



Rugged Interconnect Solutions for Autonomous and Uncrewed Systems Operating in Harsh, Disconnected Environments

Executive Summary

Autonomous and uncrewed systems including unmanned aerial vehicles (UAVs), uncrewed ground vehicles (UGVs), robotic platforms, and distributed swarm systems are increasingly central to modern military operations. These systems are routinely deployed in contested, austere, and infrastructure-denied environments where reliable connectivity is essential to mission success.

Rugged interconnect solutions form the physical and logical backbone of self-sustaining platforms, enabling command and control, sensor fusion, navigation, and coordinated operations. Failures at the interconnect level due to environmental exposure, electromagnetic interference, or mechanical fatigue can result in degraded mission performance or complete system failure.

This whitepaper examines the operational connectivity challenges faced by autonomous systems and outlines rugged interconnect technologies aligned with **MIL-STD** environmental, electromagnetic and reliability requirements, and governed by **AS9100-certified** quality management systems. By aligning interconnect design and supplier selection with these standards, the Department of Defense and its industry partners can reduce integration risk, improve system readiness, and lower lifecycle cost.

Operational Context and Problem Statement

- **Autonomous Systems at the Tactical Edge**

Autonomous and uncrewed systems are increasingly tasked with operating at the tactical edge, often beyond line-of-sight and under contested electromagnetic conditions. These platforms must function with limited external infrastructure and withstand prolonged exposure to harsh environmental conditions.

- **Connectivity as a Mission-Critical Dependency**

All self-operating functions: navigation, sensing, decision-making, and coordination depend on reliable data exchange. Interconnect failures represent a systemic vulnerability, capable of cascading into loss of command authority, degraded situational awareness, or mission shut down.

From an acquisition perspective, connectivity resilience must be treated as a mission-critical requirement rather than a secondary design consideration.

Typical Connectivity Challenges



- **Environmental and Mechanical Stress**

Stand-alone platforms encounter environmental stressors including extreme temperatures, vibration, shock, dust, sand, humidity, and moisture ingress. These conditions align with qualification requirements defined in **MIL-STD-810**, which helps assure that systems can:

- Survive harsh, fielded environments
- Maintain operational reliability
- Reduce mission failure risk
- Supports lifecycle durability for defense, aerospace, and ruggedized platforms

Rugged interconnect solutions must demonstrate survivability and performance stability under these conditions to support reliable operations.

- **Electromagnetic Interference and Spectrum Contention**

Dense RF environments, intentional interference, and electromagnetic compatibility challenges degrade communications and onboard electronics. Interconnect design, including shielding, grounding, and cable construction, plays a critical role in compliance with **MIL-STD-461** and system-level electromagnetic survivability requirements which promotes:

- Mission-critical electronics function in dense RF environments
- Systems can coexist without mutual interference
- Platforms maintain command, control, navigation, and sensor integrity
- Communications and data links remain reliable under electronic warfare conditions

Disconnected, Degraded, and Denied Operations

Self-directed missions frequently involve intermittent or denied connectivity. Platforms must maintain internal connectivity and continue autonomous operations during communication outages. This drives requirements for redundancy, failover, and local processing architectures.

Reliability and safety impacts are assessed under **MIL-STD-882** and reliability modeling practices such as **MIL-HDBK-217**, supporting risk-informed acquisition decisions.

Rugged Interconnect Technologies



- **Ruggedized Physical Interconnects**

Rugged connectors, copper and fiber-optic cable assemblies, and sealed interfaces form the foundation of reliable platform connectivity. Components qualified to **MIL-DTL-38999**, **MIL-DTL-83526**, and related specifications provide predictable mechanical and electrical performance.

Manufacturing, inspection, and release processes governed by **AS9100** validates consistency, traceability, and audit readiness.

- **Hardened Wireless and Tactical Interfaces**

Wireless connectivity allows coordination among distributed uncrewed platforms. Tactical radios, antennas, and mesh networking nodes rely on mechanically robust and electromagnetically shielded interconnects to maintain performance under dynamic operational conditions. These architectures depend on the rugged interfaces to sustain connectivity as nodes move or are lost.

Mobile ad hoc networking (MANET) is a self-configuring infrastructure-less wireless network formed by mobile devices (nodes) that communicate directly with one another and dynamically route data as the network topology changes.

- **Fiber-Optic and Hybrid Architectures**

Fiber-optic interconnects provide high bandwidth, low latency, and immunity to electromagnetic interference. Rugged fiber assemblies qualified to standards such as **MIL-PRF-85045** support high-data-rate sensor payloads and secure backbone connectivity.

Hybrid architectures combining fiber and wireless links enhance resilience and operational flexibility.

Platform-Specific Requirements

- **Unmanned Aerial Vehicles (UAVs)**

UAV interconnect solutions must balance ruggedization with size, weight, and power constraints. Reliable command-and-control links and high-throughput ISR data paths are essential. Qualification to vibration, altitude, and thermal requirements per **MIL-STD-810** is critical to mission success.

- **Uncrewed Ground Vehicles (UGVs) and Robotic Systems**

UGVs and robotic platforms experience sustained vibration, impact, and environmental exposure. Interconnects must support articulated motion, resist contaminants, and permits rapid maintenance and replacement.



Lifecycle sustainment considerations align with **MIL-STD-1388 / GEIA-STD-0007** logistics analysis frameworks.

- **Swarm and Distributed Self-Controlled Systems**

Swarm systems rely on decentralized, resilient communication architectures that tolerate node loss. Interconnect solutions must support scalability, interoperability, and dynamic network topologies, consistent with DoD **Modular Open Systems Approach (MOSA)** principles.

Design, Quality, and Acquisition Considerations

From a procurement and program management perspective, rugged interconnect selection should prioritize:

- Compliance with applicable **MIL-STD environmental, EMI, and reliability standards**
- Supplier certification to **AS9100**, implementing controlled design and production processes
- Configuration management, documentation control, and traceability
- Long-term availability, obsolescence management, and sustainment support

Early integration of standards-compliant interconnect solutions reduces technical risk and supports cost and schedule objectives.

Operational Use Cases

In desert, arctic, maritime, and urban environments, rugged interconnects provide reliable performance where commercial-grade components fail. Qualification testing and materials selection aligned with defense standards promotes mission readiness across diverse operational theaters.

Future Considerations

Emerging capabilities, including AI-enabled autonomy, integrated photonics, and future 5G/6G tactical networks—will increase connectivity demands. Rugged interconnect suppliers aligned with MIL-STD and AS9100 requirements will be critical facilitators of these future systems.

Conclusions and Critical Points



Rugged interconnect solutions are foundational to the effectiveness of autonomous and uncrewed systems operating in harsh, disconnected environments. Aligning interconnect design, qualification, and supplier selection with **MIL-STD requirements** and **AS9100** quality management principles:

- Improves system reliability and mission assurance
- Reduces integration and sustainment risk
- Supports scalable, future-ready autonomous architectures

For DoD acquisition programs and defense industry partners, standards-compliant rugged interconnects are a strategic investment in operational success.