"The Use of Optical Fiber Rotary Joints in Towed Sonar Array and Seismic Streamer Systems"

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An Introduction to Military and Commercial Towed Sonar Technology

The ocean is alive with sound, both natural and man-made. And each sound is unique, being a thumb-print of its source. Through analyzing the sound emitted or reflected by an object we can usually determine what it is, where it is, and where it may be going. This is the fundamental principal of *sonar* and can be either *active* or *passive*. An *active* system consists of a *projector* and a *receiver*, which if co-located and can perform both functions is termed a *transducer*. A sound *pulse* transmitted by the transducer travels through the water to an object where it is *reflected* back to the receiver. Sound travels in water at about 1500m/sec and the time required for this two-way sound propagation to occur defines the distance to the object.

Conversely, a *passive* system does not have a projector and is purely a *listening device* that relies only on the sound *radiated* by the object. But since the *source level* of this noise radiating from the object is not known, detecting it and identifying its' location becomes a bit more difficult. Here is where the *sonar equations* come into play with such terms as *transmission loss*, *reverberation levels*, *receiving directivity index* and *detection threshold*. These terms require apriori knowledge of the ocean as a *transmission medium* and the known characteristics of the receiver. Figure 1 illustrates a simple active and passive sonar system.

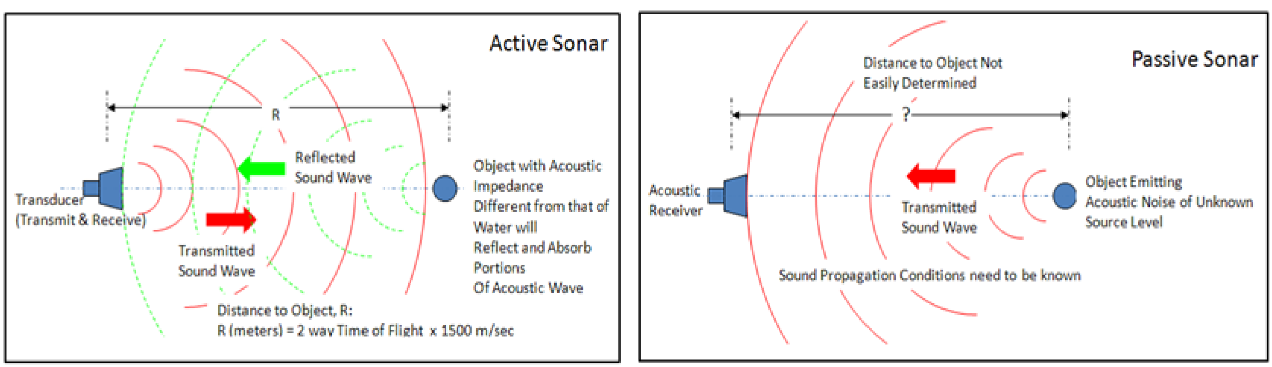

Figure 1 Basic Active and Passive Sonar Systems

One can improve the receiving performance of most any sonar system by adding length and/or separation between the receiving *acoustic sensors (i.e., hydrophones)*, and through basic *antenna theory* gives rise to *beam-patterns*. The first level of performance improvement is with two receivers forming a *dipole* just like our ears. Sound waves hit one ear before the other and we can determine the direction of the source. As progressively more sensors are added, with more separation, a long *line array* can be formed and the ability to determine the direction to the noise source improves significantly. In fact, the receiving beam-pattern of a line array has a highly sensitive *main lobe* and lower sensitivity *side lobes* that reject off-axis noise. Figure 2 shows of a progression of arrays with improved performance, with the beam pattern for a typical line array steered to 90-degrees from the forward direction, termed *broadside*, shown at the right.

