Development of a Generic Fiber-Optic Cable Repair-Kit

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Key Words: Fiber Optic Cable Repair, Repair kit, Splice enclosure

SUMMARY & CONCLUSIONS

Fiber optic communication systems have been used by the Air Force since the early 1980's. Tactical field applications of fiber optic technology consist of using ruggedized tactical fiber optic cable to connect portable operations shelters with mobile radar systems, remote personnel away from portable field radio transmitters, and to make digital signal connections between adjacent shelters. Repairing fiber optic cables so they remain operational in a tactical environment has been impossible due to the lack of commercially available repair hardware. Due to this deficiency, action was needed to design, develop, and test prototype repair hardware enclosed in a portable field kit capable of being used in a tactical/field environment. Repair hardware components enclosed in the kit include commercially available tools for removing the cable jacket and fiber buffer, a hand held cleaver, and mechanical epoxyless splices that fit inside a Splice Enclosure Assembly (SEA). The SEA surrounds and attaches to the repaired fibers (mechanical splices) to protect them from outside physical forces present under tactical usage conditions. The primary design objective was to produce a repaired fiber optic cable that exhibits the same strength characteristics as unbroken cable. The final SEA design was validated after successfully passing all phases of testing. Prototype kits were produced and transported to the field for additional testing. Action is currently underway to establish a multi-service acquisition contract to enable any DOD user the ability to easily procure the kit.

Broken (cut) tactical fiber optic cables cannot be repaired using commercial Telecom cable repair technology. The Telecom industry does not rapidly deploy their cable above ground and subsequently they do not have the mechanical repair strength requirements that are necessary in the tactical environment. Utilizing non-tactical Telecom repair hardware produces a final repair that is much less rugged than unbroken cable. Commercial tactical cable repair technology has been developed for depot level repair. It requires AC power, epoxies, and a large amount of repair tools and hardware. Out in the field or at intermediate levels of maintenance AC power may not be available. High grade epoxies typically have shelf lives less than one year which present a problem when repair kits could potentially be in depot distribution centers for periods of time in excess of one year. Therefore, it is not time or cost effective for the Air Force to rely totally on a depot level repair capability. Based on the lack of a qualified commercial product, it was necessary for the Electro-Optic Technology Center at McClellan AFB to design, develop, and test a field maintenance capability for tactical fiber optic cable applications.

In 1986 the Air Force began to implement a standard...
fiber optic cable for its tactical applications. This standardization effort came about from a Memorandum of Agreement (MOA) signed by the Joint Commander’s Group for Communication Electronics (JCG-CE). The MOA stated that all the services would use the same tactical cable for all systems designed after 1986. This standardization effort certainly makes sense and eliminates a potential proliferation of many different cable designs. Systems designed and fielded prior to 1986 were “grandfathered” from switching over to this standard cable design which meant the possibility existed that each unique fiber would need its own repair kit. In a time of shrinking defense dollars and logistic manpower, having a "generic" repair kit would certainly be cost effective i.e., one kit for ALL tactical cables. This factor was the primary motive for initiating action to see if a generic repair kit could be developed at a reasonable cost, and hence the generic concept was born.

REQUIREMENTS ANALYSIS

Prior to developing a baseline design for repair hardware, a full understanding of tactical fiber optic cable usage and the physical forces it may experience in the field must be realized. This was accomplished by sending engineers out into the field to observe first hand how cables are stored, deployed, and to evaluate existing environmental and physical force factors (ground terrain, trucks running over cable etc.). Observations from the field indicated that cables are subject to pulling forces sustained from rapid deployment. There was even one situation where personnel attempted to tow another vehicle out of the mud using tactical cable as a towline (the outcome was a severed cable). Other observations were compressive loading conditions imparted to the cable by trucks running over it. Seeing first hand how much physical abuse these cables are subjected to, it didn’t take long to realize that any repair, as a minimum, must be at least as strong and as rugged as unbroken cable. The repair must also be free from water or fluid intrusion, not be affected by freeze-thaw conditions or temperature swings, and must remain intact under any environmental condition.

