2.12 Graph shows Andolitha Gamaka

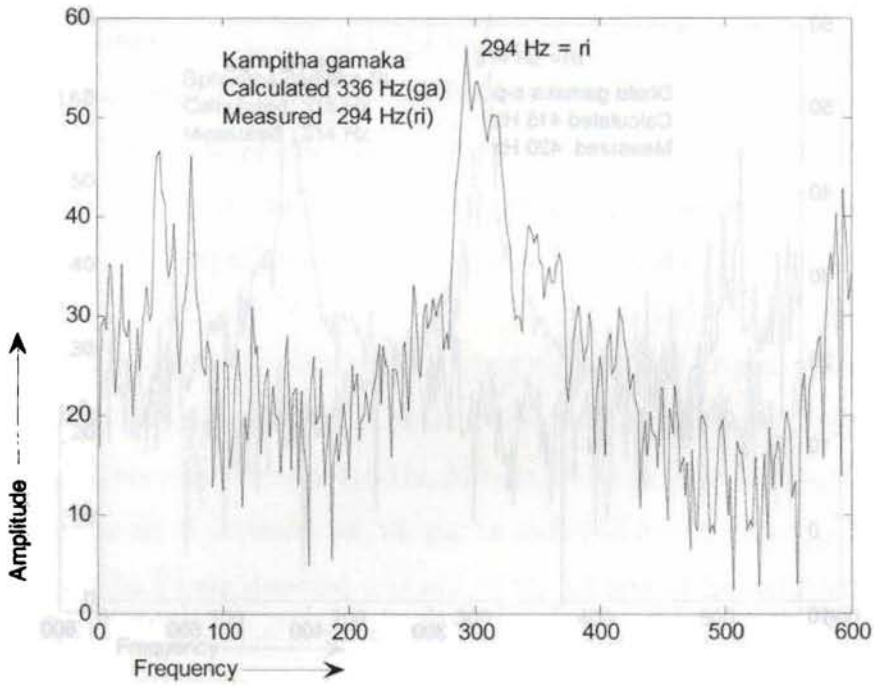

Fig 2.13 Graph shows Kampitha Gamaka applied to Swara **ga**

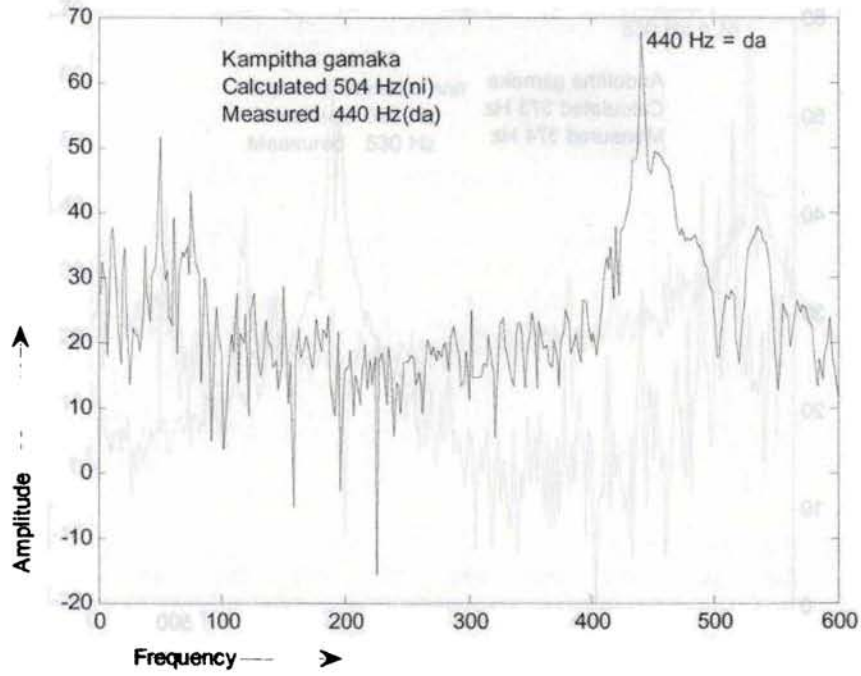

Fig 2.14 Graph shows Kampitha Gamaka applied to Swara **ni**

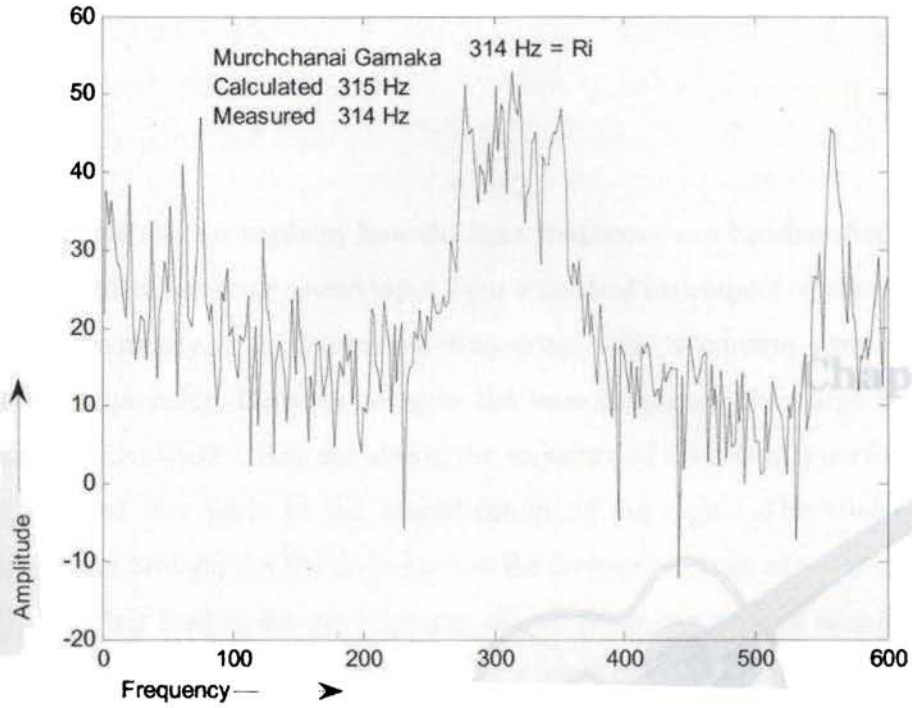

Fig 2.15 Graph explains Murchanai Gamaka

2.6 Concluding remarks:

As most academic institutions follow the 72 Melakartha Raga system, the present study is restricted to the same. However, this project can easily be extended to the 22 Sruti system also. With the present study and the tools we have come up with, it should be possible to develop study materials for courses in music under the 22 Sruti system also.