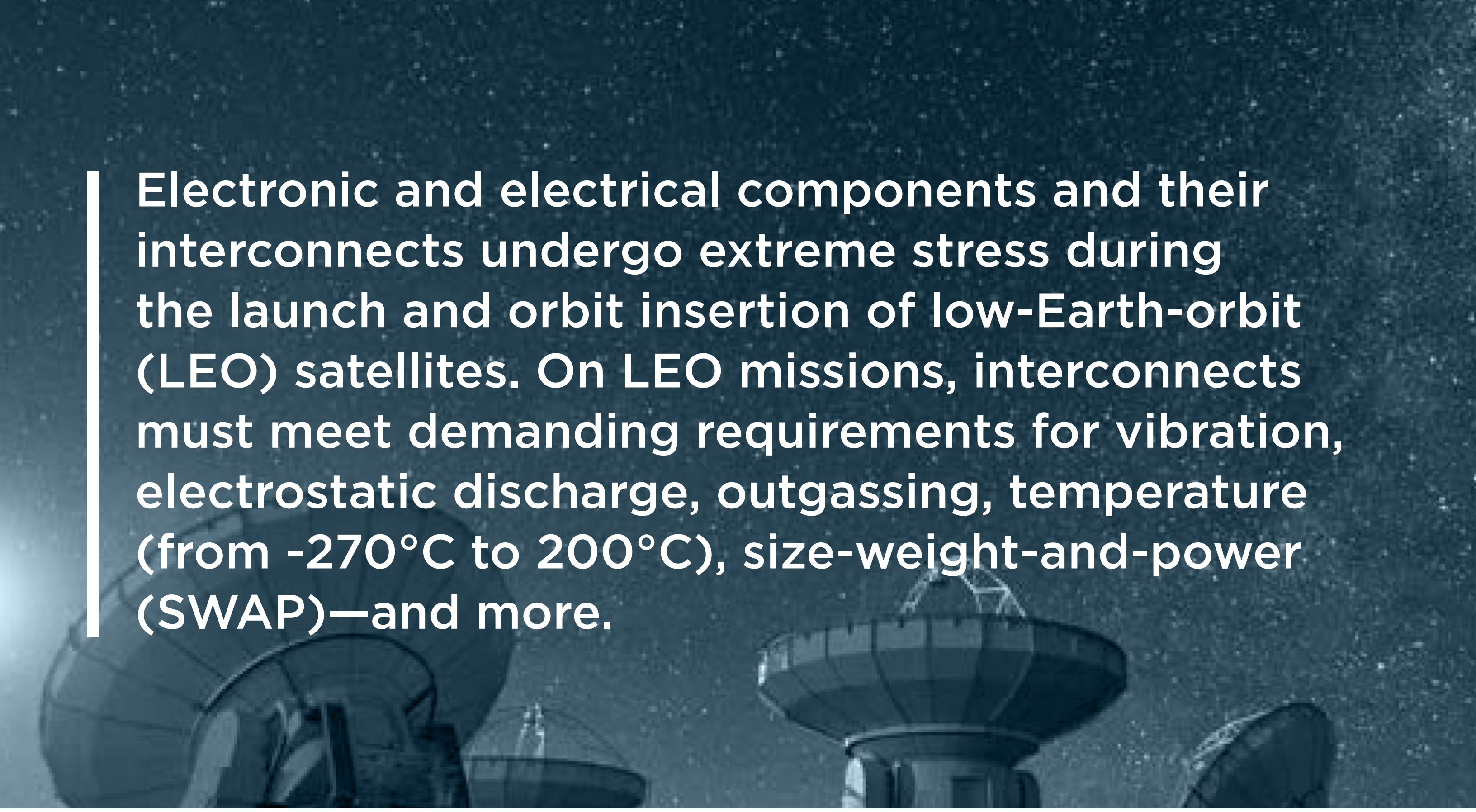
WHITEPAPER

FACTORS AFFECTING INTERCONNECTS IN SPACE

Mechanical, electrical, and optical requirements for interconnects in launch vehicles and low-Earth-orbit (LEO) satellites.



Electronic and electrical components and their interconnects undergo extreme stress during the launch and orbit insertion of low-Earth-orbit (LEO) satellites. On LEO missions, interconnects must meet demanding requirements for vibration, electrostatic discharge, outgassing, temperature (from -270°C to 200°C), size-weight-and-power (SWAP)—and more.

Addressing these challenges is essential for the many private space companies and government-owned space agencies that are pioneering the LEO-satellite frontier. New opportunities are inspiring bold innovations in satellite design, aerospace engineering, and electronic packaging. To support these initiatives, TE Connectivity extends its track record of developing interconnects for space that began with Surveyor lunar landers in the 1960's to advancing space-qualified SpaceVPX, VITA, NASA, ESA, and MIL-SPEC compliant products today. Commercial-off-the-shelf (COTS) components can also be applied under conservative design rules where LEO missions with limited life cycles can benefit from COTS and COTS+ solutions.

The following discussion examines critical factors that influence the cost and performance of interconnects in space. The goal is to help designers meet mission objectives for launch vehicles, LEO satellites, and constellations employed in today's new space economy.

1. Minimizing Size and Weight

VALUE/IMPORTANCE:

In recent years, the cost of launching a kilogram of payload into space has dropped significantly—averaging $18,500 per kilogram ($8,410 per pound) from 1970 to 2000 to about $3,000 per kilogram ($1,360 per pound) today—due in part to the reusability of major launch vehicle components. With private space companies and government space agencies operating on tight budgets, saving every ounce counts to make missions more affordable.

CHALLENGES:

Reducing interconnect size and weight involves tradeoffs. As dimensions become smaller, it becomes more difficult to maintain accurate tolerances. And as materials become less massive, it is difficult to maintain strength, mating retention forces, and resistance to mechanical stress.

