WHITE PAPER

Leveraging High-Performance RF Adapters for Enhanced Military Communications, Radar, & Sensing

Introduction

There are a few technology trends progressively spreading to nearly all technological applications. One of these main trends that appears to have a cascading effect to other types of technology is electrification. Many legacy technology platforms, including industrial machines and military/defense platforms, are increasingly being converted to electrified systems, or there is ongoing development to replace legacy systems with electrified versions. Part of this push is driven by increasingly capable electronic sensors, actuators, controls, and communications systems being developed for systems like electric vehicles (EVs), renewables, energy storage systems, or other applications that have overlapping value in other use cases.

A subset of this, is the movement toward more capable wireless communications over conducted or waveguide (including fiber optic) communications. A new feature of this trend is using wireless, not just for extra-system communications but also intra-system communications. Using wireless communications with a land mobile, unmanned system, aerospace, or naval platform isn't new, but intra-system wireless is being explored by NASA and other agencies to reduce the weight and complexity within these platforms as a response to the growing number of electronic interconnections needed with modernized platforms. Of course, no "wireless" system is truly wireless, but the wireless links merely replace long runs of digital, analog, power, RF, or other connections. In fact, many new wireless systems require more and more complex interconnect components, just not longer runs of conductive or waveguide cabling.

Another factor to consider is the ever-accelerating pace of electronics technology development. New technology development cycles are often now being shrunk to a matter of months instead of years. This is an extremely aggressive timeline, especially for military/defense applications, but one that is necessary to ensure technological competitiveness on the global stage. A consequence of this shortened timeline is the need to remain agile and to have the option to rapidly retrofit present and future systems.

Even with the push by the US Department of Defense (DOD) and other defense agencies for more integrated and compact systems, there is still a growing need for RF interconnect. The increasingly higher port counts of newer communications, radar, and sensing modules is a leading cause of need for more and denser RF interconnect.

A necessary part of this adaptability is to accommodate new RF modules and systems as they are developed with as little development time for integrating these new systems in legacy platforms as possible. A key component for this, especially with the rise of wireless links, communications, radar, and other sensing technologies are RF adapters. Specifically, RF coaxial adapters as coaxial interconnect is now one of the most common types of interconnect for between-module and between-system interconnect.

This whitepaper dives into the nuances of RF coaxial adapters for military/defense applications with a focus on the key considerations and types of RF coaxial adapters that are best suited for military/defense use cases.

Common Military Coaxial Connector Types

The origin of standardizing coaxial connectors came from the need for the US military to have commonality amongst the various new RF systems being developed and deployed. This standardization made it possible for an ecosystem of compatible RF modules and system components to emerge. As a given module or system component will typically have a fixed coaxial connector type, this standardization also gave rise to the need for RF adapters that could go in-series and between-series for various coaxial connector types. Hence, there are a diverse range of RF adapter options for bridging between common coaxial connector types used in military/defense applications.

Coaxial Connector Types

- MCX
- N-type
- SMA
- SMP
- TNC
- QPL
- BNC
- D-Sub

Example of a typical SMA coax adapter

Historically, military and defense applications have used frequencies from several kilohertz to the Ka-band (27 GHz to 40 GHz). These applications range from simple voice communications to advanced and high-throughput satellite communications. However, the most common frequency ranges used for military communications have been in the hundreds of megahertz. For radar applications, X-band (8 GHz to 12 GHz) is one of the most common frequencies used, but most militaries still use radar frequencies from tens of megahertz to Ku-band (12 GHz to 18 GHz). The divide between RF communications and radar/sensing systems is blurring as many systems are becoming multi-capable. Moreover, extremely wide bandwidths for communications and radar/sensing are also being developed as wider-bandwidths enable techniques that can be used for low-probability of detection/low-probability of intercept (LPOD/LPOI) applications. Wider bandwidth capable communications and radar also add an edge of anti-jamming.

