Abstract

The spacecraft charging causes hazardous interactions between the spacecraft skin and space energetic plasma. The spacecraft charging disturbs the scientific experiments and measurements onboard, affect communications, handling and navigation of the spacecraft. Different mitigation methods have not only been proposed but also tested. a) Passive methods using sharp spikes and high secondary emission coefficient surface materials. b) Active methods using controlled emissions of electrons, ions, plasmas, neutral gases and polar molecules. Mitigation method for deep dielectric charging has also been discussed. Advantages and disadvantages of the mitigation methods have not only been discussed critically but ideas have also been illuminated by shedding light on the results obtained from SCATHA (Spacecraft Charging at High Altitudes) and DSCS (Defence Satellite and Communication System)
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1. Introduction:

The main reason behind the spacecraft surface charging is the difference between the ambient electrons and ions fluxes. The electrons are faster than ions because of their huge mass difference. Therefore the surface has more interaction with fast moving electrons than ions. On account of this, the skin of the spacecraft becomes highly negatively charged. It has been observed that photoemission process comes into play in sunlight and photoelectrons leave the surface of the spacecraft giving the surface positive potential as shown in fig1b. The photo electrons have a few electron volts average energy, so photoelectrons can not leave the surface, if the surface of the craft gains high enough positive potential. It has also been observed that, in the absence of sunlight, the differential charging becomes prominent as the photoemission process becomes less concerned. The positive ions which are in the sheath of the negatively charged surface become attracted but the negative ions are repelled by the negative potential of the surface as shown in fig1a. The spacecraft charging is of intense interest for communication satellites which are usually at geosynchronous altitudes or in GEO Earth Orbit.

In case of the ionosphere, the spacecraft charging becomes less important because of high density, low energy and ambient charges of opposite sign may neutralize any charged surface effectively except in the auroral region where highly energetic particles slide down from high altitudes and make the spacecraft charging issue hot potato. The spacecraft charging enhances the surface contamination which degrades the thermal properties of the material. Solar radiations can ionize the molecules which are still in the spacecraft plasma sheath and can be reattracted to the negatively charged surfaces. The more the negative potential on the surface, the more the probability of the surface contamination [1].

Fig1. [2].
2. Mitigation Methods:

The basic theme behind the mitigation methods is to design or engineer the spacecraft in such a way that they minimize the chances of spacecraft charging or make it less severe. The best thing is to adopt prevention (to prevent the building up of high potential on the spacecraft surface relative to the ambient plasma) which is really a difficult job because the space environment is inhomogeneous and varies by the orders of magnitude and further it depends on the properties of the materials.

2.1 Kinds of Mitigation Methods:

Mitigation methods are generally of two kinds (1) active (2) passive. The active kind of mitigation method is controlled by commands; on the other hand, the passive one is automatic i.e. without commands.

2.2 Famous Ways to Mitigate Surface Charging:

In order to mitigate the surface potential, electrons and ions can be transported from the spacecraft to the ambient plasma. The famous ways to do that are 1) ejection of electrons 2) ejection of ions 3) the ejection of both electrons and ions.

2.3 First Approach:

If the spacecraft is negatively charged, the 1st approach of ejection of electrons can be followed. In which a device draws the electrons from the spacecraft ground and throws them into space. This method is effective only for negatively charged surfaces but ineffective for the mitigation of the surface potential of dielectric materials. On account of this, differential charging arises between the dielectric materials and spacecraft ground which paints even a worse picture of the situation than before.

2.4 Second Approach:

In the second approach of ejection of ions, the ions turn back to the spacecraft. This method is effective (ions neutralize the negative charges) in mitigating a negatively charged surface regardless of the material being dielectric or conductor. If the ions are very energetic then they can be used as secondary electron generators as shown in fig2. These resulting secondary electrons are repelled by the negative surface potential and thus the electrons carry away negative charge with them reducing the negative potential on the surface. This technique is effective to mitigate the differential potential.
2.5 Sharp spike method:

In sharp spike method, the sharp spikes arising from the charged surfaces are known to have very strong electric field $E$. It has been experimentally observed that the electric field $E$ at the tip of the spike is proportional to $r^{-2}$.

$$E \propto r^{-2}$$

Where $E$ is the electric field and $r$ is the radius of curvature of the tip. At very high electric fields the electrons which are ejecting out of the conducting surfaces consequently reduce the negative potential of the conducting surfaces in touch with the spikes as shown in the figure.

The current density $J$ can be given by the Fowler Nordheim Equation.

$$J = A E^2 \exp \left(-\frac{BW^{3/2}}{E}\right)$$

Where $W$ is the work function of the metal.

A & B are constants and their values can be determined from the boundary conditions.

$E$ is the electric field.

$J$ is the current density.

The disadvantage associated with this passive method is, during emission the electrons are drawn from the conducting ground. On account of this, differential charging may arise. The other disadvantage is that of ion sputtering (a process whereby atoms are ejected from a solid target material due to bombardment of the target by energetic ions) which can make the tip blunt and field emission ineffective, because the ambient positive ions are attracted towards the electrostatic field of the tip. Now the important thing is how can we avoid sputtering? One way is to shield the spike tip by means of ceramic material.

