FIBER OPTIC CABLE ASSEMBLY DEVELOPMENT AND ITS IMPACT ON TACTICAL COMMUNICATIONS

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ABSTRACT

A new tactical fiber optic cable assembly has been designed to withstand the stringent environmental and mechanical requirements imposed on tactical communications equipment. A completed cable assembly consists of a one kilometer cable containing two tightly buffered optical fibers, terminated with hermaphroditic connectors to facilitate field deployment. The fibers are radiation hard with dual wavelength capability having attenuation <0.80 dB/km with a bandwidth product greater than 400 MHz-km at 1300 nm. The cabled optical fibers in a ruggedized all dielectric structure exhibit an incremental loss below 0.5 dB/km over the operating temperature range -48°C to 71°C . The cable weighs less than 33 kg/km, is 6 mm in diameter and has a 1780 newton tensile rating. The ruggedized duplex hermaphroditic tactical connector has insertion loss below 1 dB. A connector weighs less than 300 grams, is less than 4 cm in diameter and field cleanable. The cable assembly has been tested in accordance with DoD-STD-1678 and MIL-STD-810 and passes all requirements. The design to unit production cost has also been seriously considered in the subject cable assembly design.

INTRODUCTION

AT&T Bell Laboratories completed the development of Tactical Fiber Optic Cable Assemblies (TFOCA) designed for use in the extremely harsh tactical field environment^[1]. The TFOCA development effort was guided by the detailed design criteria referenced in the Statement of Work for Tactical Fiber Optic Cable Assemblies dated 10 November 1985, supplied by the US Army CECOM^[2]. The tactical fiber optic cable assemblies are for use in tactical Time Division Multiplex (TDM) communication systems for distances from one to eight kilometers without repeaters.

A tactical fiber optic cable assembly includes two multimode fibers in a 1-km all-dielectric cable terminated with hermaphroditic connectors. Principle features of the TFOCA design are:

- * Radiation-hardened fibers designed to operate over both the 800-900 nm and 1200-1300 nm wavelength regions and provide 400 MHz-km bandwidth at 1290 nm.
- * Rugged all-dielectric cable with a 1789-newton load rating, diameter of only 6.0 mm, weighing under 33 kg/km, and providing -46°C to $+71^{\circ}\text{C}$ performance with ≤ 0.2 dB/km added attenuation.
- * Rugged field-cleanable hermaphroditic connector assemblies less than 4 cm in diameter, weighing under 600 grams per pair and providing less than 1.0 dB insertion loss either connector-to-connector or connector to matching bulkhead receptacle.

The constituents of the cable assembly are described in the following sections, along with required performance and testing results.

OPTICAL FIBER

The multimode fiber developed for this project is of the conventional graded-index design, modified for radiation hardness. The preforms from which the fibers were drawn were made using the Modified Chemical Vapor Deposition (MCVD) process. The preforms were fabricated on an appropriately modified AT&T Network Cable Systems Atlanta Works preform station, to facilitate the transition into large scale manufacture. The nominal characteristics of the fiber used in the development prototypes are as follows:

Fiber core diameter: 50 ± 2 μm
Clad diameter: 125 ± 1.5 μm

Eccentricity: ≤ 3 μm
Numerical aperture: 0.22

Attenuation at 850 nm: ≤ 2.8 dB/km
1300 nm: ≤ 0.8 dB/km
Bandwidth at 1300 nm: ≥ 400 MHz-km

Proof test level: 100 kpsi

The radiations hardened fiber meets the specification for operation under the environmental conditions described in CR-CS-0051-001. Fiber Optic Transmission System Long Haul - Development Specification.^[3] The radiation hardness of the fibers was measured at the NAVAL Research Laboratory. The original experiments were performed utilizing a tungsten lamp and monochromator as the light source. Restricted launch conditions were used, a spot size 70% the size of the fiber's core and with a N.A. 70% of the fibers N.A. simulating steady state conditions. The measurements were taken at 23°C , 80°C and -55°C . Fiber performance at -55°C is the most critical.

