||sūkṣhma||

The ISSS newsletter about Micro and Smart Systems in India

Vol. 9, No. 3-4; March 2016

Table of Contents

Published quarterly by the Institute of Smart Structures and Systems

Editor: Vidyashankar Buravalla

President's Message

Dear Members

Let me wish you all a very happy, healthy and productive year 2016. This is the 18th year since the formation of ISSS. It has been a very fruitful journey to the Society with the vision set by our founding President Dr V K Aatre and guided by all the subsequent Presidents of the Society. Since its formation, the Society along with the various National Programs has significantly contributed to the growth of Micro and Smart Systems area in this country.

The technology level in this area in the country has increased by leaps and bounds and today there a myriad of micro devices that are indigenously designed and fabricated in this country and ISSS has a major part to play in this effort. Some of the regular features that the members of the society enjoy include the regular News Letter Sukshma, the yearly National Conference across various parts of India, the tri-annual international conference normally held in Bangalore, and the Journal of ISSS, which is published bi-annually to propagate the awareness and growth of Micro and Smart Systems area in this country. In addition, over the years, the society has established Chapters in Coimbatore, Pune and more recently at Visakapatnam, which has helped bring awareness of this technology and bring the technical personnel working in this area together.

With my election as President of ISSS, a new look Governing Council (GC) of the Society, which is a blend of youth and experience, has taken over to run this society for the next two years. The new GC has initiated several new initiatives to take the Society to a new level. This is done by setting up several sub-committees to look into various aspects such as Membership drive, Standards, Outreach, Education, Newsletter, International relations, and Finance.

As a first initiative, ISSS will soon enter into an agreement with an international publisher Springer - McMillan to bring out the Journal of ISSS starting January 2017. This, we believe will not only bring enormous international visibility to the Society, but also elicit good papers from outside the country.

The next important aspect is the Membership drive. The goal of the society is to take the current number of life members from 800 to 3000 in the next two years. For the first time, the Society has setup a subcommittee to look at the various standards for micro devices.

We believe that these initiatives are necessary to make the Society more relevant to the current needs of the micro systems community. I hope the GC will have the support of all the members to these initiatives.

The GC is thankful to all our past presidents for their help in guiding the Society to what it is today. The GC in particular would like to thank our founding President Dr V K Aatre for setting the vision for the Society and guiding even today on various matters. Today, Microsystems in India is synonymous with Dr Aatre, thanks to his tireless efforts in propagating this technology in India. On behalf of ISSS and on my own personal behalf, the GC would like to congratulate Dr Aatre on his receiving Padma Vibushan Award from Government of India and ISSS would like to felicitate Dr Aatre for this great achievement on March 11, 2016 at Bharath Electronic Limited (BEL) Club, Bangalore.

I hope you will join us in felicitating our founding President and a great visionary.

S. Gopalakrishnan

Vol. 9, No. 3-4; March 2016

Some Design Insights into Micromachined Capacitive Accelerometers with Mechanical Amplification

G. K. Ananthasuresh
Professor, Mechanical Engineering,
Indian Institute of Science, Bengaluru
suresh@mecheng.iisc.ernet.in

Over the last decade, my students and I have gained some insights into designing micromachined accelerometers. In this article, I want to explain two of them. They are: (a) mechanical amplification helps improve the resolution of an accelerometer that uses capacitive sensing, and (b) the resolution and bandwidth, which are usually in conflict with each other, can both be improved using mechanical amplification. Well, these insights may not make immediate sense to all unless I explain in some detail. So, let us start at the very beginning, a good place to start.

Micromachined accelerometers are as old as the field of Micro-Electro-Mechanical Systems (MEMS). The presumably first micromachined silicon accelerometer was reported in a paper by L. M. Roylance and J. B. Angell in 1979. It was a very good paper that proposed the concept of piezoresistive sensor embedded in a silicon cantilever beam to which a proof-mass was attached. The paper was remarkable because it had dealt with the geometry of etching, anisotropic mechanical properties of single-crystal silicon, mechanics-based design, and electronic circuitry. After many more advances, commercialization of MEMS accelerometers began in late 1990s, the most notable being the ones used to deploy airbags in automobiles. Today, micromachined accelerometers are ubiquitous. They can be found in consumer products such as mobile phones and toys to state-of-the-art aerospace, automotive, and biomedical devices. For the MEMS field, accelerometers and pressure sensors are the flagship applications. Therefore, any academic institution engaged in the microsystems field ought to have its own accelerometer. So it seemed in 2004 when I joined IISc. The immediate question was: what new aspect do we bring to the table in a field as mature as micromachined accelerometers? Fortunately, we found our own niche early on and built on it over a decade in IISc. The key idea in our work is mechanical amplification. Let me explain how it came about.

One could buy MEMS accelerometers for less than Rs. 50 back in 2005. But such accelerometers had limited resolving capability. Such inexpensive accelerometers could resolve, and still do so even today, only 1/1000th of g, the acceleration due to gravity. Their bandwidth----the range of frequencies over which they perform well----is also quite limited, up to only kHz range. Indian Space Research organization (ISRO) needed ones that can resolve micro-g, i.e., millionth of g. Such high-resolution accelerometers existed in 2005 but their cost was exorbitant. I had real quotations from distributors that had put one accelerometer at about Rs. 32,000 to Rs. 1,03,000! I wondered why they are so expensive. It could be due to supply and demand. Who needs such high-resolution accelerometers, anyway? Defence and aero-space people. A more important question was: what exactly did those accelerometers have that the cheap ones do not? This got us thinking about the factors that control the resolving ability and bandwidth of an accelerometer.

Accelerometer 101: back to basics. An accelerometer in its simplest abstract avatar is a mass attached to a spring. Acceleration creates force on the mass. The spring restrains the displacement of the mass. The displacement can be measured and correlated to acceleration. At steady state, the displacement is proportional to the ratio of the mass to the spring constant. In symbols, we have

$$\text{Displacement} = \text{U} = \frac{\text{mass} \times \text{acceleration}}{\text{spring constant}} = \frac{m}{k} a$$

The larger the mass and the smaller the spring constant, the more the displacement. Large displacement increases the sensitivity of an accelerometer. But then, there is the opposite effect on the natural frequency. Since, the more sensitive an accelerometer is the less will be its operational bandwidth. There is thus a tradeoff between sensitivity and bandwidth. In 2007, we placed some commercially available accelerometers in a plot of sensitivity vs. bandwidth and found that this logic generally holds. Sensitivity is simply a characteristic of the sensor element. For a capacitive accelerometer, it is V/g, i.e., the voltage you see at the output for unit acceleration. What parameters of a capacitive accelerometer influence its sensitivity? To understand this, we need to consider a little formula:

$$\frac{\Delta V_{\text{out}}}{g} = K\left(\frac{\Delta C}{g}\right) = K\left(\frac{2uC_{\text{base}}}{gd_0}\right)$$

Where V_{out} is the change in voltage, C the change in capacitance, K the circuit gain, d_0 the spacing between capacitive comb-fingers that sense the displacement, C_{base} the base capacitance, and u the displacement of the sensing comb-finger. One can do the following to increase the sensitivity.

- Increase circuit gain with customized electronics (has been done; increases cost)
- Increase U by making the mass large and spring constant small (has been done; reduces bandwidth, fabrication is complicated, out-of-plane stiffness is compromised)
- Increase C_{base} by packing a lot of sensing fingers (has been done; increases the size on the wafer adding to the cost)
- Decrease d_0 (has been done; burden on fabrication accompanied by rise in cost)

All these were tried and tested by others by 2005. "What new is there to do?" we wondered. We thought we will use our bag of mechanical tricks and increase U more than the other designs had by using mechanical amplification. This was met with the usual skepticism initially because it was thought that circuit gain takes care of any amplification that is required. "Why bother with mechanical amplification?" we were asked. Soon we found a reason to argue in favour of mechanical amplification. To understand this, we need to talk about resolution and noise.

