Harsh Environment Connectivity Options for Ruggedized RF-Over-Fiber Applications

Defense budgets around the world are being squeezed by continuous government pressures to reduce spending. Defense departments are pushing systems manufacturers to provide increasingly capable and efficient systems at current or, in some cases, even reduced costs. Major systems integrators are currently dedicating substantial resources to evaluating new techniques and technologies to reduce cost, improve system performance, and provide the best possible equipment to today's warfighter. One technology that is garnering substantial attention is RF-over-fiber.

RF-over-fiber is a cognomen for the technology that allows a high frequency, data-carrying RF signal to be transmitted via optical fiber. This technology is widely used in both the CATV and wireless telecommunications markets. It is now being investigated for use in a number of defense applications such as radar, satellite communications, and battlefield wireless technologies. In its simplest terms, an RF-over-fiber system modulates light with a radio signal, transmits that resulting analog optical signal over an optical fiber, and then re-converts the optical signal to a radio signal, typically with the purpose of broadcasting that signal over the air.

Historically, RF transmissions have been made via copper wire, but there are numerous advantages to using optical fiber in defense applications. First, fiber optic cable is much lighter than copper cable. This weight savings is advantageous in making a system lighter and more easily transported and deployed by a soldier. It also reduces the overall weight of a vehicle or ship, resulting in greater fuel efficiency. The weight savings can also be used to add additional equipment to the vehicle or ship. Second, fiber optic cable is not affected by electromagnetic interference. Fiber optic cable also does not create electromagnetic interference making it difficult to detect by enemy forces. Finally, optical signals can travel much farther than equivalent signals conducted on copper wire. This allows for greater distances between communications shelters and antennas making military personnel in the field harder to detect.

The greatest difficulty in deploying RF-over-fiber systems in military applications has been the lack of ruggedized fiber optic connectors capable of meeting the stringent return loss requirements needed for quality signal transmissions. RF signals transmitted on optical fiber are analog and as a result are quite susceptible to signal degradation caused by light reflected upstream into the transmitting laser. Excessive reflected light, typically caused by connection points or passive devices in the system, cause a destructive wave interference adding noise to the optical signal. Most analog systems require a minimum return loss of 65dB.

In commercial applications, angle polished connectors (like the ubiquitous FC/APC connector) minimize return loss by directing reflected light out of the optical pathway through an 8 degree angled ferrule end face. The angled end face scatters the light rather than allowing it to reach the transmitting laser. Unfortunately, commercial connectors are not rugged enough to survive military applications. They perform poorly under vibration, shock, and in extreme environmental conditions. At critical times, they do not provide a reliable solution for conducting critical fiber optic signals.

Military grade fiber optic connectors have been used in numerous applications over the last 15 years. These connectors are designed to provide precise optical alignment under extreme mechanical and environmental conditions. Most military systems containing fiber optics use multimode fiber, but in the last 5 years single mode fiber has become much more common. The use of single mode fiber is expected to continue to increase in the future. While the military connectors used with single mode fiber are common and readily available, they are typically not able to meet the 65dB return loss requirement needed for quality analog optical signal transmission. The end faces on standard military fiber optic connectors have a spherical dome end face rather than an angled end face. Most standard military single mode connectors can offer, at best, 45dB return loss. To meet 65dB return loss for military applications, angle polished end faces need to be added to the military fiber optic connector product suite.

Fortunately, a number of options for military fiber optic connectors with APC end faces are in development or available today. These connectors are based on existing and field-proven military fiber optic connectors, but with modifications to support the needed return loss requirements.

The APC28876, manufactured by Amphenol Fiber Systems International, is based on MIL-PRF-28876 connectors that have long been used by the US Navy as its primary tactical grade shipboard fiber optic connector (refer to Figure 1). The multi-channel M28876 is designed with the precision alignment needed for a quality optical connection. Additionally, it is designed to survive extreme mechanical shocks, high vibrations, and corrosive environments found at sea. The MIL-PRF-29504 termini are made with the most robust spring mechanism available. The spring force on the terminus allows the connector system to function under extreme mechanical loads. With single mode fiber, one can expect a typical insertion loss of 0.4dB per connection and a return loss of 45dB. While this is truly exceptional optical performance for standard digital requirements, it is insufficient for analog signals.

Figure 1 – APC28876

The APC28876 takes this performance a step further. By adding a key to the M29504 terminus and polishing an angled surface onto the ferrule, an APC terminus is created. The terminus key, when combined with a custom connector insert including a keyway, allows a predictable orientation for the location of the angled surface in the multi-channel connector. These angled termini, much like the FC/APC found in the commercial world, provide the 65dB minimum return loss needed for a properly functioning analog optical system. The most important point to note is that only minimal changes are required to add the angle polish termini to an already proven connector system. The mechanical and environmental characteristics expected in the standard connector series, primarily controlled by the connector shell and backshell features, are not affected.