CABLE DESIGN

Insertion of new technology in tactical military operating systems requires minimum cost impact and redesign of field equipment previously deployed. In particular the same hardware must be used for deployment and retrieval as well as the cable reels in use for copper systems. These items led to the required cable diameter of 6.0 mm. The TFOCA cable structure provides a range of physical characteristics required for tactical deployment while maintaining the optical performance detailed above. It is an all-dielectric design 6.0 mm in diameter and weighs about 33 kg/km. It has a 1780-Newton tensile rating and will operate indefinitely with 300-Newtons tensile loading. Table 1 shows the full range of environmental and mechanical requirements for which the cable was designed, as well as pertinent specifications. The design evolved through a program of prototyping and testing in which key parameters were varied in order to surpass the requirements of Table 1. Figure 1 shows a cross-sectional view of the cable.

The cable construction begins with two radiation hardened fibers tightly buffered to a diameter of .9 mm. The buffering material is a polyester elastomer. The two buffered fibers are twisted together, forming the center of the cable. Around the two fibers, two layers of aramid yarn are stranded with lays in opposite directions. The jacket is formed directly over the yarn from two extrusions of polyurethane which sandwich four stranded epoxy-glass rods. This jacket completes the cable and brings the diameter to 6.0 mm.

Material Selection

The polyester elastomer fiber buffering material selected was based on processing ease and the attenuation performance of the buffered fibers over the required temperature range, -46°C to 71°C . The material continues to remain dimensionally stable over even wider non-operational temperature extremes. Such performance outside the cable structure aids in meeting the environmental and storage temperatures performance criteria in the completed cable. The polyester material is preferred for its low room temperature modulus and relatively low hardness as well as its temperature performance, providing good protection to the fiber from microbending loss induced by lateral loading.

The aramid yarns were selected to meet the tensile strength requirement of 1780 Newtons. The yarn requires about 3120 Newtons to elongate by 1 %. Therefore, at the 1780-Newton rating, the cable will be elongated by about 0.6 % well within the fiber proof-test level of about 1 %. The yarns are stranded around the fibers in two opposing layers to provide a torque-balanced design. As will be discussed in

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the next section, the connector anchors on the yarn to pass tensile loading across connectors.

The choice of material for the cable jacket was influenced by several factors. Polyurethane is known for durability and

Table 1. Design Requirements

Test	Specification	Requirement
Tensile Load	EIA-455-33	@ 300 Newtons no Attenuation Increase
Cyclic Flex	EIA-455-104	No Attenuation Increase or damage after 2000 cycles over a 60 mm dia mandrel
Impact	DoD-STD 1678 Method 2030	No attenuation increase or damage after 100 impacts at 3 N-m
Knot	AT&T Bell Labs	No attenuation increase 30 mm diam. knot
Cold Bend	DoD-STD-1768 Method 2020	No attenuation increase or damage, wrap 3 times around 30 mm diam. mandrel at -46°C
Radial Compression	DoD-STD-1678 Method 2040	No attenuation increase or damage after radial loading of 2000 Newton
Freezing Water Immersion	DoD-STD 1678 Method 4050	No attenuation increase or damage while immersed in freezing water
Flammability	DoD-STD-1678 Method 5010	Continued burn ≤ 30 sec flame; failure to ignite underlying tissue
Temperature Performance	AT&T Bell Labs	<0.5 dB/km increase in attenuation during temperature cycling between -46°C and 71°C

Figure 1. Tactical Fiber Optic Cable

has been commonly used in military applications. Processing requirements are therefore well known and understood. One reason polyurethane has found common usage for such applications is the relatively slow change in modulus the material exhibits over a wide temperature range, -40°C to 80°C. It is also resistant to petroleum-based chemicals and oxidation. Thus, the material retains the flexibility and integrity required to survive the outdoor environment. An additional requirement listed in Table 1, flame retardance, is more difficult for polyurethane as a family. However, flame retardant versions exist which provide adequate performance while minimally affecting other desirable properties. Only more exotic and costly materials can provide the combination of performance offered by polyurethane. Two layers are used in the cable design, the first extruded directly over the yarn-covered fibers and the second sandwiching four epoxy-glass rods, yielding a total thickness of about 1.5 mm.

