Nano-satellites Design, Development, Implementation and Application

Ajo George
B.Tech-Mechanical Student, PES University, Bangalore, India

Abstract - The increase in the use of Nanosatellites has lead to its advancement in its research and development, for its use in a wider range of applications. The cost effectiveness and functionality of these systems, in the applications such as multi point in situ data collection, in orbit inspection of larger satellites and low data rate communication using constellations of Nano-Sats has preferred it over larger satellites.

The CubeSat initiative which is being undertaken by different Universities around the world has brought about much advancement in Nanosatellite technology. Projects such as the QB50 strive to launch constellation of CubeSats for multi point in situ data collection, using a low cost launch vehicles to explore the lower thermosphere. In orbit demonstrations such as the study of re-entry of satellites, autonomous formation flying and in orbit rigidisation will be studied using the QB50 project. The project by NASA-GSFC in the magnetospheric constellation mission, which is a part of the Sun-Earth connection program, provides deeper knowledge on the impacts of space weather. The mission also incorporates miniaturized instrument technology such as the Energetic particle detector and spacecraft technologies such as Radiation hardened processors.

The paper has addressed satellite subsystems and technologies that are being miniaturized to be used in Nanosatellites. The low cost launch vehicles and their implementation along with separation systems such as the XPOD and PPOD are being analyzed. The Nanosatellite market and the demand for more efficient and cost effective implementation have been discussed in the paper.

I. INTRODUCTION

Nano-satellites are miniaturized satellites which have a wet mass of 1-10kg. They are usually deployed in groups called as "satellite swarms" or "satellite constellations". They typically have a lifetime of about three years and above. Due to their small size, they have also been employed as Fractional Satellites wich are more robust and flexible than large monolithic satellites. The satellites orbiting in formation can constitute a web, gathering information in situ, and hence analyzing data over a much wider area, as compared to the normal single unit satellites.

The NanoSats being smaller compared to the regular satellites, put forward a number of design and development challenges. The challenging areas include, the thermal design, propulsion and radiation shielding. The size of the satellite compel us to use integrated circuits which are more susceptible to radiation outside the atmosphere. This also makes us incorporate multifunctional systems into the design of the Nanosatellite.

Due to the increase in the use of Nanosatellites, organizations such as NASA are using consumer electronics to leverage the development of these satellites. This has started the commercialization of Nanosatellites in the industry, the use of commercially of the Shelf (COTS) components have allowed NanoSats to be mass produced. Companies have also developed open source software, specifically for the use of Nanosatellites.

Many organizations around the world are also setting up standards for the use of Nanosatellites, such as the CubeSat standard, which is allowing the development of Nanosatellite technology on a global scale.

The use of Nanosatellites in developing countries such as in India, could be a boon to its development. The Indian population has 70% of its people still living in rural areas. Communication using these satellites would expand our reach to people dwelling in remote parts of the country.

II. STRUCTURAL SYSTEMS

The challenge of integrating the capabilities of a larger satellite into a smaller one is of prime concern, with respect to Nanosatellites. The structural capabilities of the Nanosatellite are to match the functionalities of the larger satellites, this required miniaturizing the many subsystems present in a satellite.

A. Thermal Design

The closed packed structure of Nanosatellites makes its thermal design a challenge. The prime objective of the design is that the temperature gradient within the satellite structure must be maintained within certain limits. The NASA MMS mission controls this by having multi-layer insulation blanket inbetween the solar arrays and the highly conductive decks. The conductive decks are used for uniform distribution of heat within the satellite. The decks are also exposed, to radiate any excess heat, by the use of diamond radiators. In CubeSats, if the temperature was to drop under a certain level, miniaturised heaters could be used. To control the temperature of sensitive material such as batteries, they can be separately insulated by materials such as aluminium so as to also prevent deformation under the vacuum environment.

B. *Electrical power system (EPS)*

Most of the Nanosatellite missions use solar cells for power storage. GaAs solar cells are the generally used solar cells, due to their high conversion efficiency. Silicon cells are also used, even though they have low conversion efficiency, they are used as they are much cheaper than Ga As solar cells. The magnetospheric mission by NASA-GSFC uses an integrated module for the power systems. It is a module which also acts as a structural support for the satellite, forming the side panels. The panel consists of a solar array on the outer side, while the inner side is composed of a flat cell battery along with miniaturized electronic modules. The CubeSat mission utilizes a centralized or a distributed architectural system. Power needed is stored in secondary rechargeable, high capacity lithium ion batteries.

