Sixth Raja Ramanna Memorial Lecture

12 September 2010

Science for Musical Excellence

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and

T Ramasami

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MD Naresh

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Dedicated to the previous scientific work on Mridangam by Sir CV Raman

Introduction

Mridangam is an ancient musical instrument of India with long tradition and history. Scientific aspects of "sound" from Mridangam were first investigated by Sir CV Raman.[1,2] There have been subsequent efforts to develop mathematical models for analyzing the harmonic vibrations of Mridangam by several other groups.[3-6] However, there has been no reported experimental study for the scientific dimensions of understanding "Naadham" and the melody of Mridangam. Such investigations do really need collaboration between exponents of Mridangam and those who are trained in the discipline of science.

Dr Umayalpuram Sivaraman, one of the co-authors of this work is a renowned artist. He posed a question as to whether standardization of techniques in the construction of the musical instrument using technological means is feasible. He wondered whether "Naadham" could be better understood using scientific principles even beyond those discovered already by CV Raman. He approached one of us (TR) in Central Leather Research Institute, Chennai for collaboration in science for musical excellence.

Dr Raja Ramanna was well known for his outstanding contributions to science. His mastery in music was also equally well known. He was a good piano player. When one of us (TR) was invited to deliver the Raja Ramanna memorial lecture, it was collectively decided that Sivaraman and Ramasami should deliver a joint lecture.

The work presented here is an outcome of joint research over a period of six years. Majority of the work has not yet been published and some aspects may have relevance for the creation of intellectual properties. Therefore, the work presented here is mostly to underscore the benefits of an ongoing collaboration between a scientific group and a performing artist.

Mridangam as a Musical Instrument

Mridangam is a percussion instrument built with an air column held within a confined wood construction. Parchments are employed for playing area. A black patch is applied on parchment made from goat skins for constructing the playing area. The instrument is built with an asymmetrical wooden structure and uses parchments made up of cow hides as well as strings made from buffalo hides, and special filling materials to be deployed in the annular space between parchment membranes. An exploded diagram of Mridangam and its components is shown in *Figure 1*.

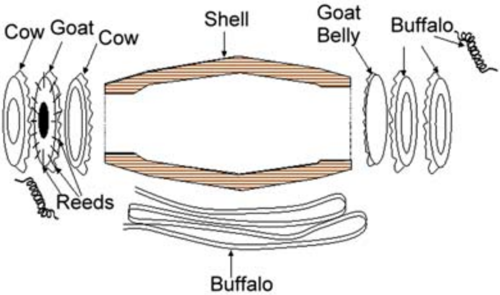

Figure 1: Exploded diagram of Mridangam

The playing area constructed with goat-based parchments, cow hide based parchment and buffalo hide derived strings employed for adjustment of tensions is depicted in *Figure 2*.

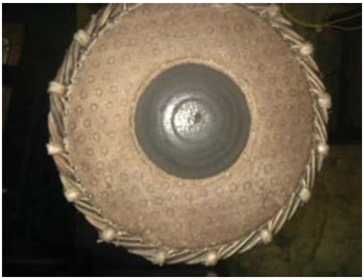

Figure 2: Playing area construction of Mridangam

In the preparation of black patches, inorganic fillers and selected adhesives are used. Sand is often the most used inorganic filler. Application of black patch material is based on subjective assessment of “Naadham” as decided by the performing artists.

Raman has investigated Mridangam as a sonic device. He discovered that a) the frequencies produced by a uniform circular membrane are not harmonic, b) application of central black patch in Indian drums produce harmonic overtones and c) the first 9 natural modes of vibrations are adjusted to produce 5 harmonics after taking into account the degeneracy of some harmonic vibrations.

Acoustics of Mridangam is derived from the structure of the conical air column with varying dimensions as shown in *Figure 3* for a 24" column device.

There are different sizes of Mridangam. The tonal qualities of the instrument vary significantly with the manner in which the device is constructed by the artisan.

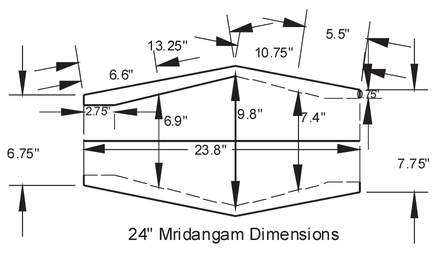

Figure 3: Structure of the conical air column for 24" Mridangam

Current methodologies adopted do not lend themselves to standardization of the tonal outcome of the instrument by the same artisan. There is a need to develop scientific techniques for assisting a performing artist to seek further excellence while playing an instrument made using standardized methods.

There have been questions as to whether source of materials employed in preparing the black patches altered the musical outcome of the instrument. Variations of "Naadham" with the player as well as the playing instrument, and conditions have been investigated in this work.

