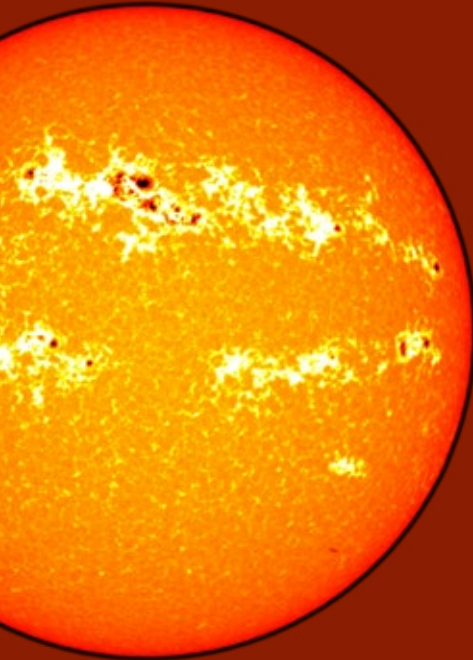


# Impacts of Space Radiation on Interconnect Wire Harnessing



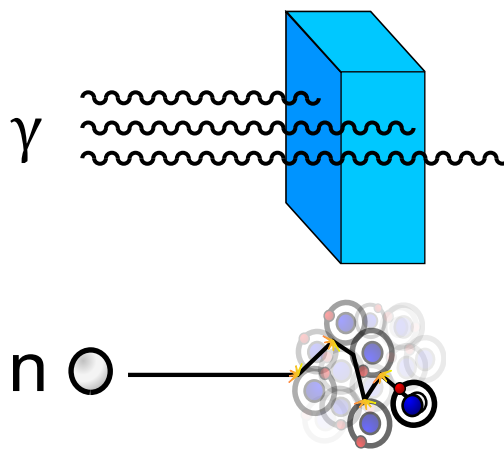
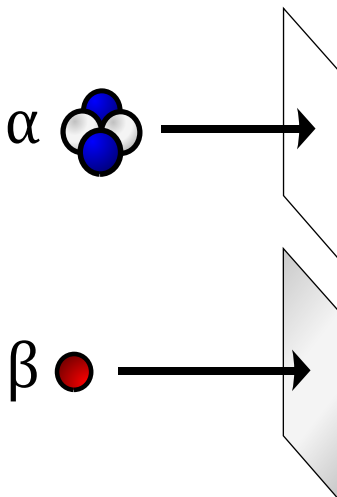
The sun is a major source of electromagnetic radiation impacting satellites in low earth orbit. Direct impacts from solar flares and solar wind dominate the radiation environment experienced by LEO satellites.

Low Earth Orbits are increasingly being utilized by satellite networks geared for principal delivery of internet content on a worldwide basis. Low Earth Orbit, or LEO, happens to be relatively free from charged solar particles as it sits below the inner and outer Van Allen belts. Ionizing radiation remains an important factor however, and polar LEO orbits do cross charged particle areas at every pass. One of the questions we get asked quite frequently at Glenair is whether or not a particular interconnect technology is resistant to space radiation. The answer to this question of course depends on the particulars and specifications of each individual application, as the physics of radiation in space—for example as it pertains to satellites in low earth orbit versus those subject to radiation effects in deep interplanetary space—are significantly different.



In general, radiation that hits a spacecraft comes from either of two sources. The first is the sun, and if we understand its direct and indirect effects we will have mastered 99% of the subject at hand. However there is a small percentage of space missions that cannot rely solely on the sun as its source of energy. Such satellites often carry a small nuclear reactor called a radioisotope thermoelectric generator (RTG) which converts heat from a nuclear decay process into electricity. Generators of this type do emit some radiation, but that's not the focus of the vast majority of the applications we see, which are almost exclusively focused on solar radiation.