Resolution, unlike sensitivity, involves noise too. A noisy sensor element is no good even if it is highly sensitive. In order to detect millionth of g, we need to be able to see it amidst noise. So, we need signal conditioning, which brings in electronic circuitry.

Then there comes noise associated with the electronics circuitry. Figure 1a shows this scenario by showing an accelerometer as a device with its sensor element and electronics circuitry on a printed circuit board (PCB). Its schematic in Fig. 1b shows the sources of noise.

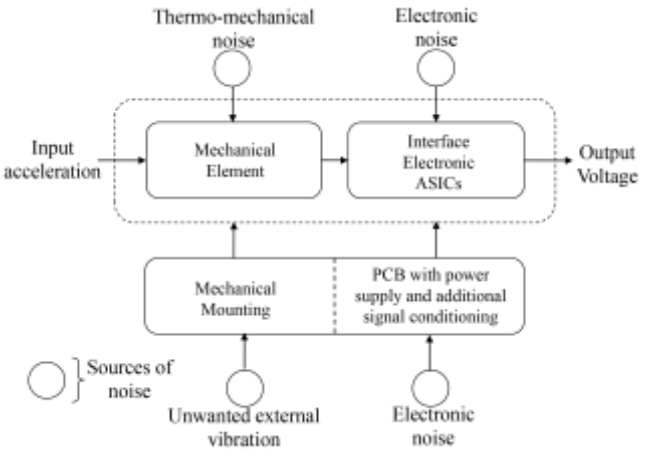


Figure 1 (a) A packaged MEMS accelerometer device (b) schematic with noise sources

The mechanical sensor element has Brownian noise. The air molecules that collide with the proof-mass will be constantly applying some force on it, ever so little but not quite negligible. Consequently, the mass keeps moving even in the absence of external acceleration. This Brownian Noise-Equivalent Acceleration (BNEA) is known to be around 100 ng/root Hz. Then there is noise in the electronic circuity. The noise sources in electronic elements are many: Johnson noise, 1/f noise, shot noise, generation and recombination noise, external interference noise, etc.

The Capacitive Noise-Equivalent Acceleration (CNEA) is known to be about 10 μg/rootHz. Now, referring to Fig. 2, let us see what happens when the effect of acceleration signal is amplified mechanically and electronically. Let us not forget that when the signal is amplified, noise too gets amplified along with the signal.

By assuming that the amplification factor is the same, say, in mechanical and electronic signals, SNR, the signal-to-noise ratio in the two cases will be

$$SNR_{mech} = \frac{Aa}{A \times BNEA + CNEA}$$

and

$$SNR_{elec} = \frac{Aa}{BNEA + A \times CNEA}$$

Clearly, we get larger SNR with mechanical amplification as compared to electronic amplification. So, we found our premise to attempt mechanical amplification. This happened back in 2006 when my MSc (Engg.) student, Girish Krishnan (now an Assistant Professor at UIUC, USA) wrote his thesis. His work sowed the seeds for mechanical amplification using what we christened Displacement-amplifying Compliant Mechanisms (DaCMs).

A DaCM is free from joints. It is an elastically flexible single body that has distributed compliance. See Fig. 2. Distributed compliance means that the elastic deformation is not limited to a few narrow flexures such as the ones found in plastic hinges we find in household lids. As opposed to them, in Fig. 2, we see that there are beam segments that deform fully. Therefore, the elastic deformation is distributed in them. Such designs have reduced stress for the same displacement.

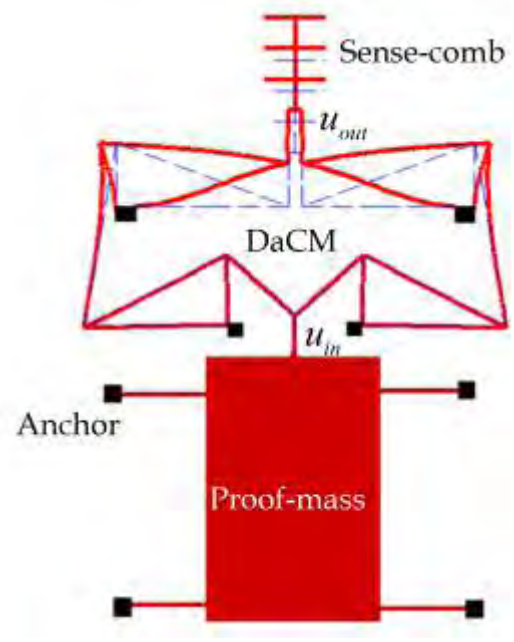


Fig. 2 A Displacement-amplification Compliant Mechanism (DaCM) appended to a regular accelerometer (blue is deformed; one may note how much more the output of the DaCM is moving while we hardly see any movement of the proof-mass.

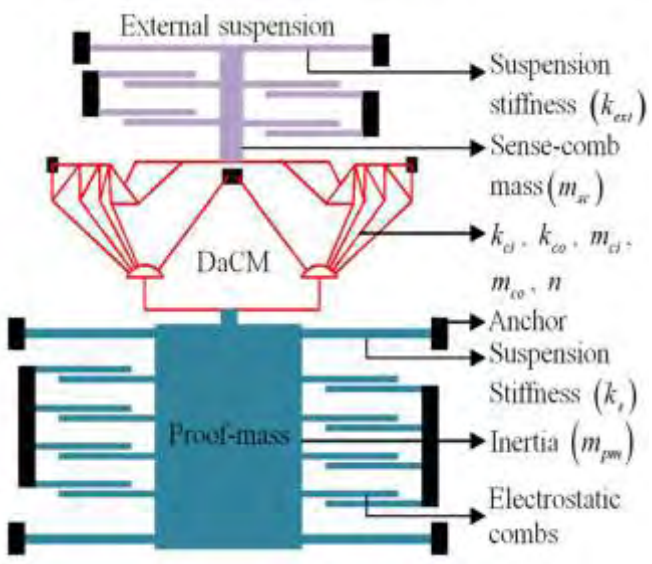
As can be seen in Fig. 2, the output point of the DaCM moves a lot more than the proof-mass. So, we attach sensing comb to the output of the DaCM instead of the proof-mass. When we use the differential capacitance principle, we know that the change in capacitance is proportional to the displacement of the sensing comb fingers. As we have increased displacement, we have enhanced change in capacitance. This is the simple idea of enhancing the sensitivity of an accelerometer with mechanical amplification.

Later, Sudarshan Hegde (now working for Bosch-Bengaluru in the electronic testing division) in his PhD thesis in my group, developed a new method to design compliant mechanisms by modeling them as a lumped parameter models called spring-lever (SL) model for statics and spring-mass-level (SML) model for dynamics. He took up accelerometer design as a case-study. Actual implementation of a DaCM into a micromachined accelerometer happened in the PhD thesis of Sambuddha Khan (now, a post-doc at UC-Irvine with a group well known for inertial sensors). Sambuddha took this work all the way to a packaged sensor for the single-axis, dual-axis, and tri-axial applications.

At this point, the reader should be convinced about the first insight mentioned at the beginning. Let us now understand the second insight. Let us dive into some details to understand this part.

