Miniaturization of the Satellite and Space Communication System using Advanced Nano and Micro Technologies

[1]Dr. Ravishankar Dudhe, [2]Tithi Desai
[1]Associate Professor, School of Engineering and IT, Manipal University, Dubai
[2]M.Tech Digital Electronics and Advanced Communication

Abstract
MEMS device has the advantage of both electronic and mechanical systems. With the development of MEMS devices for satellite, it is possible to establish much lighter and smaller nano-satellites with higher performance and longer lifecycle. Mission costs are directly proportional to the total weight, thus the trend will be to replace bulky and heavy components of space carriers, communication and navigation platforms and of scientific payloads. MEMS devices are ideally suited to replace several of these components in the future, first by substituting larger and heavier components (e.g. a gyroscope), then by replacing entire subsystems (e.g., inertial measurement unit), and finally by enabling the micro-fabrication of highly integrated pico-sats. Examples of such miniaturization and successful use of MEMS for space and planetary missions are described in this paper. Examples of miniaturization possibilities for space robots and satellites are given, focusing on the challenges and the enabling technologies. The miniaturization process and the use of advanced nano and micro-technologies in space will have a large beneficial impact in the years to come.

Keywords
MEMS, Micro-Fuel Cell, Gyroscopes, Actuators

I. Introduction
For centuries people were fascinated by making mechanical and electronic devices smaller and smaller. In 1959, various limitations for making smaller mechanical devices were explored by the Nobel laureate Richard P. Feynman who is considered the "father" of MEMS technology. These limitations included: forces, materials, magnetic behavior and friction.

Presently, the following MEMS fabrication techniques (with IC fabrication origin) are being used [1]
1. Surface Micromachining
2. Bulk Micromachining
3. LIGA
4. Wafer-to-Wafer Bonding

MEMS have been proposed for a number of space applications, as lighter and smaller replacement parts or as entire new systems [2, 3, 4], or as a means to provide affordable redundancy.

In the coming years, we will see MEMS technology in the form of more complete sub-systems, such as attitude determination, attitude control, phased array antennas, Earth sensors, optical switches, whose size and mass will be reduced significantly compared to conventional solutions. In the longer run MEMS can enable new classes of small (1-10 kg), intelligent, self-managing and relatively low-cost picosatellites operating in constellations [5].

II. MEMS Based Components
A few satellite based sub-systems that are currently being examined in MEMS included attitude control sensors, actuators, micro-fuel cells and RF switches [6].

A. Gyroscopes
Gyroscopes function differently depending on their type. Traditional spinning gyroscopes work on the basis that a spinning object that is tilted perpendicularly to the direction of the spin will have a precession. The precession keeps the device oriented in a vertical direction so the angle relative to the reference surface can be measured [7].

More than an order of magnitude improvement can be found in moving from large scale gyroscopes to the MEMS equivalent. Researchers are currently working that the MEMS equivalent quickly catches up to its macro scale equivalent which has a drift performance of 0.003 degrees per hour to 1 degree per hour [6,8].

If the power of the two types are compared we can see that MEMS require power in terms of mW due to its capacitive sensors while full large scale gyroscopes require power up to 10-200 kW [6,8].
Weight is another parameter where MEMS are way better than the large scale gyros. MEMS gyros are small and light and require only a small IC package which might be of a few grams, whereas, the large scale gyros can weigh between 1-25 kg and take up to 100 cubic centimeters of space [6,8].

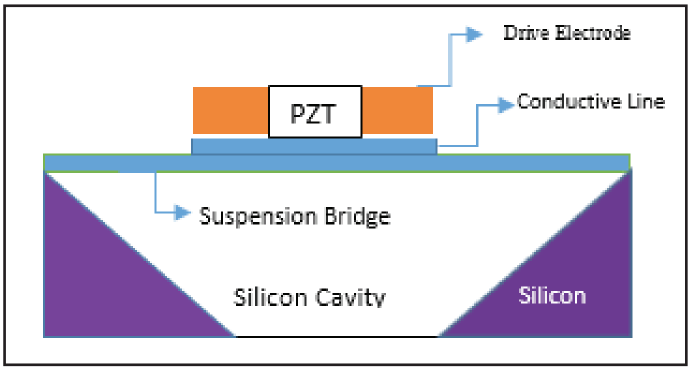

Fig. 1: Cross-Section of a Gyroscope [7,9]

The fig. 1 shows a Piezoelectric Plate Gyroscope which uses a PZT plate as its base. PZT has been used before to make macro devices and can also be used to make micro components. Its major advantage is that it requires a much smaller drive voltage to create readable outputs as the entire plate can be made of piezoelectric material.