## RADIATION TYPES



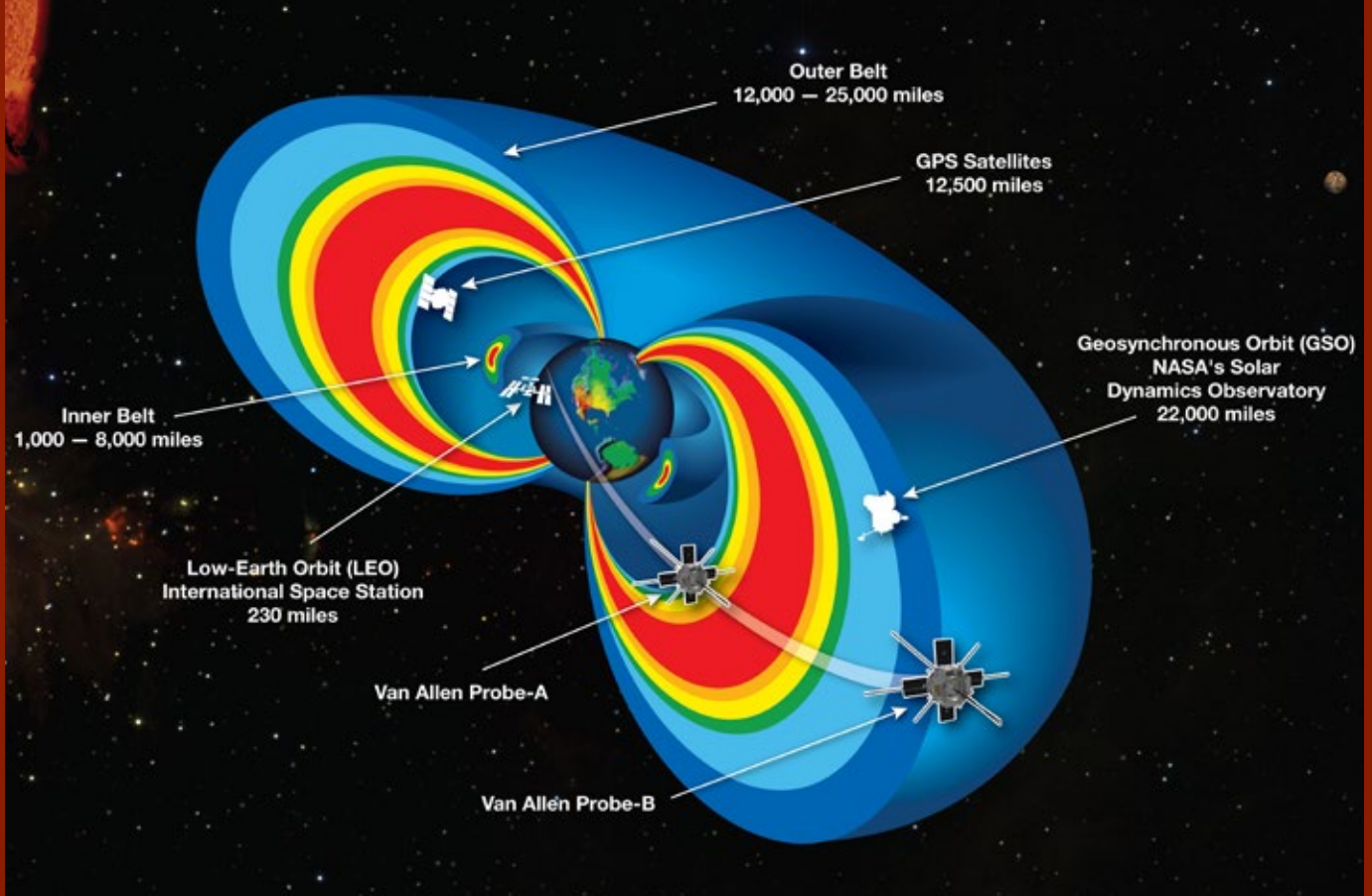
Alpha ( $\alpha$ ) radiation consists of a fast-moving helium-4 nucleus, and is stopped by a sheet of paper.

Beta ( $\beta$ ) radiation, consisting of electrons, is halted by an aluminum plate.

Gamma ( $\gamma$ ) radiation, consisting of energetic photons, is gradually absorbed as it penetrates dense material.

Neutron ( $n$ ) radiation consists of free neutrons, blocked by light elements such as hydrogen, which slow and/or capture them.

Galactic cosmic rays (not shown) consist of energetic charged nuclei such as protons, helium nuclei, and high-charged nuclei called HZE ions.

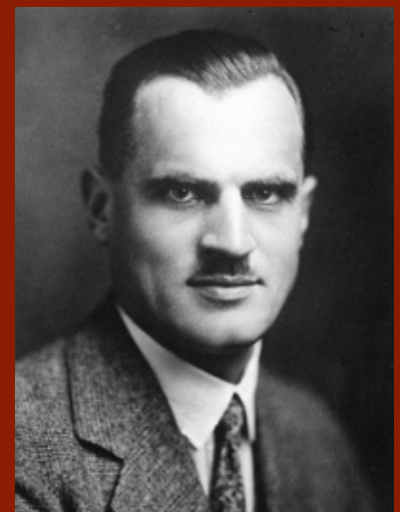


The main emissions from the sun are electromagnetic radiation and a flow of charged particles called the solar wind. These particles carry both positive and negative charges, and collectively form what's called a plasma. Think of it as a diluted gas, but it can behave very differently because the particles are charged. The impact on a satellite and its onboard equipment may be a direct result of exposure to solar wind. However, it is important to understand that this radiation has indirect consequences on a spacecraft as well. For instance, residual oxygen from our atmosphere is ionized by solar radiation and impacts the outside materials of a space craft in LEO through chemical interactions.

