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Effects of Space Weather due to Solar Radiation on High Frequency Communication Technologies

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The effects of Space Weather on technology are manifold and can be experienced in deep space as well as on the surface of the earth. Space weather effecting prevalent technologies on earth are primarily linked to the conditions in space environment, predominantly controlled by the Sun. This article describes the basic facts for understanding processes responsible for space weather effects on (i) satellites, (ii) power systems, (iii) radio propagation, (iv) communication cables and few other technologies. The events under this study are associated with CME's, flares, particle radiations and plasmas of solar origin.

Keywords: Space weather, Satellites, Solar flares, Plasmas of solar origin.

1. INTRODUCTION

The increasing complexity and susceptibility of technological systems to be perturbed by the conditions in near earth space, and with growing dependence of functionalities of society on such systems, space weather has gained considerable importance in the discipline of solar-terrestrial research. In recent years, this has led to implementation or preparation of large scale national and international space weather programs. We have arena of space weather, which occurs within a volume spanned by our entire solar system, over time scales from seconds to weeks and spatial scales from meters to billions of kilometers. Unlike the impacts caused by terrestrial weather, space weather events on the human scale are often much more subtle and change with the particular technology being used. There are, for example, no known space weather events in the public literature that have directly led to the loss of human life. The public reaction to space weather events when announced, seldom if ever reaches the level of urgency of even an approaching, severe thunderstorm. Despite the fact that, since 1990's, we become more sophisticated about communicating to the public about the potential impacts of severe space weather, these alerts are still only consumed and taken seriously by a very narrow segment of the population with technology at risk, satellite owners, power grid operators, airline pilots and the like. The historical record shows that in virtually all instances, space weather events have only led to irritating impacts; disrupted radio-communication; occasional short-term blackouts, and occasional satellite losses that were quickly replaced. Yet, when translated into the 21st century, these same impacts would have a significant larger impact in terms of the number of people affected. For instance, the Galaxy 4 satellite outage in 1998 deactivated 40 million pagers in North America for several hours. Pagers at that time were heavily used by medicos and patients for emergency services, to name only a few types

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of direct impact. Numerically, and in term of function, we are substantially less tolerant of ‘outages’ today than at any time in the past history of space weather impacts.

2. SPACE ENVIRONMENT

Space weather can be considered as solar - induced short-term variability of space environment. A terrestrial regional climate can be described by cyclic variations of conditions and "seasonal" changes of the near-earth space environment, due to the 11 year cycle of solar activity. The effect of space environment of technologies by plasmas and energetic particle radiation and to a lesser extent, magnetic fields and solar electromagnetic radiation are described below.

2.1. Plasmas

Space plasma are encountered in interplanetary space in the forms of solar wind continuously emanating from the sun, and in different parts of the magnetosphere and the ionosphere originating from various sources. The solar wind flows out with a speed of 400 km/s, corresponding to a kinetic energy of just below 1 Kev for protons and has an average density of 5 cm^{-3} at 1 AU. Both the speed and the density are variable, with a 5-95% range of cumulative probability of occurrence of 320 - 720 km/s and 3-20 cm^{-3}, respectively [1]. The two types solar wind from the equatorial regions of the Sun and the faster solar wind originating from coronal holes, usually located in the polar regions of the Sun. The solar wind consists mainly of protons (95% of positively charged particles) with a small portion of doubly-ionized helium and a trace of heavier ions. Electrons are also present in sufficient numbers to make the wind neutral. The effects of solar wind on technologies on ground and even in near - Earth space is indirect, caused by complex interactions of the solar wind and the coupled magnetosphere - ionosphere - atmosphere system. The ionosphere - magnetosphere system contains various plasma regions. At the height of few hundred kilometers (at Low Earth Orbit) the plasma is cold (~1000 k or 0.1 eV) but high density (10^3 - 10^5 cm^{-3}). In the plasmasphere an extension of the ionosphere forming the inner part of the magnetosphere up to a few’ earth radii, the plasma density is typically 10 - 1000 cm^{-3} and the mean kinetic energy of the order of I eV. At the plasma phases, the density drops suddenly, typically to 1 cm^{-3} at geostationary orbit (6.6 earth radii), while the energies are high, typically in the keV range. In the plasma sheet, in the outer magnetosphere on the night side of the earth similar conditions prevail. At high latitude Polar Regions, where the open geomagnetic field lines connect directly to the interplanetary magnetic field, precipitating electrons originating from the super thermal tail of the solar wind are encountered. In these polar regions, the electrons energies are in the keV range and densities a few electrons per cubic centimeter. The magnetosphere plasma characteristics have important consequences for space systems in particular for space craft surface charging.

2.2. Energetic Particles

When considering the "quiescent" space environment (i.e., the space climate), the major sources of high-energy ≥ 100 keV particles are galactic cosmic rays (GCR) and, within the magnetosphere, the radiation belts. Galactic cosmic rays are composed of protons (83%), ^{4}He ions (13%), heavy ions (1%) with significant fluxes up to the iron group of elements (Z=26 to 28), and electrons (3%) GCR are characterized by low intensities and high energies. The energy range where GCR are significant from the point of view of radiation effects on space system extends from about 100 MeV/nucleon up to several 10 GeV /nucleon with power law spectra above a few GeV/nucleons and a -2.7eV spectral slope.