Like other MEMS gyroscope the piezoelectric plate gyroscope works on the principle of a vibrating body. In this case, the vibrating body is a piezoelectric sheet. The sheet does not vibrate like a plate or fork. Instead the thickness vibrates which oscillates with time. This requires an AC driving voltage applied vertically across the plate, which uses the electro-mechanical properties of the PZT to create the vibration. Any piezoelectric material can be used, but PZT has high piezoelectric constants, and can be added at a precise thickness [8].

 ISSN : 2230-7109 (Online) | ISSN : 2230-9543 (Print)

A major advantage and the one that could prove most practical is the versatility of the piezoelectric plate gyroscope. It can measure rotation in two directions. In addition, if the driving voltage direction is switched, the same device can measure rotation in the third direction, although with much less sensitivity. Since this device is easily incorporated into other IC chips, it could be controlled to do more things than a ring or tuning fork gyroscope, which require three gyroscopes to measure three rotation directions.

B. Actuators

Micromechanical actuators form a class of actuators which we here loosely define as actuators which are made by micromachining technology [10].

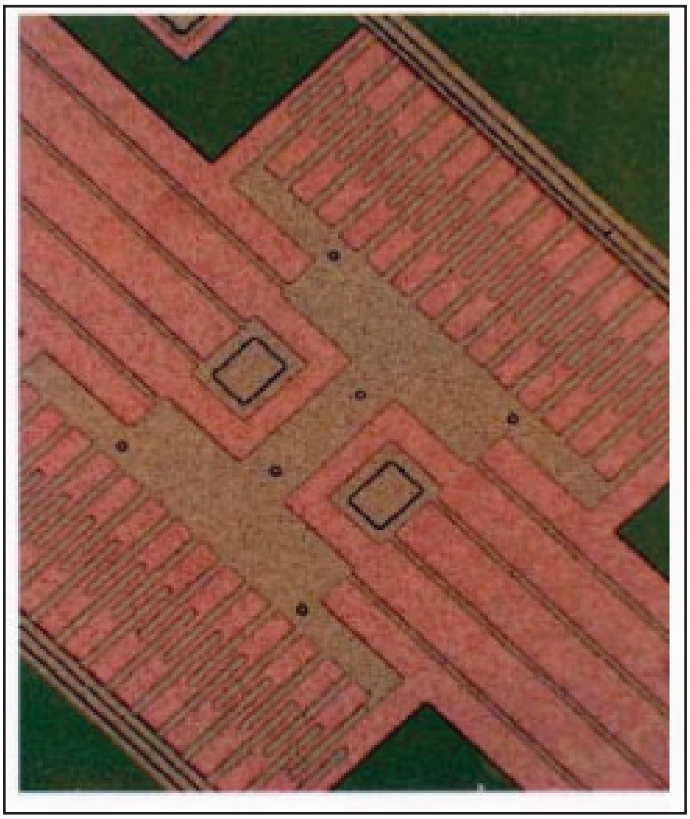

Fig. 2: MEMS Actuator [11]

Micro-actuators are based on three-dimensional mechanical structures with very small dimensions which are produced with the help of lithographic procedures and non-Isotropic etching techniques [11].

For an actuator-like displacement the most different principles of force generation are used, such as the bimetal effect, piezo effect, shape memory effect and electrostatic forces. Characteristic for micro actuators in a more narrow sense is the fact that the mechanism of force generation is integrated monolithically; in a broader sense, however, also microstructures with a not monolithically integrated force generation are numbered among micro actuators.

In order to adapt the high speed of micro motors to the industrial requirements of 100 to 5,000 rpm and in order to increase the output torque considerably, miniaturized reduction gears with similar sizes and shapes are needed [11].