C. *Integration and Fabrication*

Satellites have unique designs which are specific for their particular mission. The shell design is finalized after taking into consideration many factors such as, the environment in which it will be operating, the payload needed and the equipment it will be carrying. Factors such as simplicity in fabrication and integration, will effect the overall cost of the satellite especially while deploying satellite constellations. Designing the structure is done after taking into consideration both the static and dynamic equilibrium of the satellite. The GSFC program uses an octagonal prism as the design, to reduce voltage fluctuation and is straighter forward in fabrication compared to a cylindrical structure. Structures such as hexagonal prisms can also be used, which are similar to HookSat structure. In CubeSats, as the name suggests are cubical in shape which have standards such as, 1U (10x10x10cm), 2U (20x10x10cm), and 3U (30x10x10cm). The framework is made up of aluminium, to have a rigid, yet light weight structure. The structure will hold the multifunctional modules and also allow free passage for thermal conduction. Advances in structures, such as the use of silicon stacks along with the aluminium framework have been used. It is seen that the silicon stacks increase both the stiffness and reduces the stress in the framework of the satellite.

D. *Propulsion*

Large satellites have large propellants which can be used for altitude control of the satellites. In the case of Nanosatellites propulsion is a problem due to its size and mass constraint. New research is being done in this field of Micropropulsion which are specifically meant for Nanosatellites. The thrust produced can come from both an electrical thruster and a chemical thruster such as a solid rocket propellant. Projects such as the NASA GSFC program, the Nanosatellite has a solid rocket propellant which has been integrated into its structure. This provides high rigidity which is obtained from an array of filament-wound pressure tanks. The research in this field is mainly in two directions, using Micro-Electro Mechanical Systems (MEMS) technology and hybrid technology. The MEMS technology looks into miniaturizing existing propulsion systems, where as hybrid technologies are looking into technologies such as cold gas thruster, pulsed plasma thrusters and subliming solid thrusters.

III. REMOTE SENSING AND DATA TRANSMISSION

The use of satellites has revolutionized remote sensing on a global scale. This has allowed us to expand our understanding not only of the atmosphere but also of the lands and waters of the world. This allows us to collect information on topics such atmospheric pollution, ocean dynamics and topographic surveys. Atmospheric properties can be measured to predict weather and also for early warning systems for natural disasters such as earthquakes and tsunamis. Particle detectors designed specifically for Nanosatellites can measure radiation environments, which is being done in missions such as the magnetospheric mission by NASA. The low energy particle imaging spectrometer, developed by Boston University is specifically designed for a Nanosatellite application. The sensors used in these satellites detect not only, earthly phenomenon but play an important role in detecting and predicting space weather.

Few of the components used in satellites are vulnerable to radiation, therefore the vulnerable electronics are identified to provide sufficient shielding from radiation. The processors in these satellites are radiation hardened processors like the RAD750, which has a clock speed of about 200MHz and can withstand radiation of 100,000 rads along with a temperature fluctuation between -55°C to 125°C.

Data communication with the satellite is normally done using COTS transmitters that can transmit data at reasonable rates. Due to the increased development of commercial electronics, companies such as AeroAstro are developing X-band transponders. These miniaturized transponders will be used in NASA's Nanosatellite Constellation trailblazer mission.

The cost efficiency of NanoSats, has made it an interest for many companies to develop open source software and kits that can be used by individuals and educational institutions in developing Nanosatellites. Projects like the ArduSat is the beginning for individuals to design and develop their personal satellites. The ArduSat is an Arduino based Nanosatellite, which can be used for applications such HAM radio, meteor hunting or as hobbies for amateur space enthusiasts.

IV. FORMATIONS AND FLIGHT CONTROL

Altitude stabilization is necessary for satellites for a number of reasons, a few of which are communication with ground station, for precise data collection and to maintain heating and cooling effects of the sun. Due to the small size of transponders used in Nanosatellites, these satellites occupy low earth orbits (LEO).