Focus of the Present Study

The main focus of our work has been on seeking relationships between melodious outcome with materials, methods of fabrication and men of art using scientific tools.

Choice of Wood for building Conical Air Column

Four types of wood materials have been examined for building the air column needed for Mridangam in this work. They are a) jack wood, b) palmyrah, c) red sanders and d) *Siamese cassia*

Softness and other morphological properties of the wood employed have been investigated. Based on the results of the study, jack wood appears to be the wood of choice and it can be attributed to the physical and other morphological properties. It seems now possible to define standard criteria required in the selection of wood for constructing a good quality Mridangam. They are a) low density b) medium hardness for machining, c) good Sound Radiation Coefficient (SRC) and d) resistance to decay. Values typical to Jack wood are density 0.61 g/cc and SRC in the range of 4.7+1.0. There is an apparent correlation between density and hardness as assessed by the load in kilograms required to sink 5 mm diameter hemi-sphere to a depth of 2.5 mm. Sound propagation characteristics seem to play an integral part of the choice of wood for the four materials assessed for the resonator column.

Why Goat-based parchment?

Morphological aspects of parchments from skins of various animals have been investigated. Skin fibers are made up of collagen, connective tissue protein. The histological properties of skin like, angle of weave, angle of run and thickness of fiber bundles bear signatures of the types of animals from which the skin is obtained. It is also known that conjugation with carbohydrates influences the fiber packing in animals.[7]

The average diameter of fibre bundles of cow-based parchments are generally higher (85 microns) compared to those of goat (~25 microns) as shown in *Figure 4a &b*.

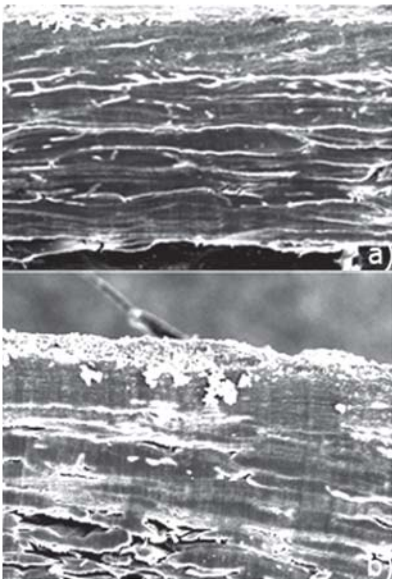

Figure 4 (a): Cow-based parchment 700+150 micron thick (150x);
(b) Goat-based parchment at 380+110 micron thick (250x)

Final thickness of the parchment used seems to influence the musical outcome significantly. The lower the thickness of the membrane, the better seems to be the tonal outcome from Mridangam. Goat skin offers highest strength for a given thickness. Further morphologically, the goat skin provides the highest compaction and tensile strength. There appear to be some special roles for goat-based materials.

Parchments made up from native skins without subjecting the material to liming are used for construction of Mridangam conventionally. Parchments can also be made after subjecting skin to a treatment with lime. Such a treatment is known to remove proteoglycan and lipids.[8]

The present study reveals that parchments made from limed goat skins in general and goat of Kolkata or Bengal origin provide the best musical outcome.

Application of Black Patch Materials

Sonic outcome of applications of various layers of black patches on goat parchments has been examined systematically using Fast Fourier Transform (FFT) analysis. Black patch materials have been applied over the same area. FFT data compiled for multiple applications of layers of black patches have been compiled and presented in *Figure 5a and 5b.*

The tonal outcome of the black patches is known to vary with the number of layers of black patch materials applied. Artisans making Mridangam apply multi layers of black patch materials until they are able to obtain desirable sonic properties as assessed by subjective methods.

Various Mridangam artists further adjust the optimal application of black patch materials to fine tune "Naadham". An attempt has been made to explore as to whether the optimization of black materials is feasible based on objective tools and FFT techniques.

Particle size, composition and constitution of black patch materials and the specific role of micro constituents have been examined. Optimum size ranges of particles (50 - 150m) have been recognized.

Application Black Patch and Tuning of Mridangam

FFT analysis of Dheem (fundamental) 01, Chappu (2^{nd} harmonic) 11, and Num/Meetu (3^{rd} harmonic) 21 modes has been made. With applications of black patch materials and increase in surface density, the frequencies of various strokes seem to decrease. The ratio between the frequencies of the Meetu and Chappu strokes (2nd to third harmonics) is optimized at about 1.5. Oscillations of ratio of Meetu to Chappu with application of black patch materials are as shown in *Figure 6a.* The ratio seems to start at about 1. 38 and settle to 1.5. Ratio between frequencies of Dheem and Chappu varies with the application of black patch materials starting from 0.66 and stabilizing at 0.535 as shown in *Figure 6b.* Application of black patch materials seems to be better optimized by analyzing the frequency ratios of Meetu to Chappu and Dheem to Chappu at about 1.5 and 0.535, respectively using FFT techniques. If Dheem represented the fundamental, ideally ratio of Dheem to Chappu should have been 0.5. This merits further comment.