Another military grade solution for APC connectors becoming popular in the market is based on the ARINC801 standard (refer to Figure 2). These connectors, made by Amphenol, Radiall, and Sabritec, are derivative of the D38999 series connector. D38999 connectors were originally designed as electrical connectors. As such, the shells are not designed for precision alignment. The ARINC801 specification overcomes this deficiency by utilizing precision inserts and a custom optical terminus. The ARINC801 termini are based on the commercially available LC connector, utilizing the same ferrule and spring as a standard LC connector. When combined with the ARINC801 precision inserts, a quality APC connection system is achieved. Insertion loss is typically 0.4dB, and the necessary 65dB return loss is also achieved. The ARINC801 is ideal for high vibration environments where mechanical shocks are not expected. The excellent vibration performance is due to the ratcheting coupling nut and low connector mass.

Figure 2 – ARINC801

A third APC connectivity solution that is emerging and will likely become the dominant military grade APC connector is based on the MIL-PRF-64266 specification (refer to Figure 3). The MIL-PRF-64266 was developed by an industry working group managed under the auspices of the US Navy. Every major military fiber optic connector manufacturer participated in this group. At its heart, the M64266 standard combines the best optical performance characteristics and alignment features of the M28876 series with the best shell characteristics of the D38999 series. The M64266 connector uses a 1.25mm ferrule combined with a terminus design reminiscent of the field-proven M29504 terminus. A robust 4lb spring provides excellent shock and vibration resistance. Insert-to-insert bottoming between mating connectors locks the terminus in place for increased stability. A suite of purpose-built backshells provides superior strain relief for virtually any cable type. As with the other solutions available, 0.4dB insertion loss and 65dB return loss are expected.

Figure 3 – MIL-PRF-64266

For all APC connectivity solutions (both commercial and military), terminus end face geometry is a critical parameter for a successful connectivity system. Fortunately, well-known commercial end face geometry standards such as Telcordia GR-326-CORE are applicable to military style termini as well. Parameters such as fiber height, radius of curvature, and apex offset map well from commercial to military applications. These features can be evaluated using

standard interferometers with minimal (if any) changes to a standard set-up (refer to Figure 4). Similarly, well established commercial APC polishing processes are generally also applicable to military style termini.

