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Use of Fiberoptic Communications and Control for a a Tethered Undersea Vehicle

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ABSTRACT

Use of fiberoptic technology in tethered undersea vehicle systems is reviewed with emphasis on communications and control. Examples are given for the Harbor Branch owned Remotely Operated Vehicle "SCOOP" (Scientific Collection and Observation Platform) which was recently outfitted with an improved telemetry system and fiberoptic umbilical.

INTRODUCTION

Remotely operated undersea vehicles (ROVs) are used in undersea operations which are of long duration or performed at such great depths that manned submersibles or other vehicles are impractical. Some specific applications of ROVs include inspection of undersea structures, work platforms for drill rig construction, scientific exploration, and search/recovery of submerged objects or equipment. The ROV and tender ship system is shown in Figure 1.

As the tasks of ROVs have become more complex, the ROV system has had to become more sophisticated. Modern vehicles may be equipped with stereo video, intensified (ISIT and SIT) cameras, low-light color cameras, spatially correspondent (SC) manipulators, and various sonar and navigation systems. Each of these systems requires some aspect of control or data retrieval. Operating depths in excess of 4000 feet are typical and payload recovery of equipment or samples is sometimes required. As a result, the modern ROV would not exist without constant improvement in two areas: 1) telemetry and communications and 2) umbilical and tether cable design. Significant advances have been made in the former area as a result of the anticipated market for integrated data services and the advent of high bandwidth, low cost fibers, sources, and detectors. In the latter area, umbilical and tether cable designs now routinely incorporate optical fibers and have been improved, through an arduous process, to be more reliable in field operations. The motivation for using fiberoptic cable stems from the continuing need to increase communications bandwidth while minimizing the cable diameter.

Before the advent of fiberoptics, signals were carried in metallic conductors resulting in well known tradeoffs between cable attenuation, size, and noise immunity. For this reason, early ROVs utilized comparatively larger diameter umbilicals to allow satisfactory communications bandwidth. The larger cables minimized signal degradation and maintained adequate signal-to-noise ratios for baseband video signals which were subject to electrical noise. The noise was usually induced from power conductors supplying the vehicles hydraulic thruster units and from other high power electrical systems. Although judicious use of signal multiplexing was somewhat effective in alleviating interference, the larger umbilical size often caused an operational problem due to the increased hydrodynamic drag. An example of a design which minimized umbilical drag was the Harbor Branch Cabled Observation and Rescue

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Device ("CORD") which utilized a single 0.30" triaxial cable for both power and telemetry[8]. In spite of its success operating in Gulfstream currents to depths of 3000', the CORD power distribution and telemetry system was abandoned in favor of approaches capable of supplying greater power and increased telemetry bandwidth. The conversion from all-electrical cables to fiberoptic is even more desirable for deep diving vehicles which are designed to conduct operations to 22,000 feet[3,4] and which necessarily utilize umbilicals several miles long. Thus, over the past decade there has been a considerable effort to develop reliable fiberoptic ROV umbilicals and to convert existing ROV designs to be compatible with fiberoptic telemetry methodology[5-7]. This paper highlights the conversion of the Harbor Branch Oceanographic "SCOOP" ROV[1] telemetry system and umbilical design to make better use of existing fiberoptic technology.