The radiation belts encircle the earth from the top of the atmosphere to the outer edge of the magnetosphere. The trapped particles are composed of energetic protons and electrons and a small number of heavy ions. In orbits passing through the radiation belts, these particles pose the most significant threat to radiation - sensitive systems.

Another source of radiation is the anomalous cosmic rays. The importance of this component is, however, much smaller than that of the GCR or the radiation belts, because at 1 AU the anomalous cosmic rays only have significant fluxes outside the magnetosphere and only at the time of the solar minimum. They also mainly composed of helium, nitrogen, oxygen and some heavier ions at relatively low energies (tens of MeV/nucleon) with a limiting penetrating power. Anomalous cosmic rays are the source of the heavy ions in the radiation belts. Another high energy particle to be taken in to account is solar energetic particle (SEP). The number of expected SEP events is dependent on the solar cycle. In terms of SEP events, the solar cycle consists of seven active years beginning two years before the year of sunspot maximum and lasting four years after the maximum [2] during the rest of the solar cycle the risk of solar particle is low.

2.3. Magnetic Fields

The solar wind carries with it a magnetic field of about 5nT that lies, due to solar rotation, near the ecliptic plane in an Archimedean spiral pattern. It has a wavy structure, which leads to a current sheet separated sector structure with the magnetic field direction alternately towards and away from the Sun. During nominal interplanetary conditions, the Interplanetary Magnetic Field (IMF) has no consequences on technological system in space, but during disturbed periods, when both the direction and strength of the IMF are highly variable, it is the most important parameter affecting the geomagnetic activity together with the velocity and density of the solar wind.

Earth's magnetic field is basically a dipole field, but is strongly distorted by the magnetized plasma of the solar wind, leading to the structure known as the magnetosphere [3]. On the dayside, during nominal solar wind conditions, the boundary' of the magnetosphere is at the distance of 10 R_E. while on the night side it extends to hundreds of R_E. The inclination of the dipole field is about 11° with respect of the earth's rotation axis and the offset from the center of the earth in the year 2000 epoch was 540 km. The geomagnetic field is significant for space weather effects from several respects. It controls the near-Earth plasma environment. The geomagnetic field traps the particles in the radiation belts and control their motion. The tilt of the dipole field with respect to the earth's rotation axis and the offset from the center result in the South Atlantic anomaly, a region where high intensity radiation reaches exceptionally low latitudes due to the low magnetic field strength.

2.4. Solar Electromagnetic Radiation

The Sun emits electromagnetic radiation at all wavelengths from gamma-rays to radio waves. The shape of the spectral distribution is such that the bulk of the solar energy lies between 150 nm and 10 μm with the maximum near 450 nm, i.e., at the visible range of the wave lengths. However, the ultraviolet portion (< 300 nm) of the spectrum is the most important in determining the effects of solar radiations on the upper atmosphere and on technological systems in space. During solar storm conditions X-ray fluxes are significant. The variability of electromagnetic radiation in the visible wavelength range is very small over the solar cycle. Other part of the spectrum can be much more variable both over the 27-day solar rotation period and over the 11-years solar cycle. For the ultraviolet part, the variability can be of the order of factor 2, and can reach orders of several magnitude for flare X-rays.

3. SOLAR EFFECTS ON SPACE ENVIRONMENT

The Sun also emits huge amounts of mass and energy, which control the solar system space environment. The fluctuation in the local energy production at the sun determines the short-term conditions in the space environment. The source of these fluctuations is the changing magnetic activity of the sun. The most important solar activity affecting the interplanetary and near - Earth space environment is explained in the following sections.

3.1. Coronal Mass Ejections

Coronal mass ejections (CMEs) are enormous eruptions of magnetized plasma from the Sun. The erupting material propagates through the interplanetary medium with speeds ranging from only a few km/s to over 2000 km/s. The CME itself contains usually coronal material or heated material from a solar filament and carries magnetic field, which sometimes has an ordered structure of a magnetic cloud. The coronal mass ejections effect technologies in mainly two ways. The direct effect is that often high-energy particles are accelerated in the coronal and interplanetary shocks associated with CME’s. Secondly, CMEs are the primary cause of large geomagnetic storms, which again can cause severe problems for technological systems both in space and on earth’s ground. The sporadic occurrence of very energetic (10MeV - 10GeV) solar particle events has been recognized as one of the most important space weather effects in the near-Earth space. Sudden intense bursts of solar energetic particle events can reach the earth within a few tens of minutes and highly enhanced flux levels (10^4 - 10^5 particles cm^{-2} s^{-1}) can last several days. Coronal mass ejections and their interplanetary counter parts are the cause of the major non-recurrent geomagnetic storms.