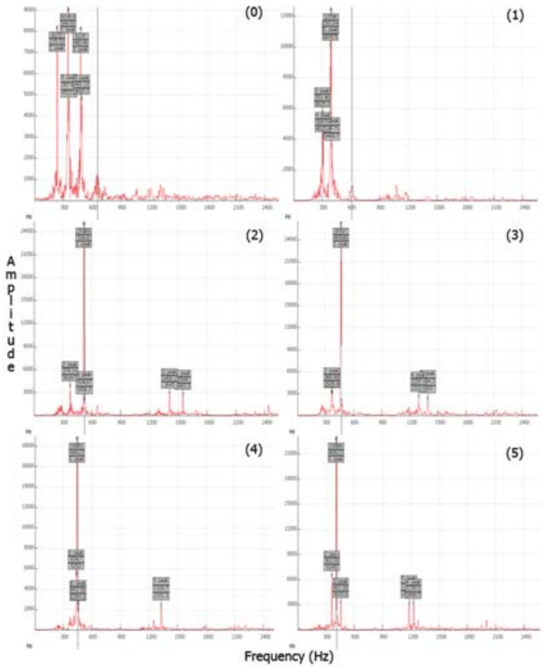

Figure 5a: FFT assessment of outcome of Chappu stroke for 0-5 layers of sequential application of black patch materials

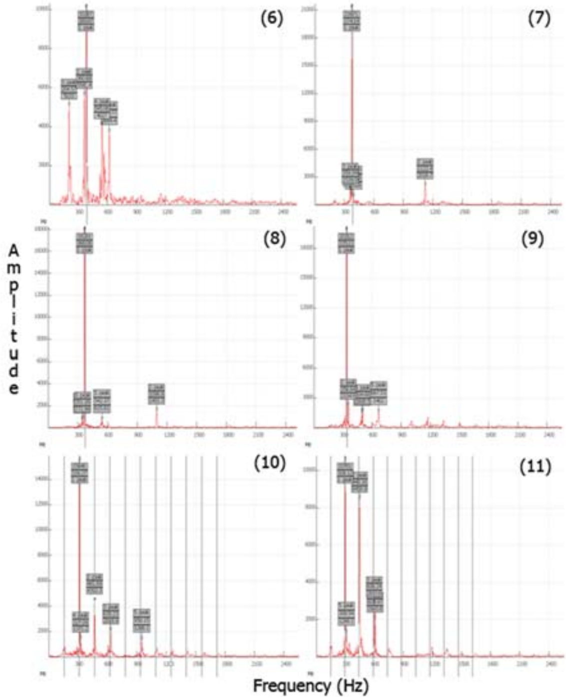

Figure 5b: FFT assessment of outcome of Chappu stroke for 6-11 layers of sequential application of black patch materials

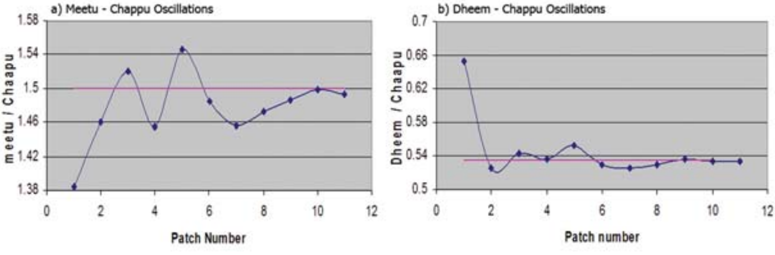

Figure 6: Ratio of oscillations

Studies on choice of materials for filling the annular space

In Mridangam, annular space between the membranes is filled with sticks, powders and several other materials which are perhaps capable of dampening the an-harmonic vibrations. Different materials with proclivity for such dampening have been investigated and some special materials have been identified. They are under further scrutiny for consistency of results for various artists.

Analysis of fundamental frequencies and their harmonics

Fundamental frequencies relevant to 24, 23 and 22" air columns have been analyzed in this study. The fundamental and harmonic frequencies are presented in *Figure 7.*

The fundamental frequencies for open / closed end air column resonators are 276, 292 and 305 Hz. for 24", 23" and 22" columns respectively. However, 138, 148, and 152 Hz. are the fundamental frequencies for 24", 23" and 22" for one end closed air column resonators respectively.

While the open/closed air column resonators produce all harmonics, only the odd ones are observed for one end closed air column. The barrel shaped Mridangam follows the latter for its low fundamental frequency but manages to support all harmonics.