SOLUTIONS:

To assure the performance of lightweight, miniaturized interconnects, material properties, quality, and tolerances must be validated. Everything in the supply chain--including raw materials and assembled parts—must meet defined standards. After final assembly, parts must be individually tested for zero defects to ensure continuous operation in a space environment.

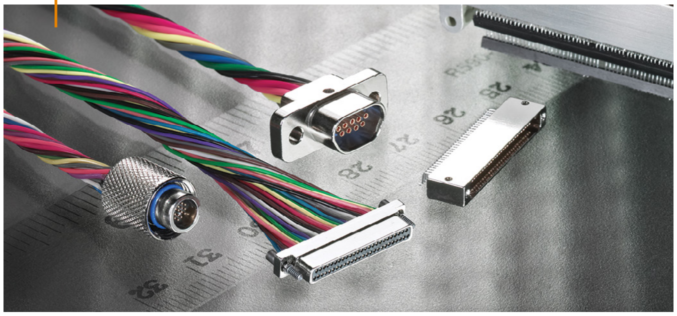
Various standards have been developed by organizations that include:

- NASA (Spec EEE-INST-002 for part selection, screening, and qualification and GSFC S-311 specifications for electronic parts and packaging)
- U.S. Department of Defense Military Standard “MIL-STD” Defense Standards or “MIL-DTL” Detail Specifications
- SAE International (AS22759/51-/54 specifications for low-outgassing, low-fluoride wire and cable)
- International Organization for Standardization (ISO 9000 standards)
- European Space Agency (ESA) (European Cooperation for Space Standardization [ECSS] regulations)
- Indian Space Research Organisation (ISRO), and Japan Aerospace Exploration Agency (JAXA)

TE PRODUCT EXAMPLES

Micro-miniature connectors

MICRODOT high-density microminiature "D" connectors are specially sized for use in miniaturized airborne and space electronics and computers with lightweight plastic or aluminum alloy shells. Electrical contact is achieved at many points around the periphery of the pin by constructing the male contact as a breathing helical spring.



MICRODOT high-density microminiature "D" connectors offer exceptional weight and space savings with rectangular and circular configuration options.

D-sub miniature connectors

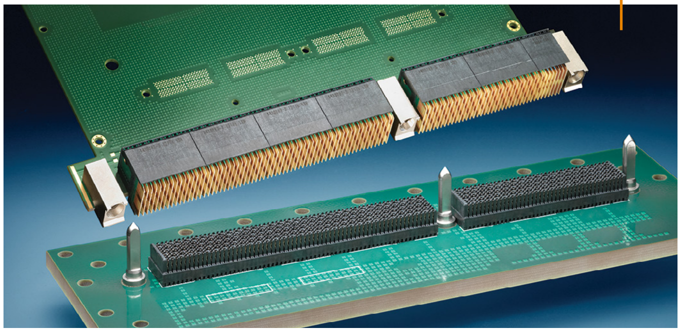
AMPLIMITE Ultra-Lite D-sub miniature connectors use a one-piece aluminum shell for a 15 to 20 percent weight reduction compared to brass counterparts. High-density designs using size 22 contacts (22-28 AWG wire) accommodate many more positions, with a size 1 shell enabling 15 positions and a size 6 shell, 104 positions. the typical "spring pin" design. This connector system uses 1.00 UNM or 1.2 UNM hardware allowing for a footprint that is smaller than the military specified product.

Nano-miniature connectors

Nanonics Dualobe family of interconnect devices feature 0.025-inch center-to-center contact spacing. Electrical contact is achieved using a "spring socket" versus the typical "spring pin" design. This connector system uses 1.00 UNM or 1.2 UNM hardware allowing for a footprint that is smaller than the military specified product.

Backplane connectors

MULTIGIG RT 2-R backplane interconnects are VITA 78 SpaceVPX compliant connectors that use pinless printed-circuit wafers instead of a traditional pin-and-socket contact system to pack more performance in less space with less weight. The gas-tight, press-fit contact eliminates the open pin field on backplanes and reduces exposure to field failure in card cage systems. Advanced thermoplastic and copper alloys enable a durable, lightweight design. The MULTIGIG RT interconnects family supports 10+ to 25+ Gbps signal rates.



MULTIGIG RT 2-S lightweight, high-speed backplane connectors meet the interface dimensions for VITA 46 VPX connectors.

2. Withstanding Vibration, Acoustic Loads and Shock

VALUE/IMPORTANCE:

While there is minimal vibration in space, vibration is significant during launch. Side to side (lateral axis) and forward to backward (thrust axis) motion function as sine wave energy. The wave ends when it reaches a static point where a "snapping" action can cause misalignment or breakage in the contact area. Wave energy is generated in several forms. Rocket engines can generate vibrations over a range of frequencies that can exceed 2000 Hz. Acoustic (noise) stress—which emanates from the cavity between the payload or subsystem and the fairing walls of the launch vehicle and the spacecraft—can surpass 180 dB. Shock—which can be generated at launch as well as by separation of the payload from the launch vehicle—can reach gravitational forces (G) that go beyond 10 G.

CHALLENGES:

Damage typically occurs at loose or improperly crimped connections, wire defects, and fatigue points, or where insufficient clearances or poorly routed points allow scrape abrasion.

SOLUTIONS:

To endure the effects of extreme vibration, acoustics, and shock, many factors—latching forces, locking mechanisms, wire fatigue, weld/solder joints, potting materials, insulation, and more—must be accounted for. Testing that reproduces launch events—such as vibration-control and shaker-table testing—can be performed in accord with MIL-STD-810 standards, VITA 47 Shock & Vibration requirements, and EIA-364-27 mechanical shock (specified pulse) test protocols.