3.2. Solar Flares

Solar flares are another important source of space weather effect. Here, X-rays, ultra violet radiation, radio emission and energetic particles play the major roles. The X-rays and UV radiation cause indirect effects through their interaction with the earth’s atmosphere. The flare particle events are generally of lower peak intensity and shorter duration ("impulse") than those associated with CME's.

3.3. High Speed Solar Wind Streams

High speed solar wind streams emanating from coronal holes can drive interplanetary shocks and create intensive magnetic fields when interacting with streams of lower speeds. During low solar activity, coronal holes can be relatively stable, lasting for months and reach low solar latitudes. Therefore, at solar minimum, the high-speed solar wind streams are the dominating source of geomagnetic storms, described in the next section. Together they along with rotation cause recurrent storms with a 27-day pattern.

3.4. Geomagnetic storms and sub storms

Interactions of coherent solar wind and interplanetary magnetic field structures with the magnetosphere cause major disturbances in the geomagnetic field [4]. The dynamic solar wind pressure can compress the magnetopause inside the geostationary orbit, leading to difficulties in space craft with magnetically controlled guidance systems. The most important consequences for space system, however, result from the enhanced plasma and particle environment.

Geomagnetic storms are initiated, when enhanced energy transfer from the solar wind into the magnetosphere in response to CME's or high-speed solar wind streams, leads into intensification of the ring current Geomagnetic activity controls the trapped energetic particle environment, in particular the outer radiation belt electron fluxes. During geomagnetic storms, relativistic electron fluxes are strongly and rapidly enhanced in the outer belt [5,6]. Extended geomagnetic activity can cause 2 to 3 orders of magnitude increases in the greater then 100keV electron peak fluxes, lasting for several days.

An extreme effect of geomagnetic storms on the earth's radiation environment is the creation of new radiation belts, i.e., filling with high fluxes of particles for duration of many weeks to months in a region in space, where no significant particle populations existed before. This is a rare incident, but was clearly observed in March 1991 CRRES spacecraft detected the formation of a second peak in the inner proton belt immediately following the sudden storm commencement on 24 March 1991. The birth of the new radiation belt was attributed by Mullen et. al. [7] to the injection of high-energy proton by the solar initiated shock accompanying the storm sudden commencement deep into the magnetosphere (2.5 R_e). Subsequently, weaker proton belt formations related to other solar proton events were reported by Gussenhoven *et.al.* [8], 1994, as well as long duration enhancements of high energy (> 2MeV) electrons in the radiation belt slot region associated with geomagnetic storms [9,10]. The effect of space weather on various technologies is described in the next section.

4. SPACE WEATHER EFFECT ON TECHNOLOGY

Space weather phenomena have a variety of effects on technology. Energetic particles thrown out from the sun interact with the earth's magnetic field producing magnetic disturbances and increased ionization in the ionosphere, 100 to 1000 km above the earth. The high energy particles affect satellites causing disoperation or equipment damage that can put the satellite out of operation. Radio waves used for satellite communications or GPS navigation are affected by the increased ionization with disruption of the communication or navigation systems.

4.1. Geomagnetic Effects on Communication Cables

The telegraph was the first man-made system to involve the use of long electrical conductors and consequently was the first such system to be affected by magnetic disturbances. In the history of these effects there are many accounts of the telegraph system being unusable when auroras were observed overhead. There are even accounts of telegraph engineers using the celestial power associated with the aurora to send messages.

In the 20th century the technology for cable communications changed but all cables have been affected by the induced voltages produced by geomagnetic disturbances.

In the early days of the telegraph, a variety of methods were used for recording the signal transmitted over the wires. Bain's chemical telegraph' used specially prepared paper, current from a stylus caused a chemical reaction leaving a coloured mark on the paper. During the magnetic storm of February 19,1852, the current increased so much that a flame of fire followed the pen and set fire to the paper.

The early phone system had ground connections only through lightning protection devices at the ends of the lines. The breakdown voltage of these devices was higher than would be produced during most geomagnetic disturbances. However, during the magnetic disturbance on March 24, 1940, phone communications in the US were disrupted and voltages in excess of 500 V were thought to have occurred. In Sweden, several magnetic storms produced voltages large enough to start arcing in the carbon protectors. Once started, the arc continued even while the voltage began to decrease and the carbon protectors were heated to such an extent that they caught fire

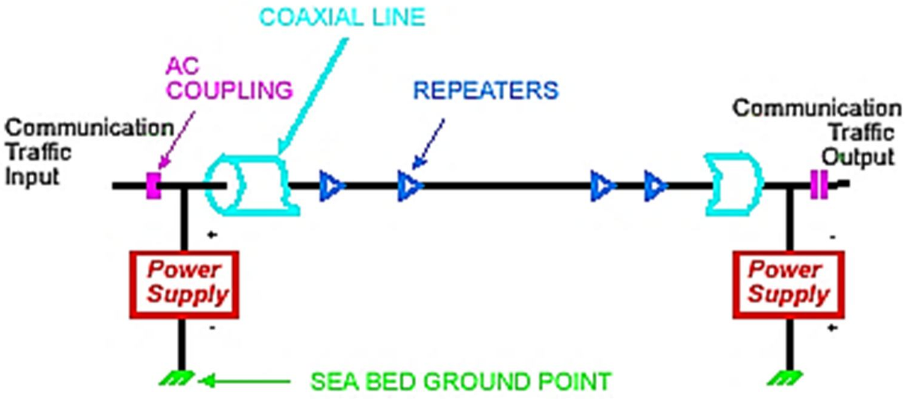


Fig. 1: Schematic diagram of under-water coaxial cable communication system.