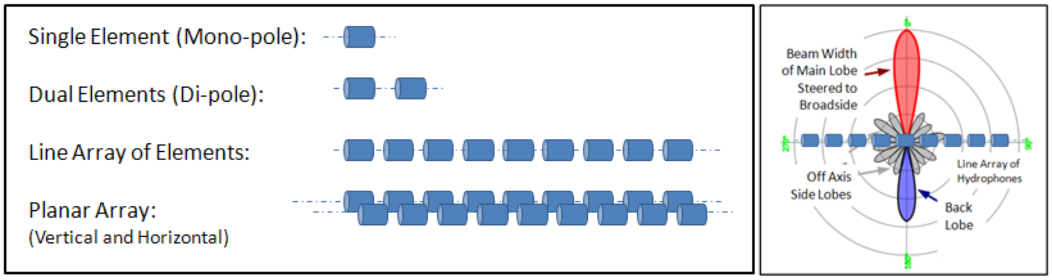

Figure 2 Array Performance Improves with Increased Elements and Length

Now that we have introduced the concept of the line and planar array, how is it used by the military and the offshore oil exploration industry? These line arrays are made into long slender flexible cylinders about the diameter of a garden hose or a fire hose. They are packed with acoustic and non-acoustic sensors and purposely made neutrally buoyant such that they tow horizontally and straight. Then they are deployed and towed from long electro-mechanical *tow cables* behind surface ships and submarines, hence the name *towed arrays* for military systems or *seismic streamers* for the offshore oil industry. These two systems share many of the same components, technology, capabilities and limitations, but are used in entirely different scenarios so having different name reduces confusion regarding their purposes.

Military *towed line arrays* are deployed and towed by naval ships to detect and localize potential underwater threats, i.e. *targets*. For surface ships, the towed arrays are deployed from a long heavy-weight cable that allows the array be towed at an optimal depth based on the local *sound propagation* conditions. For submarines, the towed array is typically deployed from a long light-weight cable since the submarine itself can define the towing depth of the system. A typical towed array, or seismic streamer, physical configuration is shown in Figure 3. Depending on the application, the length of these arrays can be from 100m to well over 6000m. They are therefore built in modular units and assembled using *inter-module connectors*.

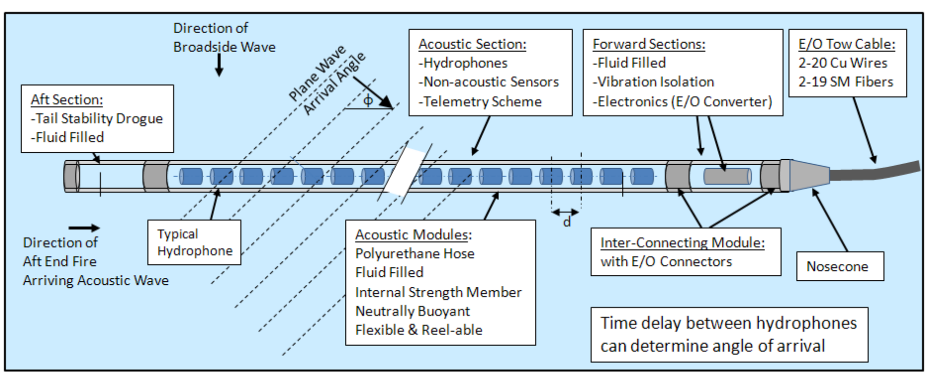

Figure 3 Typical Towed Array or Seismic Streamer Physical Configuration

Conversely, *seismic streamers* are part of an active sonar system that consists of air-gun projectors that saturate the ocean medium with periodic noise “shots” such that multiple reflections from the bottom and sub-bottom are received by the large *planar array* of acoustic sensors. The various reflections yield information (after considerable signal processing!) about the substratum and may indicate possible locations of oil or natural gas reservoirs. The GPS locations of such potential reservoirs are then logged for possible drilling at a later date to determine if oil or gas actually exists. These seismic streamers are towed close to the surface, as opposed to deep ocean like military systems, for better control of their physical location and easier signal processing regarding eliminating multiple surface and bottom reflections. A typical seismic survey with multiple streamers and air guns are illustrated in Figure 4.