In Girish Krishnan's MSc thesis, and later in Sudarshan Hegde's PhD thesis, we viewed a DaCM as a lever with a spring, as depicted in Fig. 3a. One can see the similarity between the model and the real device shown in Fig. 3b. The abstracted lumped model of an accelerometer with a DaCM has two degrees of freedom. Using this model, Sambudhha Khan, in his PhD thesis, defined net amplification so that apples and oranges can be compared fairly. Let apples be accelerometers without a DaCM and oranges be those with a DaCM. The net amplification NA is defined as when the two accelerometers with and without DaCM occupy the same area on the chip and have the same thickness. The challenge in designing the accelerometer with a DaCM is to make NA as large as possible.

$$NA = \frac{\text{displacement at the output of the DaCM when it is attached to the proof-mass}}{\text{displacement of the proof-mass when there is no DaCM}}$$



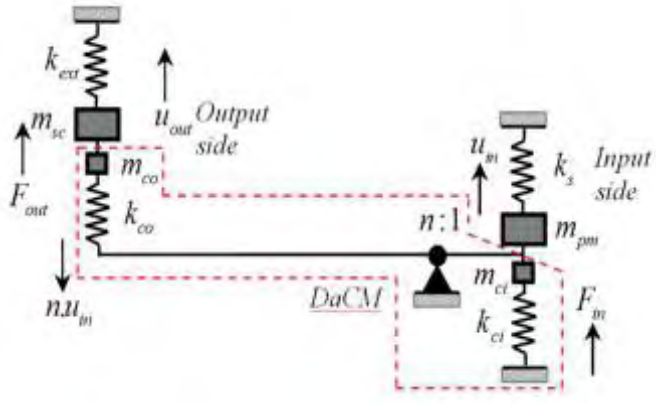


Figure 3. (a) An accelerometer with a DaCM, (b) its abstract lumped model

Then there is the natural frequency that decides the bandwidth of the accelerometer. The spring-mass-lever model helps us get a formula for the first two natural frequencies. Sambuddha Khan's PhD thesis showed that the five parameters of the spring-lever-model can be obtained to accurately predict the natural frequencies of the actual device.

$$f_0 = \frac{1}{2\sqrt{2}\pi}\sqrt{(\alpha+\beta)-\sqrt{((\alpha-\beta)^2+\gamma)}}$$

where $\alpha = \dfrac{(k_{ci}+k_s+n^2k_{co})}{(m_{ci}+m_{pm})}$; $\beta = \dfrac{(k_{co}+k_{ext})}{(m_{co}+m_{sc})}$;

and $\gamma = \dfrac{4n^2k_{co}^2}{(m_{ci}+m_{pm})(m_{co}+m_{sc})}$

the parameters in which are defined in Fig. 3b.

The analytical formula of the natural frequency told us that NA and natural frequency can both be increased at the same by choosing the model parameters correctly. From this lumped model, we went on to design the complete geometry of the DaCM, the suspensions, and the proof-mass. Details are many and they are described in our publications.

In order to convince that mechanical amplification improves the sensitivity and bandwidth, Smauddha Khan took the best accelerometers from the literature and re-designed them by incorporating a DaCM within the same foot-print. We used the following figure of merit by combining the displacement of the sensing combs (i.e., u) per unit acceleration and the natural frequency (f_o) as

$$\text{Figure of Merit} = \text{FoM} = 4\pi^2\frac{u}{g}f_0^2$$

so that the original accelerometers and our re-designed ones can be compared. As anticipated, re-designed ones fared much better.

Let us consider an example. Take a look at Fig. 4 that compares two accelerometer designs. They both occupy the same area. One does not have a DaCM while the other does. The one without the DaCM has a large proof-mass.

Hence, its mass can experience more force for the same acceleration and produce larger displacement. But the one with the DaCM, despite its smaller proof-mass, wins. This is because it takes the smaller force experienced by the proof-mass and amplifies the displacement.

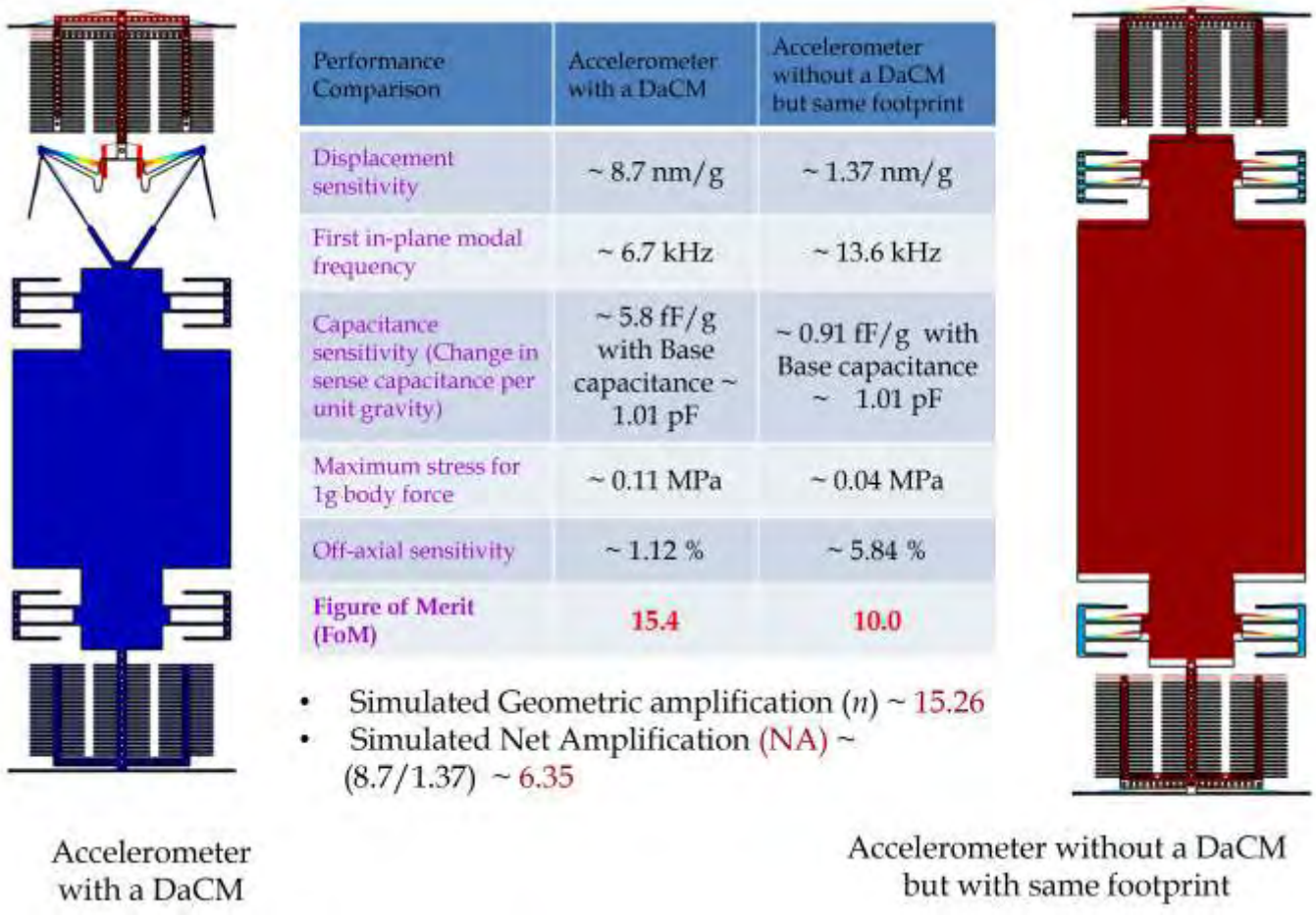


Figure 4. Comparison of two accelerometers, one with a DaCM and the other wihtout it

The one without the DaCM has a large proof-mass. Hence, its mass can experience more force for the same acceleration and produce larger displacement. But the one with the DaCM, despite its smaller proof-mass, wins. This is because it takes the smaller force experienced by the proof-mass and amplifies the displacement. A note of clarification. The DaCM is not like an operational amplifier (Op-amp). Unlike an op-amp, a DaCM does not use any extra power to amplify. What happens in a DaCM is merely a transformation. The energy and power remain the same between the input and output. The large force and small displacement at the input of the DaCM transform to small force and large displacement at the output.