TE PRODUCT EXAMPLES

Backplane connectors

- Fortis Zd high-speed backplane connectors combine multi-gigabit speeds (10 Gbps+) and extreme ruggedness by marrying an electrically advanced, high-speed contact leadframe with a rugged, reliable separable "box" contact interface. For robustness, a metal shell is used both in the mating interface and the connector's outer shell.
- MULTIGIG RT 2-R backplane interconnects handle extreme vibration with a quad-redundant contact structure and ruggedized guide hardware that increase the stability of the daughtercard-to-backplane interface.

Circular connectors

- As an AS81703-compliant family, DEUTSCH DBAS series circular connectors provide a rugged, visually verifiable, push-on/pull-off solution for power, signal, and highspeed shielded contact arrangements. A wide range of inserts, shell types, and accessories with multiple surface-finishing options enables an integrated solution to handle launch stresses.

DEUTSCH DBAS series circular connectors offer easy and secure locking with a push/pull coupling ring for 100% mating.

- As a MIL-DTL-38999 Series II compliant design, DEUTSCH DCS series connectors combine weight savings with reliable micro-screw coupling. Hermetic, EMI shielded, cryogenic, and custom configurations are available to meet requirements of launch vehicles like Ariane 5, Vega, and other space programs.

Heat-shrink tubing, tape, and insulation

- Raychem heat-shrink tubing and tape employ specially-formulated cross-linked thermoplastic polymer materials. Protection is provided by uniform wall thickness around cabling and connectors, void-free interfacial bonding, and environmental sealing.

- SPEC 55 Low Fluoride (LF) insulation system resists scrape abrasion with rugged fluoropolymer construction available in lightweight single-wall or extra-rugged dual-wall variants. Custom options are also available. Outgassing rating is less than 10 PPM based on TE test data (a 20 PPM maximum is stated in SAE specifications).
  SPEC 55 wire and cable conform to SAE-AS22759/51—/54 specifications.

- SolderSleeve devices minimize risks of foreign object damage (FOD) where spliced wire or shield termination are employed by encasing the area in a transparent, heat-shrinkable sleeve for protection and strain relief.

SolderSleeve devices for space space applications requiring low outgassing and resistance to extreme temperatures.

3. Withstanding Temperature Extremes

VALUE/IMPORTANCE:

The temperature in the vacuum of space is 2.725 Kelvin (-454.72°F/-270.4°C). However, onboard systems in LEO satellites operate within a -65°C to 125°C range depending on orbit height, solar heat gain moderated by satellite spin, and heat generated by electronics. Propulsion system components, external latches, sensors, and solar panels are subject to more extreme temperatures.

CHALLENGES:

Exposure to thermal cycling and to high peak and low cryogenic temperatures produce stresses in metal, glass, and polymer materials that aggravate minor imperfections, compromise strength, and degrade performance. Higher temperatures also increase vapor pressure and the rate of chemical reaction, which increase outgassing (see below).

SOLUTIONS:

Materials must be selected that can accommodate peak temperatures and thermal cycling stress. Beyond MIL-STD 810 temperature testing, various NASA, Department of Defense (DoD), and commercial practices can be used in qualification, acceptance, and development testing to evaluate thermal cycling and outgassing performance.

TE PRODUCT EXAMPLES

Wire/cable/contacts

- Raychem space wire and cable are NASA and ESA-qualified and are available with 125°C, 150°C, or 200°C temperature ratings. Features include a cross-linked, “non-melting” insulation system and a low-fluorine insulation system that is low outgassing.
- DEUTSCH solid contacts are rated up to 200°C for standard applications and up to 260°C for jet/rocket engine applications. Available in signal crimp, power crimp, and thermocouple contact configurations for integration in most of TE’s DEUTSCH connectors used in aerospace applications.

Sealed circular connectors

- Fully intermateable with MIL-DTL-83723 Series III connectors, DEUTSCH 983 series connectors were designed in the 1990’s especially for harsh aerospace applications. Stainless-steel versions are used on harsh constraint-facing areas such as engines, APU (Auxiliary Power Unit), wings, and leading edges, whereas the aluminum version is used in cargo compartments. Both versions are qualified to EN2997 specifications as well as Aerospace Defense and Security (ADS) ESC10, Boeing BACC63, and Airbus ABS specifications.

- DEUTSCH 9305 (available in four positions) and DCS series connectors (four and seven positions) are threaded, subminiature circular connectors that are environmentally sealed, hermetically sealed, or EMI shielded, with a temperature range from -55°C to +200°C.

Micro-D nano- and micro-miniature connectors

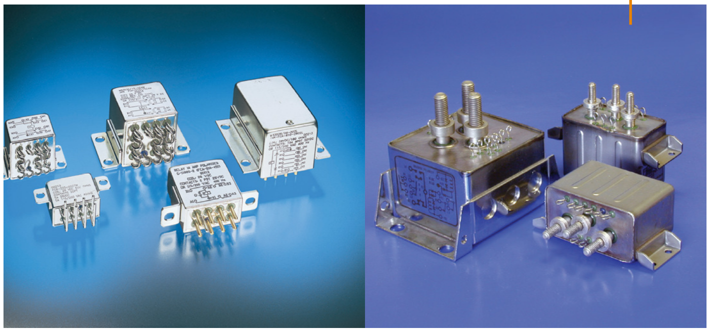
MICRODOT high-density microminiature “D” and the Nanonics family of interconnects (see above) feature space-worthy construction suitable in a -200˚C to +200˚C temperature range.

DEUTSCH CDBAS cryogenic connectors

Mate with cryogenic hermetic receptacles. Available in specific variants for -270°C up to 200°C temperatures.

Relays

CII, HARTMAN, and KILOVAC relays and contactors for space applications are available in a wide variety of configurations and ratings. All are high-reliability hermetic devices suitable for the harsh environments encountered in space. Many are designed for -55˚C to +125˚C temperatures.



Space-qualified relays in lightweight, hermetically sealed enclosures for panel mounting offer a variety of switching configurations, efficient magnetic latching, and wide range of main contact ratings.