In the twentieth century open wire systems were replaced by coaxial cables. The introduction of coaxial cables increased the bandwidth of communication systems but required repeater amplifiers to compensate for the cable losses. These repeaters are connected in series with the center conductor of the cable and are powered by a direct current supplied from the terminal stations at the ends of the cable as shown in Figure 1. The varying magnetic field that occurs during a geomagnetic disturbance induces a voltage directly into the center conductor of a coaxial cable. This voltage will add to or subtract from the voltage coming from the cable power supply.

4.1.1. Effects on Continental Cable Systems

On 4 August, 1972, an outage of the L4 coaxial cable system in the mid-western US occurred during a major geomagnetic disturbance [11]. An examination of this disturbance showed that, at the time of the outage, the Earth's magnetic field had been severely compressed by the impart of high-speed particles from the Sun.

The resulting magnetic disturbance had a peak rate of change of 2200 nT/min, observed at the Geological Survey of Canada's Meanook Magnetic Observatory, near Edmonton, and a rate of change of the magnetic field at the cable location estimated at 700 nT/min. The induced electric field at the cable was calculated to have been 7.4 V/km, exceeding the 6.5 V/km thresholds at which the line would experience a high current shutdown.

4.1.2. Effects on Submarine Cable Systems

During the magnetic storm of February 10, 1958, transatlantic communication from Clarenville, Newfoundland, to Oban, Scotland proceeded as alternately loud squawks and faint whispers as the naturally induced voltage acted with or against the cable supply voltage [12].

4.1.3. Effects on Fiber Optic Cables

New submarine cables are using optical fibers to carry the signals, but there is still a conductor through the cable to carry the power to the repeaters. At the time of the March 1989 storm, a new transatlantic telecommunications fiber-optic cable was in use. It did not experience a disruption, but large induced voltages were observed on the power supply cables [13]. Future cables, because of improvements in the fiber optics, may use fewer repeaters and require a lower driving voltage. However, downsizing the power feed equipment without taking account of the induced voltages may leave future systems more vulnerable to geomagnetic effects.

4.2. Geomagnetic Effects on Radio Propagation

The Sun emits electromagnetic radiation that spans a continuum of wavelengths from radio, through microwave, infrared, visible, ultraviolet X-ray and beyond. Ultraviolet radiation interacts with the upper atmosphere to form an ionized layer known as the ionosphere. Radio waves interact with the ionosphere in a variety of ways depending on their frequencies. For frequencies below about 30 MHz, the ionosphere can act as a reflector, and this property permits very long-distance radio communications around the world. At higher frequencies, above 30 MHz, radio signals usually pass through the ionosphere.

The ionosphere sometimes becomes disturbed as a reaction to some types of solar activity and, as a result, radio wave propagation may be degraded or disrupted. Solar flares emit electromagnetic radiation, such as X-ray emissions which can cause increases in ionization in the lower ionosphere, with consequent phase shifts in low frequency radio signals and increased absorption (fading) in HF and VHF radio signals. The wide spectrum of radio noise emitted from a flare may interfere with a wanted radio signal. These effects may be experienced at all latitudes. At frequencies above 30 MHz, unexpected reflections of the radio waves by the ionosphere may cause radio interference. Ionospheric irregularities may produce fluctuating signals (a phenomenon known as scintillation) and may distort the paths of radio waves. During geomagnetic storms and the associated ionospheric disturbances, scintillation activity may affect certain applications of navigational aids such as the Global Positioning System (GPS).

Solar flares may be accompanied by streams of very energetic particles that travel at near the speed of light. These particles (mainly protons and electrons) enter the upper atmosphere in the regions near the magnetic poles. As a result, the lower levels of the polar ionosphere become very ionized, with severe absorption of HF and VHF radio signals. Such an event is known as polar cap absorption (PCA) event and may last from days to weeks, depending on the strength of the stream of solar particles and the location of the source region on the Sun. HF radio communication in Polar Regions is often impossible during PCA events.

Large clouds of plasma (ionized gases), known as Coronal Mass Ejections (CME), are emitted from the Sun, and may reach Earth, causing disturbances in the geomagnetic field and in the ionosphere. Coronal holes, regions of the solar corona with diminished X-ray emissions, also emit streams of charged particles that can result in disturbances of the ionosphere. Ionospheric disturbances are especially significant at auroras latitudes, such as over much of Canada, and during magnetic storms and sub storms at these latitudes, HF radio communication may be unreliable.

July 8,1941 - Shortwave channels to Europe are affected [New York Times, p. 1]

September 19,1941 - Major baseball game disrupted [New York Times, p. 25].