Altitude stabilization in NanoSats can be obtained by methods such as, Gravity Gradient, Passive Magnetic and aerodynamic stabilization. Gravity Gradient stabilization, is a method of maintaining orbit of a satellite by using the inertia of the satellite along with the gravitational field around the satellite. CubeSat missions are mainly aimed at detecting space weather in the lower earth orbits, therefore the Passive Magnetic Stabilization is the most appropriate method to stabilize the satellite. As the NanoSats occupy LEO's, this allows them to use the Passive Aerodynamic Stabilization technique using aerodynamic drag present in the lower earth orbit.

Increasing applications of Nanosatellites have made them mainly use in constellations. An example of such an undertaken mission is the Magnetospheric constellation mission done by the NASA-GSFC program. The QB50 mission consisting of a string of networked CubeSats is a constellation mission undertaken by different universities around the world. The project is an educational and research mission, to study phenomenon such as the temperature and deceleration in re-entry of a satellite. Formation and mission is so designed so that even if few of the satellites fail, the project will be able to complete its mission of multi point in-situ data collection.

Nanosatellites also have the capability of acting as fractional satellites, each satellite performing a unique task but part of the same mission. Projects such as the DARPA-F6 mission, shows how fractional satellites can be more robust and flexible than single unit satellites. In both the cases one of the satellite of the group act as the server satellite which collects data from the rest of the group members to communicate with the ground station.

V. DEPLOYER SHIP AND LAUNCH SHUTTLE

As the demand for Nanosatellites increase along with its functionality, larger satellites would become obsolete. The small size of the satellite does not require large launch services to get them into orbit, this has started the use of small launchers. Organizations such as the space flight laboratory (SFL) from the University of Torronto, provide low cost launch service for nano, micro and small satellites. It was initially started for the the CanX programme but soon expanded to include programs from the entire world. Most of the Nanosatellites are secondary or tertiary loads, on a large launch vehicle with a monolithic satellite. The small launch vehicles use either solid or liquid launch propellant, at different stages to get weights of a couple of tens of kg's into a low earth orbit.

The small size of the Nanosatellite makes it have a unique deployer mechanism. The CubeSat mission employs a Poly Picosatellite Orbital Deployer (P-POD) for deploying their Nanosatellites. P-PODs are used to deploy specific configurations of CubeSat satellites. The SFL has designed an independent deployer mechanism called the XPOD which can be customized for any dimension NanoSat up to 16 kg.

The three mechanisms used in the NASA GSFC program are the classic clamp-band, rear tension member and the clamp member mechanism. Classic clamp-band device mechanism could be used, but due to the requirement of a spinning release it is not feasible. The rear tension member mechanism is a Frisbee mechanism which allows a spin release. The clam-member mechanism incorporates both the concepts of the above two mechanisms, which allows in easy integration into the space craft.

VI. SPACE STANDARDS AND REGULATIONS

The increased application and commercialization of space has deemed it necessary to have standards and regulations governing its use on a global scale.

The ISO has proposed standards and safety regulation for the technical safety and implementation while developing satellites. Standards for launch vehicle, ground support systems and protection from environmental have been set up. Countries involved in space activity will have to comply with the international treaty adopted by the United Nations. The requirements for integrated risk management and safety during testing must be monitored and controlled according to the rules defined under their respective domains.

VII. NANOSATELLITE MARKET AND APPLICATION

Space had been a relatively unexplored and inaccessible part for majority of the countries of the world till a few decades ago. The advancement in electronics for commercial use has leveraged the accessibility of space. Nanosatellites have been promising in the application of private use of satellites. Due to their small size and use of commercial electronics has allowed many organizations, including educational institutions to invest in Nano-satellites.

The applications of NanoSats include in orbit inspection of larger satellites. The loss of the space shuttle Columbia, shows the importance of independent inspection of the satellites. AeroAstro have been designing microsatellites for accompanying missions for larger satellites. The escort will do in situ inspection around the satellite, under supervision or can be made to hibernate.

VIII. CONCLUSION

The 21st century has brought about global advancements in the fields of computation and communication. Humanity is ever expanding into space, bringing the stars of the universe closer than ever before. In our connected world, the very standard of our living depends on the multiple data inputs we receive from this world of surging information and knowledge. The commercialization of space, has made NanoSats the critical link in the evolution of the space market.

This has allowed developing nations such as India to have greater opportunity in developing and investing in Nanosatellite technology. The global village of our connected world has made space accessible to people throughout the world. This will allow countries like ours to advance its commercialization of space in the international market.

IX. REFERENCES

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