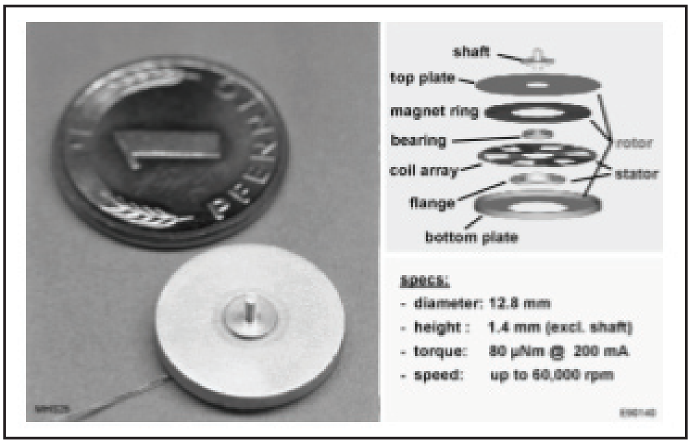

Fig. 3: Construction and Realization of the Penny Motor [1]

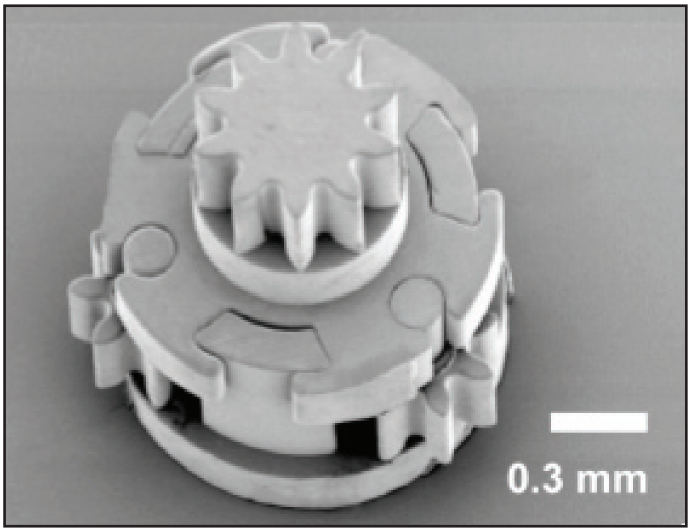

Fig. 4: Stage of the Planetary Gear [1]

Common modes for individual actuation are electrostatic, piezoelectric, electromagnetic and electrodynamic [11].

Since the 90s the micro actuators have been conquering new fields of applications - not least because the manufacturing technologies have reached a high degree of ripeness. By a slight redesign of the mechanical and fluidic construction, standard electronics can be applied which reduces costs considerably

C. Micro-fuel cell

The nano-satellites demand micro-level power having a high energy density to operate over extended periods of time due to their limited area for solar panels. MEMS-based micro fuel cells meet this requirement because their energy density is higher than energy densities of batteries [12].

The PEMFC is the most suitable to space applications due to its excellent performance at low temperatures.

Micro-power sources require high-density hydrogen storages in order to meet the overall energy density. If a high-density hydrogen storage is available in small size, the PEMFC will become the most promising fuel cell for nano-satellite applications. Several ways are possible for hydrogen storage including the compressed hydrogen, liquefied hydrogen, reforming-based chemical storage, metal hydride and chemical hydride. However, the com-pressed and liquefied hydrogen is not feasible to the nano-satellite applications.

The micro PEMFC consisted of three layers: an anode channel layer, a cathode channel layer, and a MEA in-between. Ag/Ti layer for collecting current was sputtered on each side of the anode and cathode. A small Al block for measurement was inserted in the anode and cathode, respectively. Based on our qualitative and quantitative analyses, corrosion and problems regarding energy density were resolved when photosensitive glass was used for the micro fuel cell. The hydrogen flow channel possessed a serpentine geometry for the uniform distribution of hydrogen on the MEA, while the air channel possessed a parallel geometry. The dimensions of the micro fuel cell were 20 mm _ 20 mm _ 1.5 mm with an active area of 10 mm _ 10 mm. The thickness of each layer was 500 µm and the width of the channel was 300 µm. [12].

