

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

A Survey on Smart Materials to Mitigate Spacecraft Charging

Bindu S¹, Priya R Sankpal², Lakshmi Bhaskar³

Associate Professor, Department of Electronics & Communication Engineering, BNM Institute of Technology,
Bengaluru, Karnataka, India¹

Assistant Professor, Department of Electronics & Communication Engineering, BNM Institute of Technology,
Bengaluru, Karnataka, India^{2,3}

ABSTRACT: Satellites in synchronous orbits exhibited unexplained behaviour of the electronic components present within it. The reason being space charging phenomena wherein the satellites are charged to large negative voltages by energetic electrons in the space environment. The space environment is plasma. In the recent years, on-orbit failure has been an issue. It is believed to be caused due to internal charging effects i.e. charging and electrostatic discharge events. In this paper we discuss the effects of spacecraft charging, the mitigation methods already in use and alternative method to combat the aforesaid problem.

KEYWORDS: Spacecraft charging, Space Plasma, surface charging, Deep dielectric charging, Mitigation, Conducting Polymer, PEDOT – P Polymer.

I. INTRODUCTION

Amazed by the unknown boundaries of the cosmic world, we have been attempting to explore celestial structures in the outer space by both human spaceflight and unmanned robotic probes. In reality, space is a dynamic place that is filled with charged particles, radiations and trillions of objects. The velocities range from zero to speed of light. Space environment is dynamic and has a complex structure. A few major constituents which includes electric and magnetic fields, solar radiation, plasmas, meteoroids, charged particles and space debris, each of which can cause serious damages to a spacecraft, deteriorating its lifetime and performance. A spacecraft will be driven by two sources due to any electric and magnetic fields on or near it, they are spacecraft electromagnetic interference associated with the hardware and fields associated with the interaction of the spacecraft and its environment which is dominated by plasma interaction. The interactions between a space system and its environment gives rise to multitudinous modifications in its intrinsic environment which affect the system behaviour. Numerous satellite failures and operational anomalies have been reported since the beginning of the 'space age', a significant number of which were attributed to the phenomenon of spacecraft charging and to the radiation effects on electronic systems. Rockets and satellite observations have confirmed that spacecraft charging exists and poses dangers to spacecraft operations. Several spacecraft's were launched in this period to collect, analyse and understand the effects of spacecraft charging, internal charging phenomena and radiation effects on the onboard electronics systems. SCATHA (Spacecraft Charging at High Altitude) satellite, also known as P78-2. SCATHA was launched to retrieve information about the spacecraft surface charging effects and processes. SCATHA was successful as it gathered engineering and environmental data, which allowed the development of methods/techniques to control charging. SCATHA also collected scientific data for the study of plasma wave interactions and sub storms.

In this paper, we discuss spacecraft charging, mitigation methods, conventional methods to prevent the hazards of spacecraft charging and propose alternative method of using conducting polymer.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

II. SPACECRAFT CHARGING

Spacecraft charging is defined as the phenomena of accumulation of charges both on exposed external spacecraft surfaces and in the spacecraft interior. This effect which is caused by the spacecraft encounter with the sub storm and plasma environment causes changes in the electrostatic potential of the spacecraft surface with respect to its surroundings [1]. Spacecraft charging is caused by the interaction of the spacecraft surface with the plasma environment, solar radiation, magnetic fields and high field electrons. The space system moving through the plasma space attains electrical equilibrium when charges get accumulated on the surface such that net current to the whole system and the individual insulating surfaces are zero. This equilibrium defines the potential of the spacecraft relative to the plasma environment. The spacecraft surface may consist of conductors and/or insulators. For conducting surfaces the equilibrium is established globally while for insulating surfaces equilibrium occurs on point to point basis [2].

Spacecraft Charging Environments

A. Plasma

The Earth's atmosphere is homogeneous up to an altitude of 90km; beyond which the atmospheric molecules are ionized by solar radiation with free electrons and positively charged ions produced in the process. Plasma is defined as an ionized gas which consists of equal number of positively and negatively charged particles. This geomagnetic sub storm environment - the plasma with high particle energies is a primary contributor to the spacecraft charging mechanism, when the spacecraft encounters the plasma environment as shown in Fig.1.