Understanding of Various Mridangam Strokes through FFT techniques

Dheem Stroke: FFT analysis of has been made for analyzing the tonal outcome of Dheem stroke. The prominent fundamental vibration has been mapped (*Figure 8a and 8b).*The prominent peaks are at 146 and 410 Hz. Most Mridangam artists tune their instruments to 2nd harmonics at ~275 Hz. In other words, the fundamental frequency can be computed to be about 137.5 Hz. The fundamental for 24" one end closed air column resonator is at 138 Hz.

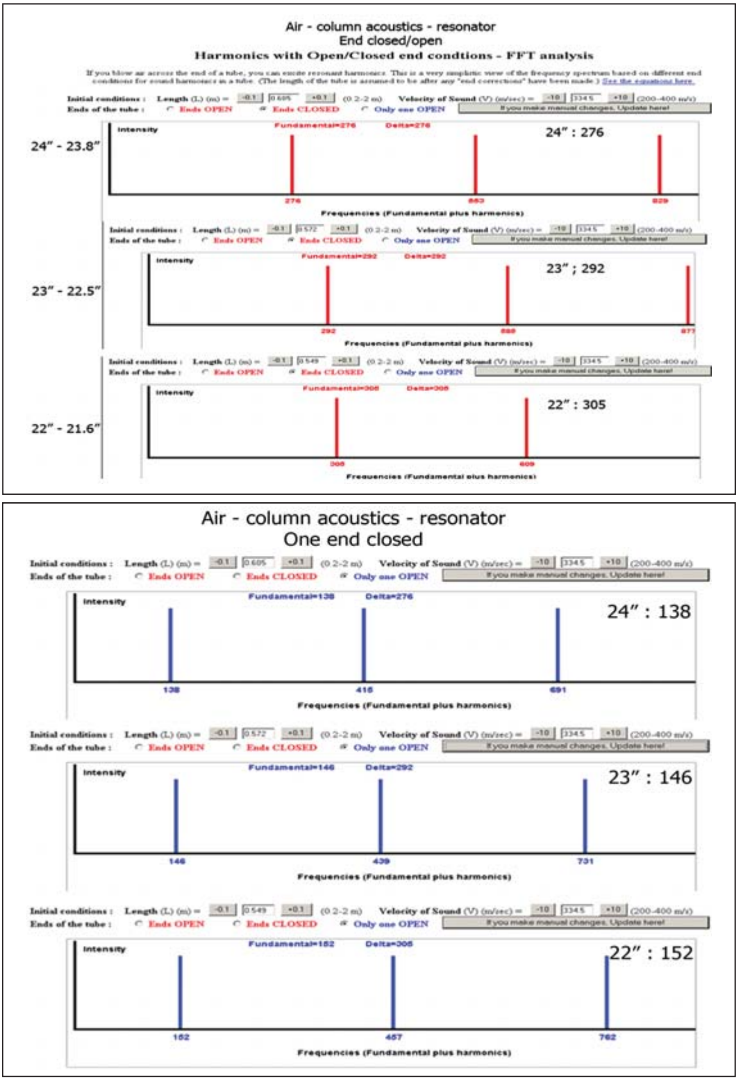

Figure 7: Fundamental frequencies relevant to
24, 23 and 22" air columns

The prominent peak of Dheem is at 146 Hz which is 1.07 times that of the fundamental (1st harmonic) for 24" one end closed air column resonator. The Dheem stroke represents 1.07 of the fundamental and this explains the ratio of Dheem to Chappu being 0.535 instead of 0.5.

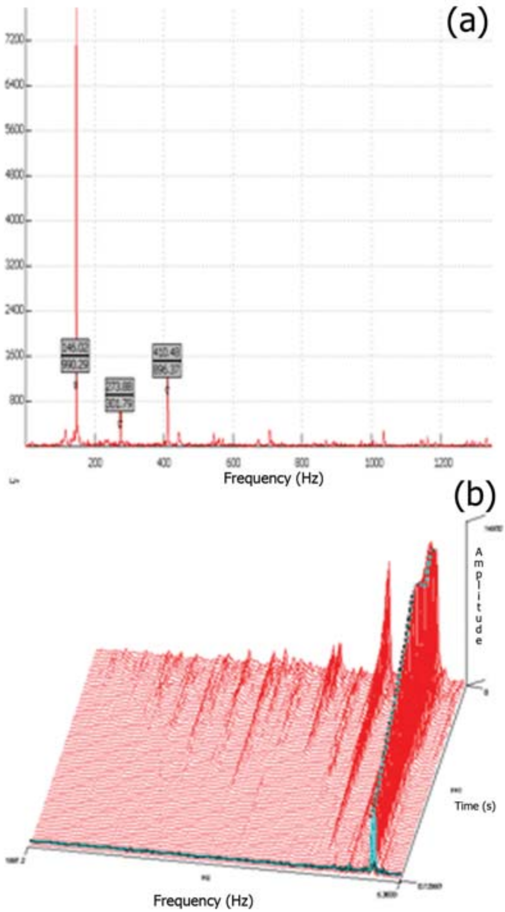

Figure 8: a) FFT analysis and b) Time-FFT plot for prominent fundamental vibration of Dheem stroke

Chappu Stroke: FFT analysis has been carried out for the tonal outcome for the Chappu stroke created by Sri Sivaraman. The prominent second harmonic vibrations have been mapped. (*Figure 9a and 9b*). Frequencies of prominent peaks for Chappu stroke are at 275 and 1100 Hz.