Main contact current ratings range from 1 amp to over 125 amps. Some devices can handle 300Vdc voltages or higher. Many are available with either magnetic-latch or single-side-stable configuration, as well as multiple mounting and auxiliar contact configurations.

Backplane connectors

MULTIGIG RT 2-R connectors are constructed with thermoplastic material designed for -55°C to 125°C temperatures.

4. Minimizing Outgassing

VALUE/IMPORTANCE:

Outgassing occurs when gases trapped in non-metallic materials—such as polymers used in connector inserts, seals, adhesives, or potting materials—are released in the vacuum of space or by high temperatures. The released gases can condense on and contaminate sensitive surfaces, eventually degrading the performance of charge-coupled-device (CCD) sensors in satellites, thermal radiators, or solar cells.

Moreover, the gas discharged from materials contributes to regimes of critical pressure during ground test and flight that create the environment for a corona (partial) discharge or a Paschen (full) electrical breakdown event.

CHALLENGES:

NASA ASTM E595-77/84/90 testing and the MIL-W-22759 (M22759) | SAE AS22759 specification cover a material's performance when exposed to high heat or a vacuum. Materials considered low-outgassing materials must meet requirements for a total mass loss of 1.00% or less and a collected volatile condensable material (CVCM) of 0.10% or less.

SOLUTIONS:

Inorganic materials are immune from outgassing and can be used, for example, in connector shells employing aluminum with an electroless nickel finish. Materials can also be selected that meet NASA requirements for low outgassing in thermal oven bakeout testing.

Plasma ball illustrates a corona discharge.

TE PRODUCT EXAMPLES

Cable/molded parts/harnesses/insulation

- SPEC 55 LF insulation system and SPEC 55 LF products are insulated with a modified radiation cross-linked ETFE polymer with an outgassing rating less than 10 PPM (supplied only in a -65°C to 200°C temperature rating and with silver-copper or silver-coated high-strength alloy construction).
- Raychem SPEC 44 /041 x hook up wire combines the outstanding physical and electrical characteristics of radiation crosslinked polyalkene with the excellent mechanical and chemical properties of radiation cross-linked polyvinylidene fluoride (PVDF) (rated at 135°C with tin or silver constructions.
- Low Fluorine (LF) low-outgassing insulation systems are also used in:
  - Molded parts for TE backshell adapters for strain relief
  - MIL-STD-1553B data bus components

.

Wire-splice and shield-termination protection

SolderSleeve devices minimize risks of outgassing where spliced wire or shield termination are employed by encasing the area in a transparent, heat-shrinkable sleeve for insulation that meets low-outgassing parameters of ASTM E-595.

Connectors

- Space-qualified Micro-D nano- and micro-miniature interconnects include MICRODOT high density and Nanonics connectors.
- DEUTSCH UR AND RE series rectangular connectors are utilized in satellite applications.
- 369 Series Connectors feature a compact, rectangular form factor and a low-outgas option.

369 small form factor connectors are suitable for blind mating or low visibility conditions with a mechanical scoop-proof interface that helps prevent contact damage.

Backplane connectors

MULTIGIG RT 2-R connectors employed in SpaceVPX modules and Fortis Zd connectors use low-outgassing thermoplastic material.

5. Controlling Electrostatic Discharge (ESD)

VALUE/IMPORTANCE:

Reports indicate that 54% of spacecraft anomalies/failures are caused by electrostatic discharging and charging. For example, in April 2010, the Galaxy 15 telecommunications satellite wandered from its geosynchronous orbit with evidence that spacecraft charging caused the anomaly. Worse was the Advanced Earth Observing Satellite 2 (ADEOS-II), which lost power in October 2003. Forensic research identified that charging by high-energy auroral electrons was followed by a discharge event between power cables causing loss of the satellite.

CHALLENGES:

On Earth, a material can become electrically charged when electrically dissimilar materials rub together. But in wires and cables used in spacecraft, a static charge can be created by the impact of charged particles on the material. Satellites in geosynchronous Earth orbit (GEO) are particularly susceptible because of higher charge density in deep space. When the charge builds up in wire and cable of electrical interconnection systems, a sudden discharge can damage connected logic circuits, electronic instruments, and computer chips.

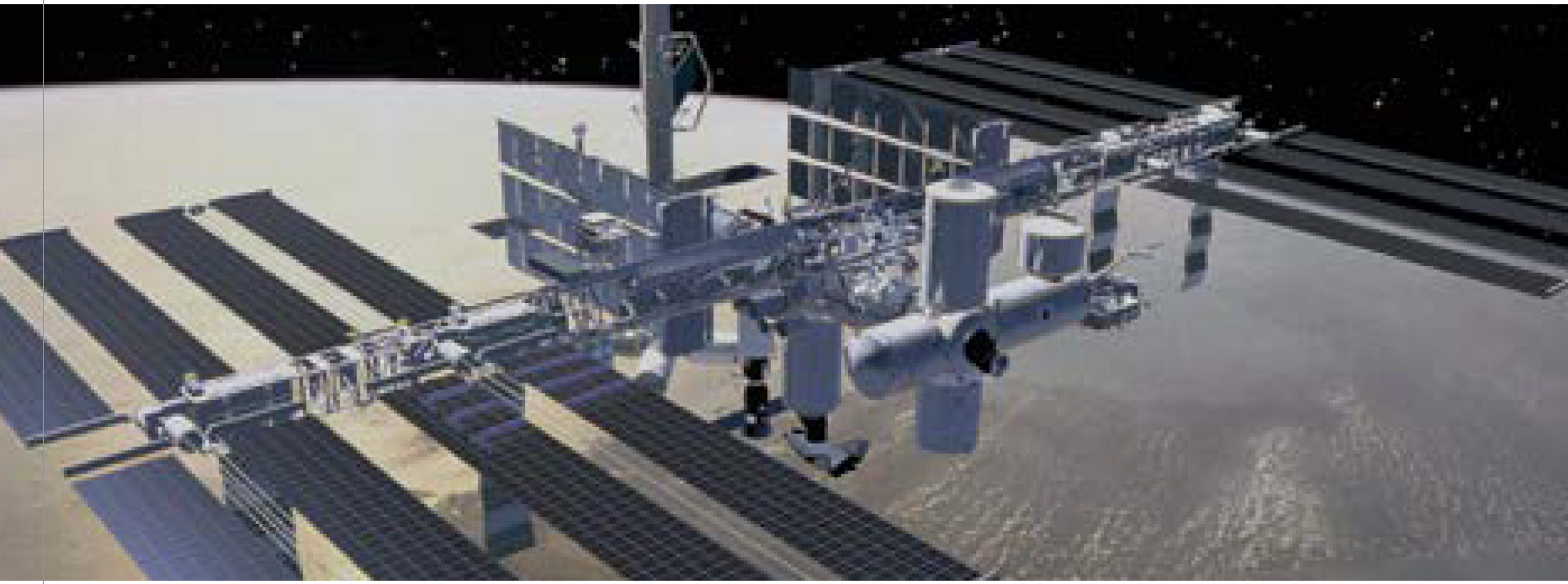
An example of insulation erosion caused by partial-discharge activity. These sites are often referred to as "electrical trees."