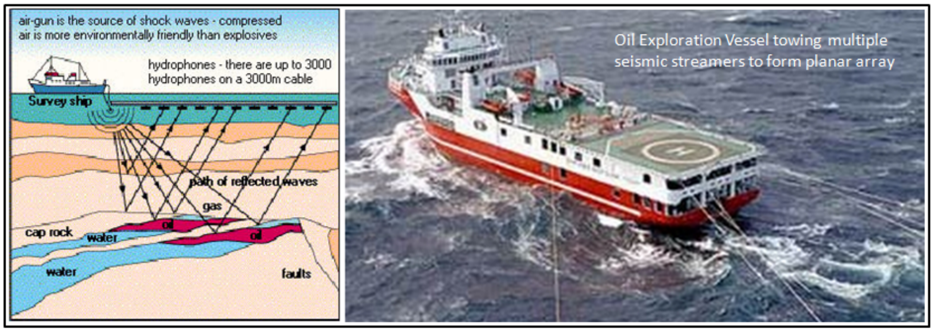

Figure 4 Oil Exploration using Planar Array of Seismic Streamers

Fiber Optic Applicability to Towed Line Arrays and Seismic Streamers

Up until now, the discussion has assumed that the acoustic sensors in these towed arrays were *piezoelectric crystals* that emit a small electrical charge when physically deformed as with the passing of an acoustic pressure wave. This small charge is then amplified, conditioned and usually multiplexed onto a Copper (Cu) coaxial cable along with many other sensors for transmission through the tow cable to the host towing platform. This also assumes that the entire system is electrical in nature, with Cu wires carrying DC power to the hydrophone pre-amplifier and the coax providing the return data path. There are many electrical multiplexing (MUX) schemes that have evolved over the years but the increase in channel count density (for better target and oil reservoir resolution) has hit the limits of conventional electronics and now requires the bandwidth capabilities of optical fibers for the return data path.

There have been extensive R&D programs to develop an all-optical towed array (or seismic streamer) system that incorporates *fiber optic sensors* along with the optical signal path MUX schemes. The basic principle is that a very small change in the optical fiber dimension (as when acted upon by an acoustic wave) will change the path length of a fiber wrapped around a *compliant air-backed mandrel*. This will result in a phase difference between the light traversing the compliant mandrel path when compared to the phase of light traveling through a *rigid mandrel* with the same length of fiber. The basic concept is derived from a *Mach–Zehnder interferometer*, illustrated in Figure 5, but there are many variations with different sensors and optical transmission telemetry approaches.

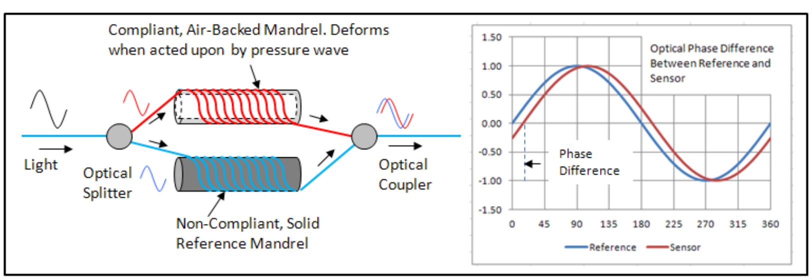

Figure 5 Fiber Optic Sensors and Resulting Phase Delay of Output Relative to Reference

Unfortunately, fiber optic sensors are extremely sensitive to other physical disturbances and require that the entire wet end (i.e., optical cables, optical components, FO connectors, circulators, etc.) be very physically stable, vibration-free, well protected, and account for any hydrostatic pressure and temperature variations. Finally, the topside launch optics and receive optics/DE-MUX can be quite expensive and bulky. The sum of these problems has resulted in little success in fielding a truly *all optical towed system*, although the technology is well suited for a more stable *bottom mounted fixed array system.* Such all optical bottom mounted systems are currently being incorporated into *harbor defense systems* for military applications and by the offshore oil industry for *ocean bottom cables* (OBC) where the systems are deployed on the bottom for long periods of time to monitor oil reservoir migration prior to exploratory drilling.

Fiber Optical Rotary Joint Installations in the Signal Path

So where is the near-term future of fiber optics in towed arrays and the offshore oil industry? It's in the *signal path*, which consists (from the wet end upward) of the electro-optical (E/O) convertor at the piezoelectric sensor, the E/O cabling, the E/O connectors, the E/O towing cable, and finally the *fiber optic rotary joint* (FORJ) in the shipboard handling system and over-boarding winches. The acoustic and non-acoustic sensors still need a modest amount of electrical power, but the output signal from these many sensors require a fiber optic path and ultimately requires a hybrid E/O tow cable, E/O connectors and an Electro-Optical Rotary Joint (EORJ). The key to transmitting large amounts of *signal path data* on a minimal number of optical fibers is optical Time Division Multiplexing (TDM) and Wave length Division Multiplexing (WDM)[2], and sometimes using both techniques. But even with multiplexing in the towed array signal path, the number of optical fibers used in towed systems can be quite large.

Fiber Optic Cable and Connectors

As expected, the benefits of using optical fibers for the signal path come with a price: limitations on the number of fibers that can be *bundled into a cable and connectorized* for sea going operations in a reasonable diameter, with high reliability and at a low cost. Two (2) and four (4) optical fiber cables with connectors are very common but are quickly being surpassed by the need for 8-20 optical fibers, and often with multiple copper (Cu) electrical path requirements. In general, the number of optical and electrical paths depends on the number of sensors, the telemetry scheme employed, and the desired redundancy. For example, a typical high density electro-optical tow cable is shown in Figure 6. This cable consists of 8 multimode (MM) fibers in a central Stainless Steel tube surrounded by six (6) AWG#11 (DC power) and six (6) AWG#20 Cu wires (ground drain wires). A typical MIL-SPEC optical connector is shown to the right of the tow cable in the figure below.