February 21,1950 - Sun storm disrupts radio cable service [New York Times, p. 5]

August 20,1950 - Radio messages about Korean War interrupted. [New York Times, p. 5]

April 18,1957 - World radio signals fade [New York Times, p. 25]

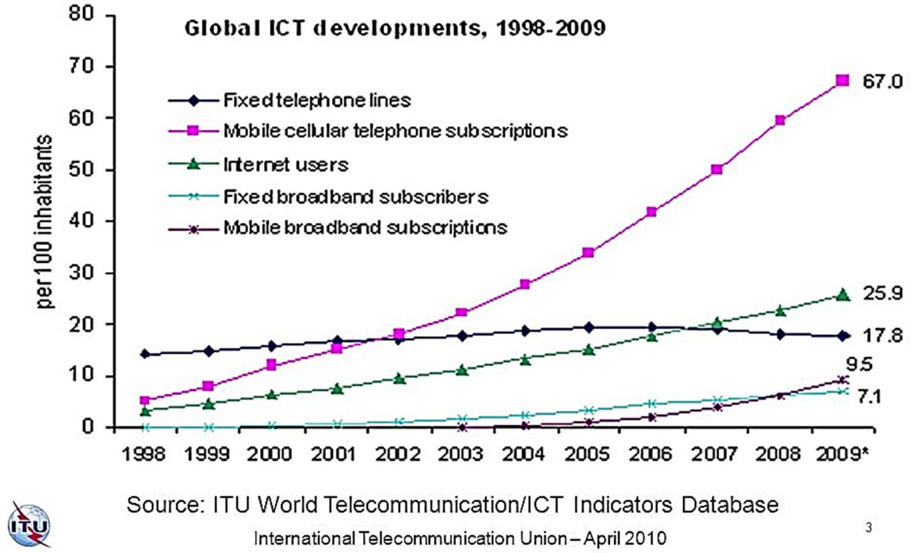
February 11, 1958 - Radio blackout cuts US off from rest of world. [New York Times, p. 62]

On August 9,2011 a major solar flare caused fade-outs in the SW broadcasts of Radio Netherlands World, but after an hour, broadcasting had returned to its normal clarity [14].

Solar flare disrupts RNW short wave reception [RNP, 2011]. This was the first major SW blackout in China since the X7.9-class flare on January 21, 2005, which affected Beijing and surrounding eastern population centers [15].

On February 15, 2011 another large solar flare disrupted southern Chinese SW broadcasting. The China Meteorological Administration reported an X2.2-class flare at that time [15].

Although telephone calls by land lines are among the safest communication technology and the most resistant to space weather effects, they have also been in rapid decline thanks to the wide spread adoption of cellular and mobile phones, especially among the under-30 population. According to an article in the Economist, 2009 [16], customers are discontinuing landline subscriptions at a rate of 7,00,000 per month, and that by 2025 this technology will have gone the way of telegraphy. Between 2005 and 2009, the number of house hold unit cell phone-only subscription rose from 7% to 20%. From the Figure 2, it is clear that landline subscribers are increasing day by day. This is because without an electrical power grid, conventional land lines fail, and cell phones may not be recharged even though the cell towers may have emergency backup power capability.


Global ICT developments, 1998-2009

Source: ITU World Telecommunication/ICT Indicators Database

International Telecommunication Union – April 2010

Fig. 2: Growth in global telecom markets since 1998-2009.

A new report from the International Telecommunication Union finds that at the end of 2009, 67 percent of all people on earth were cell phone subscribers (solid line).The number of land line subscribers is now in decline(dotted line) having reached a maximum of 19% of world inhabitant in 2005 [17]

4.3. Geomagnetic Effects on Power Systems

Geomagnetic disturbances can have a serious effect on power systems. Currents induced in power lines flow to ground through substation transformers. Here they cause saturation of the transformer core which can lead to a variety of problems. Increased heating has caused transformers to bum out. Also, extra harmonics generated in the transformer produce unwanted relay operations, suddenly tripping out power lines. The stability of the whole system can also be affected as compensators switch out of service. Such a sequence of events led to the Quebec blackout of March 13, 1989, which left the whole province without power for over 9 hours. [18]