Another major portion of the requirements analysis was to identify the entire range of cable diameters and fibers used in all tactical fiber optic communication systems. Once this information was obtained, a specification was produced which included design parameters, and mechanical & environmental performance criteria. Test procedure candidates were identified which consisted of EIA Fiber Optic Test Procedures (FOTP’s) and DOD Standards.

Design Objectives

This effort focused on developing a single repair process (kit) for all DOD tactical fiber optic cables. Major component elements of this process would include a Splice Enclosure Assembly (SEA), epoxyless mechanical splices, hand held cleaver, cable jacket and fiber buffer stripping tools, and miscellaneous items such as alcohol pads, exacto-knife, optical viewer for fiber cleave evaluations etc.

Specific design objectives were to: 1) develop one cable repair process for all tactical optical cables, 2) minimize required repair hardware and field repair time, 3) ensure the mechanical integrity of the final repair IS equal to the mechanical strength of unbroken cable, 4) require no more than a skill level 5 maintainer classification (high school education) to perform cable repairs, 5) produce an SEA that requires NO tools to assemble and utilizes commercially available mechanical epoxyless splices (> 0.2 dB loss per splice), 6) evaluate and select commercially available field kits and cable repair preparation hardware, and 7) integrate and package all repair items into a ruggedized field storage kit.

PROTOTYPE DEVELOPMENT

Prototype development was separated into 2 areas of concentration. These areas include: 1) development and testing of the SEA and 2) testing and evaluating of commercially available tools, splices, and selection of a ruggedized portable field kit. Each one of these areas will be discussed in the following paragraphs.

SEA Development

Several conceptual designs were produced under contract by Scientific Applications International Corporation (SAIC) for the SEA. Separate designs were prepared for various components of the SEA (approx. 6 X 1.5 inches when fully assembled) which include the housing body, a Kevlar retention device, splice holder, and environmental seals. Each SEA can accommodate up to 6 optical fiber splices in separate organizers with cable sizes ranging from a maximum of 7.5 mm to a minimum 4.0 mm. Prospective materials were analyzed, tested and selected for the SEA and are discussed later in this paper. Each component of the SEA is illustrated in figure 1. Figure 2 shows what the assembled SEA looks like with repaired cable attached.
Fiber Optic Splice Enclosure Assembly (SEA)

Figure 1

Parts
1&9- End Cap
2&10- Teflon Washer
3&11- Environmental Seal (Grommet)
4- Splice Tray
5- Kevlar Retention Screw
6- O-ring
7- Kevlar Retention Screw
8- Housing

Figure 2
The splice enclosure housing must encapsulate and protect the repaired fiber from both mechanical and environmental effects. The original first run prototype was fabricated from 316 and 17-4 stainless steel, and 7075-T6 aircraft grade aluminum. The 316 grade did not meet compressive loading tests as per the specification. The 17-4 grade steel passed loading tests but was difficult to machine. The 7075-T6 aluminum passed loading tests, was lightweight and easy to machine and was therefore selected as a final candidate.

The function of a splice tray is to hold and organize optical fibers inside the housing. Since the splice tray must accommodate a wide range of commercially available splices and that space inside the housing was rather limited, it was decided a better approach would be to have nickel-plated spring steel clips directly mounted on the housing body. These clips provide enough splice retention force so they remain rigidly and firmly attached to the housing when subjected to low frequency random vibration testing. Aluminum rivets are used to attach the spring clips to the housing body.

In order to firmly attach the repaired fiber optic cable to the housing body, the Kevlar material inside the cable jacket must be securely fastened to the enclosure body. Five designs possessing various retention hardware were considered. These designs included a cam-actuated clamp, wound bobbin, braided Kevlar rope clamp, compression cone, and a knuckle thread. The knuckle (or lightbulb) thread was selected because of its simplicity and because it easily passed all tensile force pulling tests. The knuckle thread consists of the same anodized aluminum alloy as the housing is made from and is attached to the internal end cap and threaded with aluminum machine screws. The operation of this device is quite simple, the Kevlar is held in place by the frictional forces provided by the knuckle threads. What makes it more unique is that no tools (except two hands) are required for this procedure.

