OMNETICS
CONNECTOR CORPORATION

Design Analysis For Reliable Connectors On Leo Satellites

Reducing circuit degradation from radiation, noise and thermal cycling

Low earth orbit satellite systems are providing the world significant new methods of surveying, communicating, and sharing information. From their position above, they are being used for surveillance to collect, process and transmit images and/or to enhance communications from earth to earth and/or within space.

Images from LEO satellites arrive on earth with very high resolution because of their immediate position over their targets, aided by being optically close to them. Satellite constellations are often placed in necklace-form to insure constant communication. Precision position tracking of devices on earth and data transfer time is almost instant because LEO is so close. In addition, a LEO orbit can be adjusted or tilted to nearly any angle and circumference circling the earth and offers various routes for different functions as well as room for more satellites to serve our world. Another advantage in using the lower level orbits is that it is significantly lower cost to deliver and replace satellites in compared to higher elevations, such as MEO. In response, we see launch and satellite delivery technology improving.

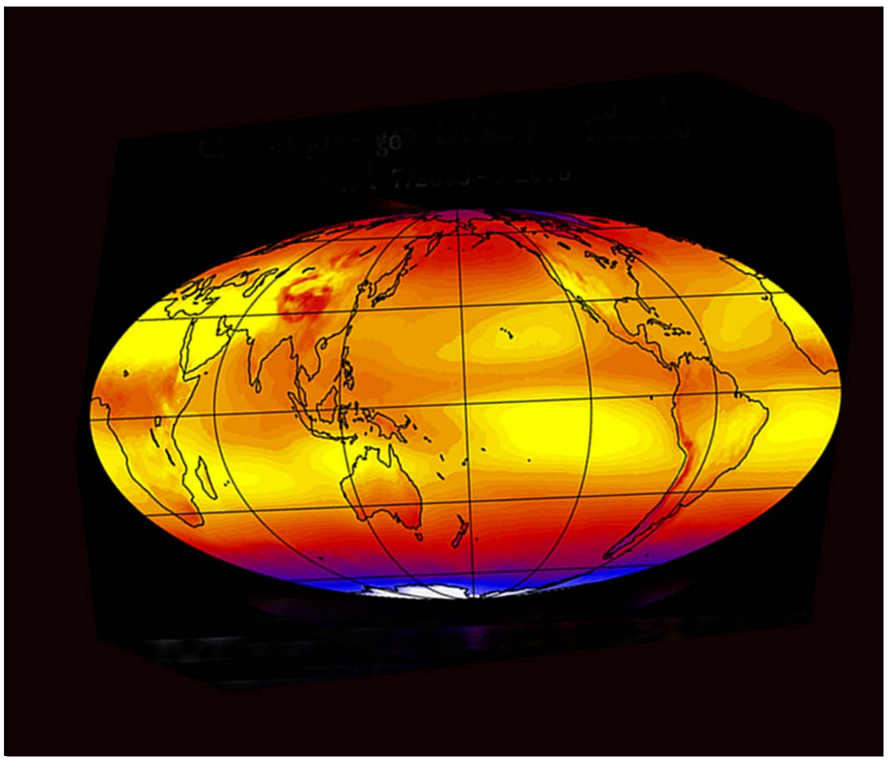
Nearly every developed nation in the world is building and launching their own satellites into LEO space orbit. New satellites are offering extended technologies and applications; new industries want satellites to help with defense, safety, agriculture, mining and oil research. We are seeing an explosion in things we can do with satellites in and out of this world. Fortunately, LEO has a wide range of useful altitudes ranging from as low as 250 miles (400 kms) to over 1000 miles (1600 kms) above earth. The LEO level is filling but there is more space in space, they say!

Satellite design and deployment begins with planning for long range performance, reliability and longevity in a different environment than here on earth. As we learn more about the LEO environmental radiation and thermal events, the information gathered can be used simultaneously to develop new device types requiring a number of technical disciplines. Our new circuits may vary in signal performance sensitivity to the constant cyclic environmental effects. An important first step includes reviewing the materials required and electronic signal types to be used. Satellites needed for long term service will require a collection of high reliability space qualified materials. Circuit boards, computer chips, cable and connectors are usually selected to match ESA and NASA specifications. As the plethora of satellite designs evolve however, we are designing orbital devices in space that may be built by a wide range of engineering disciplines and experience. This paper hopes to focus on some of the lesser known and misunderstood factors that could contribute to the degradation of new satellites.