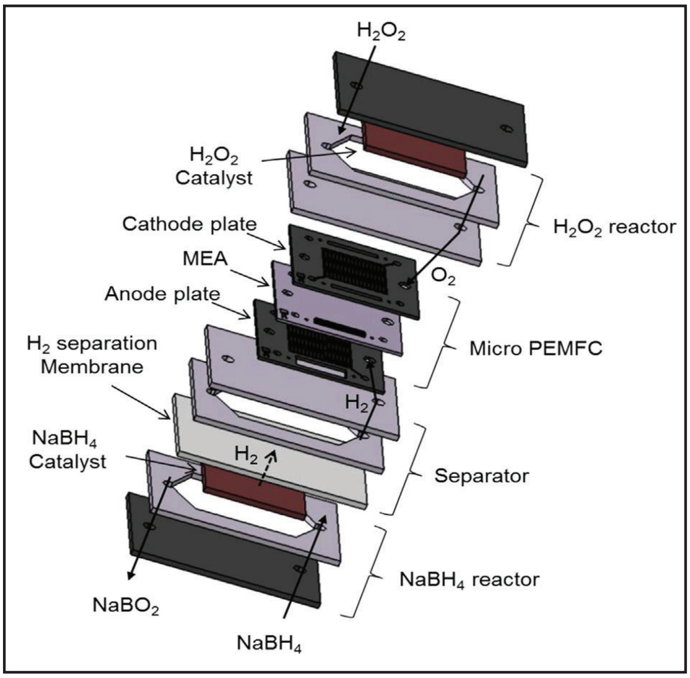

Fig. 5: Structure of Micro PEMFC System Combined With $NaBH_4$ Hydrogen Generator and H_2O_2 Decomposer [12]

The integrated performance of the micro fuel cell with the hydrogen generator was measured as a complete power generation system. Fig. 3 shows the performance curve of the micro fuel cell operating with the hydrogen generated by the reactor. The maximum power output was 174.6 mW for a current of 0.45 A. There was no the performance difference between the integrated test and the pure hydrogen test of the micro fuel cell. This indicates that the micro reactor generated pure hydrogen from the $NaBH_4$ solution [13].

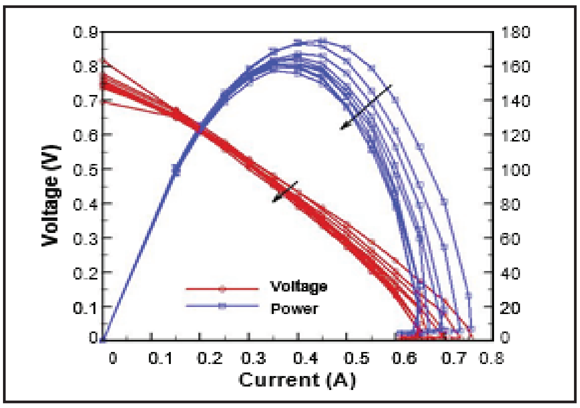

Fig. 6: Performance Curve of the Micro Fuel Cell Operating With the Hydrogen Generated by the Reactor [12]

D. MEMS Tunable Filters

High performance MEMS tunable filters are considered the "Holy Grail" of microwave technology.

The frequency and bandwidth tuning ability is essential for the next generation of communication satellites since this enables user reconfigurable satellites. In addition, the custom tuned, fixed frequency filters can be replaced by electrically tunable filters, hence standardizing the front end of the communications payload. This has the potential to significantly reduce the satellite cost and fabrication span. MEMS tunable filters are the primary candidates to achieve this ambitious goal. Two basic concepts are presently under consideration: switchable filters or switchable element filters (using MEMS switches) and tunable filters using MEMS variable capacitors. In such lumped element filters both filter elements namely inductors and capacitors can be realized using MEMS technology. MEMS tunable filter is shown in fig. 7.