The final major constituents of the design are the four epoxy-glass rods embedded in the polyurethane jacket. As shown in Figure 1, the rods are spaced equally within the

jacket with a helical lay. The rods inhibit the axial contraction of the cable as the polyurethane cools immediately after extrusion and thus minimize increased attenuation. They also inhibit contraction when the cable is operated at low-temperature extremes, again minimizing added loss. The rods thus maintain minimal compressive fiber strain, eliminating microbending effects.

Temperature Testing

A key performance criterion for tactical cable is stable attenuation behavior over a wide range of temperatures. As noted in Table 1, the cable was designed to operate over the specified range of -46°C to 71°C with less than 0.5 dB/km increase in attenuation at 1300 nm. This performance was verified by cycling early design iterations of the cable over the required temperature range using the temperature cycle shown in Figure 2.

Figure 2. Temperature Cycles

The average change in attenuation at -46°C was less than 0.2 dB/km at 1300 nm. All variations of the final design performed well in the temperature cycle, achieving ≤0.5 dB/km added loss at both 850 nm and 1300 nm wavelengths. The final design selection was based on mechanical durability and cost efficiency. The following section highlights the mechanical performance of the final design choice.

Mechanical Testing

The cable design was tested to determine its mechanical integrity for military applications. These tests included impact, knot, radial compression, cyclic flexing, operating cable tensile load, cable tensile strength, cold bend and freezing-water immersion. These tests are listed in Table 1 along with requirements and were performed in accordance with DoD-STD-1678 except where noted. All tests were conducted at 25 ±5°C except the freezing water and cold bend test.

The combination of cable design and material selection outlined above enabled the TFOCA cable to perform well during mechanical testing. The yarns not only provided the tensile strength for the cable but also cushion and protect the buffered fibers from impact and radial loads. The four glass rods reinforce the sheath to resist compressive loads and large sheath deformation due to impact, flexure, lateral compression and cold bending. Finally the polyurethane jacket resists tearing and splitting due to mechanical abuse.

The cable samples were used in each test. Each sample consisted of a 20-meter length of cable with each fiber individually connectorized with biconic connectors. For most of the mechanical test the cable were connected to portable field-loss test sets before the start of the test and at Extreme Temperature remained connected throughout. Any initial cable loss was zeroed out with the loss set so that loss measured during testing constituted added loss due to the test. The test sets use LED sources at both 825 and 1300 nm with measurements accuracy of ±0.1 dB. For the freezing water immersion test, which required several hours to run, a stable white-light source and monochromator were used to make comparative absolute loss measurements. Passing performance was defined as less than 0.2 dB increase in attenuation and no observed damage to the cable.

The TFOCA cable passed all mechanical requirements shown in Table 1 with no measurable change in attenuation or observed damage. Note especially the use of a greater energy level in the impact test than normally required by DoD-STD-1678 Method 2030. The normal level is 100 cycles at 2.2 N-m; yet the cable was developed to withstand 3 N-m. In fact, one cable sample was tested beyond the requirement and withstood 500 cycles at 3 N-m.

Another example of performance beyond the requirements was shown in the cold bend test, conducted per DoD-STD-1678 Method 2020. The mandrel size used was 30 mm, less than half the 64 mm required for a 6 mm cable by the specification. As noted above, the design passed this test with no measurable increase in attenuation at either 825 or 1300 nm.