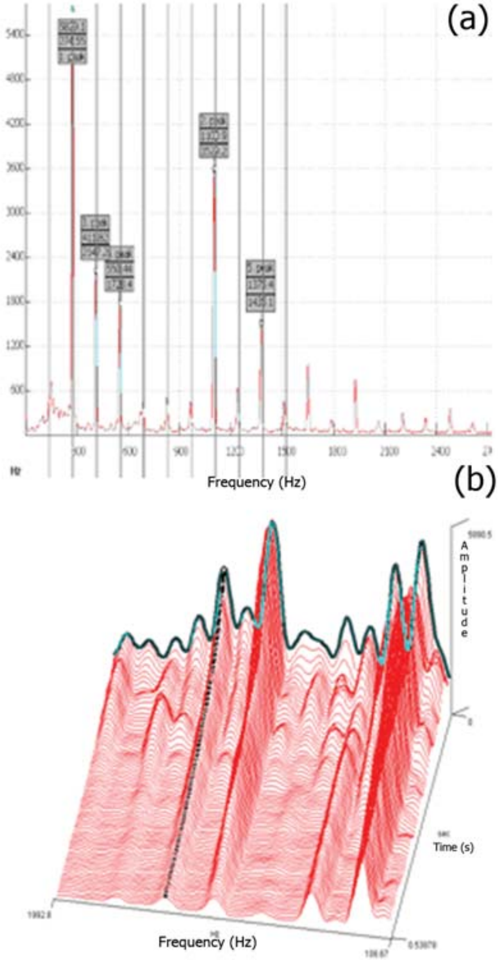

Figure 9: a) FFT analysis and b) Time -FFT plot for prominent fundamental vibration of Chappu stroke

Meetu Stroke: FFT analysis has been carried out for the tonal outcome of the Meetu created by Sri Sivaraman. The prominent third harmonic vibration has been mapped in *Figure 10a and 10b*. Frequency of the most prominent peak for Meetu stroke is at 410 Hz, which is 1.5 times the tuned second harmonic at 275 Hz.

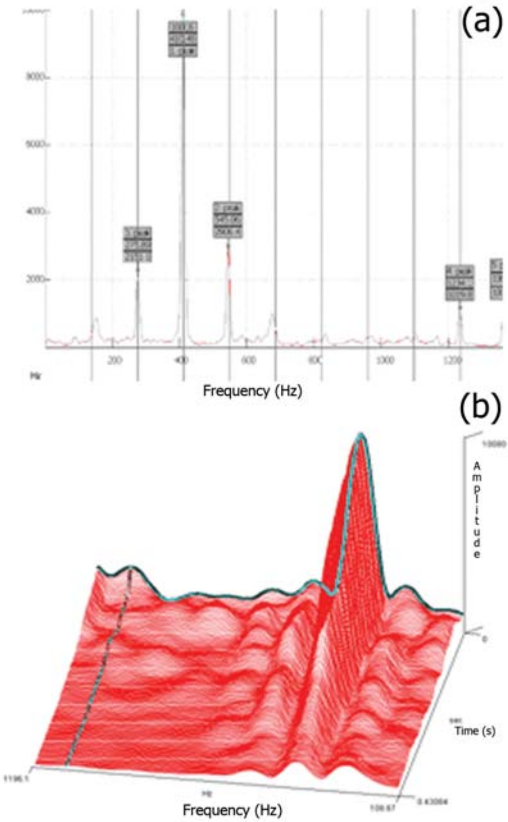

Figure 10: a) FFT analysis and b) Time-FFT plot for prominent fundamental vibration of Meetu stroke

Arechappu Stroke: FFT analysis has been carried out for the tonal outcome of the arechapu stroke created by Sri Sivaraman. The prominent fourth harmonic vibration has been mapped. (*Figure 11a and 11b*). Frequencies of prominent peaks for Arechappu strokes are at 275, 550 and 1100 Hz. Arechappu character of the stroke is typical of 2^{nd}, 4^{th} and 8^{th} harmonic frequencies.