Radar Frequency Bands

Band Designation	Frequency Range	Typical Usage
VHF	50-330 MHz	Very long-range surveillance
UHF	300-1,000 MHz	Very long-range surveillance
L	1-2 GHz	Long-range surveillance, enroute traffic control
S	2-4 GHz	Moderate-range surveillance, terminal traffic control, long-range weather
C	4-8 GHz	Long-range tracking, airborne weather
X	8-12 GHz	Short-range tracking, missile guidance, mapping, marine radar, airborne intercept
K_u	12-18 GHz	High resolution mapping, satellite altimetry
K	18-27 GHz	Little used (H_20 absorption)
K_a	27-40 GHz	Very high-resolution mapping, airport surveillance
mm	40-100+ GHz	Experimental
Source: AIAA (American Institute of Aeronautics and Astronautics)		

As part of the shift to wider bandwidth operating communications and radar, many military/defense organizations around the world are also moving to higher frequencies. Part of this move is to avoid spectrum congestion in the sub-6 GHz and now even sub-10 GHz range, as consumer and industrial applications move to higher frequencies to take advantage of the extended bandwidths available in these portions of the spectrum. Another advantage that is making higher microwave and millimeter-wave frequencies attractive for military/defense applications is that atmospheric attenuation is much greater at higher frequencies. Higher atmospheric attenuation and narrower beamwidths can result in more targeted communications that are less likely to be intercepted.

Moreover, higher frequency antenna designs also tend to allow for higher directivity. This can be additionally advantageous as higher frequency antennas can also be made much more compact and combined in antenna arrays for advanced/active antenna systems (AAS) or actively electronically scanned arrays (AESAs). As a product of this, there has been a growing use of upper microwave and millimeter-wave coaxial connectors and adapters for military/defense applications.

Upper Microwave & Millimeter-wave Connector Types

- 1.85 mm
- 3.5 mm
- 2.4 mm
- 2.92 mm
- 1.0 mm
- 0.8 mm

High frequency 1.85mm connector

Key Technical Considerations for RF Components for Military Applications

Any component placed within the RF path impacts the performance of that path, which is why the RF adapters made for rugged applications must also meet the environmental, mechanical, and electrical performance requirements as the rest of the system. There are also several features that are commonly used to ruggedize RF adapters, many of which were originally developed for military/defense applications.

Compliance & Testing to Military/Defense Standards

To be used in military/defense applications there are ever evolving standards and requirements that must be met that typically include construction methods, testing methods, materials, traceability, country-of-origin, and handling. These standards apply to RF components/equipment that will be used or operated in specific government and military/defense use cases and doesn't necessarily apply to all RF adapters and other equipment used to support governments and militaries. For instance, there are specific and distinct standards for any equipment to be used in space, airborne, naval, land mobile, or military/government fixed installations. For test and measurement, maintenance, installation, or other applications may not require RF adapters and other components to be held to the same standards but may have to go through similar procurement processes.

Common US Military Specifications & Standards for Coaxial Adapters

- MIL-STD-348
- MIL-PRF-39012
- MIL-STD-202
- MIL-PRF-55339
- IEC
- EIA
- EN

The military/defense standards that govern coaxial connectors, and hence RF adapters, typically also include various other standards for materials and constructions from industry and government organizations. This creates a very complicated set of requirements for producing RF adapters that meet military/defense application requirements. MIL-PRF-39012 is an example that is a general specification for RF coaxial connectors, but encompasses many standards, some from ASTM and other US standards organizations.