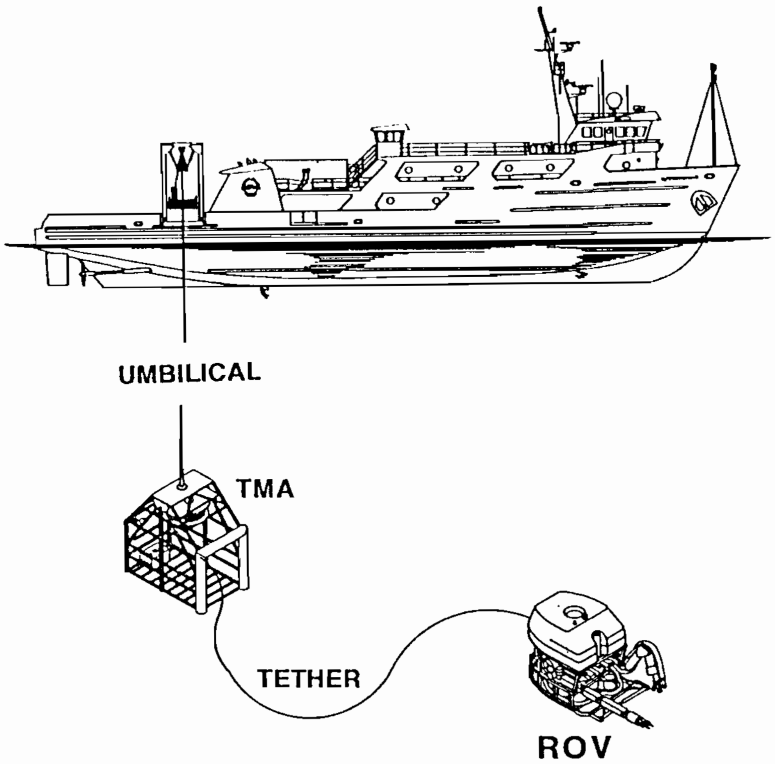

Figure 1. Typical ROV Configuration

UMBILICAL

An ROV umbilical is required to support the weight of the vehicle, withstand dynamic loading during launch, operation, and recovery, carry power to the on-board systems, and supply communication channels for control and sensor data. Deep diving designs typically use armored contrahelically wound steel sheathing for mechanical load bearing capability and durability. These cables incorporate single-mode fibers designed to operate at 1300 or 1500 nm where attenuation is significantly reduced, thereby allowing maximum physical length. Shallow water designs may use either Kevlar or metal jacketing and often employ multimode fibers which exhibit greater attenuation and smaller bandwidth-length products. In addition to the requirements for strength, power handling capacity, and channel capacity, there is a necessity for redundancy in any umbilical design due to the potential for damage as a result of operator error and adverse field conditions. Additional consideration must be given to the procedures necessary for rapid cable repair and retermination at-sea under poor conditions.

The recent HBOI conversion uses a Southbay cable design consisting of six 50/125 multimode fibers encased in a gel-filled stainless steel tube at the center of the umbilical crossection (Figure 2). This location has proven to be the most reliable for many umbilical designs. The cable is 1.54 inches in diameter, weighs 2160 pounds per 1000 feet in water, and allows a maximum load of 25,000 pounds. The bend radius is restricted to a minimum of 20 inches to avoid damage to the fibers. The fiber loss is 3.5 dB per kilometer and the bandwidth-length product is 400 MHz-km at 830 nm.