Satellite performance ageing and degradation from radiation, thermal cycling and noise, can be avoided if we plan and implement well. To accomplish the many new ideas and applications of orbital electronics, we are implementing a broad range of sensor and data collection devices that employ advanced semiconductor chips, new generations of CCDs, surveillance cameras, laser beaming communication devices and position management components that track master stars tens of millions miles away. These new ideas are what astrophysics has been assuring us can be done, but how we design and build them is key for longer term operation in the ever-changing satellite environment.

Evolving satellite assemblies are often stacks of functional arrays with data acquisition sensors, electronic circuits to convert analog signals to digital data,

Earth's Orbital Satellites



Radiation Cloud (courtesy of NASA)

Satellite Module (courtesy of NASA)

data processing and analysis, storage, and in many some cases transmitting the info onward. In addition, they will need power and propulsion methods to manage attitude and adjust orbit, if needed. Their electronic designs use the combination of individual circuits on boards connected from one to another via cable and connector networks. As the individual subsections are joined within a carrier module, the cable and connector systems becomes the umbilical cord of energy that routes data and signaling from board to board. This architecture system has evolved to a standard that also focuses on physical shape, high density and low weight. Its overall size and shape must also fit well into lift off and distribution modules which transfer it to orbit. This drive to tightly pack more electronics into small packages adds to the value of the satellite package.

Simultaneously, we are collecting more digital data, and processing it much faster than in past years. As the new digital signals are operating on very low voltages, the signal rise and fall time is shorter, increasing data volume handled. The lower voltage digital signals and the shorter signal length can become more vulnerable. Adjacent signals must be isolated to avoid crosstalk, nearby power distribution must be shielded to avoid EMI (electromagnetic noise interference) and since the highest speed digital signals are very short and small, cable wiring must use higher density shielding to prevent signal escape through open areas in cable braiding. In addition, the interconnection cable and connectors must meet numerous electronic matching specifications. These can include providing power, high speed digital transmission, individual signal shielding and isolation from adjoining signals. Digital signals may also require interconnects to have a matching impedance to the circuitry they are serving. Constant signal integrity also includes connector pin to socket formats that can prevent static or signal interruptions during physical shock and vibration.

LEO orbit environmental factors can help in design and construction.

- LEO is generally from 250miles, (400km) to 1200 miles, (1600km), above the earth.

- Orbiting satellites travel at 7.8km/sec. (1750 mph), circling earth 16 times/day.

- The international space station in LEO is at 250 miles or up to 420 miles high.

- Satellites cycle temperature each orbit from -50C to +125C, (5760 times/year).

- Aircraft fly up to apx. 14km, (46,000ft.) high.