MIL-PRF-39012F Materials

Material	Applicable Specifications
Steel	ASTM A484/A484M, ASTM A582/A582M
Brass	ASTM B16/B16M, ASTM B36/B36M, ASTM B121/B121M, ASTM B455
Phosphor bronze	ASTM B139/B139M
Soft copper	ASTM B152/B152M
Copper	ASTM B88, ASTM B124/B124M
Copper-Beryllium	ASTM B194, ASTM B196/B196M, ASTM B197/B197M
PTFE fluorocarbon	ASTM D4894, ASTM D4895
FEP fluorocarbon	ASTM D2116
Silicon rubber	A-A-59588

US DOD Standards Used In MIL-PRF-39012

- MIL-STD-202 - Test Methods for Electronic and Electrical Component Parts
- MIL-STD-202-101 - Salt Atmosphere (Corrosion)
- MIL-STD-202-106 - Moisture Resistance
- MIL-STD-202-107 - Thermal Shock
- MIL-STD-202-112 - Seal
- MIL-STD-202-201 - Vibration
- MIL-STD-202-213 - Shock (Specified Pulse)
- MIL-STD-202-302 - Insulation Resistance
- MIL-STD-202-301 - Dielectric Withstanding Voltage
- MIL-STD-348 - Radio Frequency Connector Interfaces
- MIL-STD-889 - Galvanic Compatibility of Electrically Conductive Materials Dissimilar Metals
- MIL-STD-1285 - Marking of Electrical and Electronic Parts

Ultimately, what standards apply and how they apply depend upon the specific application and the requirements of the requisitioning the equipment. This is why RF coaxial adapters have such a diversity of features. The following will include some details of BNC requirements to MIL-PRF-39012 as examples of what US standards for military/defense RF adapters are.

MIL-PRF-39012 Coaxial Connector Standards

- BNC
- N
- TNC
- SMA
- SMB
- SMC
- SMP
- SSMP
- SOP
- OSSP
- OSMM
- SSMA
- SC
- QMA
- UMCC
- SSMT
- MMCX

Designed To Meet Defense Architectures

In addition to military/defense standards there are also defense architectures and programs, such as EU's Generic Open Soldier Systems Architecture (GOSSRA) and the US Nett Warrior and Joint Battle Command - Platform (JBC-P), which are geared toward developing a platform for more advanced dismounted soldier systems. These architectures/programs and others like them have requirements for interconnect that must be

met in addition to all relevant military specifications. As RF communications are a key part of these architectures/ programs RF adapters can be crucial in enabling the adaptation of various RF communication systems and antennas either to these programs and from program developed equipment to other systems.

Shock & Vibration Resistance

As part of MIL-PRF-39012 coaxial connectors, including adapters, RF adapters for US military/defense applications must meet specific shock and vibration standards. European and other governments have similar standards.

For shock testing, BNC connectors must withstand acceleration to 50 G's at 7 milliseconds without discontinuities (<1 microsecond) to MIL-STD-202-213. For vibration, the high frequency standard as specified in MIL-STD-202-204 test condition B without any discontinuities. This means that an RF adapter must be able to withstand high frequency vibrations and acceleration to 50 G's at 7 milliseconds while continuously operating to the other specification and requirements.

Corrosion Resistance & Moisture Resistance

There are a variety of potentially corrosive environments that RF adapters may be used. The most common and of concern to military/defense organizations is generally salt spray, as ionized water can lead to extensive corrosion of many metals and alloys. According to MIL-PRF-39012, corrosion testing must be done to MIL-STD-202-101 test conditions B to be viable for US military use. A moisture resistance test is also done, and the connectors must pass without any damage while maintaining the specified dielectric withstand voltage and insulation resistance.

Coaxial cable with MIL-390-12 spec TNC connectors

Operating Temperatures, Storage Temperature, and Temperature Cycling

As an environmental condition, temperature and thermal variability is one of the most complex. Not only must an RF adapter meet its specification during normal operating conditions, but also over a wide temperature range for military and defense applications. For these applications many RF adapters also need to meet severe temperature cycling specifications, such as MIL-STD-2O2-107, but with high temperatures to 200 degrees C. RF adapters for these applications must also withstand being stored at even greater temperature ranges without degradation over a specified storage lifespan.