The tensile strength test was conducted sequentially following the operating tensile load on the same sample. The cable termination employed a 60 cm diameter mandrel at each end to secure the cable as required in DoD-STD-1678 Method 3010. The operational test was first conducted by loading the sample to 300 Newtons and recording the attenuation performance. The tensile strength test then continued the loading of the operational sample beyond the required 1780-Newton tensile strength. The three cable samples showed no increase in attenuation even when loaded to 24400 Newtons, well beyond the required tensile strength.

Using the cable termination technique described above, the tensile test included the contribution of the four epoxy-glass rods to the tensile strength of the cable. Through previous measurements of their stiffness, the effects of the epoxy-glass rods were subtracted to ensure that the yarn alone would provide the required tensile strength. The rods therefore increase the actual tensile strength of the cable well beyond that required, although they are not terminated as strength members at the connector. Tensile testing of the cable/connector termination described in the next section verifies the tensile strength of the yarn alone.

The remaining mechanical test, cold bend, cyclic flex, radial compression and freezing water immersion were all conducted according to their respective DoD or EIA specifications against the requirements stated in Table 1. No measurable increase in attenuation or damage to the cable occurred in any of these tests.

Flammability

The TFOCA cable is required to be flame retardant per DoD-STD-1678 Method 5010. A flame retardant polyurethane was selected with a limited oxygen index of 29.5 and minimal drip when burned. Three 600 m cable samples were tested which a gas flame over 1000°C was applied perpendicular to a sample mounted at 60° to the horizontal for 30 seconds. According to Method 5010, such a sample may not continue to burn for more than 30 seconds or ignite tissue located below the sample with flaming drips.

The cable passed this test easily, all samples self-extinguishing within 4 seconds after removal of the flame, with no flaming drips. The flame-retardant polyurethane jacket contributes most to the cable design's flammability performance, charring when burned rather than dripping. This material also retains the mechanical properties of no-flame-retardant polyurethane required for over all durability.

CONNECTOR DESIGN

A cable assembly consists of a length of cable terminated on each end with a hermaphroditic heavy duty connector. This duplex connector builds on the AT&T commercial simplex biconic connector which was inserted in a militarized closure to meet the harsh military environment. Large-scale manufacture and field installation of this connector in several simplex configurations began in 1979. The following is a brief discussion of the basic design.

Biconic Connector

The simplex biconic connector consists of a plug on each cable end, an alignment sleeve and some peripheral hardware to contain and mount the sleeve and to hold the assembly together under load. The plug ends have the shape of truncated cones, and the sleeve has two corresponding internal tapers. The design of the connector was based on the observation that transverse offset of fiber ends contributes about twenty times more loss in a fiber optic connection than longitudinal end separation of the same amount. A taper was chosen for the aligning surface so that production isotropic variations in nominally identical molding materials would not manifest themselves in transverse offset but in the less critical end separation. A taper also provides for easy insertion with low abrasion.

TFOCA Connector

The duplex-configured TFOCA connector, one of the two fiber channels terminates with a biconic alignment sleeve and the other with a plug. The connector is rugged, waterproof and resistant to the stringent environment typical of tactical military applications.

Companion bulkhead receptacles developed for the system differs from the connector in external features but shares a common hermaphroditic interface assembly. Hence any cable end will mate with any other end or with a receptacle.

Connector

The sealed connector-insert assembly shown in Figure 3 contains two plugs and an alignment sleeve. It is made from an impact-resistant thermoplastic and comprises the heart of the TFOCA connector and receptacle. The spring-loaded plugs must be free to move axially and radially to align with their counterparts in a mated connector. A fluorosilicone bellows seal allows the necessary float and prevents water entry around the plugs. The insert assembly provides ample isolation to achieve, without duplex penalty, the consistent performance characteristics of the biconic connector in its simplex configuration.