This NASA illustration shows that the Low Earth Orbits are relatively well protected below the inner and the outer belts, while GPS satellites and Geosynchronous orbits are on the rims of the outer belts.

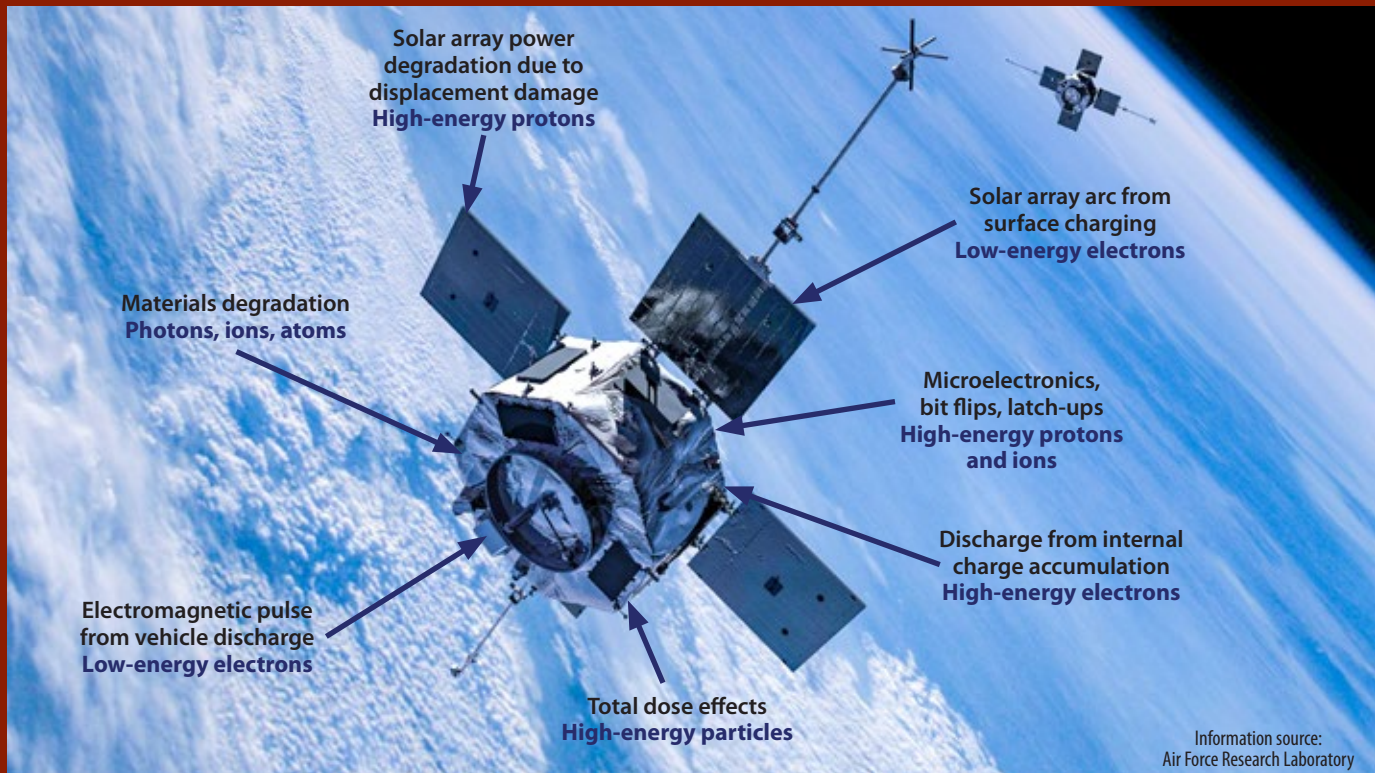
One way to parse the direct emissions from the sun is to focus on particle charge. This distinction is useful because charged particles interact strongly with matter and can be absorbed quickly (depending on their energy, or speed). The absorption will add a unit of charge to the material and may trigger secondary emissions which must sometimes be taken into account.