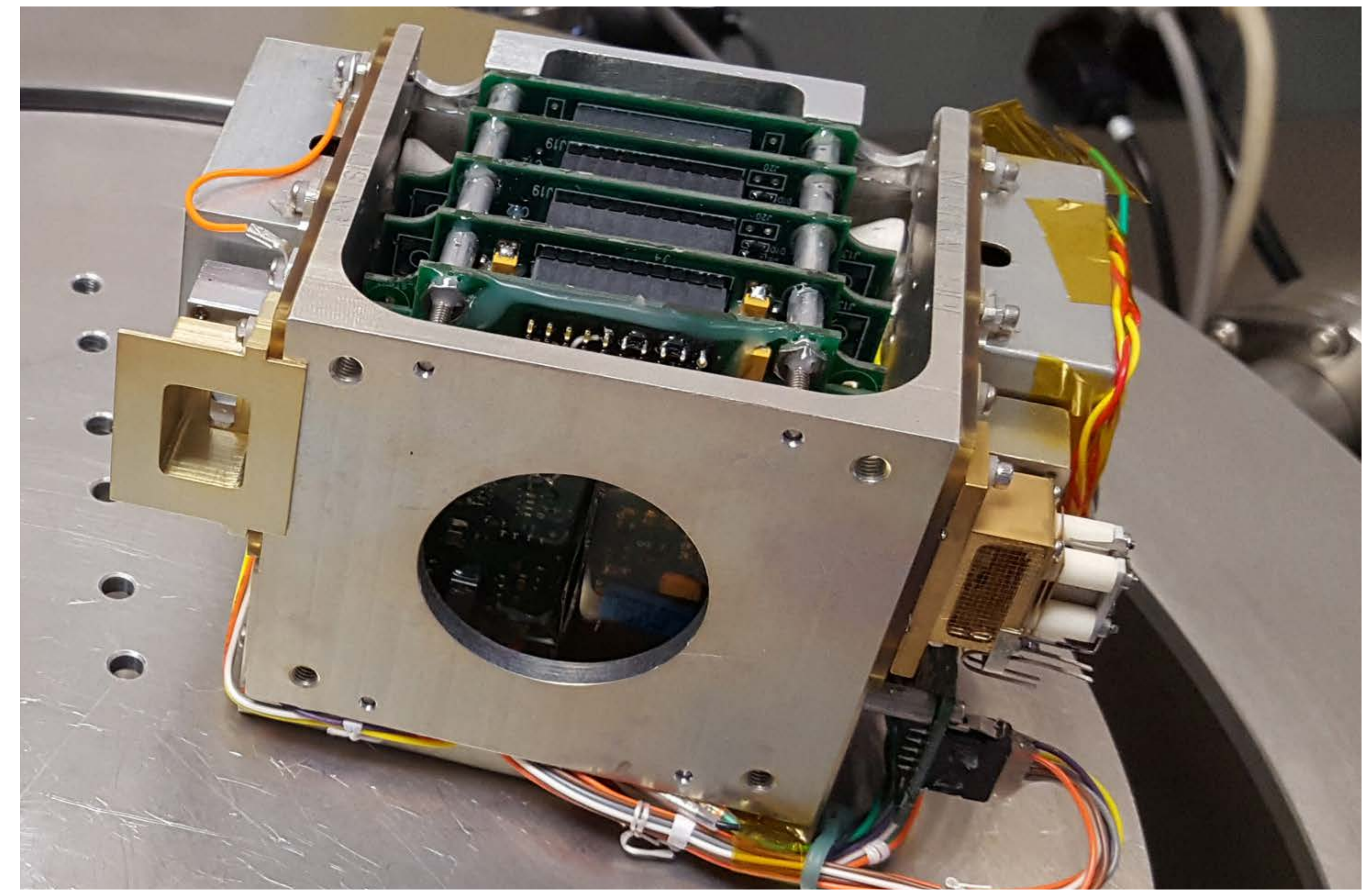
Designers can fill specific needs based upon satellite application and orbital area:

1. **Shock and Vibration** is often experienced during launch and lift off. Connector designs that meet full military standards for shock and vibration should be considered high priority as these tests are certified and on record by the manufacturer. Typical shock and specifications are: Nano-D connectors withstand 100g and Micro-D connectors perform to 50g peak during launch. Vibration may not occur in space, but space connectors should pass standard EIA and ESA fundamental specifications.

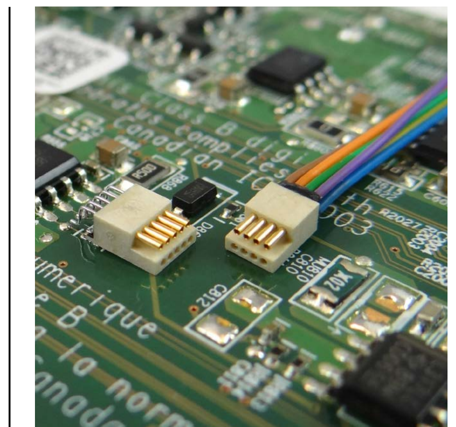
2. **Thermal cycle** work should be directly related to LEO use. Solder joints in LEO cycle from -50 degrees C to above 125 degrees C thousands of times per year causing thermal expansion and compression between different materials in the assembly. These cycles cause deformation and position migration between the materials and within the joints themselves. Solder joint degradation and failure is directly related to stress-strain energy in solder joints temp-cycled over a range of time. Eventually the joints degrade in strength and conductivity, netting finally in open circuitry.