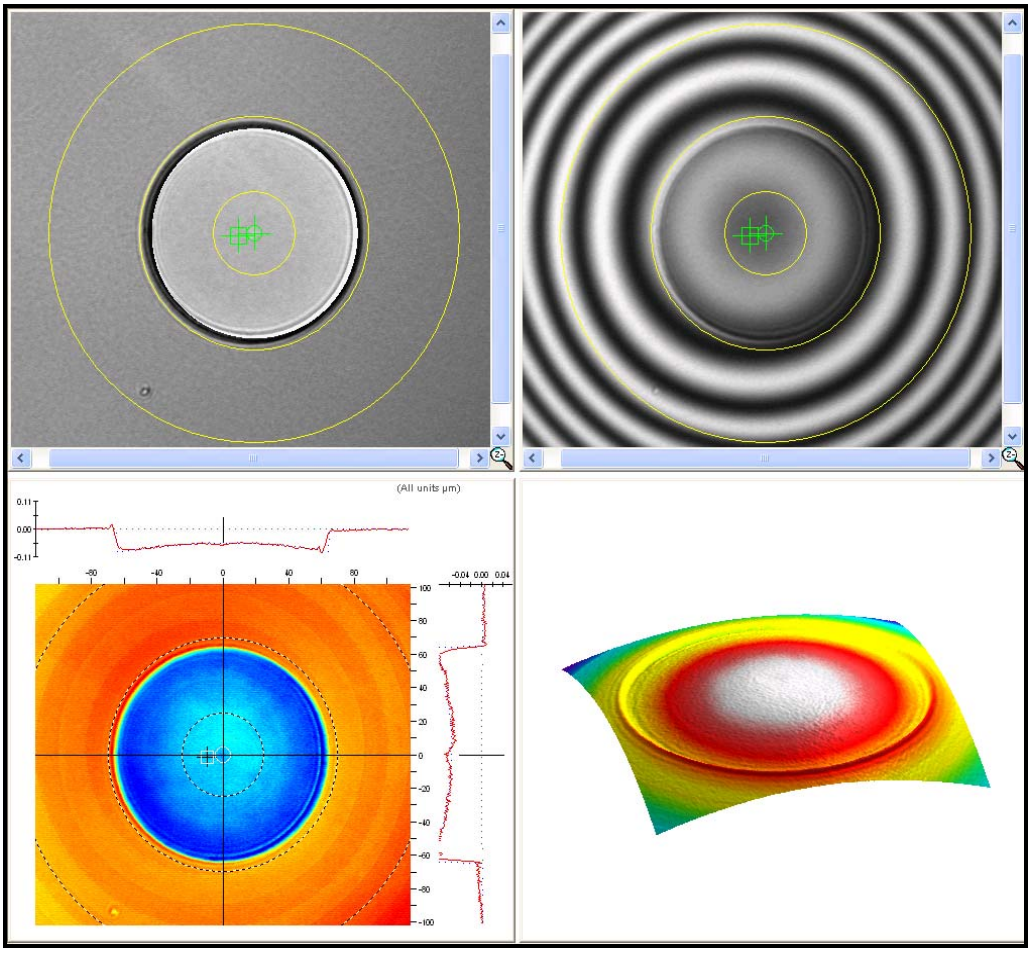

Figure 4 – End Face Interferometry Check

Since many RF-over-fiber optical systems operate at relatively higher optical power levels, terminus end face cleanliness is another parameter critical to a highly functional connectivity system. Debris, contaminants, and scratches can all lead to optical signal degradation. In extreme cases, these defects can result in physical damage to the terminus end face during use. Proper cleaning using lint-free wipes and laboratory grade isopropyl alcohol is usually sufficient to prevent loss due to contaminants. As with end face geometry, commercial end face quality standards (such as IPC-8497-1) are applicable to military APC termini also. Compliance with this standard can be verified using standard bench top equipment such as JDS Uniphase's FiberChek2 system (refer to Figure 5).

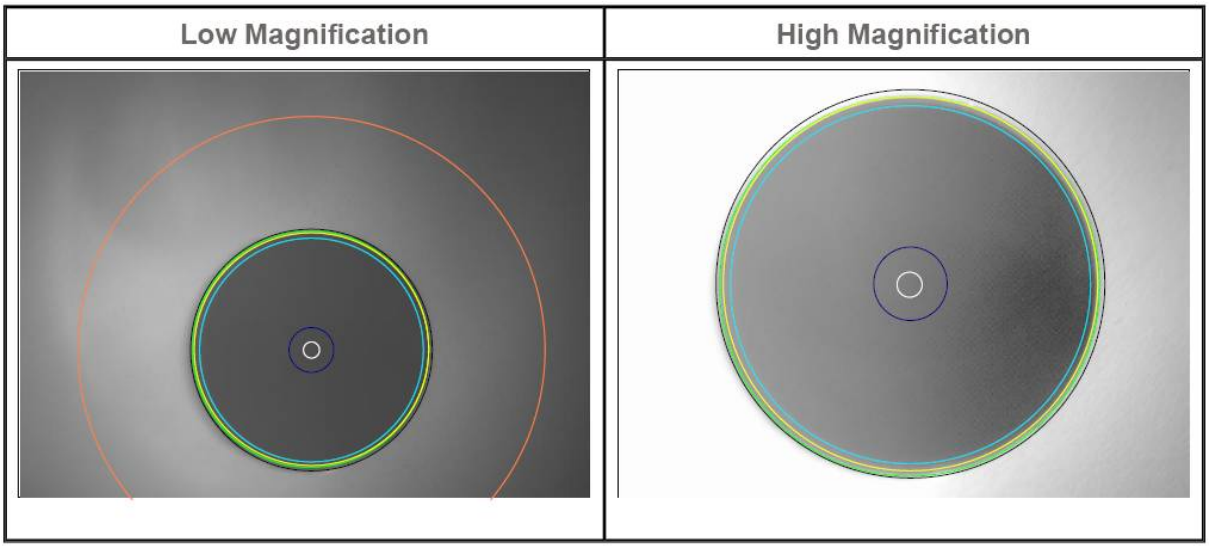

Figure 5 - End Face Quality Check

High performance RF-over-fiber optical communication systems hold great promise for advances in numerous areas of defense technology. From state-of-the-art radars to cutting edge wireless battlefield communication systems, RF-over-fiber technology is poised to revolutionize military network technology. Recent advances in harsh environment fiber optic connectivity bring this technology one step closer to the warfighter.

Amphenol
Fiber Systems International

Company Overview

Amphenol Fiber Systems International (AFSI), a division of Amphenol, provides reliable and innovative fiber optic interconnect solutions that withstand the harsh environments of military (ground systems, avionics, shipboard), energy and broadcast applications. After more than 18 years in business, AFSI maintains its position as a global leader in fiber optic interconnect components and systems such as termini, M28876, 38999 assemblies, MIL-ST, TFOCA and the TFOCA-II® connector, which AFSI developed and patented. AFSI has delivered millions of fiber optic connectors in more than 34 countries. Whenever there is a need for superior cost-effective fiber optic systems and products that will stand up to demanding operating environments, you can rely on AFSI for engineering know-how, top-quality products and expert technical support.

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