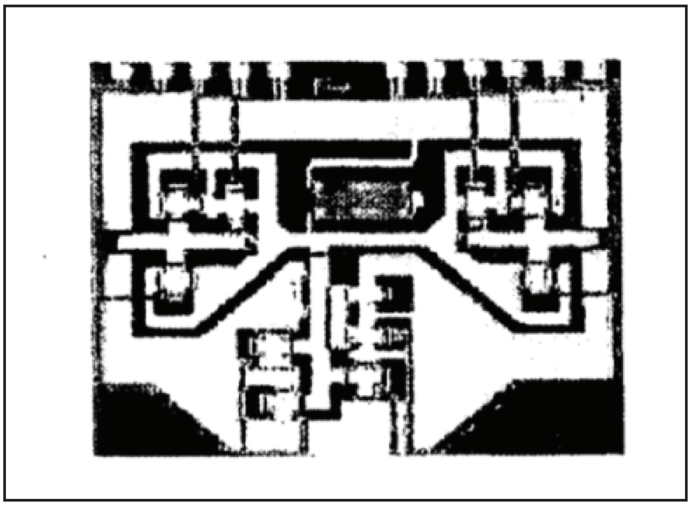
Fig. 7: MEMS Tunable Filter [1]

These devices have distinguished themselves as having very low loss, requiring practically no power consumption, and having very high linearity [14].

III. Future Aspect of Mems

The performance and cost benefits of using MEMS based subsystems are derived in three areas: the small size and weight, the power consumption, and the low manufacturing cost due to batch fabrication [6].

By using MEMS wherever possible not only is there a weight and volume benefit from the device itself but from the lack of associated connectors, cabling, casework and packaging.

MEMS technologies will enable miniaturized, low mass/power, modular versions of many of the current inventory of traditional spacecraft components. MEMS offers the benefits of significantly reduced mass and power consumption, translating directly into decreased costs, and allows for higher system redundancy.

The ability to perform and enhance tasks in the micro world, in ways that are impossible using conventional technologies in the macro world, makes it a genuine breakthrough technology for space. MEMS is an enabling technology for advanced missions such as formation flying, rendezvous, and inspections.

In the coming years, we will see MEMS technology in the form of more complete sub-systems, such as attitude determination, attitude control, phased array antennas, Earth sensors, optical switches, whose size and mass will be reduced significantly compared to conventional solutions. In the longer run MEMS can enable new classes of small (1-10 kg), intelligent, self-managing and relatively low-cost picosatellites operating in constellations [5].

However, to reach the ultimate goal of sending completely micro fabricated and integrated MEMS systems into space, many challenges lie ahead. Long term reliability of MEMS need to be assessed by experiments in space, which will require frequent launches in the near future. The top-down approach to this is to replace existing heavy and bulky components by MEMS, while the bottom-up approach is to send purely MEMS-based systems on special platforms [5].

IV. Application of MEMS in Space

Find in table 1, a list of MEMS parts which are used in the satellite communication.

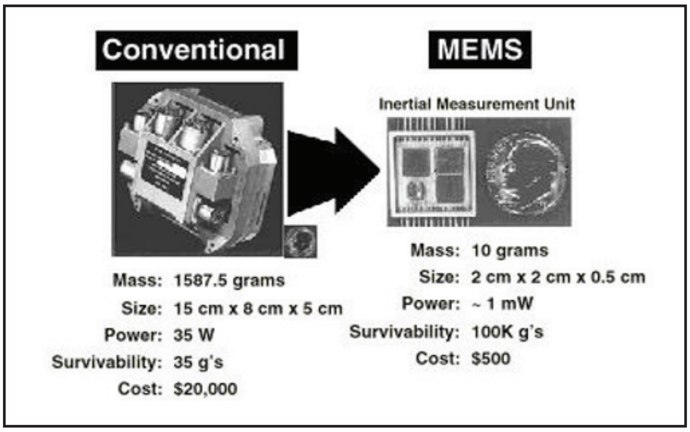

Fig. 8: A Comparison of MEMS and Conventional System [5]

Table 1: Application of MEMS devices in Satellite communication

Type	Spacecraft	purpose	Launch	Note
Acceleration sensor	MARS Polar Lander	Practical use	1999	
RF switch	PICOSAT	Experi-mental	2000	
Gyroscopic acceleration sensor	MEPSI	Experi-mental	2002	
RF switch	ARCADE (balloon)	Practical use	2006	35 km high
Vibration gyroscopic sensor	TacSat-2	Practical use	2006	Inertial compass combined with a star camera

V. Conclusion

Applications of MEMS technology in microwave components and subsystems ore growing very rapidly. This technology is very attractive for insertion in communications satellites where, size, weight, and cost reductions are essential. Implications of this technology for these demanding systems were discussed and examples of candidate satellite MEMS components were shown.