Of course, a part of the input energy is used by the DaCM to store as strain energy as it elastically deforms. This completes the main story. The two insights are not enough to complete the work. Design is only the beginning. To get to the collage of pictures shown in Fig. 5, there was a lot of toil. Fabrication, packaging, testing, and calibration took very long. This is because at the time Sambuddha Khan did this work, CeNSE facilities in IISc were not yet set up. Microfabrication was done with SOIMUMPs MEMS foundry and ECS Partners, a start-up fab company of the University of Southampton, UK. We had to run from pillar to post for every little thing. Such simple things as the wire-bonding took months.

Once, a PCB design had to be trashed because the location of the capacitance-extraction ASIC was a little too far from the MEMS die! I used to tell Sambuddha that all these little nagging things should find a place in his PhD thesis so that someone else can benefit by reading his thesis. We also had help from several quarters. SI Microsystems in Bengaluru and Dr. Girish Phatak of CMET-Pune helped us a great deal with packaging. Professor Jamadagni of Electronic Systems Engineering at IISc was also a great help with regard to electronics (he was a co-adviser of Sambuddha's PhD thesis).

The development of MEMS devices is a lot easier now with the setting up the world-class fabrication and characterization facilities at the Centre for Nanoscience and Engineering (CeNSE) in IISc. I remember one late evening when Sambuddha was showing me his device under test in the newly setup mechanical characterization lab in CeNSE. He was using the Laser Doppler Vibrometer in the squeaky clean space. The new pieces of equipment were shining their glory. The walls and floor were immaculately clean. It was getting dark outside.

As we looked through the window, the newly planted saplings and lawn added to the green ambience. It was silent and serene just like the Backs in University of Cambridge. Sambuddha had gone on a visit to Cambridge for integration and packaging work but that was not fruitful. But he had vivid memories of that great university. As we got back to work, Sambuddha's accelerometer worked and he was elated. Then he told me something that I often tell many people today. Looking at the ambience inside the lab and outside through the window, Sambuddha told me that it felt like he was in the University of Cambridge. Yes, now that ambience is here, he had felt. What excuse do we have now not to do cutting-edge research in micro and nano devices?

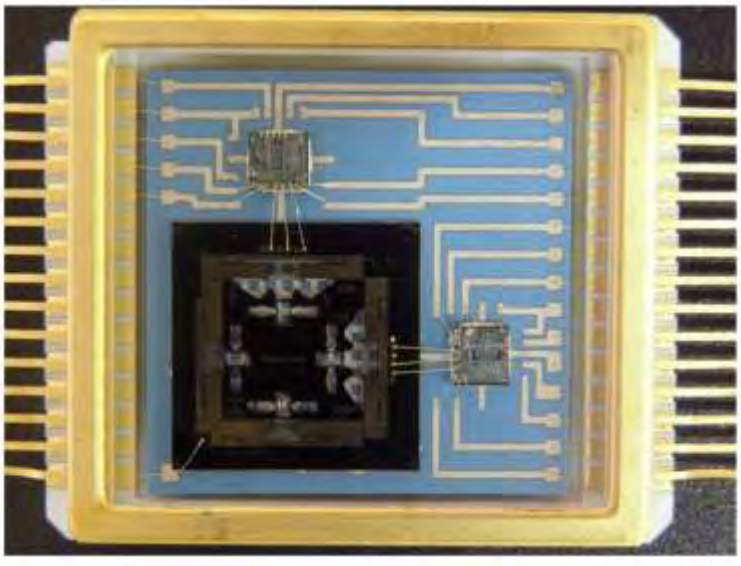
FURTHER READING

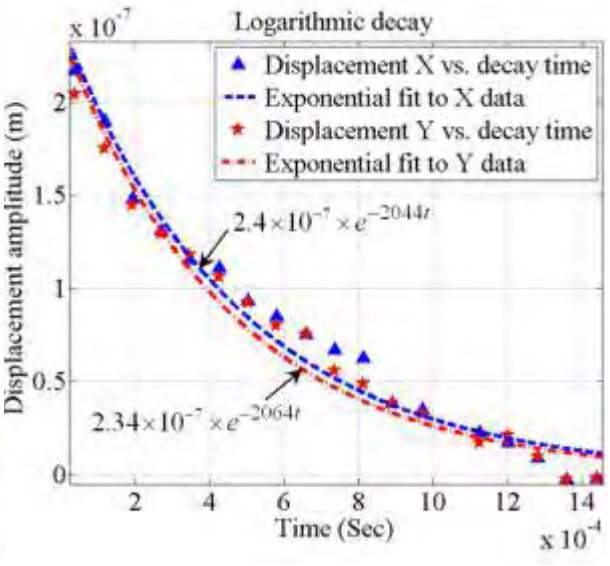
1. Khan, S. and Ananthasuresh, G. K., "Improving the Sensitivity and Bandwidth of In-plane Capacitive Micro-accelerometers using Compliant Mechanical Amplifiers," IEEE Journal of Microelectromechanical Systems, 23(4), 2014, pp. 871-887.

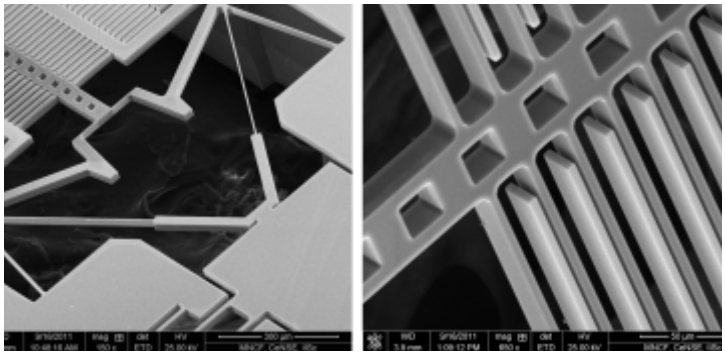
2. Khan S. and Ananthasuresh, G. K., "A Micromachined Wideband In-plane Single-axis Capacitive Accelerometer with a Displacement-amplifying Compliant Mechanism," Mechanics-based design of Structures and Machines, Vol. 42(3), 2014, pp. 355-370.

3. Krishnan, G., Kshirasagar, C.U., Bhat, N., and Ananthasuresh, G.K., "Micromachined High-Resolution Accelerometers," The Journal of the Indian Institute of Science: A Multidisciplinary Reviews Journal, Vol. 87 (3), 2007, pp. 333-362.

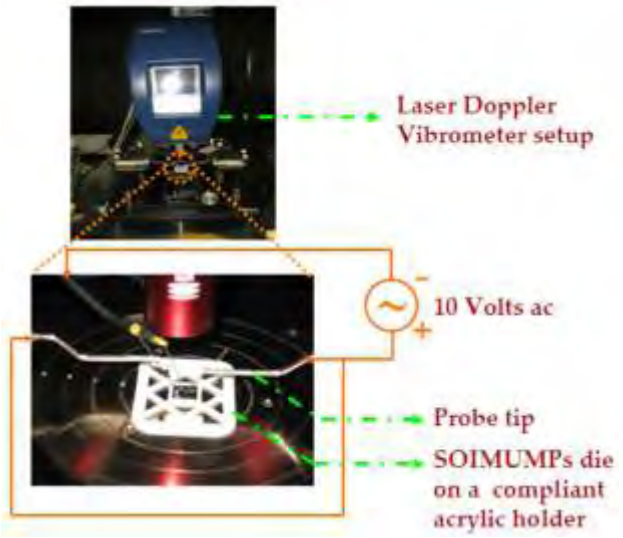
4. Krishnan, G. and Ananthasuresh, G. K., "Evaluation and Design of Compliant Displacement Amplifying Mechanisms for Sensor Applications," Journal of Mechanical Design. Volume 130, Issue 10, 2008, pp. 102304:1-9.