Neutral particles and electromagnetic waves can still cause molecular or atomic changes in materials, but they can penetrate deeper into solid materials. Neutrons, for instance, will mostly interact with the nucleus of an atom, which is tiny, dense, and surrounded by a void. Electromagnetic particles (also called photons) must be parsed into bins of different energies. The higher the energy of a photon, the shorter its wavelength and the deeper it penetrates. This is easy to remember when you think of X-rays and UV light. X-Rays can penetrate through our bodies because they have much shorter wavelengths than UV rays. That's why in the illustration on the left you see some of the wiggles making it through the blue block of material and others not. The ones going deeper have a shorter wavelength. For the purpose of our conversation, the important aspect is how far do the particles penetrate, and how much potential damage will occur over time.



American physicist Arthur Compton (1892 - 1962) won the Nobel Prize for his discovery of the Compton Effect, which demonstrated the particle nature of electromagnetic radiation.

The most common effect of electromagnetic radiation (or photon impact) is the Compton effect. High energy photons (UV, X-ray, Gamma-ray) can interact with an electron orbiting an atomic nucleus, and provide it with a boost of energy sufficient to liberate it from its atomic confinement. What remains is an atom with a positive charge and a free electron. The Compton effect impacts the tenuous regions of



This picture illustrates some of the impact ionizing radiation and low-energy charged particles can have on a satellite.

earth's atmosphere in a similar manner. The charged ions and free electrons create a layer of conductive gas (plasma) in our upper atmosphere, called the ionosphere. LEO satellites at altitudes between 100 and 300 kilometers are in that zone. For these satellites, it's important to consider the exact orbit and their orientation with respect to the sun in order to truly assess the potential impact of charged particles on their surfaces. For example, higher concentrations of charged particles are present in the Van Allen belts closest to earth's magnetic poles, while lower concentrations exist in equatorial regions. This has a very practical impact on orbit the trajectories of LEO satellites, as they are relatively safe from charged particles except and if their orbits traverse the Van Allen belts.

Avoiding long transits through dense belts is an important consideration when engineers select the optimal orbit of a satellite. Sometimes there is no choice, a geosynchronous satellite above Central America will necessarily feel the impact of the outer belt and will have to be designed accordingly.

### Material degradation due to radiation

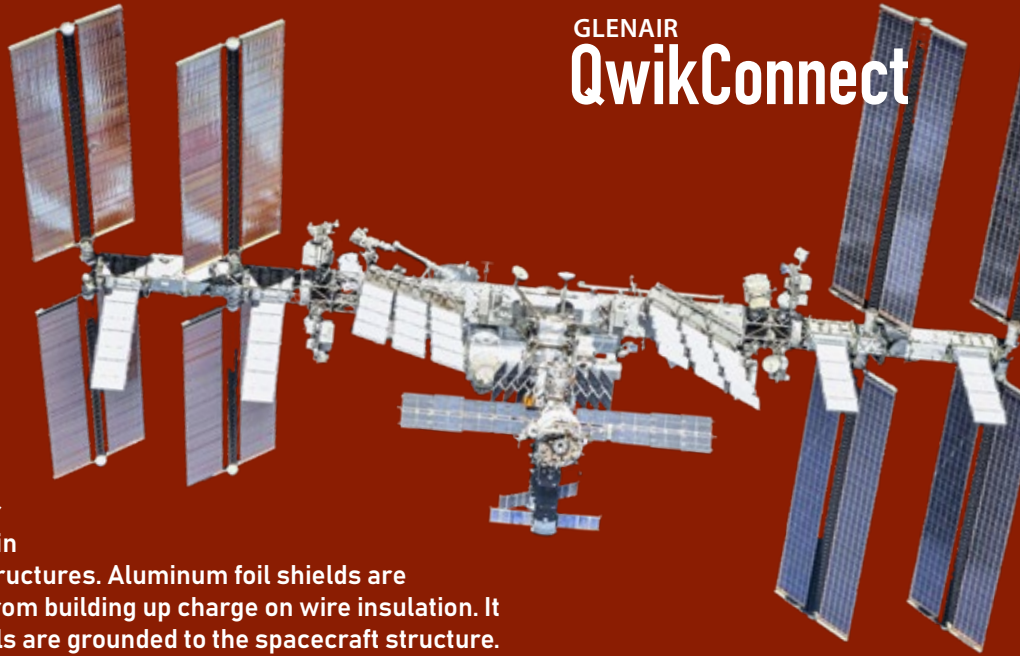
In terms of what damage particles can do, scientists employ a unit of measurement called the Rad, which measures how much energy was deposited by radiation into a unit of mass. It is the preferred unit when evaluating a material (how many Rads can it handle before degrading), or when comparing orbits, or calculating the lifespan of a spacecraft. Laboratories use electron beams and gamma rays from Cobalt 60 to simulate radiation exposure, again measured in Rads.