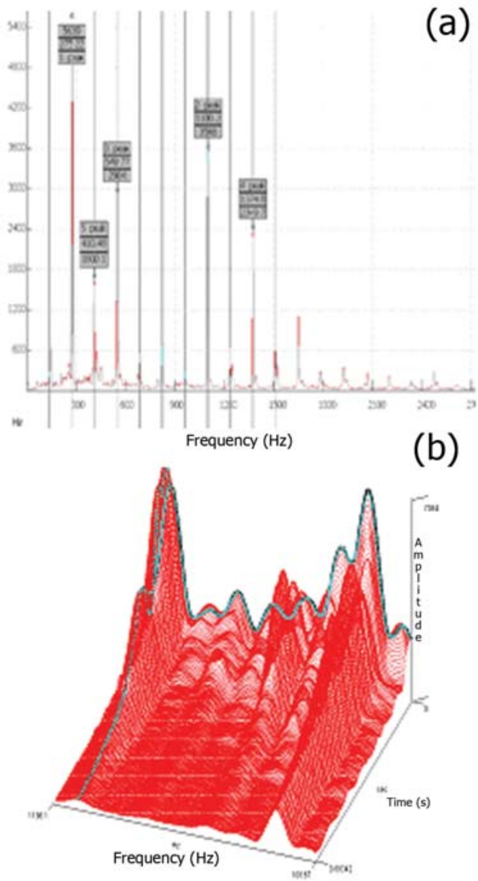

Figure 11: a) FFT analysis and b) Time-FFT plot for prominent fundamental vibration of Arechappu stroke

Observed Harmonic Sequences of Different Strokes of Mridangam

The main strokes of musical value are apparently Dheem, Chappu, Meetu and Arechappu. The prominent peaks for these strokes form 1.07, 2nd, 3rd and 4th harmonic frequencies, respectively. Musicians seem to tune their instrument to the 2nd harmonics, Chappu stroke. These raise some fundamental questions of relevance to musicians.

Time Decay Profiles of various strokes

Time decay profiles of prominent peaks of each stroke have now been analyzed systematically. Decay profiles of each harmonics in Chaapu stroke vary as shown in *Figure 12.* The fourth harmonic vibration at 550 Hz decays fast. The Chappu (2nd harmonic) vibration at 270 Hz displays a long induction phase before decay. This could well form finger print of different Mridangam players. It appears that such tools could be used to train artists in playing different strokes.

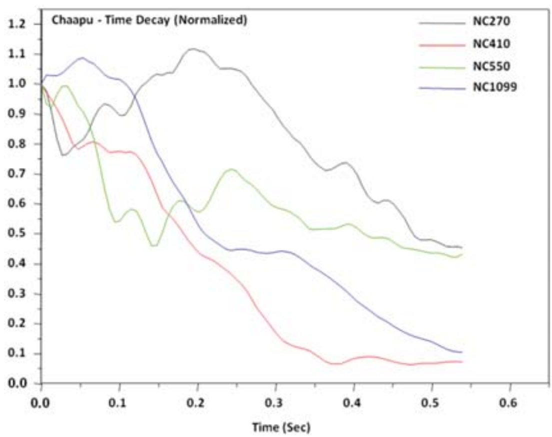

Figure 12: Decay profile for Chaapu

"Naadham" or Tonal Quality

The artistic excellence of each Mridangam player is expected to vary. Musical excellence of artists being different, it may not be correct to standardize music. However, an attempt has now been made to finger print the FFT profiles of various artists playing the Chappu stroke (*Figure 13a and 13b)*.

Some indicative examples of FFT profiles of Chappu stroke are presented here more as evidence. No analysis has been made and no inference would be drawn therefore.

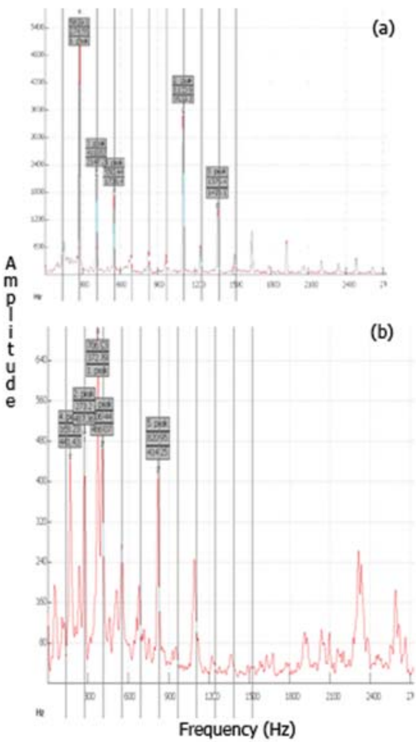

Figure 13: FFT profile of Chappu stroke of (a) Sri Sivaraman and (b) unnamed artist

The prominent peaks in Sri Sivaraman's stroke are 274.6 Hz with amplitude of 5829 units and second peak at 1100 Hz with amplitude of 3529 units, respectively. Harmonicity with high signal to noise ratios is evident with periodicities of 275, 410, 550 and 1100 Hz peaks being prominent.