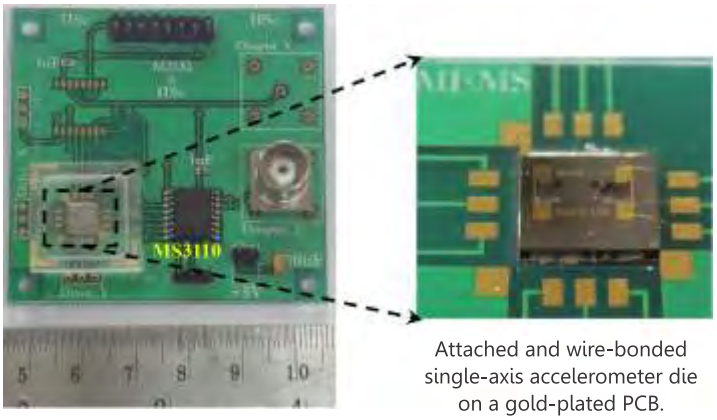




FABRICATED SINGLE - AXIS ACCELEOMETER - SEM Images

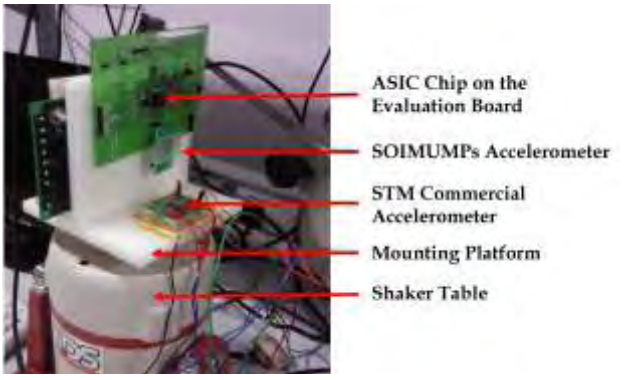


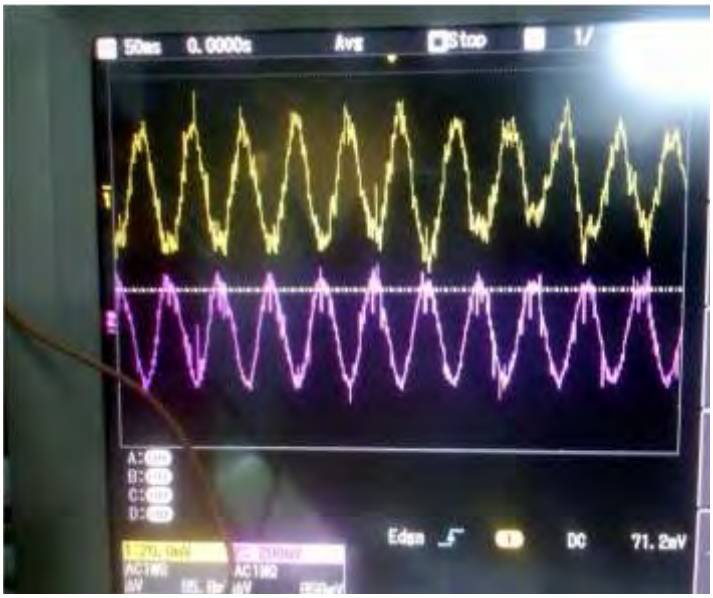
Experimental setup

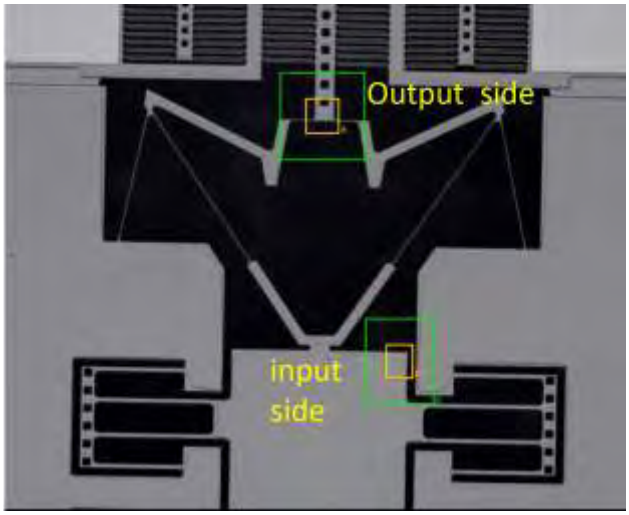


Attached and wire-bonded single-axis accelerometer die on a gold-plated PCB.

Packaged Single-axis accelerometer on a PCB







Institute of Smart Structures and Systems, Seventh ISSS National Conference - A Report

Dr. V. Natarajan, NPOL

Kochi, a premier defence R&D lab under the has established core competency in and related technologies with credible partnership with industry, academia and Indian Navy. NPOL, the flag bearer of SONAR technology in the country, has always endeavored to keep abreast of the technology developments in this niche area to be on par with the global competitors. NPOL has been the pioneer in the area of underwater transducers in the country over the decades and this has remained one of the core strengths of the laboratory. The lead of the laboratory in this area is maintained with the efforts invested over decades in the development of sensors. As a part of this, NPOL has ventured into the technologically challenging area of micro sensors, MEMS since 2003. It is one of the four regional MEMS centers of DRDO identified for the development of MEMS based devices catering for naval, acoustic and other underwater marine environment.

ISSS NC-7, the seventh in this series was organised by NPOL, CUSAT and C-MET, Thrissur, under the aegis of ISSS. The national conference had participation of researchers from industry, academia, experts in MEMS foundries, and other professionals in the field of MEMS, Smart Materials Structures and Systems across the country with a special emphasis on piezoelectric materials, sensors and systems.

Two pre-conference workshops 'Advances in Piezoelectric Ceramics and Sensors' and 'Advances in MEMS & NEMS' was arranged on 23 Sept. 2015 that were addressed by experts in two parallel sessions. About 100 researchers attended/ participated in the workshop. ISSS Awards lectures followed the workshop session. Award winners of ISSS Young scientist, PhD Thesis, M Tech Thesis and Technology delivered their presentations. Citation and cash prizes were distributed, thereafter.

WORKSHOP 1

ADVANCES IN PIEZOELECTRIC MATERIALS AND SENSORS

PIEZOELECTRICS AT DIFFERENT LENGTH SCALES AND APPLICATIONS

Prof. S B Krupanidhi
Indian Institute of Science, Bengaluru

SCIENCE & TECHNOLOGY OF PIEZOCERAMIC ACTUATORS AND ITS APPLICATIONS

Dr. N. Raghu
Senior Scientist, Centre for Materials for Electronic Technology, Thrissur, Kerala.

GROWTH AND CHARACTERISATION OF EPITAXIAL PEROVSKITE THIN FILMS

Prof. M.K. Jayaraj
Nanophotonic & Optoelectronic Devices Laboratory, Cochin University of Science & Technology, Kochi

APPLICATIONS OF PIEZOELECTRIC TRANSDUCERS

Dr. R. Ramesh
Scientist 'F', Naval Physical & Oceanographic Laboratory, Kochi.

YOUNG SCIENTIST AWARD

Dr. A. Arockiarajan
Associate Professor, IIT Madras for the work on "Temperature Dependent Electrical Fatigue Studies on Bulk" and Dr Chirasree Roy Chaudhuri, Associate Professor, Indian Institute of Engineering Science & Technology, Shibpur, Howrah for the work "Nanostructured Porous Silicon Oxide - A Unique Platform for Selective Label Free Impedance Biosensors".

PhD THESIS AWARD

Dr. K.B. Vinayakumar
IISc, Bengaluru for the work "Microneedle and Micropump based Transdermal Drug Delivery System".

M TECH AWARD

Mr. Arunabha Mitra
Real time Design and Implementation of Cost Effective MEMS sensor based Positive Airway Respirator System".