SOLUTIONS:

The speed and size of an electrostatic discharge are determined by a material's ability to hold a charge (capacitance) and its ability to reduce the flow of electrons (resistance). One solution is to employ metallic shielding to create a path that promotes electron flow to dissipate the charge. Another solution is to engineer more dissipative polymer formulations. Ethylene tetrafluoroethylene (ETFE) is widely used in spacecraft electrical interconnection systems because of its high melting point and high strength-to-weight ratio. Unfortunately, EFTE's high volumetric and surface resistivity tend to promote electric charging. Disordered carbon black molecules can be used in ETFE resins to make the material electrically dissipative. Another formulation employs nano-carbon cross-linked ETFE, which is more dissipative by an order of magnitude than conventional carbon black ETFE and provides the same class of ESD control as foil-wrapped wire.

TE PRODUCT EXAMPLES

- SPEC 55 space wire and cables are ESA-approved and insulated with modified radiation cross-linked ETFE polymer known to help control electrostatic discharge.



6. Reducing Electromagnetic Permeability

VALUE/IMPORTANCE:

Magnetic permeability—signified by the Greek letter Q—denotes a material's ability to form a magnetic field. Materials with high Q become highly magnetic when a magnetic field is applied; low Q materials are less responsive and exhibit lower levels of magnetism. While materials with high Q are suitable for some applications, strongly magnetic materials in electronics can degrade circuit performance, signal clarity, and instrumentation accuracy.

CHALLENGES:

In space applications, connectors and other interconnect components with a maximum permeability of 2 Q or lower are generally required. To ensure low Q, designers must avoid ferromagnetic materials—such as carbon steel commonly used in older MIL-DTL-24308 D-Subminiature connectors.

SOLUTIONS:

Non-ferromagnetic materials—such as aluminum, copper, titanium, and austenitic stainless steel—generally exhibit low magnetic permeability. For example, aluminum with an electroless nickel finish is often used as a connector shell material. Relevant standards include EIA-364-54: TP-54A Magnetic Permeability Test Procedure for Electrical Connectors, Contacts, and Sockets and MIL-STD 1344 Test Method 3006 Magnetic Permeability. Moreover, space applications can also require interconnects that exhibit low residual magnetism, also known as low magnetic field retention.

For example, brass shell materials with gold-over-copper flash finish are typically used in D-Subminiature connectors.

TE PRODUCT EXAMPLES

Connectors and terminals

- DEUTSCH 38999 Series III composite or aluminum circular combine low electromagnetic permeability with EMI/RFI shielding and are qualified to stringent MIL-DTL-38999 Series III specifications.

- DEUTSCH UR and RE SERIES connectors offer low magnetism in a lightweight, high-density connector well suited to satellite applications. The companion RE series is intermateable and recommended for non-flight applications.

- Gold-plated crimp terminals provide nonmagnetic, mechanically reliable, low contact resistance required for space.

Backplane connectors

- Fortis Zd connectors support speeds up to 12+ Gbps and include options with integrated EMI shields.

Gold-Plated terminals

- TE's portfolio of gold-plated crimp terminals offers mechanical reliability, excellent corrosion protection, and low contact resistance. These nonmagnetic components support design flexibility and performance needs and are available in multiple configurations.

7. Controlling Corrosion

VALUE/IMPORTANCE:

Corrosion affects interconnects differently in space than on Earth. During spacecraft manufacturing and storage on Earth, galvanic corrosion can occur when two dissimilar plating materials are in direct electrical contact with each other in the presence of an electrolyte. In the contact area, the less resistant material acts as an anode, and the other material acts as a cathode creating a galvanic cell that attacks—or corrodes—the anode.

In space at LEO altitudes between 200 km and 700 km, UV excitation of the remaining O2 molecules at the fringe of the atmosphere forms monatomic oxygen. Atomic oxygen (ATOX) corrosion occurs when these highly reactive monatomic oxygen molecules erode aluminum and plastics.

CHALLENGES:

Some materials commonly used in commercial interconnects are not suitabl in space. 100% tin plating can grow “whiskers” that can cause catastrophic electrical short circuits. Silver plating is significantly affected by ATOX corrosion. Cadmium is unstable in vacuums. Plastics are very sensitive to ATOX as well as ionizing radiation.