3. **Solder alloy combinations** can and will vary in deformation characteristics and rate of change. Even solder composition grain sizes can affect rate of stress and energy strain induced by thermal cycling. Detecting and preventing thermal creep and with solders used in orbital may become beneficial in reducing satellite replacement cycles. Scientists have developed prediction models that are readily available in the literature, such as the Coffin-Manson, the Engelmaier or the Darveau method.

4. **Epoxy used for connector bodies, inside pin assemblies and on cable interfaces**: two critical elements must be addressed with cross-linked polymers used in satellite electronics. Constant temperature cycling is less critical on HT epoxies. One material by Frey Engineering offers a wide stability range, from -40 degrees centigrade traveling up to 204 degrees centigrade. This is well within most temperature cycles in the LEO orbit groups. Outgassing specifications are well defined by NASA and ASTM E595 and should be tested before employing unknown epoxies in space products. Some of the leading epoxy developers can offer test data and performance that match the design needs and pass thermal and outgassing specifications. Radiation resistance of hardened epoxies can be controlled by with selective use of initial epoxy oligomer and the hardener selected. Radiation resistance of epoxies with additive materials will depend specifically on what filler is used. Carbon composite fillers can remain stable from 50 up to 100Gy. Working with the supplier's technical team, the designer can pick and choose how much and what kind of filler may fit his application best.



Single Stacked Module



PZN Connectors on Space Module

Nano-D Space Connectors

Space Sealed Connectors

5. **Radiation effects and protection**: Astrophysicists claim the source was from the Big Bang Radiation deep in space. The radiation seems to have been formed from high speed matter racing through black holes bursting into our galaxy creating waves of electromagnetic radiation and collisions with other particles. The high speed collisions can rip elements and molecules into minute highly charged ionized pieces. Understanding the amount of radiation involves dosimeters and smart circuits to transmit radiation levels to earth for monitoring. Satellites have exhibited gradual degradation since we began space exploration. Today, we see roving clouds of elements emitting alpha, beta and or y radiation from broken down helium, and other broken electrons and photons. Radiation in LEO levels are milder but is still ever-present and waves of ion charged materials that can reach into and begin to breakdown basic elements, changing their basic material properties. Structural strength, electrical resistance or conduction and molecular bonding of polymers become weak and change. For example: items such as LCP (Liquid Crystal Polymers) are broken down more readily than PEEK (Polyether Ether Ketone) materials. PPS (Polyphenylene Sulphide) includes long carbon fiber structures that insures its potential use in connector design because of its excellent radiation resistance.

Over the years, we have seen integrated circuits degrade and/or fail if under radiation in space environments. Recognizing and planning ion protected materials is becoming a key factor in long life satellite performance. Since many ions are heavy and travel at extreme speeds, beginning solutions can include simple coating and materials that slow down or reduce ion penetration into the materials we use in LEO satellites. This procedure can extend the life of our orbital constellations in use today.

6. **Radiation Guide for LEO**: According to NASA and ESA (*Guide Of Space Grade Requirements For Electrical Connectors, Melanie Ott Swales, Aerospace/Goddard Space Flight Center*):

- Electromagnetic radiation: 2220 ESH/y to 5800 ESH/y (altitude dependent).

- Particulate radiation: protons, electrons, alpha-particles.

- Atomic oxygen: 1020 to 1022 atoms/cm2-y (altitude dependent).

- Reduced gravity: 10-5 m/s2 to 10-2 m/s2 (10-6 gn to 10-3 gn).

- Charged plasma: 0.3 atoms/cm3 to 5x104 atoms/cm3, 0.1 eV to 0.2 eV.