Figure 3. Connector Insert Assembly

The sleeve retainer is the forward most part of the insert assembly. Geometric alignment and orientation features preclude mismatching connectors, provide a hermaphroditic profile and protect the biconic components during impact. A cylindrical base on the retainer houses the sleeve, and two protruding lobes partially encircle and shroud the plug. The base and lobes are of stout proportions to insure positive engagement and to withstand the impact if the connector is dropped on its end without its protective dust cover.

Figure 4 shows in section the complete TFOCA connector assembly. A metal shell encloses the insert assembly above. It also provides storage space for enough slack fiber to reterminate the ends and retains the cable-termination hardware. A free-turning threaded coupling nut tightens the joint between two connectors or between a connector and receptacle. The coupling threads are a modified 60° stub for strength with a double lead for easy engagement. The connector shell and coupling nut are designed to elastically withstand a 1780 Newton tension across a connector.

The connector is joined to the cable by capturing the aramid yarns between locking tapers. The steel cable retention assembly shown consists of three pieces - a tapered bushing, wedge and thrust nut - which are easily put together without special tools.

The cable end is threaded through the internal tapered bushing before removing a 25 cm length of cable jacket. The exposed yarn is trimmed to a 10 mm length and splayed by a breath of air. The wedge is slipped over the buffered fiber and under the splayed yarn. The tapered bushing is brought forward trapping the yarn between the two tapers which are subsequently secured by screwing the thrust nut onto the bushing with a light wrenching torque. At final connector assembly, the cable-retention assembly is sandwiched between the connector shell and end cap so that any subsequent tension is transferred to the metal shell.

A seal blocks the water path along the cable and into the connector shell. When it is compressed by the steel cable-seal wedge, the flange is forced against the end cap and the inner diameter is compressed radially onto the cable jacket. These simultaneous deformations effectively stop water migration and mechanically isolate the cable-retention assembly against cable twist. An insert-molded bend limiter provides the thrust to compress the cable seal as it is threaded onto the end cap. An elastomeric seal between the connector shell and end cap along with a face seal at the front of the shell complete the design measures necessary to make the connector assembly water-tight to a depth of two meters.

A dust cover is provided to prevent water or dust entry into an unmated connector. The dust cover contains a mounted sleeve retainer identical to the one comprising the front face of the connector-insert assembly. This assists in mating the cover and connector by bringing them into proper

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alignment. A short coupling nut on the cover screws onto the connector shell to secure the cover and to compress the face seals. The cover is also hermaphroditic so that when two connectors are mated, their respective dust covers can be similarly joined to prevent contamination. A flexible stainless-steel lanyard prevents inadvertent separation of the connector and cover.

Cleanliness is essential to a repeatable low-loss fiber optic connection and a significant attribute of the TFOCA connector is that it is easy to clean. After soaking an uncovered connector in mud, it is necessary merely to rinse it in a pail of water and to wipe the biconic components dry in order to restore unaffected optical transmission. No special cleaning kit is required. If mud encrustation is particularly severe, the sleeve retainer's captive screws permits its removal in the field to gain greater access to the plugs and sleeve for a more thorough cleaning.

With regard to size and weight, a mated connector pair is less than 4 cm. in diameter, measures 15.25 cm. in length excluding bend limiters and weighs 581 grams including dust covers.

Figure 4. TFOCA Connector

Receptacle

The forward end of the receptacle shell and the connector-insert assembly are identical to corresponding parts of a connector. Hence, any TFOCA cable end will mate with the bulkhead receptacle. Variations of the receptacle design are available in TFOCA Back-to-Back style, TFOCA to ST* or with buffered fiber or single fiber cable pigtailed which may be terminated with Biconic or ST* simplex connectors. The receptacle may be mounted through a D-hole in panels up to 6.4 mm thick with a standard AN-series jam nut. As the jam nut is tightened a elastomeric seal under the mounting flange is compressed and seals the panel-receptacle interface. The receptacle protrudes less than 2.5 cm from the bulkhead and measures about 4 cm in diameter at the mounting flange. An unmated receptacle is protected by a lanyard-attached dust cover identical to the one provided for the connector. The Electro-Magnetic-Interference shielding requirement was met by a seal in the receptacle and cadmium plating of both the receptacle and the connector.