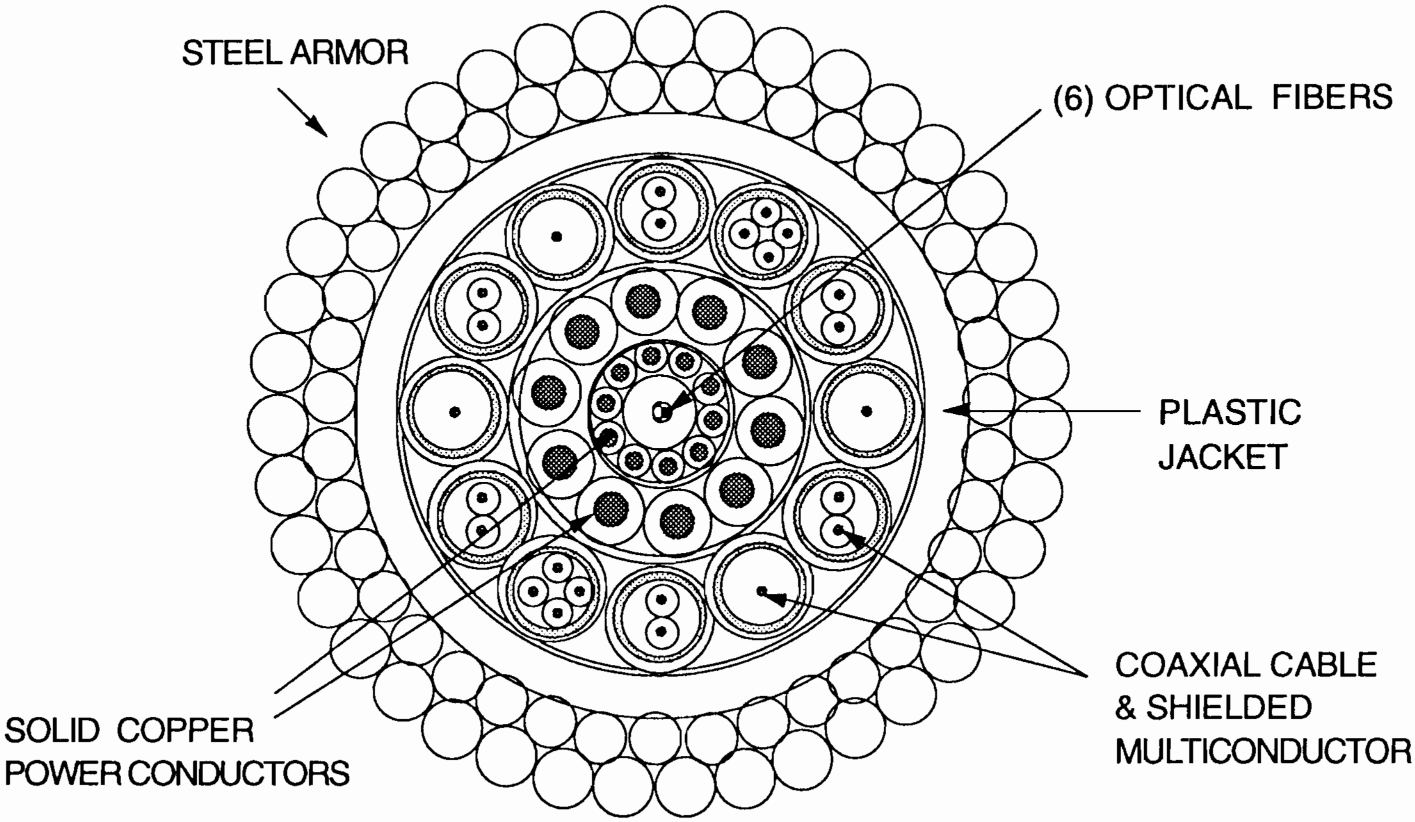

Figure 2. Crossection of SCOOP umbilical cable

All fibers are contained within the umbilical which is wound on a deck mounted winch drum for storage. The umbilical is directly attached to the ROV Tether Management Assembly (TMA) without any breakouts. In order to access the optical fibers and the electrical conductors topside, connections must be made between the rotating winch drum and the stationary winch platform. Both fiberoptic and electrical sliprings are used for this purpose. In some cases, where rotary optical joints are not desired, optical to electrical conversion is performed within the winch drum, and signals are coupled through electrical slip rings to the vehicle controller.