Flexible environmental seals are required to tightly surround the cable at each end of the SEA. This is necessary to keep fluids like water or oil from entering the internal portion of the SEA where the optical splices are located. Since tactical fiber optic cable will be deployed at ground level, it may encounter water in depressions or ditches and therefore the SEA must be watertight when fully assembled. Several seal designs were evaluated which consisted of shrink tubing and various types of rubber grommets. Shrink tubing was eliminated because it is difficult to work with in the field. The end result was a custom molded neoprene grommet which would fit tightly enough to surround the entire range of cable diameters.

**SEA Testing**

Completed SEA prototypes were delivered by SAIC to an independent testing laboratory to ensure that all specifications were met. Without describing each test set-up and test procedures in detail a general overview of test results will be discussed. There were 9 tests conducted on 6 SEA prototypes. All tests were successfully passed. The same group of prototype SEA’s were used in successive tests. The sequence and test type are as follows: 1) Attenuation Installation 2) Compressive Loading Strength 3) Fluid Immersion 4) Tensile Strength 5) Cable Twist 6) Temperature Cycling 7) Vibration 8) Impact and 9) Freeze Thaw. Pass/fail criteria for these tests are listed in figure 3. Specifications were also developed for SEA construction materials such as salt fog corrosion, resistance to sunlight degradation, and fungus resistance. Historical test data on known metallic materials was used to ensure specifications met i.e., salt fog, fungus etc. Optical power monitoring was required for test 1,2,4,5,6, and 7. Each SEA had either 2 or 6 active spliced fibers inside with outside reference fibers (see figure 4). Optical attenuation or changes in optical throughput could be continuously monitored in real time for any particular test. A synopsis of each test is given below.

**Attenuation Installation:** Optical power was measured after completing a cable repair and prior to sealing the SEA. Once the SEA was completely assembled the difference in optical attenuation was not to exceed .1 dB. Typical optic power variations between pre and post conditions were on the order of 0.03 dB.

**Compressive Loading:** Six fully assembled SEA’s were subjected to 9,600 lbs. force normal to a point on the SEA cylinder wall for 30 minutes. The SEA cylindrical wall diameter was measured with vernier calipers before and after the force was applied. The amount of allowable pre to post SEA deformation could not exceed 3%. Typically, only about 1% wall deformation was experienced with about .3 dB optical attenuation present during maximum loading.

**Fluid Immersion:** Fully assembled SEA’s with repaired cable attached were immersed in a column of water with a hydrostatic pressure head of 6 PSIG (equivalent to a water depth of approx. 4.3 meters).
### Maximum Optical Attenuation (dB)*

**Figure 3**

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<th>2</th>
<th>3</th>
<th>4</th>
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* Referenced to pre-test throughput

**Figure 4**

... Environmental Test Chamber...
Fluorescein dye was added to the water at a concentration of 10 grams/2 gals. Each SEA was left submerged for 10 days at which time they were removed and the inside of the SEA was examined under ultraviolet light. No sign of dye penetration was present.

Tensile Strength: Assembled SEA’s with repaired cable attached were positioned in a test fixture and tested using the methods outlined in FOTP-6 (Cable Retention Test Procedures for Fiber Optic Cable and Interconnecting Devices). 3 fully assembled SEA’s including 2 with 2 fibers in their cable, and one 6 fiber cable were tested. They were subjected to an axial load of 400 lbs. force for 1 minute followed by 114 lbs. force for 30 minutes. Optical throughput power was continuously monitored before, during, and after loading to determine any attenuation due to pulling the cable. Attention never exceeded .5 dB between pre and post pull conditions.