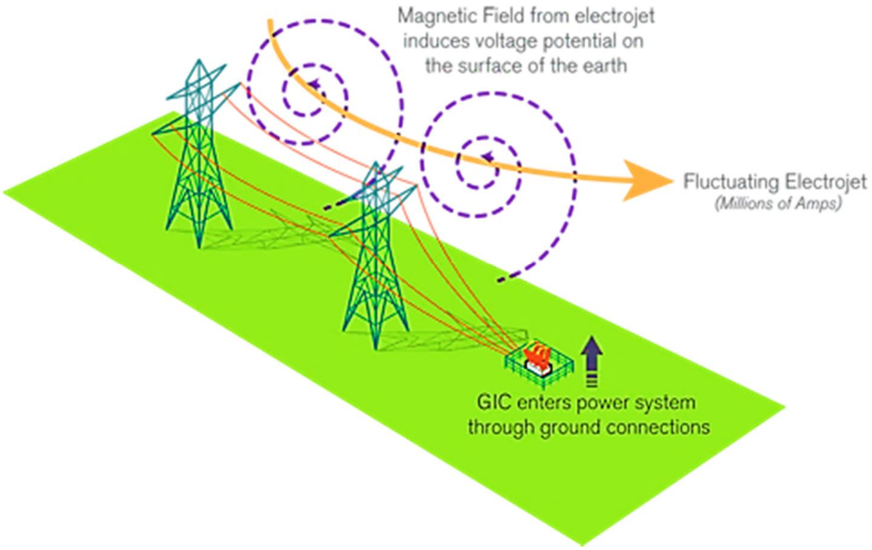


Fig: 3: Geomagnetically induced currents (GIC) are driven by the electric fields produced by the magnetic field variations that occur during a geomagnetic disturbance.

Because of their low- frequency compared to the AC frequency, the geomagnetically induced currents appear to a transformer as a slowly-varying DC current. GIC flowing through the transformer winding produces extra magnetization which, during the half-cycles when the AC magnetization is in the same direction, can saturate the core of the transformer. This results in a very spikey AC waveform with increased harmonic levels that can cause disoperation of relays and other equipment on the system and lead to problems ranging from trip-outs of individual lines to collapse of the whole system.

4.3.1. Transformer Heating

Saturation of the transformer core produces extra eddy currents in the transformer core and structural supports which heat the transformer. The large thermal mass of a high voltage power transformer means that this heating produces a negligible change in the overall transformer temperature. However, localized hot spots can occur and cause damage to the transformer windings.

March 13, 1989 **-** The Quebec Blackout Storm - most newspapers that reported this event considered the spectacular aurora to be the most newsworthy aspect of the storm. Seen as far south as Florida and Cuba, the vast majority of people in the Northern Hemisphere had never seen such a spectacle in recent memory. At 2:45 AM on March 13, electrical ground Currents created by the magnetic storm found their way into the power grid of the Hydro-Quebec Power Authority. Network regulation failed within a few seconds as automatic protective systems took them off-line one by one. The entire 9,500 MW output from Hydro-Quebec's La Grande Hydroelectric Complex found itself without proper regulation. Power swings tripped the supply lines from the 2000 MW Churchill Falls generation complex, and 18 seconds later, the entire Quebec power grid collapsed. Six million people were affected as they woke to find no electricity to see them through a cold Quebec wintry night. People were trapped in darkened office buildings and elevators, stumbling around to find their way out. Traffic lights stopped working; Engineers from the major North American power companies were worried too [18].

Some would later conclude that this could easily have been a $6 billion catastrophe affecting most US East Coast cities. All that prevented the cascade from affecting the United States were a few dozen capacitors on the Allegheny Network (Odenwald, 1999) [19].

Fig. 4: Melting of transformer windings due to Eddy’s current produced by GIC.

October 30, 2003 **-** Malmo Sweden, population 50,000 lost electrical power for 50 Minutes [20]. The blackout was caused by the tripping of a 130 KV line. It resulted from the operation of a relay that had a higher sensitivity' to the third harmonic (150 Hz) than to the fundamental frequency (50 Hz). The excessive amount of the third harmonics in the system has been concluded to have resulted from transformer saturation caused by GIC. Currents as high as 330 Amperes were recorded on the Simpevarp-1 transformer.

4.3.2. Increasing Vulnerability

The vulnerability of a power system to geomagnetic disturbances is increased when the system is more heavily loaded. Increasing power demand and industry deregulation have both led to power systems being operated closer to their limits making them more vulnerable to outside disturbances. A distinctive feature of GIC effects on power systems is that the problems occur simultaneously on many systems. This is contrary to other types of power system problems, e.g., lighting strikes or equipment failures, which are more localized. The interconnections of modem power systems are designed to provide safeguards against the localized failures, but may be contributing to an increased vulnerability to GIC.

4.4 Space Weather Effects on Satellites

Satellites are operating in an environment populated with charged particles as shown in the Figure 5.

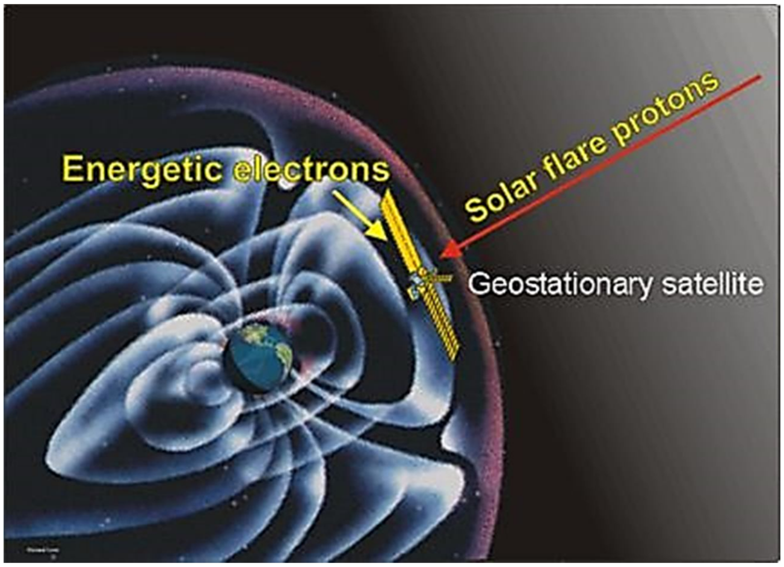


Fig. 5: Geostationary Satellite is operating in an environment populated with charged particles.