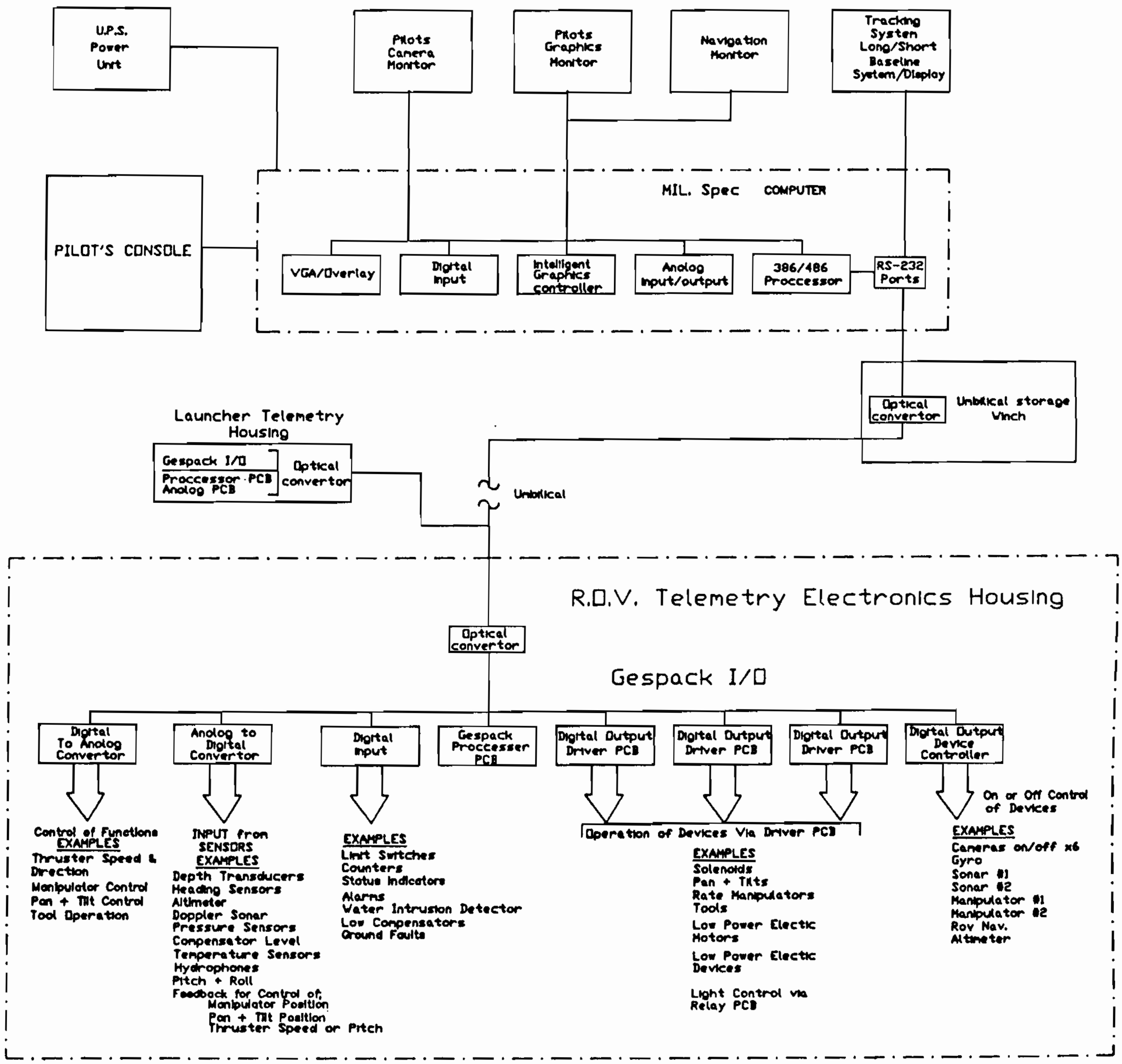

Figure 3. "SCOOP" Telemetry System

Since the umbilical is the primary communications channel, the integrity of the fiberoptic strands is of paramount importance for system operational reliability. Mishandling, operator error, and adverse conditions at sea often result in damage to a portion of the umbilical cable; however, in many cases, at least one fiberoptic strand remains functional. For this reason, it is desirable to have the ability to monitor or pole the fibers available during operation, to provide for either automatic or manual switching ability between fibers to maintain critical control functions, and/or to provide a failsafe mode in the event communications are lost.

TELEMETRY

The SCOOP telemetry is a state-of-the-art system using software control. It was specifically configured to achieve the follwing objectives.

- High-speed ROV control
- Easy reconfiguration
- Expandability for mission driven tools and/or instrumentation
- Automated system diagnostics
- Communication between the vehicle and other system computers or controllers; for example, tracking systems, navigation system, ships dynamic positioning system, pipeline trackers, etc.
- Use of off-the-shelf low cost hardware for ease of replacement in the field
- All signal conditioning and calibrations implemented in software rather than hardware
- Vehicle performance/handling characteristics easily adjusted for change in configuration, tools, and environment.