Dust/Debris

In many cases outside of military specifications it is useful to keep dust and debris outside of RF connections without requiring hermetically sealed components. This is why some RF adapters include O-rings, dust caps, and other measures to prevent ingress of dust/debris into the inner portions of the connection interface. These measures may also be necessary to meet certain military specifications (moisture resistance, corrosion, etc.) depending on the design of the connector interfaces.

Hermetic Seal

Some applications may be in environments where there is essentially no other viable alternative to hermetic sealing to ensure that a system either maintains a given pressure internally or prevents external environmental ingress due to high pressures. If a hermetically sealed system is required, typically for pressurized applications, then RF adapters would need to meet MIL-STD-202-112 for US military/defense use. This includes meeting typical hermetic requirements to a leakage rate sensitivity of 10^-8 cubic centimeters per second.

EMC Shielding/RF Leakage

Standards also exist to ensure that RF connectors don't leak internal RF energy and prevent ingress of external RF energy. These shielding and leakage standards are vital for secure signals but also to prevent dynamic range reduction and possible interference from high energy external signals. These high energy signals of concern may even be created by other systems on the same platform or other friendly systems on other platforms in the same theater.

Blind Mate

There is an increasing use of blind-mate style coaxial connectors in many RF and high-speed digital applications. Several of the smaller blind-mate style coaxial connectors reach relatively high frequencies and can be installed with little training and no tools. In many cases, these blind mate connectors can also be matted in tandem for a much more efficient board-to-board interconnect. There are specific standards for ensuring the blind mate connectors, and hence RF adapters with blind mate connector types, which must be met for military/defense use. These standards include all of the similar requirements of other coaxial connectors but also additional ones for the amount of force needed to connect/disconnect, and the maximum insertion force the connectors can withstand.

Longevity

Specific applications may have requirements for a mean-time-between-failure (MTBF) or other measure of the life cycle of a coaxial connection. This could also be the number of times a given connection can be cycled before dropping below specified levels. This is typically controlled in military standards by requirements for workmanship and finishes that are designed to ensure a useful working life of a connector. This is one of the reasons that copper beryllium is often used in military/defense applications as it is a rugged and corrosion resistant material that also has good RF properties.

Non-reflective Finishes

Certain applications, typically of those that may be in active combat or stealth operations, may require finishes that conform to a color scheme or prevent reflection. RF adapters with these non-reflective finishes would be ideal for manpack radios, land-mobile vehicles, and other applications where the reflectivity of typical metals used to construct RF adapters could present operational difficulties or are otherwise not desired.

RF Adapter Types Vital for Military/Defense

There are several RF Adapter types that can be particularly useful in military/defense applications. Some specific RF Adapters may even be designed to deliver several of the features of the adapter types in the following list.

RF Adapter Types for Military/Defense

- Hermetically Sealed Adapters
- Field Replaceable Contacts
- Bulkhead Adapters
- Bullet Adapters
- 2-hole & 4-hole Flange Adapters
- Push-Connect Adapters for Board-to-test
- Upper Microwave & Millimeter-wave Adapters
- Angled Adapters
- Angled Bulkhead or Flange Adapters
- Low PIM Adapters
- High Temperature

For instance, there are hermetically sealed bulkhead adapters that operate to millimeter-wave frequencies that may also be used as bullet adapters if needed. These connectors may also operate to extreme temperatures. Several features of these RF adapters, however, are exclusive of other features. For instance, RF adapters with field replaceable contacts aren't also hermetically sealed adapters. It also may be difficult to deliver low PIM performance in a hermetically sealed adapter.

Conclusion

RF coaxial adapters are evolving as military/defense requirements and standards evolve. The ongoing evolution of these often-critical RF components means that there are frequency new types and RF adapter features being developed to accommodate the dynamic landscape of needs for more compact, lower weight, more rugged, lower pitch, faster interconnect, longer lifespan for the modern defense theater.

References

1. https://landandmaritimeapps.dla.mil/programs/milspec/ListDocs.aspx?BasicDoc=MIL-PRF-39012