Satellite anomalies

Satellite anomalies are malfunctions on the spacecraft. In most cases these malfunctions do not affect operations or services, but occasionally an anomaly can have serious consequences leading to interruptions to service, component failure or in extreme events the total loss of the satellite.

Energetic particles can affect satellites in many ways and cause satellite anomalies. Some examples include

- Electrostatic discharge (ESD) arising from internal charging and caused by high energy (MeV) electrons
- Electrostatic discharge arising from surface charging and caused by medium energy (keV) electrons
- Corruption of memory and logic circuits caused by solar energetic particles and cosmic rays, particularly heavy ions

Energetic electrons can penetrate the skin of a spacecraft and build up inside dielectric materials such as cable insulation and insulation in microelectronic circuits. If the charge builds up faster than it can leak away this can break down the material and cause an electrostatic discharge. In some cases this can launch a phantom command which causes the satellite to do something unexpectedly, or result in the disruption or failure of electronic components.

Medium energy electrons can charge up the surfaces of different components on the spacecraft to different potentials. Given that half the satellite is in sunlight and the other half is in darkness, the sunny side is emitting electrons in accordance to Einstein's photoelectric effect while the dark side is not. If the outer surface is not perfectly conducting, or grounded, and a large injection of electrons takes place during a space weather event the surfaces can charge up to very different potentials and cause an ESD.

Solar energetic particles and cosmic rays can penetrate the electronic components on the spacecraft and cause single event upsets which damage the memory and logic circuits. They can also cause temporary blindness in start tracker devices used for station keeping. Solar energetic particle events cause loss of power in solar arrays, by up to 2-3% for one large event.

Satellite anomalies related to space weather

It is very difficult to determine whether the cause of a satellite anomaly is due to space weather due to the lack of information on the space environment and the difficulty of assessment. However, research shows that there is a statistically significant correlation between satellite anomalies and elevated electron flux >2 MeV at geostationary orbit [Iucci, et al., 2005], and a clear magnetic local time dependence of anomalies related to surface charging [Gubby and Evans, 2002].

There are also several other well known events where an anomaly occurred during a space weather event and resulted in a serious loss of service, or total loss. These include:

- On 20th January 1994 Intelsat 4, Anik E1 and Anik E2 all suffered an anomaly resulting in the loss of attitude control. Intelsat 4 and Anik E1 were recovered after a few hours but Anik E2 was only recovered after 6 months. 100,000 customers had to re-point their satellite dishes. The anomalies occurred during a period of enhanced relativistic (>2 MeV) electron flux [Baker, 2001] and most likely cause was identified ad electrostatic discharge due to internal charging by radiation belt electrons [Wrenn, 1995].
- On the 11th January 1997 Telstar 401 suffered an abrupt failure of telemetry and communications resulting in a total loss. The anomaly was traced to an electrostatic discharge that occurred during a space weather event associated with the passage of a magnetic cloud pass the Earth's magnetosphere.
- On 19th May 1998 Galaxy IV suffered an anomaly that caused the satellite to rotate and lose fixed orientation, and the backup system also failed. The satellite was unable to maintain a stable Earth communications link and was lost from useful service, affecting 30 million customers or more relying on telephones, pagers, and other communications devices [Baker et al., 1998]. The anomaly occurred during the highest electron enhancement in1997-1998 suggesting internal charging as the cause of an ESD [Baker, 2001]. The official report suggested an engineering failure.
- Between 23rd October and 6th November 2003 47 satellites reported malfunctions and the Midori 2 scientific satellite costing US$640m was a total loss. These anomalies occurred during the so-called Halloween geomagnetic storm where there were rapid and variations in the radiation belt with enhanced electron flux, and associated solar energetic particle event [Webb and Allen, 2004].
- On 5th April 2010 Galaxy 15 suffered an anomaly and would not respond to ground control. The satellite drifted around geostationary orbit and several other satellites had to take evasive action to avoid

interference. There was also a risk of collision. The satellite ran out of power and was brought back under control in January 2011. Although solar activity was low, the anomaly occurred during a large geomagnetic storm and during passage out of eclipse.

Data on satellite anomalies are very sensitive and difficult to obtain due to the large sums of money involved in constructing and operating satellites. A modern telecommunications satellite typically costs €250m. The cause of a major loss may also be the subject of a large insurance claim and possible legal action.

The SPACECAST project can help reproduce the space radiation environment retrospectively to help resolve the cause of an anomaly.

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