A diagram of the telemetry system is shown in Figure 3. The system consists of a surface computer, pilots console, and vehicle I/O processor. The surface computer is an industrial model 386SX utilizing a 96-channel digital I/O board, 16-input/8-output analog board with 16-bit resolution, a Matrox intelligent graphics board, and a VGA overlay graphics board. The major control functions of the ROV are accessible from the control console. These include joystick motion control (analog output), on/off functions for each subsystem, digital outputs, and rate manipulator control. The vehicle I/O is a EUROBUS format and is controlled by a 68000-based embedded microcomputer.

The surface computer takes commands from the console and graphics monitor and communicates in RS-232/422 format to the vehicle processor. The RS-232/422 signals are converted to optical format in the umbilical winch drum and at the vehicle. The surface computer also performs calculations for the autopilot functions (i.e. depth, altitude, heading) and sends controls signals to the vehicle processor. In return, the vehicle processor sends sensor information and function command status to the surface computer. The surface computer checks function command status against console status and derives error signals which are input to the autopilot controller. This information is also displayed on the graphics monitor for the pilots use as a navigational aid.

Future expansion of the SCOOP ROV incorporates the use of all six fiberoptic strands. Presently, the vehicle system control signals for SC manipulators, sonar, and navigation systems are hardwired to the vehicle via coaxial cable or twisted shielded pair throughout the umbilical and tether. Video and other functions are carried by three of the fiber strands. Through the use of optical conversion and multiplexing of all system control signals, vehicle telemetry, and video channels on fiberoptics, the following advantages are expected.

- improved signal performance with hardwire backup.
- additional optical networking capability with the potential for advanced manipulator control and improving ROV "telepresence" capability[9, 10]
- a reduction of umbilical size by purchasing a design free of coaxial and twisted shielded pair cables. This modification allows an umbilical which is smaller in diameter, and much lighter in weight, thereby allowing increased operational depth with similar deck launch equipment.
- System bandwidth improvement to accommodate advances in video and imaging systems expected in the future.
- The incorporation of self-diagnostic capability and supervisory monitoring/failsafe control.