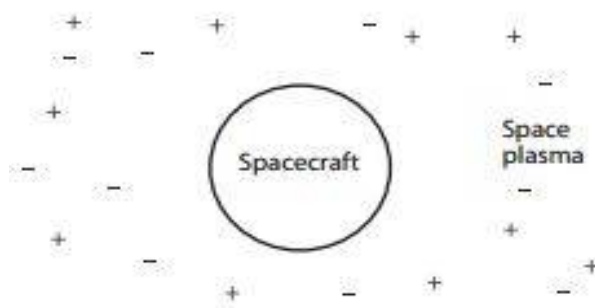


Fig. 1. Depiction of Space Plasma Environment as depicted in [4].

Latitude and Altitude are two major deciding factors of Plasma environment. The particle densities and the energy characteristics of the natural space plasma in Low Earth Orbits(LEO), Geosynchronous Orbits(GEO) and polar Orbits is illustrated in Fig. 2,taken from NASA Reference Publication,1375.

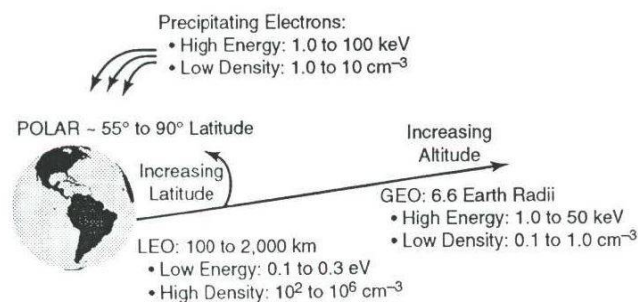


Fig. 2. Properties of natural space plasma.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

B. High energy electrons

The Auroral regions at the high altitude Arctic and Antarctic are populated with high energy electrons which have a characteristic temperature. The potential at the surface of the spacecraft varies directly varies as the electron temperature in the absence of the plasma environment and the photoelectrons. At the auroral latitudes, the low energy plasma component is shown to be reduced and the high energy electrons become beam-like, which triggers high level surface charging in these latitudes.

C. Solar Radiation

The UV (Ultraviolet) and EUV (Extreme Ultraviolet) photons generated have a considerable impact on the surface charging. The EUV is a solar radiation that covers the wavelength 10-120 nm of the electromagnetic spectrum. It is highly energetic and absorbed in the upper atmosphere due to which it ionizes the upper atmosphere. These photons interact with the spacecraft surfaces, undergo photoelectric effect and photocurrent is generated that hugely drives the charging effects.

D. Magnetic Fields

Earth's magnetic field influences the motion of plasma and trapped high energy particles. When a spacecraft moves through the Earth's magnetic field, potentials are induced across the spacecraft [3].

Types of Spacecraft Charging

There are two types of spacecraft charging: Surface charging and Internal/Deep dielectric charging. Surface charging is further classified as Absolute charging and Differential charging.

- **Absolute Charging** - Absolute charging occurs when the spacecraft potential is said to be uniform with respect to the ambient plasma environment. Absolute charging occurs when the surface is made of conductors only.
- **Differential Charging** - Differential charging is the phenomena observed when different parts of the spacecraft are charged to different potentials relative to each other. This is observed when the spacecraft surface is made up of dielectric materials. Differential charging is dangerous as it leads to electrostatic discharge (ESD) [3]. ESD is a sudden flow of electricity when two charged bodies come in contact.

Internal/ Deep dielectric charging: Internal charging is the build up of the charges inside the spacecraft due to the penetration of high energy electrons. The charges get accumulated on the subsystem elements. Internal charging is dangerous as it affects the cable wraps, wire insulation, circuit boards, electrical connectors etc [4].