Dr. K. Vijayaraju, Scientist 'G' and PD, NPMASS and **Prof K. Natarajan,** Past President, ISSS were felicitated on the occasion for their significant contributions towards propagating MEMS activity in the country. The conference was inaugurated by Dr Kota Harinarayana, formerly, Programme Director, LCA and Director, ADA at 09:30 hrs on 24th Sept. 2015 at Seminar Complex, CUSAT. Dr. Kota Harinarayana, in his keynote address, stressed the significance of IVHM, Integrated Vehicle Health Monitoring for enhancing and improving the capabilities of systems. Dr. V.K. Aatre, formerly Secretary, DDRD; DG, DRDO & SA to RM and Mr Mohan P Mathew, Director-in-charge, NPOL and Prof SB Krupanidhi, President, ISSS addressed the gathering. Dr. V. Natarajan, Scientist 'G', NPOL was the convener of the conference.

About 150 researchers from premier R&D establishments and academia in the country participated in this three day scientific conference. The conference had 3 Plenary lectures, 13 Invited lectures and 80 paper presentations. The excerpts from A news item featuring the keynote lectures on Nanotechnology by Prof. Rudra Pratap (IISc) and Prof. V. Ramgopal Rao (IIT-B) was covered by the local edition of Times of India on 2nd Oct 2015. A snippet of the same in included herein.

The event provided a common forum for all those working on R&D related to MEMS technologies on the recent developments and trends and understood each other's competencies so as to utilize their expertise in realising state of the art micro sensors and systems.

The occasion provided an opportunity to speakers for brief presentations on the recent achievements and ongoing activities in smart materials and sensors related technologies.

WORKSHOP 2

ADVANCES IN MEMS & NEMS

MEMS SENSORS FOR UNDERWATER APPLICATIONS
Dr. V. Natarajan
Scientist 'G', Naval Physical & Oceanographic Laboratory, Kochi

IMPROVING THE PERFORMANCE OF CAPACITIVE ACCELEROMETERS USING MECHANICAL AMPLIFIERS
Prof. G.K. Ananthasuresh
Indian Institute of Science, Bengaluru

MEMS SENSORS PACKAGING AND QUALIFICATION FOR AEROSPACE SYSTEMS
Prof. M. M. Nayak
Centre for Nano Science and Engineering,
Indian Institute of Science, Bangalore

ESSENTIALS OF MICROWAVE INTEGRATED CIRCUIT COMPONENTS
Dr. S. Raghavan
Senior Professor, National Institute of Technology, Trichy

Nature nurtures these nano techies

New Research Develops Devices By Studying Insects, Animals

HERE'S THE FUTURE

Papers were published in the form of Conference Proceedings. The conference concluded with a valedictory function addressed by Dr VK Aatre, Prof SB Krupanidhi, Dr KJ Vinoy, Mr. S. Kedarnath Shenoy, Director, NPOL. The convener thanked the ISSS executive committee for providing an opportunity to conduct the conference at Kochi.

National Workshop on 'MEMS & Microsystems'- A Report

Compiled by: **Dr. Girish J Phatak**

The National Workshop on MEMS & Microsystems' was organized by MAEER's Maharashtra Institute of Technology, Pune, MAEER's Arts, Commerce and Science College, Pune and ISSS Institute of Smart Structures and Systems Pune Chapter. This workshop was held on 12th and 13th February 2016.

Dr. Guruprasad, Director, R & D Engineers, Pune, was the Guest of Honour for the inauguration function. The Principal of MAEER's MIT Pune, Dr. L. K. Khirsagar presided over the inauguration and motivated the students with his inspiring speech. Unfortunately, Prof. K. J. Vinoy, ECE, IISc, who was the supposed to be sharing the stage as Chief Guest, could not attend the inaugural function due to unexpected delays in arrival at Pune.

Dr. T. N. More, Principal of MACS College, addressed the audience & encouraged all the participants. During the inauguration Prof. (Ms) S. A. Gangal-Professor (Retd.), Dept. of Electronic Science, SPPU, Pune & Dr Girish Phatak- Scientist, C-MET, Pune provided brief introduction of MEMS and dwelled upon the need for such a Workshop on MEMS. They explained different applications such as mobile phone Mobile-gyroscope sensor as well as aerospace and biomedical applications. They said that there is no limit in the development of MEMS technology. Prof. Gangal specifically mentioned that the development of this technology in India is mainly due to the initiative by Prof. V. K. Aatre, who is also the founder of ISSS.

Prof. Aatre also initiated the two National Programmes on MEMS and smart structures. Dr. P B Joshi, Founder, Managing Trustee, & Head Department of Mechanical Engineering, MIT Pune, also talked on emerging areas and emphasized the importance of materials. He pointed out that we in India still import many materials. For instance, titanium used in knee replacement is imported from Germany.

Materials play a crucial role even for energy- security for a country. In addition, in the realm of Automation, materials are critical. Focussed on this aspect he said, GE has established a global center for materials R&D in Bangalore.

PROCEEDINGS OF DAY 1
Session I

Prof. Siddhartha Duttagupta, Department of Electrical Engineering, IIT Bombay, Mumbai, addressed the first session and shared his views on the topic, "Bridge Technologies used for Advanced Applications".

He explained integrated micro electronic systems He said MEMS has now assumed many meanings. They are used to form Cantilever, beam, Membrane, Actuators, sensors, Transmitters, energy converters etc and have been fabricated using Si and many other low cost platforms.

Dr. T. N. More addressing the audience

Prof. Siddhartha Duttagupta

Prof. G. K. Ananthasuresh

Prof. Vinoy K. J.

Representative from COMSOL

Prof. S. A. Gangal

Session II

1st lecture

In the second part of this session, Prof. G. K. Ananthasuresh, Dept. of Mechanical Engineering, IISc, Bangalore, shared his views on mechanical design of MEMS devices. It was a live-streamed video conference talk from IISc-Bengaluru. He gave details on;

1. MicroN:-micro newton force sensor
2. Soil moisture sensor
3. Intercarnial pressure sensor
4. Accelerometer

He underlined use of mechanical amplification as against electronic amplification, especially in view of their high signal to noise ratio.

In the third part of this session, Prof. Vinoy K. J. Dept. of Electronics and Communications Engineering, IISc, Bangalore, shared his views on RF MEMS. He explained how MEMS are used in various applications such as Mobile phones, Micro Switches, RF Integrated systems etc. He also explained how communication technologies have changed through the years. He also covered different types such devices, their working and presented an overview of their fabrication.

Session III

Representatives from COMSOL and Intellisuite companies presented their company software details for various MEMS related simulations.

Day - 2

Session I

On the second day, in the first session, Prof. S. A. Gangal, Professor (Retd.), Dept. of Electronics Science, Savitribai Phule Pune University, lectured on 'Bulk Micro Machining: Fabrication of accelerometer'. She covered various topics such as, what are MEMS, MEMS basic structures, fabrication techniques, micromaching, MEMS production process, process classification, MEMS materials. She also discussed accelerometer and its types, different methods & steps of fabrication such as cleaning, oxidation, diffusion, deposition & etching. Towards the end of the lecture she discussed various MEMS devices & their applications.

Mr. Jaising Pednekar, Scientist 'D', R & D E (Engineers), Pune, spoke on the topic, 'Surface Micromachining and LIGA processes for MEMS fabrication'. He discussed topics such as MEMS history, needs, different MEMS fabrication technologies, various deposition methods, MUMPS, poly MUMPS, LIGA, UV LIGA, SMM, & case study of different LIGA types.


Mr. Jaising Pednekar


Dr. (Ms) Nidhi Maheshwari


Dr. (Ms) K. Nageswari


K.V.S. Ravikrishna

Dr. Dhananjay Bodas

Dr. Girish J. Phatak

Session II

In the second session, Prof. Nidhi Maheshwari, Dept. of Electrical Engineering, IIT, Bombay, Mumbai, spoke on 'Polymer MEMS/NEMS Sensor systems'. She articulated the goals of mems, a low cost cardiac diagnostic system based on MEMS.