In some materials (optical fibers, semiconductors, dielectric insulators) it is also important to understand how fast the radiation is implanted into the matter. In these cases, we use either the Fluence (power per surface area—important for solar cells for instance), or the flux (particle count per unit time into an angle area).

We will consider the impacts starting from the outermost layers of the spacecraft. The most prevalent particle for those areas are low energy electrons. Low energy means they don't have enough speed to penetrate deep into the structures. When they get absorbed, they add a unit of negative charge to the material they collided with. If it's a metallic (or conductive) material, the additional charge is free to move around and will change the voltage balance of the spacecraft with its



Materials under test to determine potential damage from absorbed radiation, such as silicone-based microelectronics, are exposed to radiation doses measured in "Rads". Doses in excess of 100 mRads can result in material hardening and embrittlement, making them unsuitable for use in satellite applications.



environment ever so slightly. If the charge hits an insulating material, it will not be free to move around, and that insulator will build up charge with every electron that hits it in this area. When charges have nowhere to go, they accumulate, and before long, a voltage builds up and may be discharged, typically with an arc to a nearby conductor at a lower voltage. For this reason the outermost layer of a spacecraft needs to be conductive, or at least able to 'bleed' off charge fast enough so as to prevent a voltage build-up. This is particularly important for wires, since their outermost layer is non-conductive and they are often in close proximity to grounded metallic structures. Aluminum foil shields are a popular means to prevent electrons from building up charge on wire insulation. It is important to make sure that those foils are grounded to the spacecraft structure.

You may wonder, what happens if a spacecraft keeps accumulating electrons? Does that impact the electrical networks on board? How does one control the voltage when charge keeps accumulating on a ground structure? The answer is that unlike on earth, Satellites do not have an absolute ground. If we could tie a wire between earth ground and a satellite, we might measure a huge voltage difference. But since nothing on the spacecraft is tied to earth ground, the electronics 'don't know' that they are operating with a different zero volt reference than their cousins on earth. Think of it like the tide of an ocean; when boats float in the open waters, they don't feel the tides, and as long as they don't come close to shore, the height of the tide does not matter. When two spacecraft come in contact however, they do need to level out their ground structures in order to avoid an un-controlled discharge.

The surface of the spacecraft is also where most of the electromagnetic radiation hits. Most organic molecules suffer long-term damage from this radiation. They become brittle, shrink, and lose adhesion. In electrical systems, this can impact impedance.

As mentioned earlier, in low earth orbit we also have a large amount of ionized oxygen, ready to oxidize and add resistance to certain metallic surfaces like aluminum. For this reason, gold is the preferred choice for surface coverings. It is very resistant to corrosion, reflects a broad spectrum of electromagnetic radiation, is immune to absorbed radiation, and is an extremely good conductor. At NASA, the tongue-in-cheek answer to the question, "why is everything plated with gold on your satellites?" is, "because we didn't have enough budget to use solid gold!"



Satellite plating with gold is used when insulation alone is inadequate to protect the satellite from radiation from heat, light, and impact. Gold is effective in reflecting radiation away from the satellite, is a good heat and electrical conductor, and does not react to atomic oxygen.

Material	Acceptable Dose (Mrad)
Bipolar Power Transistors	0.2 Mrad
MOSFET Transistors (on SiC)	1 Mrad <sup>1</sup>
Schottky Diodes (on SiC)	1 Mrad <sup>1</sup>
Epoxy Resin	100 Mrad <sup>2</sup>
Kapton (polyimide)	400 Mrad <sup>3</sup>
Kynar (PVDF)—mild damage	10 Mrad <sup>2</sup>
Silicone rubber	1 Mrad <sup>4</sup>
Teflon (FEP)	0.1 Mrad <sup>2</sup>
Epoxy-Glass Laminates	10 Mrad <sup>2</sup>

Acceptable radiation doses for typical materials used in electronics. Measurements were performed using <sup>60</sup>Co Gamma radiation.

<sup>1</sup> Steffens et.al. RADECS 2017

<sup>2</sup> Hanks et.al. NASA-CR-1781, 1971

<sup>3</sup> Gollither et.al. NASA/TM-2001-210245

<sup>4</sup> NASA Langley SP-8053, June 1970

A table of acceptable radiation levels for a few popular materials used on spacecraft. Small semiconductor components will certainly have an additional aluminum shield around them.