III. SPACECRAFT CHARGING: ASSOCIATED RADIATION ENVIRONMENT

Spacecraft charging can have damaging effects on the spacecraft elements thereby leading to system failure. Therefore the hazards caused by the spacecraft charging must be understood to find a solution to prevent the damages caused by it. Two important orbits for which more charging data exists are the low earth orbit (LEO) and geosynchronous orbit (GEO). LEO is around 100 to 2000 km altitude; GEO is about 36,000 km. At LEO spacecraft experience low-energy, high-density electrons; whereas GEO spacecraft encounter high-energy, low-density electrons. Energy level affects voltage potential whereas density determines charging current density. The space radiation environment can be classified into trapped radiation environment and non-trapped radiation environment [2].

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

[1] *Trapped Radiation Environment*

It includes Van Allen Radiation Belt and South Atlantic Anomaly.

1) *Van Alley RadiationBelts:*

This belt consists of electrons and protons. They originate from the decay of neutrons due to the interaction between cosmic rays and low altitude charged particles. The neutron decomposes to proton, electron and neutrinos. Neutrinos being almost massless escape into the cosmos. The protons and the electrons are magnetically trapped by the Earth's magnetic field belts called Van Allen Radiation Belts. The energized Van Allen belt electrons exists in two regions- inner zone and outer zone. The inner zone electrons have energies $< 5\text{MeV}$ while the outer zone electrons have energies around 7MeV . The concentrations of electrons and protons are dynamic in nature i.e. their concentration is affected by solar storms, geomagnetic activities.

2) *South Atlantic Anomaly (SAA)*

SAA is a region where the inner Van Allen belt makes its closest approach to the planet's surface. The result is that the radiation intensity is higher at some altitudes when compared to the other. The anomaly is due to the fact that the Earth's magnetic field is not perfectly aligned with its geographic centers and poles which means that the magnetic field is slightly stronger in the North, leaving the area around Brazil and South Atlantic closer to the radiation belts. SAA is a region of low magnetic field and this presents significant hazards to elements of spacecraft in low altitude, low inclination orbits.

[2] *Non-Trapped Radiation Environment*

This environment consists of solar, galactic rays and solar flare particles which includes high energy electrons and heavy ions.

1) *Solar Cosmic Rays*

Solar Cosmic rays include solar energetic particles consisting of solar flare protons. Alpha particles, electrons and ions are also emitted. They are produced when part of solar magnetic field reconfigures itself. Generally, the flux of the ions is very low but during the solar events the flux is very high that is enough to damage the electronics of the spacecraft.

2) *Galactic Cosmic Rays*

The highly energetic particles of Galactic cosmic rays constantly bombard the Earth. They originate outside the solar system and formed by supernova. The highly energetic particles ranges from hydrogen to uranium each of the atoms are said to be ionized. These rays are highly energetic and have huge amount of energy per nucleon. These particles can penetrate the spacecraft and cause internal charging.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

3) Geomagnetic Field Effects

The geomagnetic field prevents any damage that can be caused by galactic and solar cosmic rays in the low Earth Orbit environment. Geomagnetic shield is less effective for geo satellites therefore the energetic cosmic rays can penetrate the spacecraft [2].

IV. SPACECRAFT CHARGING EFFECTS

Spacecraft Surface Charging has adverse effects on the internal electronic systems; it houses and also interferes with the various scientific measurements. The resulting effect of Spacecraft Charging referred to as electrostatic discharge (ESD) is worthy of concern. The advancements in the integrated circuits technology and microelectronics are reflected even in the design of Spacecraft systems. The electronics on the spacecraft are affected due to Spacecraft charging. The miniaturization of computer chips has also influenced the improvements in the Space related systems with its inclusion in it. Logical circuits are employed alongside these components in the design. However, these delicate electronics are susceptible to charging, anomalies or damage, which results in catastrophes. Undesirable currents entering circuits by conduction, via electromagnetic waves through inadequate shielding or through pinholes may cause disturbances. Such disturbances often cause anomalies in the telemetry of the data of the measurements [3].

Energetic particles of the space environment can impact upon semiconductor devices and lead to transient upsets. The loss incurred due to damage to electronics systems by these effects is huge. Therefore, arises the need to protect the devices against the detrimental effects of Spacecraft Charging.