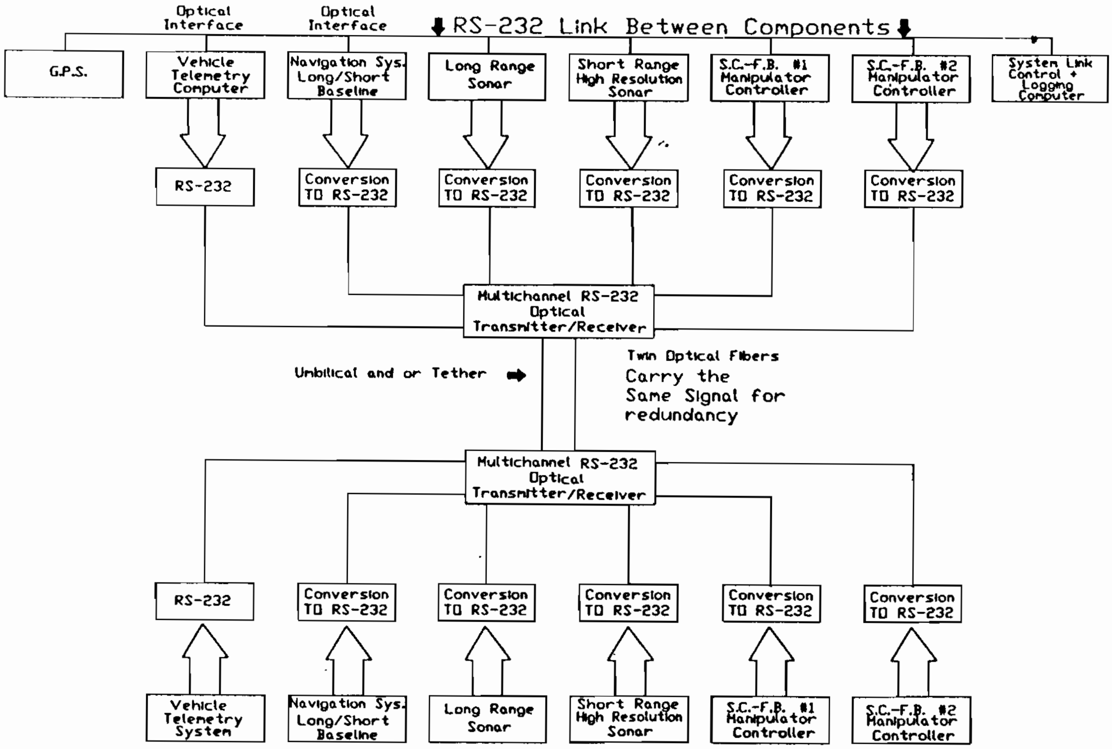

Figure 4. Basic ROV System Optical Link

A basic optical control link is shown in Figure 4. In this scheme major system components such as sonar, mechanical manipulators, navigation system, and vehicle telemetry utilize existing RS-232/422 interfaces. A multichannel optical converter is used to carry these signals on twin optical fibers for redundancy. The Advanced Micro Devices "TAXI" chipset functions as a parallel to serial optical convertor and is well suited for converting multiplexed electrical signals to broadband optical format at 100 Mbits/second.

Another method for accomplishing redundancy is to use a counter-rotating ring-type optical LAN between the topside and submerged systems as shown in Figure 5. The architecture is compatible with IEEE 802.5 or FDDI standards. Signals are transmitted around the ring with each node retransmitting the data packets. In order for a station to send a transmission it must first gain control of a special message unit or "token". The token circulates when no active message is present. To gain control, the station changes the structure of the token by modifying its start of frame sequence and adding the message unit to form a packet. Included with the new packet are address information, control and status fields, and the end of frame sequence. The station then sends the packet onto the ring and checks for proper transmission. The next station on the ring regenerates the packet and sends it on to the next station, and so on. The address is recognized by the destination station and is accepted in this process. The packet returns eventually to the originating station where the message is removed and a new token is issued. This token is available for the next station in the ring and if there is a message to send it will repeat the process. Eventually the token will return to the originating station where it will be available again for message handling. A limit is placed on the time each station can transmit, thereby reducing potential for any one station or node to monopolize the network. Failure of one of the nodes (or fibers) can be alleviated by using an optical bypass switch which reroutes the signal path, or alternately, by having the transmitting node read its own transmittted data from the ring and reroute the transmit direction. In this application it is also possible to route additional pairs of fibers for added redundancy as shown in Figure 6. As a potential improvement in reliability, integrated strain could be sensed in the umbilical fibers using standard sensing techniques to provide an indication of marginal operating conditions, strain history, and damage throughout the life of the cable.