ESA Radiation acceptable standards for connector and cable are reported in conjunction with IEEE 323, and IEEE 383. (*ESA - Radiation: satellites' unseen enemy*)

Robotic devices operating in nuclear environments are examples of exposure beyond human capability. For example, the connectors are made from stainless steel to resist radiation, and the cable glands are hermetically and environmentally sealed using EPDM, which resists radiation, can operate in high heat, and protect the connectors against both fluids and gases. Some connectors within the line use PEEK inserts, which are also radiation-proof. Knowing radiation levels in LEO can help design and build interconnection systems and complete modules to last significantly longer in space. As we cram more electronics into each module that is potentially bombarded with high speed radiation that can destroy chips, circuit boards as well as the more exposed cable and connectors, one must also plan for circuit density. Radiation and electromagnetic fields travel at light speeds and plated metal reflects much of the radiation away while helping reduce ion energy and heat absorption. Based on expectations and life cycle demands, metal connectors and back shell shields will be fabricated with stainless steel. Plating of gold, copper and or silver can be used to help deter radiation with thin, lighter weights that by using solid pieces.

A number of cable and connector companies have previous experience in planning for reliability in satellite design. Designers are welcome to call and work directly with Omnetics Connector Corporation and other companies certified in both NASA and ESA product support. For example, Omnetics has low profile connectors operating on Mars rovers as well as orbiting at multiple applications from communication orbits to Star Tracker devices. When special metals and/or plating is needed, they would know how to protect your product.

Cable Developers and Special Material Engineers are also expanding their experience and product lines to extend orbital life cycles. Specialty material companies like Solvay Materials Group offer a line of materials used for cable systems in medical radiation environments. Their products are supported with detailed test data for reliability in physical as well as radiation exposure in sterilization and radiology applications using KetaSpire® PEEK Polyether ether Ketone jacketing for long life and multiple radiation exposures. Their KT-820 NT material data shows performance data derived from gamma radiation testing by measuring dosage to 20 kGy and also 40kGy. Results showed excellent material property retention. Wire and cable companies can work directly with Solvay to use their materials to build space related cable and devices for testing and use. Additional cable suppliers offer radiation exposure wiring such as Nissi Tec, Axon Cable, Dacon and Gore®.

Experienced connector companies have extensive experience in shield, wrapping, cable braiding and over-plating metal on cable as needed. Charts are available showing the electromagnetic isolation levels capable from a wide range of metal cable and connector methods. Metal backshells that are 360 degree sealed to metallized cable exist today and are easily applied to satellite cable systems. In addition, one company listed on the web is SAT Plating LLC who is advertising a new process for plating on PEEK using their proprietary process called *Surface Activation* for use with surface preparation for plating high performance composites with strong adhesion.

As we stack multiple sets of circuit boards loaded with advanced high speed chip technology, we are faced with collecting and routing the resulting data from section to section of the orbital instrument.

Most often a cable or flat-folding interconnection is needed. Very often it must me small, lightweight and very low profile as it links from one section to the next circuit inside the orbital assembly. In addition to data, we often will need to distribute low levels of power to extended portions of the module.

Connectors can be rapidly modeled to contain both power and signal within one housing to save space and weight. This is a good time to call an interconnect design engineer for design ideas, planning long term reliability and to insure signal integrity of the cable system. Today's connector design specialists are available that use on-line solid modeling to work through options and various wire routing ideas. Most often, discussions begin with answering questions about size, space and weight. The design specialist can offer examples of proven space connector and cable systems that are in flight today. From those models, a new or modified design can come up quickly on the solid modeling system. After discussions and final opinions, a 3D printed model can be made and sent to the space system design engineer. When needed, adjustments can be made again and finally a hard-model will be sent to the system group to insure it fits the need.

References

- "Guide Of Space Grade Requirements For Electrical Connectors" (Melanie Ott, Swales Aerospace/Goddard Space Flight Center)

- "Predicting Fatigue of Solder Joints" (Hillman, Blattau, Lacy)

- "Solder Fatigue Predictability" (nasa.gov)

- "Radiation: satellites' unseen enemy" (ESA)

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Satellite Communications Board