V. SPACECRAFT CHARGE MITIGATION BY CONVENTIONAL METHODS

The effects of Spacecraft Charging on the electronics systems in the spacecraft is found to be controlled by making all the spacecraft surface materials conductive. Surface coatings in use for this purpose include conductive conversion coatings on metals, conductive/antistatic paints, and transparent partially metallic vacuum deposited films, such as indium tin oxide. Eltron Research and Development created antistatic paint which has silent discharge capability for protecting the spacecraft polymers from attack by atomic oxygen thereby prevents charge buildup. This paint is used to bleed out the charges accumulated on the polymers to prevent discharge of static electricity. This paint adheres well with a number of metals, ceramics and plastics. They are nonflammable and contain no volatile components [5].

The usual method for radiation protection is material shielding by equipment and spacecraft structures (usually aluminum), possibly augmented by polyethylene in human spaceflight where the main worry is high energy protons and cosmic ray ions. Additional shielding with materials of a high atomic number can be advantageous on unmanned spacecraft in high electron dose environments such as medium Earth orbit (MEO) or Jupiter missions. On long duration manned missions, advantage can be taken of the good shielding characteristics of liquid hydrogen fuel and water. Hydrogen does not fragment when impacted by radiation and it does not re-radiate like metals. Additionally, hydrogen can diffuse or break down radiation. But, it has its disadvantages. A few notable disadvantages of using Hydrogen are that it is potentially flammable in its gaseous state and, in that state, tends to permeate through many materials. Another solution is to coat the surface with a thin layer of conducting polymer material [5].

VI. PROPOSED ALTERNATIVE TO COMBAT SPACECRAFT CHARGING EFFECTS

Conducting polymers are semiconducting materials having several unique properties which combine that of both metal and polymers used for variety of applications [6, 7]. Semiconducting polymers have conductivities ranging from semiconductor to metals which are light weight and hence an alternate material to conductive paints used for space craft discharge. Researchers have reported that polymers having excellent metallic conductivity have the ability to

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

prevent space charge hazards [5]. Conductive polymers are precisely referred to as intrinsically conducting polymers. These are organic polymers that conduct electricity. The greatest advantage is their processability, mainly by dispersion. There are several conducting polymers available but only few are highly conductive enough to be used for spacecraft discharging. It is reported that PEDOT-PSS [8] (Poly (3, 4-ethylenedioxythiophene) polystyrene sulfonate) and Poly aniline can be coated onto the subsystems to remove the static charges.

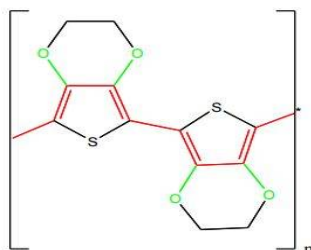


Fig. 3. Chemical Structure of conductive polymer poly (3,4 ethylenedioxythiophene) PEDOT [11].

Poly (3,4-ethylenedioxythiophene) or PEDOT is a conducting polymer that has attracted the attention of scientists during the last decade. It is based on 3, 4-ethylenedioxythiophene or EDOT monomer as represented in Fig. 3. The advantages of this polymer are high stability, optical transparency in its conducting state and moderate band gap and low redox potential. However, a large disadvantage is witnessed in its poor solubility.

The solubility problem of PEDOT is overcome by using a water-soluble polyelectrolyte, poly (styrene sulphonate) (PSS) as a charge-balancing dopant during polymerization to yield a PEDOT/PSS aqueous composite that is believed to consist of a colloidal suspension in which PEDOT chains decorate segment of higher molecular weight PSS chains and in which there is a changeable excess of PSS.

PEDOT: PSS has a conductivity of 10 S/cm. However, after doping with redox, the conductivity can be improved up to several hundred S/cm. The combination, PEDOT: PSS was first developed extensively by the scientists at the Bayer AG research laboratories located at Germany in the late 1980s, which resulted in a water-soluble polyelectrolyte system with visible - light transmission, good film-forming properties, high conductivity and excellent stability.