We have presented several applications of MEMS components for space, going from simple integration of earth-bound, commercially available components, to highly dedicated and specially designed instruments. We can conclude that using MEMS instead of large scale components can help us reduce the power, size and cost of the satellite.

References

[1] Slawomir Jerry Fiedziuszko,"Applications of MEMS in Communications Satellites Space Systems", LORAL 3825 Fabian Way, Palo Alto, CA.

[2] H. Helvajian,"Microengineering Aerospace Systems", the Aerospace Press, 1999.

[3] S. Cass,"MEMS in Space", IEEE Spectrum, p.56, July 2001.

[4] Robert Osiander, M. Ann Garrison Darrin, John L. Champion (Editors),"MEMS and Microstructures in Aerospace Applications", CRC (2005) 400 pages, Chapter 11, Micro propulsion technologies, J. Schein, pp. 229.

[5] N. B. H. van der Schoot et al,"Microsystem technology for biological experiments in space, development of a miniature bioreactor", Proceedings Transducers '93

[6] Joel Reiter, Thomas Schetter, Brian Tjaden, Rob Grover, "Intelligent Satellite Teams for Space Systems", NASA Institute for Advanced Concepts (NIAC).

[7] Aaron Burg, Azeem Meruani, Bob Sandheinrich, Michael Wickmann,"MEMS Gyroscopes and Their Applications".

[8] Larson W., Wertz J. Torrance,"CA: Microcosm, Space Mission analysis and Design", 1992.

[9] He, Nguyen, Hui, Lee, Luong,"Design and Analysis of a Micro-gyroscope with Piezoelectric Plate Smart Material Structures", 1999, Vol. 8., pp. 212-217.

[10] Gijs Krijnen, Niels Tas,"Micromechanical Actuators", MESA+ Research Institute, Transducer Technology Laboratory University of Twente, Enschede, The Netherlands.

[11] Hartmut Janocha,"Micro actuators-Principles, Applications, Trends", Laboratory for Process Automation (LPA) Saarland University, Saarbrucken, Germany.

[12] Jongkwang Lee, Taegyu Kim,"Micro space power system using MEMS fuel cell for nano-satellites".

[13] J. Lee, T. Kim,"Micro PEM fuel cell system with NaBH4 hydrogen generator", Sens. Actuators Phys. 177, 2012, pp. 54–59.

[14] James Brank, Jamie Yao, Mike Eberly, Andrew Malczewski, Karl Varian, Charles,"RF MEMS-Based Tunable Filters", -+ Goldsmith Raytheon Systems Company, Dallas, Texas.

[15] Tetsuhito Arakawa "Study of MEMS Devices for Space Applications", The 20th Microelectronics Workshop October, 2007.

Ravishankar S. Dudhe received his B.E. degree in Electronics from Nagpur University, INDIA, in 1992, the M.Tech. degree in Microelectronics (VLSI) from Indian Institute of Technology (IIT) Bombay , INDIA, in 1999, and the Ph.D. degree in Organic Field Effect Transistor based Electronic Nose platform for Explosive Detection from Indian Institute of Technology (IIT) Bombay , INDIA, in 2011. He was a lecturer, Assistant professor, Professor with Department of Electronics and Telecommunication, Mumbai University, in 1992, 2000 and 2011 respectively. His research interests include microelectronics, VLSI, MEMS, Nano technology, Embedded systems and organic Electronics. He has written six books and a book chapter as well. At present, He is working as an Associate Professor and Program Coordinator in Electronics and Communication department, School of Engineering and IT at Manipal University, Dubai.

Tithi Desai received her B.Tech degree in Electronics and Communication from BITS Pilani-Dubai, UAE, in 2012, and is currently pursuing her M.Tech degree in Digital Electronics and Advanced Communication from Manipal University Dubai, UAE. She is working with one of the biggest cloud computing companies as an IT Analyst. Her research interests include satellite communication, MEMS, VLSI design and nanorobotics.