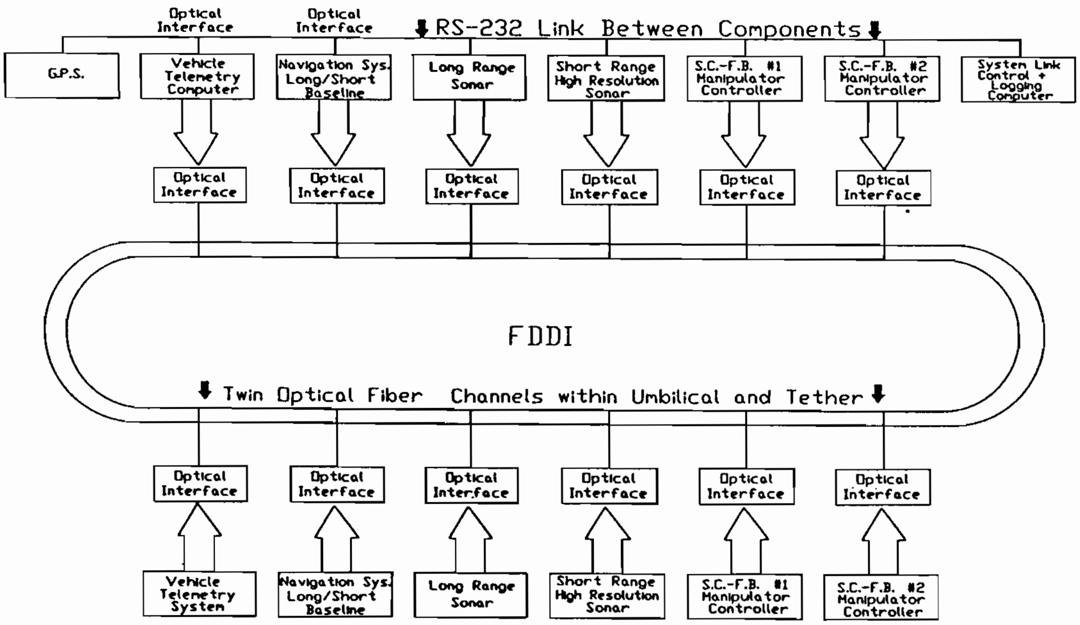

Figure 5. Redundant ROV Umbilical Link using Rotating Ring Topology LAN.

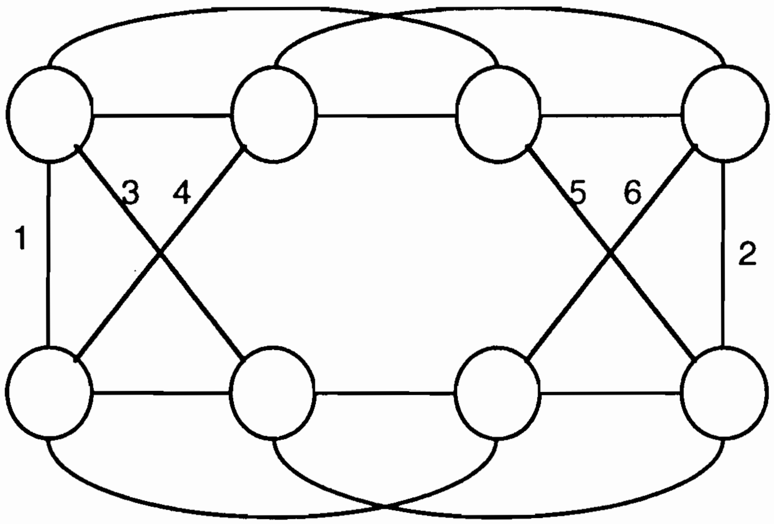

Figure 6. Double link ring LAN with six umbilical fibers

OFFSHORE FIBER TERMINATION

Because the umbilical may fail in an offshore environment, correct termination of the fiber optics is necessary to ensure good quality transmission. It is also necessary to make a timely repair since offshore operation time is costly. Our previous experience indicated that the fiber termination time was a significant portion of the entire umbilical repair procedure. Part of this time was consumed with fiber polishing and preparation activities. In order to eliminate the need for fiber polishing, it was determined that an already terminated pigtail, in conjunction with a reusable mechanical splice requiring a minimum number of tools, would be best suited for this application. After researching and examining various components, a procedure was developed and tested using preferred components.

One-meter long fiber pigtails were ordered and mechanical splices not requiring a UV-cure were tested. Of these, the AMP Finger Splice was chosen for its speed of installation, reliability, and low loss. Special tools are not required and the splice is reusable. Instead of furcation tubing, heat shrink tubing was chosen for strain relieving the splice, and a special splice sleeve was designed and fabricated at HBOI. The completed termination appears as shown in Figure 7. All necessary components are carried offshore in a Fiber Optic termination kit.