She talked about Isens a project from mems which is designed to save a person from heart attack. She also discussed several topics such as polymer cantilever- Piezo resistive transduction.

Dr. K. Nageswari, INUP, IIT Bombay, Mumbai, shared her views various topics such as 'Indian Nano electronics users', INUP lab, VLSI design, Tech CAD, types of training held at many centers, types of projects, financial models, academic research project life cycle, different training modules, how to do proposal submission, steps of proposal and associated timelines. She also gave details of several ongoing projects at different research institutes, colleges, & companies.

Session III

In this session a commercial session was held by Entuple from ANSYS. Use of ANSYS for producing MEMS devices, piezo resistive sensors, gyroscope, piezoelectric fan, damping, design exploration was highlighted. Several related software features, ease of use, robustness for nonlinear, support for distributed & shared memory, parallel processing were briefly mentioned during this session.

Dr. Dhananjay Bodas, Scientist 'D' Agharkar Research Institute Pune, talked on 'Microfluidics' and 'Microreaction technology'. He explained concepts like microfluidics, lab on a chip, what can microfluidics do? Why microfluidics? Market for microfluidics, Diffusion & mixing at microscope. He also presented some simulation studies using COSMOL Multiphysics.

Dr. Girish J. Phatak, Scientist 'F', C-MET, Pune, presented on Packaging and microsystems in LTCC. Where he gave details on Packaging Functions, How is it inside the package, multichip modules (MCM) & its types, Sensor packaging & microsystems its applications & markets. Different packaging techniques sensor & MEMS. He also talked on electronic packages, packaging density, materials & propagation delay, microwave test circuits, development of JT cooler at a laboratory. He also explained the underlying concepts like LTCC, Die stacking & TSV.

All the sessions were interactive and included discussion among the participants and the speaker.

Valedictory Session

The workshop ended with a validectory program wherein Dr. Girish J. Phatak gave the overview of the two days' workshop & Prof. S.A. Gangal spoke about future need of MEMS. Prof. Sunil Chaudhari gave a vote of thanks. Overall 45 Teachers and 30 students participated in the workshop. All the participants were given a certificate of participation.

Interaction with participants

Valedictory Session

Vol. 9, No. 3-4; March 2016

ISSS Felicitates Dr. V. K. Aatre on Receiving Padma-Vibhushan

Dr. P. D. Mangalgiri

It was Dec. 1996. An International Conference on Smart Materials and MEMS was in progress in the JN Tata Auditorium of IISc Bangalore. The deliberations in the Conference brought home two points to a large, wide-spectrum Indian audience: one, that this technology has huge potential for applications in almost all areas and therefore a huge international interest, and the other, that there is a significant number of research groups in India working on several related areas.

Here was an opportunity to be grabbed to develop an important new technology and be on par with the international development. Leading that line of thought was an eminent scientist and technocrat in the country - Dr Vasudeva K Aatre - who was then the Chief Controller R&D in DRDO. In his unique, calm but persuasive, style, he made a very insightful remark to a group of Indian scientists gathered there: "India has missed the electronics revolution. But, India shall not miss the Smart revolution. We must all work for that."

Over the next few months he created a "movement", gathering together a bunch of interested enthusiastic scientists and engineers from various disciplines - from Mechanics to Electronics, from Medicine and Biology, from Industry, from Academia and from R&D labs. Spearheading this movement, Dr Aatre saw a need for creating awareness about smart technology and MEMS amongst the vast spread of Indian Universities, Labs and Industry and to promote related activities.

In addition, he envisioned that the country would need a reasonable infrastructure of modern facilities and would have to create a large human resource with requisite expertise and knowledge if we have to create useful applications and commercial products from this technology. True to his style of functioning, he immediately set out to address both these issues. With the close-knit group of people who were inspired by his remarks at the 1996 Conference, he founded a Society - the Institute of Smart Structures and Systems (ISSS) - to provide forum for people from different disciplines to come together and discuss issues and means for promotion of MEMS and Smart technologies.

On the other front, he formulated a concept of a "National Programme" on Smart Materials and MEMS in which people from diverse disciplines could participate and contribute to the technology development.

Inspired and guided by Dr Aatre, the Society - ISSS - has grown from strength to strength having more than 700 Life members today and with Chapters in Coimbatore, Kochi and Pune and with significant presence in Hyderabad and Delhi. It runs annual National Conference and triennial International Conference - events which have become important fora for national and international participation.

ISSS has run innumerable workshops in creating awareness across the length and breadth of the country. Thanks to the vision and encouragement provided by Dr Aatre, ISSS has also started a scientific journal "The Journal of ISSS" published twice a year since 2014. The society has also instituted Awards for Students, Young Scientists and Accomplished Industrial Technocrats to appreciate their work and encourage more such people to participate in this endeavor. Dr Aatre, of course, has set more ambitious goals for the Society - increasing membership several folds, raising standard of the journal, formation of several more Chapters, etc., - so that ISSS becomes a truly representative and active forum and voice of the Smart Community across the entire country.

While ISSS has provided a forum for awareness and interaction of interested people and for promotional activities, Dr Aatre's other big initiative, the National Programme, has seen great success in creating an excellent foundation for the development and deployment of Smart technology and MEMS.

Formulated during the years 1998 - 2000, the concept of a National Programme to develop infrastructure, expertise and technologies in a new technology domain (such as MEMS and Smart Materials) was a bold step in a milieu of institution-run and controlled R&D programmes. The concept proposed by Dr Aatre was quite novel: the funding would be entrusted to a group of scientists in the area; the scientists would decide what projects to formulate, how to formulate, how to run and who should run them.

It was an innovative experiment in eliciting widespread participation of scientists with very little bureaucracy, yet

complying with all financial rules and guidelines. On one hand, it allowed a kind of flexibility in fine tuning the work and doing mid-course corrections, which are so vital to pursuing new research areas and exploring unknown territories. On the other, it ensured that the work did not deviate from the programme goals.

Dr Aatre was successful in convincing and persuading the Government to fund such a programme with a sufficiently large funding. And he was successful as well in putting together a team of committed scientists and engineers from various institutions and disciplines to run the programme when the first programme called the National Programme on Smart Materials (NPSM) was sanctioned in year 2000. He instituted review mechanisms to monitor the Programme as well as the individual projects. The whole scheme paid rich dividends and looking at the success of NPSM the Government had no hesitation in sanctioning a follow-up programme called National Programme on Micro and Smart Systems (NPMASS) with a larger budget (~200 crore) and with more ambitious goal of not only creating technologies but also creating applications and prototype products.

It is to the credit of Dr Aatre that the Government reposed faith in his vision and his executive acumen even though he had already superannuated from his position as Scientific Advisor to Raksha Mantri and Secretary Defence (R&D). Dr Aatre participated very actively in the execution of the two programmes, especially so of the NPMASS where he also enthused several industries to come forward in this technology development effort. The faith put by Govt. was well rewarded as NPMASS completed its tenure with great success and several significant achievements.

The ISSS was closely associated with the two National Programmes and Members of ISSS were deeply involved in running the programme and undertaking work under various projects. Dr Aatre's initiatives on these two fronts worked very well, each energizing the other and thereby contributing to the success of both, the ISSS and the National Programmes.

Thanks to these untiring efforts of Dr Aatre, the country now has significant growth in the infrastructure to conduct smart systems and MEMS related activities. To name a few, there are 68 MEMS Design Centers, Industry Level MEMS fabrication facilities at SCL, BEL, SITAR and R&D Facilities at several institutions like CEERI Pilani, IIT-B, IIT-D, IIT-Kgp, IISc, and a few other universities and over 5000 people who have undergone various training workshops, courses, special workshops, and Conferences; several expert groups in various academic institutions and National labs. A world-class MEMS Testing and Characterization facility is created at CeNSE, IISc, an LTCC Packaging at C-MET Pune, RF MEMS Characterization at IIT-D and polymer MEMS fab at SITAR.

