



Radiation-Resistant Wire and Cable for Space and High-Altitude Platforms

Summary

Space and high-altitude platforms operate in extreme environments where electrical systems must endure radiation, vacuum, thermal cycling, and mechanical stress. Radiation-resistant wire and cable are essential for maintaining system reliability over extended missions. Typical considerations include material degradation, outgassing behavior, and rigorous qualification standards. This whitepaper explores material selection, environmental effects, design strategies, and testing requirements for robust aerospace wiring solutions.

Introduction

Electrical wiring and cabling are mission-critical components in spacecraft, satellites, and high-altitude platforms. Failure of wiring can compromise power distribution, communication, or instrument operation. Unlike terrestrial applications, these environments present unique hazards:

- **Ionizing radiation** from cosmic rays and solar particle events.
- **Temperature extremes** from -150°C to +125°C or higher.
- **Vacuum conditions**, which can accelerate material outgassing.
- **Mechanical stress**, including vibration, bending, and thermal cycling.

Radiation can induce material degradation in polymeric insulation, leading to embrittlement and dielectric failure. Simultaneously, outgassing in vacuum can deposit contaminants on sensitive optics or electronics. Understanding these mechanisms and adhering to qualification standards promotes long-term system reliability.

Material Degradation under Radiation

Radiation interacts with wire and cable materials primarily through **ionization** and **displacement effects**, which can degrade mechanical and electrical properties:

Polymer Chain Scission and Crosslinking

- Ionizing radiation breaks molecular bonds, resulting in **chain scission**, which weakens mechanical strength and increases brittleness.



- Crosslinking can occur in some materials, increasing hardness but reducing flexibility.

Insulation Embrittlement and Cracking

- Radiation-induced embrittlement reduces bending tolerance, potentially causing cracks at sharp bends or connection points.

Dielectric Degradation

- The breakdown voltage of insulation decreases with cumulative radiation dose, increasing the risk of short circuits or leakage currents.

Material Examples:

- **PTFE/Teflon:** Excellent radiation tolerance; retains flexibility up to 1×10^8 rad.
- **PEEK:** High radiation resistance with superior mechanical retention post-exposure.
- **Polyimide/Kapton:** High thermal stability but may become brittle at very high total ionizing doses.

Outgassing Concerns in Vacuum

Outgassing is the release of volatile compounds from polymeric materials in vacuum. This is a significant concern for space systems:

Contamination of Sensitive Components

- Deposited outgassed materials can obscure optical sensors, reduce thermal control efficiency, or interfere with electronics.

Material Selection

- Low-outgassing materials are specified per **ASTM E595**, which measures:
 - **Total Mass Loss (TML):** Overall material loss in vacuum.
 - **Collected Volatile Condensable Materials (CVCM):** Fraction of volatiles that condense on nearby surfaces.
- Materials such as **PTFE, PEEK, FEP, and ETFE** exhibit low TML and CVCM, making them preferred for spacecraft and high-altitude applications.



Processing and Coating

- Curing, baking, or protective coatings can reduce outgassing.
- Multi-layer insulation (MLI) often provides additional protection.

Radiation-Resistant Materials for Wire and Cable

Material	Radiation Tolerance	Mechanical Properties	Outgassing	Common Use
PTFE (Teflon)	High (up to 1×10^8 rad)	Flexible, low friction	Very low	Power, signal wiring
FEP (Fluorinated Ethylene Propylene)	Moderate to high	Flexible, chemical resistant	Low	Signal wiring, coaxial cables
PEEK (Polyetheretherketone)	Very high ($5 \times 10^7 - 1 \times 10^8$ rad)	Excellent mechanical, thermal	Low	High-reliability wiring
Polyimide (Kapton)	High	High thermal stability	Moderate	Flexible printed circuits, spacecraft harnesses
ETFE	Moderate	High abrasion resistance	Low	Aerospace harnessing

Cable Design Considerations for Radiation and Vacuum Environments

Conductor Design

- Stranded conductors maintain flexibility under embrittlement.
- Silver-plated copper enhances corrosion resistance and ensures reliable conductivity.

Insulation Thickness and Layering

- Adequate thickness enhances radiation shielding.
- Multi-layer insulation or protective jackets mitigate mechanical damage.



Shielding

- Metal braids or foils reduce EMI, though shielding does not prevent high-energy particle damage.

Environmental Testing

- TID and DDD testing to simulate cumulative radiation exposure.
- Thermal cycling under vacuum to assess combined mechanical and radiation effects.

High-Altitude Platform Considerations

While HAPs experience lower radiation levels than satellites, they still face:

- **UV and ozone exposure**, which can degrade insulation.
- **Low-temperature brittleness**, which can reduce flex life.
- **Outgassing risks** for sensitive sensors.

Design choices include:

- UV-resistant fluoropolymers (ETFE, FEP).
- Lightweight, flexible cabling for moving parts.
- Verification of low outgassing to protect optics and instruments.

Qualification Standards and Testing

To establish reliability, aerospace wiring and cabling must meet strict standards:

Radiation Testing

- **Total Ionizing Dose (TID)** and **Displacement Damage Dose (DDD)** to evaluate cumulative effects.
- Radiation tolerance is matched to mission profile LEO (Low Earth Orbit) and GEO (Geostationary Earth Orbit), deep space.

Thermal and Vacuum Testing

- Simulates orbital temperature cycles and vacuum outgassing.



- ASTM E595 measures TML, CVCM, and Collected Volatile Condensable Material (WVR).

Mechanical and Flex Life Testing

- Bending, vibration, and torsion testing under radiation exposure.
- Guarantees harnesses maintain integrity over mission duration.

Industry Standards

- NASA-STD-8739.4: Soldered electrical connections.
- MIL-DTL-27500: General specification for electrical cables.
- ESA ECSS-Q-ST-70 series: Space wire harness and connector testing.

Applications

- **Satellite Harnesses:** PTFE-insulated power and telemetry wiring.
- **Space Station Systems:** Kapton or PEEK harnesses for robotics and payloads.
- **High-Altitude UAVs:** Lightweight ETFE-jacketed signal wires for sensors and communications.

Best Practices:

1. Match material selection to mission radiation and thermal environment.
2. Assure low outgassing for vacuum and optical cleanliness
3. Conduct rigorous TID, DDD, thermal, mechanical, and outgassing testing.
4. Confirm vendor data and follow industry qualification standards.

Conclusion

Radiation-resistant wire and cable are critical enablers of space and high-altitude platform missions. Material degradation, embrittlement, and outgassing present serious risks, but can be mitigated through careful selection of PTFE, PEEK, Kapton, FEP, or ETFE. Proper design, protective layering, and adherence to rigorous testing and qualification standards validate that electrical systems maintain reliability over extended mission durations. By proactively addressing radiation, outgassing, and mechanical stress, engineers can design wiring systems that are robust, mission-ready, and resilient in the harshest aerospace environments.