The prominent peaks are at 168, 273, 372, 406 and 820 Hz with amplitudes of 441, 487, 706, 466 and 414 units, respectively for the unnamed artist.

It does seem possible that FFT analysis enabled teaching and practicing methods could be developed based on the finger printing technique developed in this work.

Designing transport friendly Mridangam

Scientific approaches have been taken to design and develop Mridangam which are transport friendly and could be dis-assembled and assembled at will without loss of tonal outcome. These design innovations will be revealed at appropriate times after standardization of results.

General discussion on science for musical excellence

The present investigation has focused essentially on scientific methods and tools useful for design and development of Mridangams. As the study progressed, several new questions emerged. Originally, the assistive role of science in standardization of fabrication methodologies alone was raised and examined. There are deeper questions currently.

Mridangam artists employ 35 thalas as shown in *Table 1* below. They recognize as many as 14 prime numbers among them. Although in our work Mridangam was perceived only as a sonic device bearing an air column, understanding of “Naadham” through the tools of science of physics does not seem unrealistic today. Black patch is no longer a black box. It seems possible to standardize the constituents as well as composition for optimal tonal qualities. Understanding of the chemistry of black patch materials has made it possible even to develop white patch alternatives.

Table 1. Thalas and prime numbers involved

NAME	Form	3	4	5	7	9
Dhruva	IOII	11	14	17	23	29
Matya	IOI	8	10	12	16	20
Rupaka	OI	5	6	7	9	11
Jhampa	IUO	6	7	8	10	12
Triputa	IOO	7	8	9	11	13
Ata	IIOO	10	12	14	18	22
Eka	I	3	4	5	7	9

Where 1,3,4,5,7,9 denote form, Thisra, Chatusra, Khanta, Misra and Sankeerna, respectively.

Applications of materials science come handy in the selection of materials for filling the annular space and dampening and even controlling the an-harmonic vibrations. Choice of parchment and selection of animal breed for optimal tonal outcome has been possible based on analysis of morphology and histology of skin as a biomaterial. Applications of engineering and technology in designing a transport friendly Mridangam are round the corner.

“Naadham” of Mridangam is truly a musical outcome caused by a set of carefully created sound vibrations on human nervous system. Human auditory system has evolved over time with an ability to receive a finite number of harmonic vibrations within specified time intervals. Control on the various an-harmonic vibrations is evolved through forms of artistic practices. Our artists of excellence seem to have found these scientific facts, even ahead of scientists.

The most important question is whether it is possible to deploy scientific tools to augment the musical excellence of creative artists? The question is deep and answers at this time are not easy. There are people who may say that it is better to leave the creative art untouched by the logic of science. May be, there are some unexplored domains of knowledge, where cultures of both science and music could undergo fusion elevating the levels of excellence even "beyond Raman" in Mridangam.

It has now been possible based on this work to gather evidence that there are more than five harmonics in the tonal outcome of Mridangam. It has been possible to formulate some parameters like Sound Radiation Coefficient for the selection of wood. Properties required to match the goat parchment used for making black patches have been better understood. Tuning to the frequency ratios of Meetu to Chappu and Dheem to Chappu through finer adjustments of black patch material application seems realistic. Designing and construction of even a travel friendly Mridangam seems entirely plausible. All these findings, though not yet conclusive, are a result of fusion of two cultures attempted under this unusual collaboration.

Fusing Cultures of Excellence in Art and Science: Scope for New Models

It is well known that the culture of scientists of excellence is to a) measure, b) discover, c) standardize and d) calibrate.

On the other hand, the culture of artists of excellence is to a) Feel, b) Create, c) Differentiate and d) Set Standards.

A new paradigm of creating cultures of excellence by fusing the two domains of knowledge could be a) *Discover to create;* b) *Feel to measure,* c) *Differentiate to standardize* and d) *Set standards to calibrate.*

Concluding Remarks

The work is a culmination of collaboration between two streams of professionals who have been trained differently. In every sense of the word, this is an unusual synthesis of cultures. Music has remained sublime. Science for many in the society has been a concrete reality. Languages are different between those who practice science and those create musical excellence. This work has broken the barriers between the two knowledge domains. It does seem possible now to attempt the fusion of two cultures.

The world does seem ideal if only fusions of the kind attempted in this work are feasible. This is a beginning. We need to try further because there have been people before who have fused art and science.

Raja Ramanna is a shining example of one of them. Therefore, in honor of the man whom we remember through this work, let us hope that the first principle science of India will be able to assist the Indian musical instrument, Mridangam sing. Let the songs of Mridangam be heard worldwide and for long.