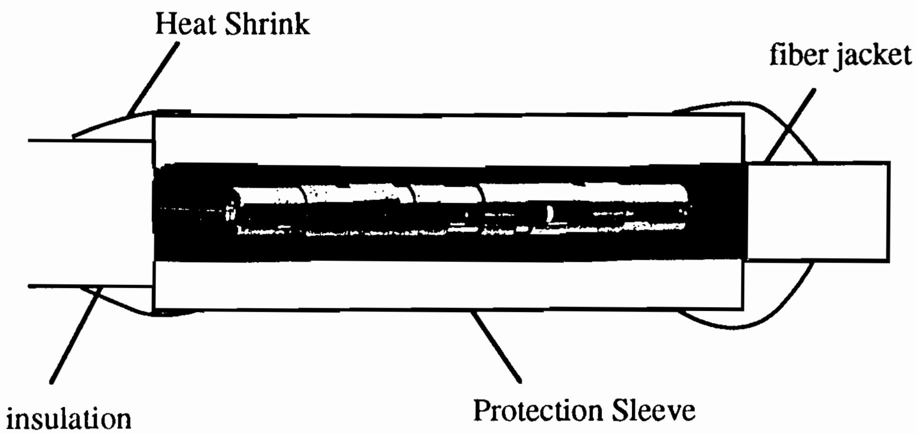

Figure 7. Fiber termination with AMP Finger Splice

The following procedure was found to produce acceptable results for terminating and connecting the umbilical fibers to an SMA-terminated fiber whip. A loss of approximately 0.3 dB per splice was observed.

1. The insulation is stripped around the steel tubing baring the fiber so that the exposed tubing measures roughly 3 inches.

2. A wirecutter or a sharp knife is used to scribe the steel tubing 0.5 inches from the cable exit point.

3. The fiber is wiped clean of the protecting gel with a lint free optical grade tissue.

4. The fiber coating is removed in two or three steps with a fiber stripper set at 250 μm.

5. Each fiber is cleaved with a fiber cleaver adjusted for length. With the recommended AMP finger splice, the fiber is cleaved approximately 6-7 mm from the end of the coating.

6. The end finish is inspected to ensure a smooth finish-free of defects such as fractures and burrs.

7. Fiber pigtails are prepared and kept in the spares kit following a similar procedure. Each pigtail is prepared by stripping a 1.5" length of jacket, followed by removal of excess sheath protection to expose the 900μm buffer, and then the 250μm coating.

8. Two separate 1 inch lengths of heat shrink tubing are then slipped onto each fiber end and the finger splice is attached. The heat shrink tubings are then slipped over the splice-steel tubing and splice-buffer, respectively, and heated.

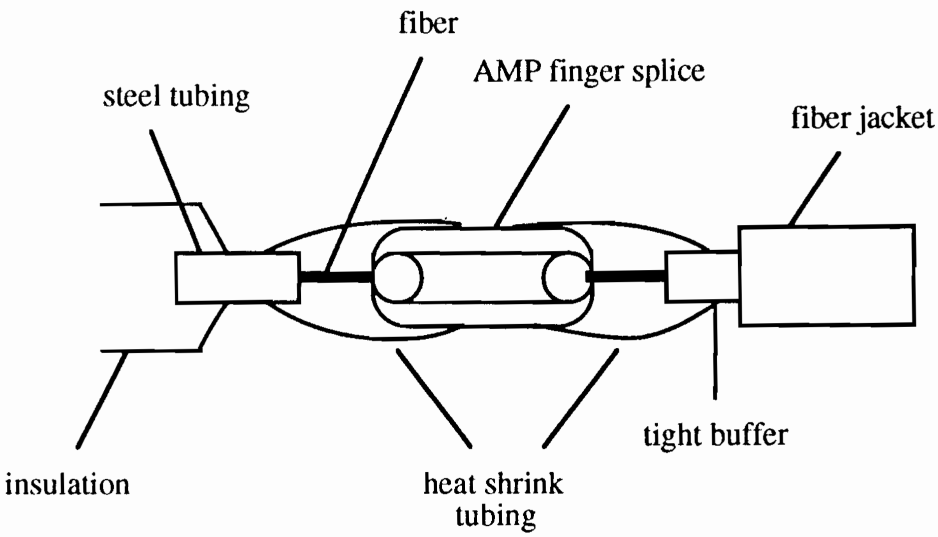

Figure 8. Splice Detail

CONCLUSIONS

Various considerations involved with the development of reliable fiberoptic telemetry systems for Remotely Operated Vehicles have been discussed. Although umbilical design has matured considerably over the past few years, damage to optical fibers carrying control signals and sensor data is still a concern in adverse field conditions. Recently implemented improvements in the communications network architecture for the HBOI "SCOOP" ROV have been reviewed and several more advanced networking concepts using fiberoptic technology have been proposed. In addition, a field proven method for reterminating umbilical fiberoptic strands offshore has been presented.

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