These particles can affect satellites in a variety of ways, either directly by penetrating into the satellite electronics, or indirectly through spacecraft charging with the resulting discharge causing problems. These processes can result in phantom commands, damage to electronics, loss of control, and even satellite failure.

4.4.1 Solar Proton Effects

When high velocity ions plough through semiconductor devices they produce a large number of electrons and holes that carry currents within these devices as shown in Figure 6. Large numbers of electron-hole pairs introduced into sensitive regions like memory cells can alter information and result in phantom commands. Effects can be devastating if ion impacts occur in control systems or decision-making circuits. In addition, these impacts degrade semiconductor lifetimes.

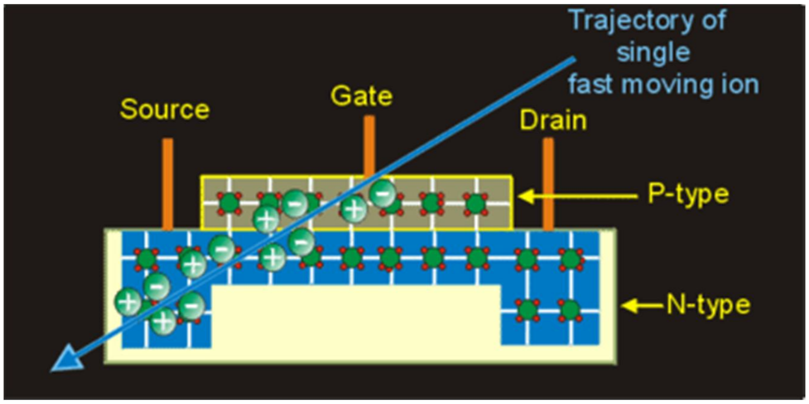


Fig. 6: High velocity ions plough through semiconductor devices produces a large number of electrons and holes that carry currents within these devices.

4.4.2 Surface charging

Surface charging of spacecraft in synchronous orbit can occur due to incidence of a large incoming flux of electrons in the absence of sufficient charge drainage by mechanisms such as photoemission. "Hot" electrons with energies in the range of several to several tens of keV are mainly responsible for surface charging. Intense fluxes of these electrons are closely related to sub-storm activities; hence surface charging occurs more often in the midnight to dawn sector. The differential charging of spacecraft surfaces can give rise to destructive arc discharges, causing satellite operational anomalies.

4.4.3 Internal Charging

The occurrence of highly energetic (relativistic) electrons with energies greater than 2 MeV represents adverse space weather conditions hazardous for geosynchronous satellites. When this happens, there is a high likelihood of internal charging of satellite components by energetic electrons, with possible electric discharges that could result in malfunction or even complete failure of the satellite. Such an event was the likely cause of a number of satellite operational anomalies in January 1994 as shown in Figure 7.

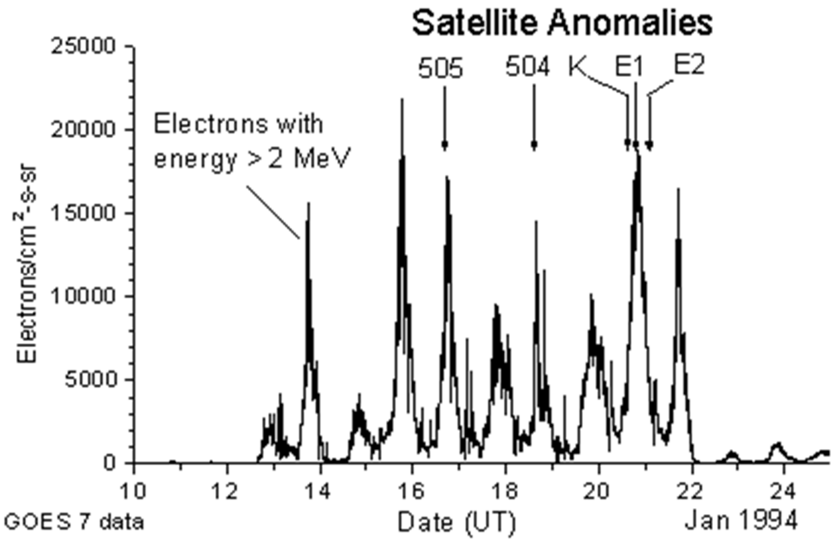
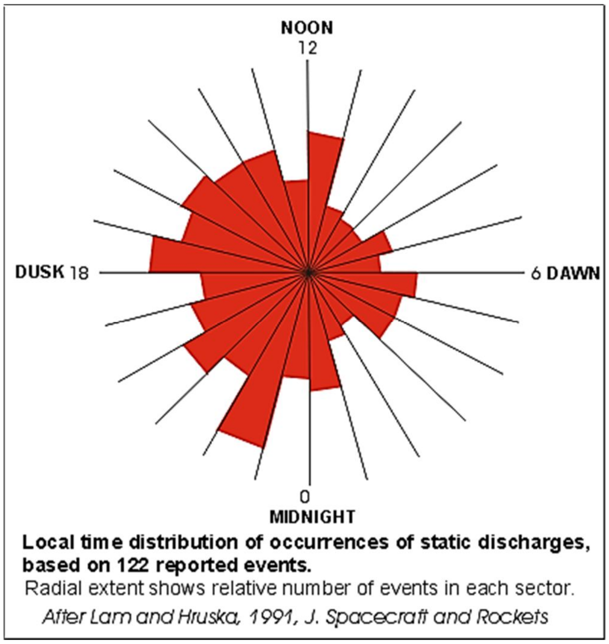