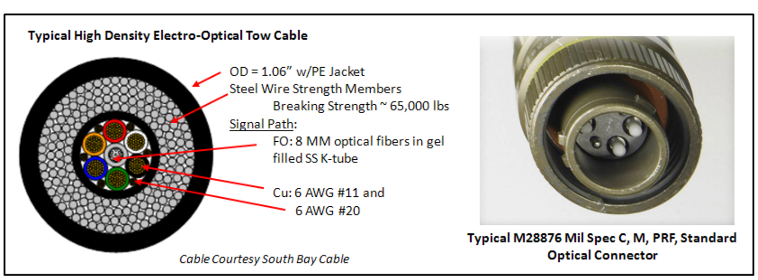

Figure 6 Towed Array E/O Tow Cable and MIL-SPEC Connector

The Interface at the Towed Array or Seismic Streamer Handling System Winch

The large diameter, long, heavy E/O tow cable used for towed array or seismic streamers is installed on a handling system *winch* for storage, and ease of deployment and retrieval. This winch system can be located on the weather deck of a surface ship, or installed in a flooded ballast tank or within the pressure hull of a submarine, depending on the system. In either case, a FORJ or EORJ is required to enable interrogating the towed system without stopping the deployment (or retrieval) and continuously mating/de-mating E/O connectors to gather data. Such frequent mating/de-mating of E/O connectors causes excessive wear on the optical portion of the connectors and leads to increased optical losses and back-reflection. A high quality FORJ or EORJ is therefore required to assure continuity and interrogation with the towed system during its deployment, during normal towing operations, and then system retrieval. A typical location for a FORJ or EORJ installation for a seismic streamer deck mounted winch is illustrated in Figure 7.

Figure 7 Locations for FORJ or EORJ Installations on Seismic Streamer Winch

Virtually every winch system that handles a cable with optical fibers needs a FORJ or a hybrid EORJ. This extends beyond the above towed arrays and seismic streamers to include Remotely Operated Vehicle (ROV) tethers, side scan sonar tow cables, and many other oceanographic "tools of the trade" that use optical fibers for the signal path. Deploying and retrieving expensive instrumentation that use optical fibers for the signal path cannot afford to stop during deployment, hook up the E/O connector to interrogate the system, verify its operation, then disconnect and continue deployment. It is vital to have the ability to continuously monitor the sensors functionality <u>during</u> deployment and retrieval via the FORJ or EORJ, not afterwards. A high quality, continuous contact, FORJ or EORJ should be a part of every towed sensor system and mounted on their sea-going winches.

A Fiber Optic Rotary Joint for Every Applications

The Princetel FORJ and EORJ design incorporates rotating *Dove prisms* that allow for the continuous passage of light, uninterrupted, during 360-deg of rotation with minimal optical loss or back-reflection. The significance of this is there is no intermittent loss of optical signal during rotation…ever! These FORJ designs can be as simple as a single channel optical fiber rotary joint, or as complex as an E/O hybrid of 2-to-20 Cu paths with up to 2-to-48 optical paths. Figure 8 below shows the family of FORJ that Princetel has developed, with more details and typical applications shown in Table 1 below.

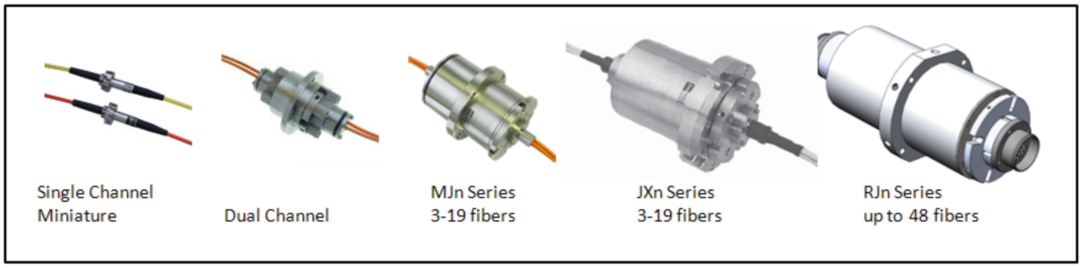

Figure 8 Princetel Fiber Optic Rotary Joints

Table 1 Summary of Princetel Fiber Optic and Hybrid Rotary Joints

Optical Paths	Cu Paths	Princetel Model #	Typical Applications
1 SM or MM	n/a	RPT, RFC, RST	Most common single fiber applications; rugged and long lasting
1 SM or MM	n/a	RPC	ROVs or any underwater applications
1 SM	n/a	MJP, MJX	Biomedical devices such as OCT; high speed, low reflection
2-MM Fibers	n/a	MJ2	Industrial and wind turbines; duplex Ethernet
2-POF (MM)	n/a	PJ2	Industrial such as SERCOS
2-7 SM or MM	n/a	MXn	Tethered aerostats; mining machines; ROVs
3-19 SM or MM	n/a	MJn or JXn	Tethered aerostats; mining machines; ROVs
20-48 SM or MM	n/a	RJn	Rotating theater stage; military
1 SM or MM	12 Cu	SRG12-MJX	Surveillance cameras or common video application
1 SM or MM	24 Cu	SRF24-MJX	Surveillance cameras or common video application
1 SM or MM	4 Cu	SRH04-MJX	Rotating sensors/actuators that require high current; radar
1 SM or MM	30 Cu	SR202-MJX	Rotating sensors/actuators that require high current; radar
1 SM or MM	2 Cu	SRP90-MJX	Military & Commercial Towed Arrays
1 SM or 2 MM	1-10 Cu	SR223-RPT or MJ2	Rotating sensors/actuators that require high current; radar
3- 19 SM or MM	1-20 Cu	SR221-MJn or JXn	Tethered aerostats; mining machines; ROVs; Towed Arrays

As Used Aboard US Navy Submarines and Surface Ships

The US Navy deploys towed arrays from virtually all of its submarines and many of their surface ships. And due to increased bandwidth requirements, many of these towed array systems are now transitioning from all electrical systems to electro-optical signal paths that require an E/O hybrid rotary joint at the over-boarding system winch. Princetel has FORJ and EORJ suitable for these platforms. For example, Princetel *Model SPR90-22* customized 1x2 EORJ satisfies the requirements for the electro-optical TB-34 Next Generation Towed Array that may be installed on many fleet submarines. Although the signal path for this towed array consists of two (2) optical fibers and two (2) AWG#18 Cu wires, the two optical data paths are multiplexed onto one (1) optical SM fiber at the input and output of the rotary joint to greatly simplify the design, cost and physical size. Virtually every boat in the US submarine fleet could soon have this hybrid FORJ install onboard its' inboard handling system. It is depicted below in Figure 9.

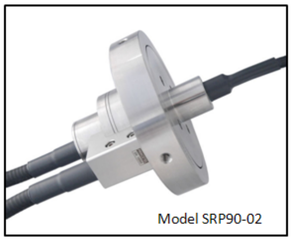

Figure 9 Princetel Model SPR90-22 1x2 EORJ

In addition, the US Navy surface fleet will soon deploy the new TB-37/U Multi-Function Towed Array (MFTA) on some ships. This towed array system uses an electro-optical tow cable requiring up to eight (8) optical fibers and up to twelve (12) Cu paths. To satisfy this requirement at the handling system interface, Princetel has offered the *Model JXn* series (shown previously in Figure 8) which can pass up to 19 SM fibers and 20 Cu paths, all in a small form factor design with excellent optical performance.

Summary and Conclusions

The new generation of military towed arrays, commercial seismic streamers, and bottom mounted systems rely on a large number of acoustic and non-acoustic sensors to provide the high resolution needed for military target or oil reservoir identification and location. The resulting data band width requires the use of optical fibers in the data signal path, yet still retaining Cu paths for DC power. And the need for continuous access to the signals even during system deployment (or retrieval) from its' rotating storage winch requires a high performance Fiber Optic Rotary Joint (FOJR) with no loss of optical signal at any time during winch rotation. Princetel has the solution with a family of FORJs and hybrid Electro-Optical Rotary Joints (EORJ) that can pass up to 48 optical fibers and up to 20 Cu conductors. These systems have been built, delivered, installed and their performance proven in the field. And the future for all optical towed arrays and seismic streamers is clearly *bright*, as the technology improves over time.

Team up with Princetel to face your signal path challenges with an all optical or hybrid electro-optical rotary joint and *never lose sight of your optical data again*!

[1] Jesse Diggs is a consultant with Coastal Engineering LLC and Barry Zhang is President of Princetel, Inc.
[2] "*Optical Fiber, WDM, and FORJ Transform Undersea Telemetry*", B. Zhang and F. Canizales, article originally published in the May/June (2003) issue of Underwater Magazine, updated October 30, 2011, also see www.Princetel.com, web site "Learning Center"