Cable Twist: Repaired cable was attached to each end of an assembled rigidly positioned SEA. Each cable end was twisted 90 degrees in one direction, 180 degrees in the opposite direction, and 90 degrees to center again. This procedure was followed for 100 cycles. Optical transmittance was measured before and after mounting, after the load was applied, and during and after twist cycling. No degradation was observed due to twisting the cable.

Temperature Cycling: Several SEA’s with repaired cable attached were subjected to temperature cycling tests. Optical power stability was monitored over the range of -55 to +85 C in increments of 5 degrees C for 30 minutes at each increment. Total test time for this cycling range ran for 18 hours. Maximum power loss at any temperature did not exceed 1 dB from measurements made at +25 degrees C.

Vibration: 3 SEA’s with repaired cable attached were tested for resistance to low frequency random vibrational forces. The direction of force motion traversed the X-Y-Z axis. Light sources remained on throughout testing as power measurements were taken before, during, and after testing. Vibration frequency ranged from 10 to 55 Hz, with power readings taken every 30 seconds for the 1 hour test duration. The maximum allowed power loss compared to reference was .5 dB with typical measured deviations ranging from .15 to .20 dB.

Impact: Impact tests were conducted on six fully assembled SEA’s to determine SEA wall deformation due to impact forces. A cylindrical steel head weighing 2.25 kg was repeatedly dropped on the assembled SEA from a height of 60 cm. Each SEA was subjected to 24 impacts at a height of -18 C and +38 C for a total of 48 impacts. There were no observable degradations noted on tested samples.

Freeze Thaw: Assembled SEA’s with repaired cable attached were placed in fluorescein dye treated water covering them by about an inch. The temperature was cycled 30 times from -10 C to +60 C and ramped up/down in 5 degrees C increments. Each SEA was left at the low and high temperature extreme for a period of 2 hours. At the end of each test no dye penetration was observed under ultraviolet light inside the SEA.

Repair Tool, Splice, and Kit Selection

The only field tools required are for stripping cable jacket and fiber buffer, cleaving, and miscellaneous items for cleaning fiber and viewing the cleaved fiber etc. The SEA comes pre-assembled and requires only two hands to put together. Several sets of buffer stripping tools and small hand held cleavers were purchased for in-lab evaluation. The intent was not to “reinvent the wheel” if a commercial product could do the job. The same strategy was applied to mechanical epoxyless splices. Several commercially available splices were purchased and evaluated. Tests conducted in the laboratory were performed to see how closely their respective specifications conformed to real world test data. Once a candidate list of splices were identified, the splice spring clips (holders) were designed generically to accommodate all acceptable splices. The tools, SEA’s and splices were then packaged in a commercially available ruggedized field kit. Criteria for kit selection was based on construction material, weight, durability, and cost. The intent is to package enough material in the kit to repair eight 6-fiber cable breaks. All items in the kit are reusable with the exception of the mechanical splices. All items in the kit will also be separately stocklisted for individual ordering.

CONCLUSIONS

The final SEA design was validated from successfully passing all phases of testing. Prototype kits were produced and transported to the field for additional testing. Field test results indicate this kit will operate in the field as designed and produce a repair that will withstand usage and remain operational in a tactical environment. A multi-service acquisition plan is currently being developed to enable any DOD organization requiring this kit to easily procure it.
Designing a generic field repair kit for use in air and ground support communication systems requires hardware design efforts addressing Reliability and Maintainability (R&M) issues. Significant cost savings will result due to the reduction of required fiber optic cable spares. Operational readiness and war capability of deployed tactical communications systems will also increase significantly due to lower repair time requirements. Decreased manpower requirements will be evident from lowering the amount of broken cables requiring transportation to depot. On-site field maintenance of fiber optic cables will be able to be performed instead of waiting for replacement cables from the supply system.

BIOGRAPHY

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Ted Schantz is an Electrical Engineer specializing in developing, marketing, prototyping, and testing fiber optic designs for resolving communication/weapon system performance problems. He graduated from Western Michigan University in 1986 with a Bachelors Degree in Electrical Engineering and has been employed with the USAF since.