Acknowledgement

The experimental work is being carried out in Central Leather Research Institute, Chennai. The authors thank the Director, CLRI for his encouragement and help. The Mridangam designed and developed for the experiments were built by Sri Johnson, an artist who has practiced the profession of building Mridangam as a family profession. We thank him for protecting the profession itself and contributing to this work immensely. Sri Kalaiarasu, a retired employee of CLRI has participated in the development of transport friendly Mridangam. We thank him. Dr V. Arumugam and Dr R. Sanjeevi, retired scientists of CLRI have generously participated in the work. We thank them.

One of us (TR) thanks the Government of India. We thank the Director, National Institute of Advanced Studies for providing the first formal opportunity for the team to present the work through the public lecture named after "Raja Ramanna".

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Sri Umayalpuram K. Sivaraman

Sri Umayalpuram K. Sivaraman, the topmost mrudangam vidwan is the son of Dr P. Kasiviswanatha Iyer and Smt Kamalambal. Sri Sivaraman learnt this divine art under four great and illustrious masters: Sri Arupathi Natesa Iyer, Sri Tanjavoor Vaidyanatha Iyer, Sri Palghat Mani Iyer, Sri Kumbakonam Rangu Iyengar. As a boy of ten, Sivaraman had his 'arangetram' (first concert) and the debut was held in the precincts of Kalahastheeswaraswami temple in the temple town of Kumbakonam The pursuit of this art under the gurukula system for well over fifteen years did not deter him to qualify for law. He is a double graduate of The University of Madras (B.A., B.L.).

Besides his professional career, he had undertaken the very laudable task of doing original research in the art of mrudangam. He has introduced the fibre glass mrudangam to Carnatic music for the first time, improvised a mechanical jig to eliminate human error in the moulding of skins for both sides of the instrument

His new techniques, innovations and creative ability in accompaniment, solo renditions, and jugalbandhi programmes with his North Indian counterparts have earned him a special place in the world of art, worthy of emulation by other artists. Sri Sivaraman is a 'A' Top Grade artiste in All India Radio and Doordarshan Television. He was conferred the title of 'Sangeetha Kalanidhi' by the Music Academy, Madras, in 2001. Sri Sivaraman has been appointed as the Director for 'Tanjore Vaidyanatha Iyer School for Percussion' started by the Music Academy, Madras. He was awarded with the Padma Vibhushan, India's second highest civilian honor, on January 26, 2010and received Honorary Doctorate from University of Kerala in 2010.

Dr T Ramasami

Dr T Ramasami, currently Secretary to the Government of India, Department of Science and Technology, holds a Master's degree in Leather Technology from the University of Madras, India and PhD in Chemistry from the University of Leeds, UK. He has also worked on energy research in Ames Laboratory Iowa, USA and on electron transport phenomena in the Wayne State University, USA prior to returning to India for undertaking his scientific career. He joined the Central Leather Research Institute, Chennai as a scientist in 1984 and served as its Director for more than 10 years during the period up to May 2006. He is known among the scientific establishments in the country for his leadership to the Central

Leather Research Institute. The institution earned a global leadership status during his tenure as its Director as evidenced by the 30% global share of publications, >7% share of global patents, positions in fashion forecasting and the level of public-private partnership built in leather research.

Dr Ramasami has assumed the role of Secretary S&T in the Government of India since May 2006. He is currently engaged in the development of policies and programs for attraction of talents for study and careers with science, rejuvenation of research in universities, stepping up of international S&T cooperation, development of public-private partnerships in R&D sector and accountability of public funded research, development and demonstration. The Department of Science and Technology is aggressively engaged in the development of new models and mechanisms for enhancing the role of public funded institutions in innovations and research and development.

Dr Ramasami has a large number of publications in highly peer-valued journals and significant number of patents, which are under commercial exploitation. His research experience spans over several fields and areas in both basic and applied sciences. He has made some important contributions in the fields of inorganic chemistry as well as chemical and leather related technologies. His contributions to the understanding of the chemistry and applications of chromium as well as leather science and environment related technologies have earned him several professional recognitions in both India and abroad. These include Shanti Swarup Bhatnagar Prize for chemical sciences in 1993, election to all major science academies as a fellow as well the Third World Academy of Sciences and the National civilian award Padma Sri in 2001.

M. D. Naresh

Dr. M. D. Naresh, is the only son of renowned Music Director M.D. Parthasarathy of yesteryears at Gemini Studios, Madras. Having lost his father at a tender age of 9, he pursued academics at Loyola and Presidency colleges Madras. Joining CLRI in 1978 after completing masters in zoology, he got trained in microscopy. He did his doctoral thesis on the morphology and mechanical properties of fish skins. Most of his publications deal with structure property relationship of leather and allied materials with emphasis on developing objective methods to assess subjective properties. He is currently working as a scientist in the biophysics laboratory of CLRI.