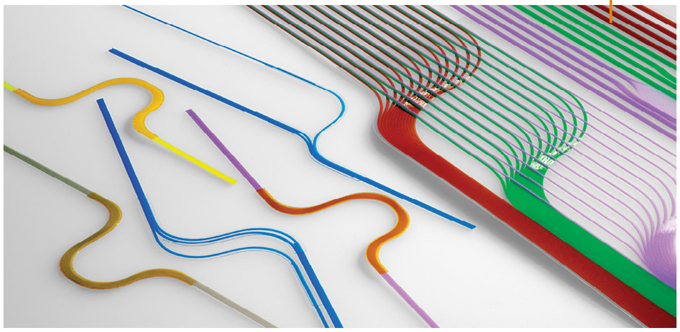
SOLUTIONS:

The ideal protection against galvanic corrosion is employing the same material in both contacts: aluminum with aluminum, zinc with zinc, etc. Alternatively, it is helpful to employ materials with low galvanic potential, such as space-grade polymers, thermoplastic composites, and glass (fiber optics). Plating and coatings can be used with alloys to avoid forming an electrolytic cell. Copper-alloy wiring and terminals exhibit relatively low galvanic potential when coupled with nickel, tin, and silver. Gold plating resists ATOX corrosion because Au is a noble metal that normally resists oxidation. Silicon-dioxide coatings can protect polymers from ATOX corrosion because SiO2 is already fully oxidized.

TE PRODUCT EXAMPLES

Fiber

- Rugged Fiber Optic (RFO) Optical Flex circuits take advantage of the zero galvanic potential of glass fibers in a robust, multifiber solution that is customizable for high-speed electronic packaging for card-to-card and backplane applications.



High-density Optical Flex circuit cable can be utilized for card to card or backplane applications with multiple options in cable assembly design, connectorization, and routing.

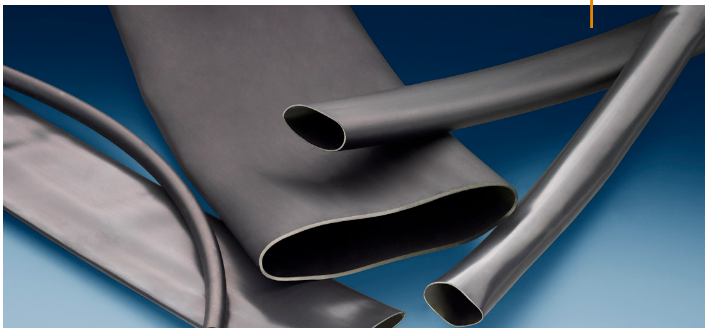
- High-density multiple MT ferule-based connector systems—as referenced in the VITA 87 standard—provide a space-and-weight-saving solution offering up to 96 fibers in a MIL-DTL-38999 size 15 connector.

Coaxial Cables

Cheminax line of coaxial cables offers lightweight, small-diameter constructions that meet more exacting specifications than standard radio-grade (RG) constructions. Conductor and shielding options include silver-plated copper and silver-plated high strength copper alloy or tin-coated copper if the environment will not promote the growth of tin whiskers.

Tubing

Raychem tubing protects contact areas, splices, and bi-metallic joints from corrosion with a UV-resistant and adhesive-lined polyolefin tubing material.



Raychem heat-shrinkable tubing offer significant protection against tough launch and orbit conditions.

Enclosures

Composite enclosures are extremely rugged and corrosion-resistant, offering nearly 50% less weight than aluminum and customizability for EMI shielding, antennas, and more.

Connectors and Terminals

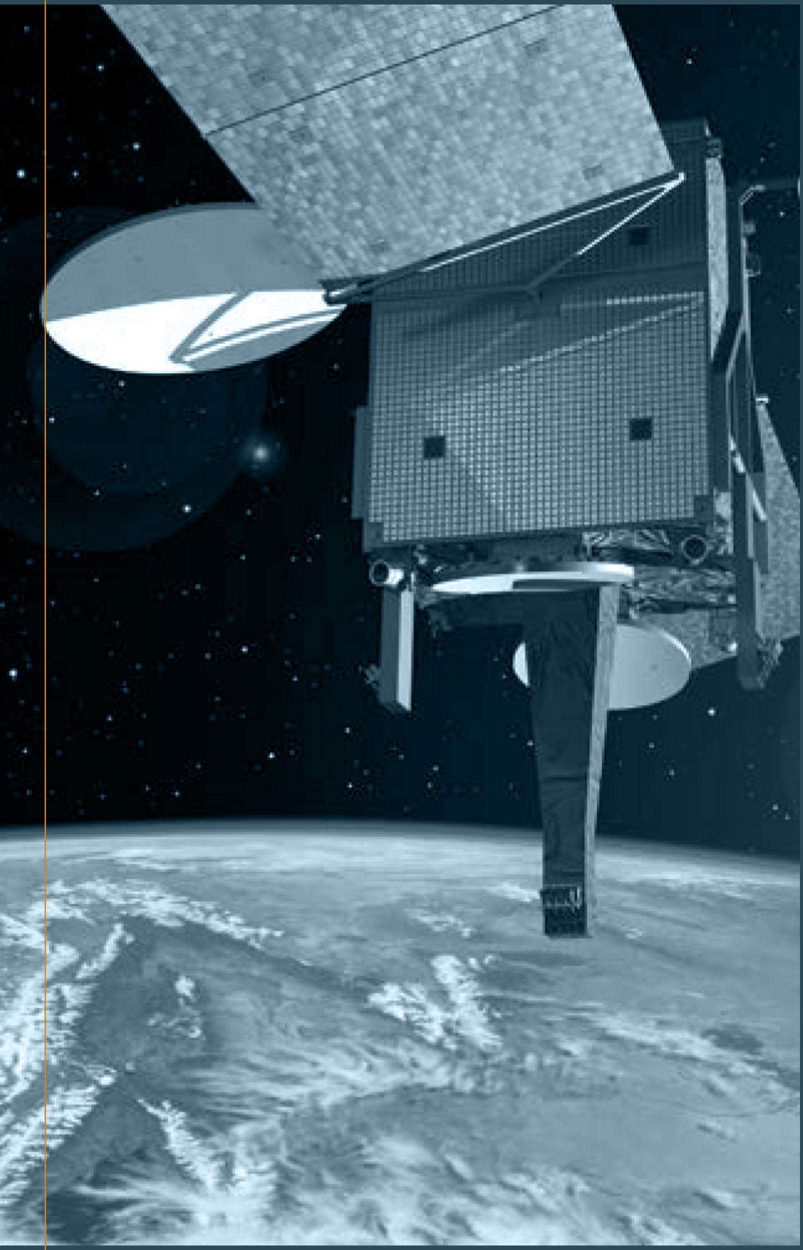
- MIL-DTL-38999 hermetic connectors address uncertainty about application conditions by providing a sealed glass-to-metal connection. This construction offers a continuous gas-tight seal against the environment, plus it creates a bond between shell, insulator, and contacts by fusing the glass insulator to the metal components, thereby offering inherent resistance to galvanic corrosion.