Smart Materials like Shape Memory Alloys in bulk and wire form, Shape Memory polymers, Piezo materials and Piezo stack actuators are developed and some of them are being routinely produced. Expertise on novel smart materials exists.

MEMS Pressure sensors for LCA are ready, Proof-of-concept devices and application demos have been done such as for accelerometers, Gyro, Micro-heaters, Micro-needles, Micro-pumps, Micro-Cantilevers; various RF MEMS devices such as switches, varactors, Phase Shifters; GMR Sensors, Hall Effect sensors; MAP and TMAP sensors for automotive applications. Point-of-care biomedical devices for uropathogen diagnosis, Cardiac Markers, Food quality sensors, retinobalstoma detector, explosive detector etc have been developed and some of them have already undergone clinical trials.. Smart Applications such as Aircraft Airdata Probes, Active Noise Controlled Helmet for LCA pilots, De-Icing, Engine Mounts vibration suppression, Morphing Structures and Structural Health Monitoring are now within reach of actual applications. The list is long, and with the expertise developed in the country, the list is getting longer by the day.

With all these developments, Dr Aatre has brought us to a stage from where we should look forward to taking off into the bigger domain of commercial and strategic products. That is a narrative of how Dr Aatre has inspired a generation of scientists and engineers to take up the challenge of promoting, developing and nurturing the smart technology and MEMS. But, the larger story started decades earlier.

Born in 1939 and hailing from Kalkunte, a village near Bangalore, Dr Aatre obtained his BE (Electrical) from University of Mysore in 1961 and ME (Electrical) from Indian Institute of Science, Bangalore in 1963. He earned his Ph.D in Electrical Engg from the University of Waterloo, Canada in 1967. In 1977, while pursuing an illustrious career in teaching and research in Canada, Dr Aatre came to Indian Institute of Science, Bangalore as a Visiting Professor and stayed back to play a major role in Country's technological development.

He joined Defence R&D and served as Director of Naval Physical and Oceanographic Laboratory at Kochi from 1984 to 1991.

Later, he became Chief Controller R&D in the Defence R&D HQ in Delhi and went on to become Scientific Advisor to Defence Minister and Director General of Defence R&D, from which position he retired at the end of Aug 2004.

During his years in the Government, Dr. Aatre spearheaded many developments apart from the smart technology and MEMS. These include development of underwater technology for the Navy through the design and productionization of state-of-the-art transducer and sonar suits; construction of first indigenous ocean acoustic research ship Sagardhwani and Programmes to bridge gaps in supply and manufacture of electronic components and devices.

Perhaps, after the "formal" retirement, Dr Aatre has become busier. While teaching and guiding the younger generation at IISc, he is actively involved in lending a helping hand through his advice and guidance to several other institutions and committees of government. Dr Aatre has written several research papers and published text books for graduate and undergraduate levels.

His enormous contributions have brought him several fellowships, awards and honour in the past including Fellowships of several prestigious academies and professional bodies and Padma Bhushan by Govt. of India in 2000. Recognizing his varied and enormous contributions once again, the Govt. of India has bestowed on him this year the well-deserved honour of Padma Vibhushan. We heartily congratulate Dr Aatre on receiving this great honour.

REPORT on Inaugural Event of ISSS AP - Chapter

Seminar on Smart Sensors and Systems (S2S - N15) 8th - 10th December 2015

The ISSS AP-Chapter was initiated with the objective of driving the R&D activities in the broad area of MEMS and Nanotechnology in Andhra Pradesh. The first formal meeting was conducted in the Department of Instrument Technology, Andhra University College of Engineering (A) The following Life Members were appointed as the office bearers of ISSS AP-Chapter.

1. **Prof. D. V. Rama Koti Reddy** Chairman
2. **Prof. Y. Srinivasa Rao** Co-Chairman
3. **Dr. B. Rajesh Kumar** Secretary
4. **Dr. S. V. Jagadish Chandra** Joint Secretary
5. **Dr. P. Swapna** Joint Secretary
6. **Sri M. Nagesh** Joint Secretary
7. **Dr. A. Daisy Rani** Treasurer

As an Inaugural event of ISSS AP-Chapter, a three-day Seminar on Smart Sensors and Systems (S2S-N15) was succefully organized during 8th - 10th December 2015. The inaugural function was held at Sri YVS Auditorium, Andhra University College of Engineering (A) on 8th December 2015. The function was graced by Prof. V. K. Aatre, IISc, Bangalore, Prof S. Mohan, IISc Bangalore, Prof G. S. N. Raju, Vice-Chancellor, Andhra University, Dr. V. Bhujanga Rao, Former DG DRDO, Sri. K. Sairam Kumar, Visakhapatnam Steel Plant and Prof Ch. V. Ramachandra Murthy, Principal, AU College of Engineering (A). The event was presided by Prof D. V. Rama Koti Reddy, Head, Department of Instrument Technology. Dr. V K Aatre announced officially the inception of ISSS AP-Chapter from the dias. Following the inaugural function Dr. V K Aatre, Prof. S Mohan and Dr. V Bhujanga Rao delivered technical lectures on the broad areas of Micro and Nano systems.

On the second day (9th December 2015) Prof G. K. Anantha Suresh, IISc Bangalore, Prof K J Vinoy, IISc Bangalore and Dr. Jonathan Joshi, delivered lectures. The expert lectures were followed by paper presentations by the participants. Nearly 40 papers were shortlisted and were presented at the seminar. On the third day (10th December 2015) Dr. H. S. Jatana and Prof Gaurav Trivedi delivered guest lectures. This was followed by the valedictory function which was graced by Dr. H B Singh, Director, DST, NewDelhi.

Following are some of the future activities planned to be taken up by the ISSS - AP chapter.

1. Organizing National Conference NC - ISSS.
2. Organizing Regional Workshops at Vijayawada, Ongole and Tirupathi.
3. Increasing Number of life members under ISSS AP - Chapter to 100 within a year


7TH ISSS NATIONAL CONFERENCE
MEMS, Smart Materials, Structures and
IPOL

ISSS-NATIONAL CONFERENCE

28-30 SEPTEMBER 2016, IIT-KANPUR

IIT Kanpur is organizing the eighth edition of ISSS National Conference on MEMS, Smart Materials, Structures and Systems, ISSS-NC8, at IIT Kanpur under the aegis of ISSS. This conference will attract researchers, industries and other professionals in the field of MEMS, Smart Materials, Structures & Systems, across the country.

The focus is on the following topics:-

- Smart Multifunctional Materials
- Structural control and Health Monitoring
- Intelligent System Design
- Applications: Structural Health Monitoring, Bio MEMS/ NEMS, RF-MEMS, Automotive sensors
- Other allied research areas

Pre-conference workshops are scheduled between 28th and 30th Sep. 2016. A special session is also earmarked for ISSS Annual Awards presentation during the conference. This year, the Student Awards are restricted to demonstration projects, wherein the student is required to demonstrate a working physical prototype/device. This is to promote "Make-Build" culture among students. Please note the following key dates regarding paper submission and registration.

IMPORTANT DATES

Submission of full paper
15 June 2016

Acceptance of full paper
01 July 2016

Submission of revised paper
31 July 2016

Conference registration
16 Aug. 2016

For details on ISSS awards, paper submission formats etc.,
Please log-on to http://www.isssonline.in or email isssnc8@gmail.com

The Editor gratefully acknowledges the efforts of all those who contributed to this edition of Sukshma. Any feedback from the readers is more than welcome - **Vidyashankar**