Materials

The connector and receptacle shells are aluminum die castings. The connector end cap, dust cover and both coupling nuts are machined from wrought aluminum. All aluminum components have been cadmium plated for appearance, EMI shielding and corrosion resistance. The cable-retention assembly and other internal metal items are passivated stainless steel. The dust-cover lanyard is a stainless-steel stranded cable. Except for the biconic components, the connector-insert assembly is injection molded from filled resins having excellent dimensional stability, high impact strength and good chemical and heat resistance.

TFOCA CONNECTOR TESTS

The primary design objectives of the TFOCA connector are low coupling loss and field ruggedness. The assembly is required to remain optically and mechanically functional under environmental exposures typical of tactical field applications. To assess the progress toward these goals, test were conducted at critical intervals on prototype connectors to evaluate performance with respect to: coupling loss, shock drop, cable retention, flex life, water immersion and mud immersion. These tests are reviewed and results

summarized in the following paragraphs.

Coupling Loss

The coupling loss was measured at 825 and 1300 nm. LED source with over-fill launch conditions were used in conjunction with large-area PIN detectors and Equilibrium Mode Simulators consisting of 3-turn 20-mm diameter mandrel-wraps.

The initial coupling loss measurements were made to compare the TFOCA connector with the standard multimode biconic which has a well characterized laboratory and field performance average under 1 dB on jumper-quality fiber. Differential loss measurements were made by first connecting standard product and, after zeroing the test set, replacing all hardware components (except the biconic) with the TFOCA connector hardware. In a series of 3 tests the average differential (added) loss was 0.05 dB when excess fiber was not stored in the connector shell. Storing sufficient excess fiber to allow retermination of the biconic plug without disassembly of the cable retention fixture increased the differential loss by about 0.25 dB per terminated end. The cable retention fixture permits quick and simple cable retermination.

In a series of 30 reconnection tests (multiple insertions) the standard deviation was 0.03 dB. The above results indicate that with the TFOCA connector hardware, highly repeatable connections can be made and no measurable loss is added to that achievable with standard biconic fixtures. Added loss does however result from the stored-fiber configuration.

Absolute coupling loss measurements were made with the TFOCA connector by the cut-and-insert method of EIA Fiber Optic Test Procedure #34. Biconic plugs of single-mode and multimode fiber quality were used to terminate TFOCA cable samples with fiber meeting the following requirements: core diameter 50 $\pm$ 1.5 μ m; eccentricity $\leq$ 3 μ m. They are consistent with those we obtained with standard jumper-grade except for the stored-fiber penalty. With that penalty a consistent loss of less than 1 dB will likely require single-mode fiber quality plugs.

Shock Drop

This test was conducted to determine if the connector termination can withstand accidental drops without damage. Four unmated plug samples were dropped without dust covers from a height of 10 feet twenty times onto a wood slab over concrete. No physical damage, loose parts or mechanical malfunction occurred as a result of the impacts. The test was repeated with one mated pair while optical transmission was monitored. No added loss resulted from the impacts.

Cable Retention

The cable retention assembly was tested for its load bearing capability when connected to prototype TFOCA cable samples. Short (36 cm) cable lengths were terminated on each end with retention fixtures and loaded axially to failure at room temperature in an Instron tensile machine. All twenty-five such samples exceeded the minimum 1780-Newton requirement. The average, low and high failure loads were 4280, 3220 and 5874 Newtons respectively. The failure mechanism was separation of the aramid yarn.

An additional five samples were subjected to thermal shock cycling between -61°C and 71°C before testing at room temperature. The load bearing capacity was not measurably changed by thermal exposure.