- MIL-SPEC RF compliant connectors are available for a range of radio frequencies up to 100 GHz and beyond. Center contacts are commonly plated with gold for its low contact resistance, superior mating properties, and corrosion resistance.

- DEUTSCH ACT Series MIL-DTL-38999 Series III composite shell connectors are lightweight, corrosion-resistant, and qualified to both MIL-DTL-38999 Series III and EN3645 specifications.

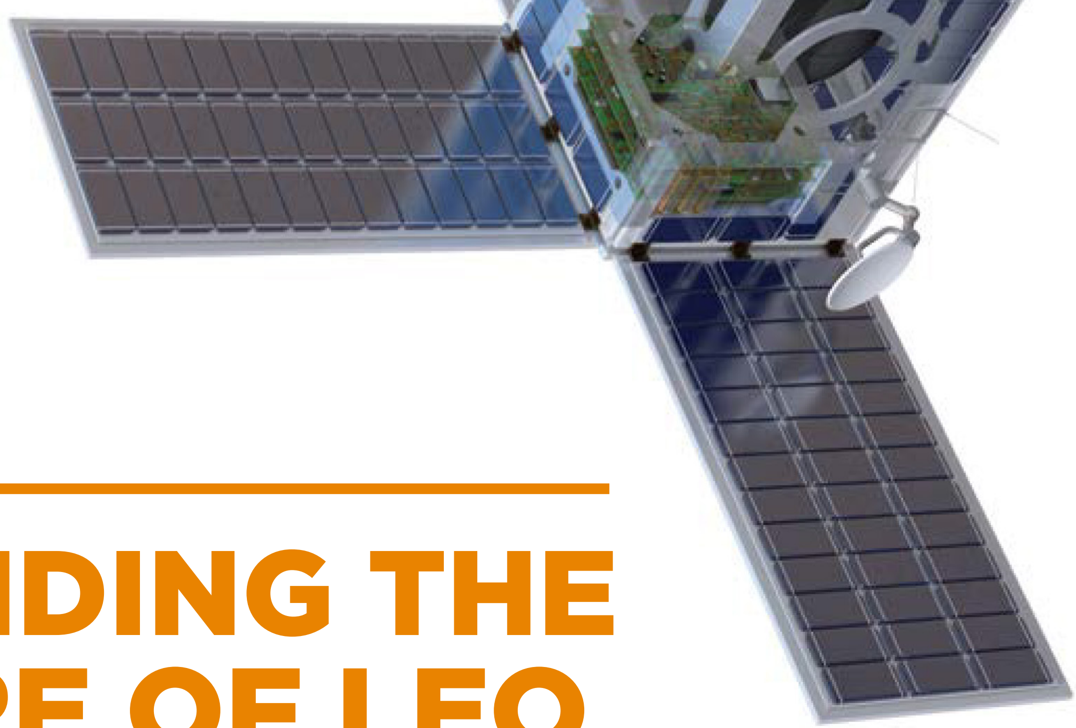
- AMPLIMITE subminiature-D connectors include ultra-lightweight, one-piece aluminum versions meeting NASA 311P specifications offering compact pin-and-socket connections especially designed for high-density packages.

- Gold-plated terminals enhance the reliability of wire connections for space applications with the inherent corrosion protection, mechanical reliability, and low-contact resistance of this noble metal.



Tin Whiskers: An Old Risk That Is Still Present

According to NASA, the first reports of "tin whiskers" dates back to the 1940s. Satellite control processor failures due to tin-whisker induced short circuits continue to be reported in recent years. Tin whiskers are crystalline structures of tin that can grow several millimeters long from tin or electroplated-tin surfaces. They appear as microscopic splinters in electronic contact pins that increase the risk of electrical shorts. Whiskers may also form in other metals, including tin alloys, zinc, and cadmium. The mechanism that propels hair-like whiskers to stretch out into space is not fully understood. What is known: Shorts, metal vapor arcs, and debris/contamination from tin whiskers can scuttle aircraft and spacecraft. Tin whiskers cannot grow through plastic housings and thick dielectric coatings. Growth commonly occurs in the interior portions of the contact (contact retention areas) where compressive stress is highest. Whiskers are not a problem for power circuits (high voltages electrically break down whiskers), but they may be an issue for surrounding circuitry. The risk of whisker growth can be minimized through controlled plating processes and approved tin-based plating formulations involving nickel (Ni), palladium (Pd), and gold (Au) coatings where lead (Pb) is not acceptable. TE's LITESURF plating technology using bismuth (Bi) has been developed for press-fit pin applications employed in the automotive industry. Risk of shorts also decreases as the separation distance between contacts increases.