Addition of organic compounds such as sorbitol, ionic liquids further increases the conductivity of PEDOT: PSS by many orders of magnitude. Spectroscopic methods such as Raman, Infrared (IR), X-Ray and ultraviolet photoelectron spectroscopy applied to the investigation of the electronic structure and characterization of PEDOT:PSS films have resulted in various revelations. The work function of this polymer material changes with PSS quality, thus flexible conductivity PEDOT:PSS films can be formed. Another advantage of PEDOT:PSS in view of our proposal is its transparency and high ductility. Nearly 200 million photographic films produced in a year are coated with a thin, stretched layer of virtually transparent and colorless PEDOT: PSS. PEDOT: PSS is used as an antistatic agent to prevent electrostatic discharges during production and during the film use. The major distinct supporting stance to our proposal is that PEDOT: PSS has the desired higher conductivity for Spacecraft Charging prevention. It can mitigate the charge build up in applications on advanced Spacecraft, particularly on large ultra light weight space structures. It can replace the conventional surface shielding by aluminium for all intents and purposes as it has lesser weight than aluminium, suitable for space applications. Further, its conductivity upsurges by post-treatment with various compounds such as Dimethyl sulphoxide (DMSO) [9], ethylene glycol comparable to the conductivity of Indium tin oxide (ITO) which is used as surface coatings in solar cells and Optical solar reflectors. Embedding a network of Carbon nanotubes and silver nanowires into PEDOT:PSS results in increased conductivity triple the magnitude of conductivity of ITO.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 7, July 2017

VII. CONCLUSIONS

Spacecraft Charging is a major concern as it limits the life of the spacecraft and its subsystems. Numerous space failures have occurred from the beginning of space age, significant number of which is contributed by the phenomenon spacecraft charging. Static Charges that build up on the satellite produce an intense electromagnetic pulse that tend to destroy the delicate electronic components. In this paper an attempt was made to highlight the effects of spacecraft charging, the mitigation methods already in use and alternative method to combat the aforesaid problem. PEDOT: PSS a conducting polymer collects the static charges on the subsystems and ejects it to the plasma state. By using conducting polymers the weight of the subsystem is not affected and with the same fuel the spacecraft can travel more altitude. This conducting polymer increases the lifetime of the subsystem and in turn the spacecraft.

REFERENCES

- [1] Carolyn K Purvis, Henry B Garrett, A C Whittlesey, N John Stevens, "Design Guidelines for Assessing and Controlling the Spacecraft Charging Effects", *NASA Technical Paper 2361*, 1984.
- [2] Tsoline Mikaelian, "Spacecraft Charging and Hazards to Electronics in Space", *Physics of the Space Environment*, May 2001.
- [3] "Introduction to Spacecraft Charging", *Princeton University Press, Princeton*, princeton.edu.
- [4] Roeder, J. L., and J. F. Fennell. "Differential charging of satellite surface materials." *Plasma Science, IEEE Transactions on* 37.1 (2009): 281-289.
- [5] R J Fleming, "Space Charge in Polymers particularly Polyethylene", *Brazilian Journal of Physics*, vol. 29, no. 2, June, 1999.
- [6] Bindu, S., R. Anil Kumar, and M. S. Suresh. "Development of technique for making Ohmic contacts to PEDOT-PSS films." *Proceedings of International Conference on VLSI, Communication, Advanced Devices, Signals & Systems and Networking (VCASAN-2013)*. Springer, India, 2013.
- [7] Bindu, S., and M. S. Suresh. "Ohmic Contact Formation to PEDOT-PSS Films Using Graphite-Clay." *British Journal of Applied Science & Technology* 6.4 (2015): 342.
- [8] Wilfried Lövenich, "PEDOT—Properties and Applications", *Polymer Science, Ser. C*, 2014, Vol. 56, No. 1.
- [9] Bindu, S., and M. S. Suresh. "Measurement of bulk resistance of conducting polymer films in presence of rectifying contacts." *Intern J Sci Res Pub* 19 (2014): 15.