Flex Life

The purpose of the flex test is to determine the likelihood of damage at the cable/connector-interface region as a result of cable flexure during handling. One connectorized cable sample was flexed for 2500 cycles of $\pm 90^\circ$ at room temperature. The maximum loss change was less than 0.05 dB and no physical damage occurred in any part of the connector/cable assembly.

Water Immersion

This test is used to determine the susceptibility of mated connectors to leakage when under water. The effectiveness of the assembly's watertight seals was evaluated by submerging the coupled ends of plug-terminated cable samples under two meters of water for 24 hours. The connectors were then decoupled, disassembled and examined for evidence of leakage. There was no evidence of leakage. Condensate was found on some assembly parts but there was no evidence of leakage.

Mud Immersion

The TFOCA connector was designed to allow easy access to the precision alignment parts so that they can be easily cleaned after mud immersion. This aspect of the design was evaluated by subjecting a plug connector pair to 10 cycles of the following sequence:

- a. decouple and immerse each end in a mud bath for 5 minutes;
- b. water rinse, wipe clean, air dry;
- c. recouple and measure loss change.

The maximum observed loss change was 0.05 dB.

Single Fiber Optic Cable Assembly (SFOCA)

The single fiber cable was designed to meet rapidly deployable systems requirements as specified in reference 4 entitled Fiber Optic Cable Coil Packs for Air Deployment. The cable design was recently enhanced with the insertion of single mode microbend insensitive fiber developed for high speed payout applications.

The test results of the SFOCA single fiber cable are presented in detail in reference 4. The current design cables were delivered to Naval Oceans Systems Center Hawaii for evaluation under the Unmanned Ground Vehicle Program. The wheel test is a unique system requirement, Single Fiber cable is wrapped around the tire of the vehicle. The vehicle is then driven over various types of terrain and damage to the cable is measured. The results of this evaluation generated sufficient confidence to the Program Manager to proceed with acquisition of additional cable lengths to support system demonstration. As a result of continuous cooperation and coordination under the TRI-SERVICE Fiber Optic Coordinating Structure, we achieved timely and cost effective development of products to meet challenging requirements, including robotics and other rapidly deployable applications.

CONCLUSION

Under TRI-SERVICE coordination, CECOM developed multimode and single-mode Tactical Fiber Optic Cable Assemblies⁽¹⁾ in both duplex and simplex fiber exceeding specified requirements. As an example multi mode TFOCA in field environment was demonstrated to perform at 15 kilometers without the need for signal regeneration (8 km required). The ruggedness and flame retardance characteristics were proven in critical situations i.e. PATRIOT Missile Systems deployed at Desert Shield and Desert Storm, where the fiber optic technology was battle tested for the first time and performed flawlessly exceeding user expectations. The Single Mode Fiber Optic Cable Assemblies were also demonstrated in the field and in the laboratory where the unrepeatable link length requirement of 15 km was significantly exceeded at 23 km. Production assembly performance is 1.6 dB and 1.1 dB per one kilometer for the multimode and single mode fiber respectively.

Recognizing the diverse needs of the TRI-SERVICE for secure fiber optic communication systems and to meet the challenge in an environment with shrinking resources, we have achieved to insert the Single Mode Fiber Optic Cable Assembly in the prototype secure system undergoing evaluation.

The proven performance of the TFOCA contributed to the wide acceptance of fiber optic technology in a variety of tactical communications systems. It is observed that both the twin metallic coaxial cable and the twenty six pair cables are being replaced by the TFOCA which achieves simultaneously enhanced system performance and cost effectiveness by minimizing the logistics and training support.

The Tactical Fiber Optic Cable Assemblies have been designed, developed, field tested and placed into production. A TFOCA contract was awarded to AT&T to meet the requirements of the TRI-SERVICE. The TFOCA was designated as a TRI-SERVICE standard for all tactical communication systems. This standardization has resulted in significant savings in the area of logistics and training while forcing interoperability between the services.

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