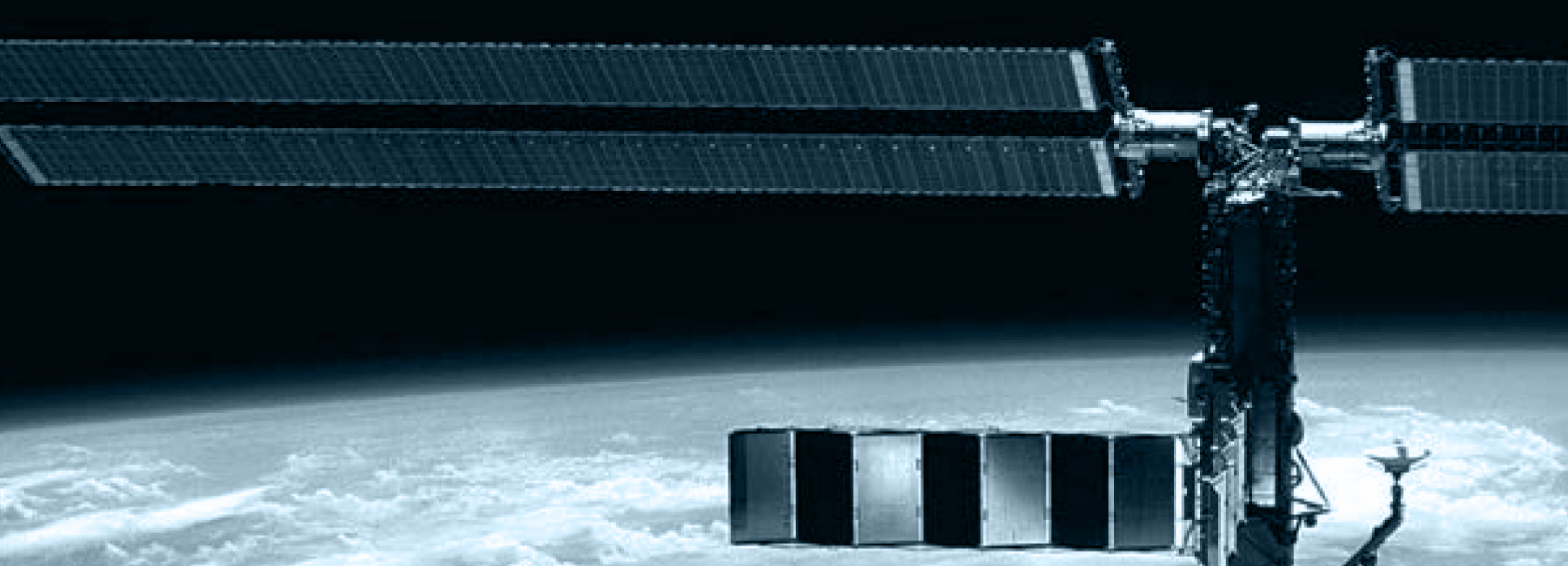


EXPANDING THE FUTURE OF LEO SPACECRAFT CONNECTIVITY

Today, the frontier of LEO-satellite networks is rapidly expanding thanks to enterprising private space companies and committed government-owned space agencies. New constellations of cross-linked satellites are spanning the planet with digital data, phone, voice, and Internet access.

These opportunities have inspired bold innovations in satellite design, aerospace engineering, and electronic packaging requiring a wide range of interconnects.TE supports LEO initiatives with space-qualified SpaceVPX, VITA, NASA, ESA, and MIL-SPEC compliant products—but also with COTS and COTS+ components to help meet mission profiles on strict time and cost budgets. With a heritage dating back to the days of the Surveyor lunar lander, Explorer 1 satellite, and Project Mercury manned flights, our expertise encompasses multiple solutions for spacecraft as well as launch vehicles and ground-support equipment.

Count on world-class interconnect development and manufacturing capabilities to scale with your mission—from satellite launch to deploying entire constellations.



References

[1]Jones, Harry W., “The Recent Large Reduction in Space Launch Cost,” NASA Ames Research Center. Paper presented at 48th International Conference on Environmental Systems, Albuquerque, New Mexico, July 2018, accessed 1/31/22, https://ttu-ir.tdl.org/bitstream/handle/2346/74082/ICES_2018_81.pdf?sequence=1&isAllowed=y

[2]Dynamic Range Corporation: Jeannette Plante and Brandon Lee, “Environmental Conditions for Space Flight Hardware – A Survey,” (NASA Electronic Parts and Packaging [NEPP] Program, 2004), accessed 11/18/2021, https://nepp.nasa.gov/DocUploads/C5E0869C-0469-4D11-9FAA8012C8F52351/Environmental%20Testing%20Survey.doc

[3]“Protect Against Corona Discharge and High Voltage Breakdown (1960’s-Present),” Lesson Number 598, NASA Jet Propulsion Laboratory, July 7, 1998, accessed 12/22/21, https://llis.nasa.gov/lesson/598. Also see “Space engineering: High voltage engineering and design handbook,” European Cooperation for Space Standardization (ECSS), ECSS-E-HB-20-05A, December 12, 2012, accessed 12/22/21, https://escies.org/download/webDocumentFile%3Fid%3D63541

[4]Koons, et al., Sixth Spacecraft Charging Technology Conference, Sept. 2000 cited by Chris Yun, “Dissipative ETFE Dielectric Polymer Helps Control Electrostatic Discharge in Wires and Cables,” TE Connectivity, 2017, accessed 11/18/2021, https://www.te.com/content/dam/te-com/documents/aerospace-defense-and-marine/white-papers/TE_Connectivity_Antistatic%20SpaceWire_ChrisYun-Whitepaper_2017.pdf

[5]Michael Sampson and Henning Leidecker, “NASA Whisker Failures”, NASA, August 3, 2009, accessed 11/18/2021, https://nepp.nasa.gov/whisker/failures/index.htm#satellite

te.com/space

Contact TE Connectivity