Fig. 7: Satellite operational anomalies in January 1994.

4.4.4. Electrostatic Discharge

Electrostatic discharge results from spacecraft charging, be it surface or internal. Once the generated electric field due to charging exceeds a certain threshold, an arc discharge occurs, generating an electromagnetic transient that couples into spacecraft electronics and causes spacecraft operational anomalies. The Figure 8 shows the local time distribution of occurrence of discharges.



Local time distribution of occurrences of static discharges, based on 122 reported events.
Radial extent shows relative number of events in each sector.
After Lam and Hruska, 1991, J. Spacecraft and Rockets

Fig. 8: Local time distribution of occurrence of discharges.

On August 25, 2011 South Africa's $13 million LEO satellite SumbandilaSat failed, and the explicit cause was stated publicly to be damage from a recent solar storm, which caused the satellite's onboard computer to stop responding to commands from the ground station. This was not, however, the first time this satellite was damaged by radiation. Shortly after its launch in September 2009, radiation caused a power distribution failure that rendered the Z-axis and Y-axis wheel permanently inoperable, meaning that the craft tumbles as it orbits and has lost the ability to capture imagery from the green, blue and xantrophyll spectral bands [22]. The reason given for the lack of proper radiation hardening was that there was not enough money to do this properly, and the satellite was built from commercial off-the-shelf (COTS) equipment.

Moreover, SumbandilaSat was intended only as a technology demonstrator [21]. The case of the Anik F2 'technical anomaly' on October 6, 2011 is a replay of similar stories during the 23rd cycle. The satellite entered a Safe Mode that caused it to stop functioning and turn away from Earth. The Boeing satellite was launched in 2004 and was expected to function for 15 years. The owner of the satellite Telsat, indicated in public news articles that they did not believe the problem had to do with the arrival of a CME that reached Earth early the same morning, but was caused by some other unspecified internal issue with the satellite itself. It is the first serious anomaly of its kind since the satellite was launched in 2004. What the news reports failed to mention was that the sun has been relatively quiet for the majority of this 7-year period [22].

April 5, 2010 - Galaxy 15 experienced an electrostatic discharge that caused a severe malfunction, rendering the satellite capable of re-transmitting any received signal at fullpower, but not able to receive new commanding [23]. Reports cited a space weather event on April 5 as the probable cause of the electrostatic discharge that was the likely triggering event, however although Intelsat acknowledged the ESD origin but scientist [24] refuted the space weather cause in the April 5 solar event, preferring to declare that the origin of the ESD was unknown. A consequence of this type of satellite failure is that Galaxy-15 was potentially able to interfere with other GEO satellites as it came within 0.5 degrees of their orbital slots. Thanks to careful, and complex, maneuvering of the satellites to maximize their distance from this satellite as it entered their orbital slots [25], AMC-11. Galaxy-13, Galaxy-18, Galaxy-23 and SatMax-6 and Anik F3 [26] were able to reduce or eliminate interference, and no impacts to broadcasting were reported or acknowledged. “The fact that you haven't heard about channels lost or interference is the proof that we have been able to avoid issues operationally,” said Nick Mitsis [27], an Intelsat spokesperson.

5. CONCLUSION

As a result of above study, we arrive at the following conclusion:

a) A proper understanding of the space environment provides useful information for space weather effects in deep space as well as on the surface of the earth.
b) The specific component of the space weather environment that are known to cause human impact are solar X-ray flares, coronal mass ejections, Geomagnetic storms, galactic cosmic rays, electrostatic discharges and energetic particles in the magnetosphere.
c) Solar flare emits radiations that ionize the ionosphere causing increased absorption of HF wave. Most class x-flare and some class-M flare produces short wave fadeout that affect HF communication.
d) Space surface charging due to substorm injections of energetic plasma clouds are the most important cause of environmental spacecraft anomalies, but several observations indicate that internal charging by very energetic electrons accelerated in coherence of geomagnetic storms also play a significant role.
e) More careful observation and monitoring the conditions on the sun and to characterize in detail the nature of solar emission could provide timely warnings and forecasts for high frequency communication anomalies.

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