Fig 3a. Electrons emission from a sharp spike and a hot filament [1].
2.6 **Hot Filament Emission Method:**

As the name suggests the electrons are emitted from hot filaments. The filaments that are used in this method are hot or non-melting filaments otherwise we will have ion or plasma emission. Richardson's thermionic emission reads the formula for current density as follows.

\[
J = AT^2 \exp\left(-\frac{W}{KT}\right)
\]

Where \(J\) is the electronic current density.
- \(A\) is the constant.
- \(T\) is the temperature.
- \(W\) is the work function of the metal.
- \(K\) is the thermal energy of the electrons.

Since the electrons carry away negative charge with them therefore they are effective to reduce the charging level of the spacecraft ground but at the same time this method is ineffective for dielectric materials, because such situation is favorable for differential charging. [1]

2.7 **The electron and ion emission method:**

If we want to mitigate the negative potential of the spacecraft then it can not be achieved only by the emission of electrons. The emission of low energy ions is highly effective in mitigating the negative potential of the charged surfaces and it has been experimentally confirmed from SCATHA (spacecraft charging at high altitude). The scientist prepared computer simulations in order to have deeper understanding of this phenomenon. The positive ions can’t go far away from the surface of the spacecraft.

\[e\phi_s\] Represents the potential energy of the spacecraft.

\[e\phi_i\] Represents the potential energy of ions.

The mitigation process will remain effective, if the following condition holds.

\[\phi_s > \phi_i\]

For instance, if positive ions of energy -1 keV are emitted from the surface of the spacecraft having potential -3 kv. The ions can’t escape and return to spacecraft where they not only land at hot spots but also emit secondary electrons. The emitted secondary electrons are repelled and hence they take away negative charge with them reducing negative potential as shown in fig4. When the spacecraft potential becomes -1 kv and equilibrium is achieved then further mitigation stops.
2.8 DSCS Charge Control Experiment:

An active and effective mitigation method of spacecraft charging is the emission of both electrons and ions i.e. plasma. It unifies the advantages of electron and ion emission method. This charge control experiment was carried out on DSCS and the results support its effectiveness. DSCS at the GEO altitude along with two dielectric materials i.e. Kapton and Quartz on the ram side of the satellite. A device called field mill was in contact with the two materials which recorded the potential difference of the samples relative to the spacecraft ground. A spacecraft in sunlight has a little positive potential. When the dielectric material Kapton gains a potential of -1.5 kv an ionized gas i.e. Xenon is released automatically or by command. In fig 5 and 6 the upper panel gives the release rate of the plasma from DSCS. And the lower panel gives Kapton (red) and Quartz (green) potentials relative to spacecraft ground. Fig.5 shows, on day 67,1999 Kapton charges to -2 kv and Quartz up to -1.4 kv relative to the spacecraft ground. At about 10000 UT the plasma starts releasing. Potential responses quickly and instantly decrease to its initial charging level. The release stops at about 13,000 s. Fig. 6 illustrates a similar release on day 116, 1998 as a mitigating way. Once charging is stopped, it starts again at about 10, 000 s.
Fig 5. Mitigation experiment on DCS, day 67, 1999. The top panel indicates the plasma release rate (arbitrary units) from DCS, and the lower panel gives the kapton (red) and quartz (green) potentials relative to the ground [1].

Fig 6. Mitigation experiment on DCS on day 116, 1998 [1]

Fig 7. Mitigation experiment on DCS, day 106, 1996 [1].
In fig.7 on the day 106, 1996 there is no indication of plasma release even the relative potential of Kapton is -3.5 KV which is of course greater than -1.5 KV and shows absence of potential control.

### 2.9 Deep Dielectric Charging:

When a spacecraft is orbiting in Polar Regions at an altitude of low earth orbit (LOW) the spacecraft suffers deep dielectric charging. The flux of auroral electrons falls on the insulators of spacecraft which become a cause of accumulation of huge space charge within the material. This charge accumulation causes high electric field within the material. Metalized dielectric materials can be useful and effective in mitigating deep dielectric charging. When metal atoms are introduced randomly at the interstitial lattice sites of the dielectric materials, they change the conductivity and its spatial distribution is inhomogeneous. For sophisticated electronics, we need homogeneous conditions.

If we introduce atoms at the molecular level instead of interstitial lattice sites, gives an effective trick to mitigate deep dielectric charging. Dielectric discharging may induce large currents within the material which is a potential hazard for astronauts and crews. The mitigation of deep dielectric charging requires us not to use the materials with high internal resistance. [1]

![Fig.8. Current components to a surface on a spacecraft][3]
3. Conclusion:

In this project, we have tried to criticize spacecraft charging and mitigation methods while keeping an eye on advantages and disadvantages of each method. The situation demands, which method should be used either passive or the active one. Some of the mitigation methods like sharp spikes or electron beams are not efficient because they lead to differential charging between metallic and dielectric surfaces. If we use surface materials having high secondary electron emission coefficient, then charging may be avoided in low temperature atmosphere (plasma atmosphere). If the temperature of the electron becomes higher than the critical temperature of the surface material, the surface charging starts again. The active method in which low energy plasmas (electrons and plasmas) are released or the neutral gas which gets ionized when it releases, works efficiently and is highly recommended. With regard to deep dielectric charging, in which metallized dielectrics are produced by introducing atoms at the molecular level instead of lattice sites is effective and efficient.

4. References:

