OPTICAL FIBER AND CONNECTORS: CRITICAL COMPONENTS OF MANY ADVANCED SUBSEA SYSTEMS

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Abstract

Since the first connectorized, subsea fiber-optic data link was installed on the Phillips "Little Dotty" field in January of 1997, the subsea oil industry has seen a number of projects, where optical fiber has been either critical to the program or has offered significant cost or performance advantages. These projects have been at the forefront of recent tieback technology development, and have been as diverse as the Norsk Hydro Troll Pilot subsea separation system and the Petrobras SBMS multiphase pump project, to new downhole gauges with remote, real time monitoring, such as the Shell ETAP program. Many of these projects have already been installed or are scheduled for phased installation over the next year or two.

Optical fiber has been critical to these programs for a variety of reasons, ranging from data security for fiscal metering subsea through communication bandwidth and electrical noise immunity, to CAPEX reduction for Integrated Service Umbilicals for very deep-water installation (>2000 m).

Many of the goals for the tieback community can be achieved only with the aid of fiber-optic communication. Long step-out distances, or eventually tieback to shore, can benefit from fiber's unrepeated communication distances of greater than 100 km. High-power, subsea pumps needed to pressure boost fluids over these step-out distances need electrical noise immunity, inherent in optical fiber. Umbilicals designed for long step-outs can be more cost efficient using optical fiber in high-density, small cable designs. While the control systems for complex subsea installations need increased bandwidth, which can easily be supplied by optical fiber, while wet-mate hybrid connectors allow modular installation.

Introduction

To date, the use of optical fiber in the offshore oil and gas industry has been restricted to a few critical applications, where electrical communication or sensing was not a technically feasible alternative. This solution-driven development is now starting to give way to the true commercial advantages of optical fiber. This is in contrast to a subsea telecommunications industry that has already installed 750,000 km of fiber-optic cable.

Optical fiber offers 6 main benefits that should be reviewed for any new tieback proposal:

- Communication bandwidth.
- Unrepeated communication distance for long tiebacks (Ref 1).
- CAPEX reduction in umbilical construction.

- EMI noise immunity for high-power motors and systems.
- Sensors and sensor support.
- Data security and fiscal metering.

Communication Bandwidth

Many of the new technologies for advanced tieback systems like subsea processing and multiphase pumping, either require or can benefit from improved controls support. Why should many advanced systems be limited to a share of a 1200 baud communication line? Norsk Hydro a.s. have recently completed commissioning on the Troll Pilot subsea separator. The separator control system handles a 1000 fold increase in data transmission. At the same time, it operates in an environment which includes the risk of EMI interference from the high-power supply umbilical to the MWatt re-injection pump that resides on the separator manifold. The Troll Pilot program took the decision at an early stage to use only fiber-optic communication.

A dual-redundant fiber-optic backbone runs from the surface control system through the ISU (Integrated Service Umbilical), which includes the high voltage supply lines to the re-injection pump, to the wet-mate fiber-optic connectors on the Umbilical Termination Assembly (UTA). From the UTA, oil-filled jumper assemblies link to ROV installed wet-mate, fiber-optic connectors on the individual control systems for the separator and the water injection x-tree (see photo 1).

Photo 1: ROV Installation of Wet-mate Fiber-optic Connector

Electrical communication offers data rates up to 9.6 kbit/sec for subsea control systems, while optical communication can easily support 200 Mbit/sec and with existing modem technology, can move this to 2.5 Gbit/sec without modifying or replacing any installed single-mode fiber.

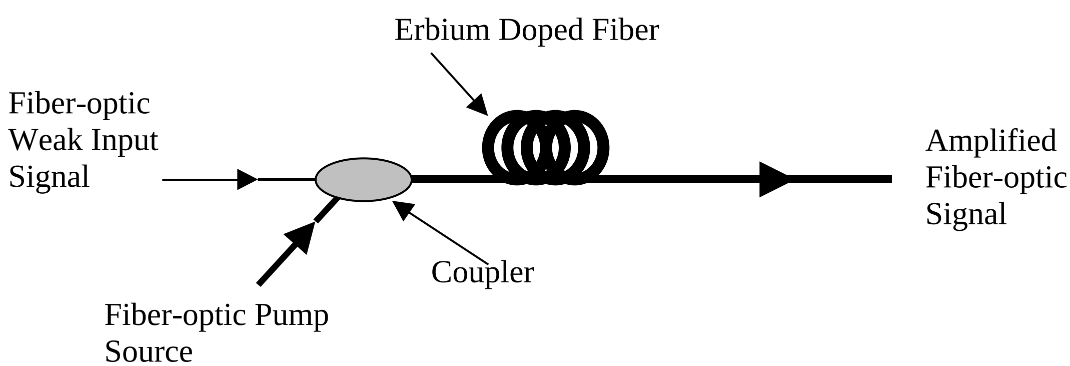
Many of the proposals for subsea infrastructure aimed at reducing facilities topsides load or at supporting long distance fluid flows already include, or will need to include, sophisticated control and sensor systems. These control systems will need to operate in real time and will produce data in large volumes. They will only perform to their true potential if supported with a high bandwidth communication system.

Unrepeated Communication Distance for Long Tiebacks

Although adequate for most step-out distances to date, electrical communication begins to struggle over more than a few tens of kms. Many of the goals of future tieback technology are aimed at extending the step-out distance, and so increasing the area of coverage that an existing or future facility can cover. For mature regions, like the North Sea and Gulf of Mexico, the ability to add marginal fields to existing developments is extending the lifetime of many platforms. As step-out distances continue to increase, unrepeated electrical communication distances are becoming a limiting factor. Extending transmission requires a repeater system at a suitable location in the umbilical. This increases the cost of manufacture and installation and decreases the reliability.

Single-mode optical communication provides very long distance unrepeated communication. A long haul optical fiber communication system is one proposal for the West Delta Deep Program offshore Egypt. The distance is mainly limited by optical signal dispersion in the fiber and is bit rate dependent. At 200 Mbit/sec, single-mode fiber can support an unrepeated transmission distance in excess of 100 km.

Using EDFA (Erbium Doped Fiber Amplifier) technology from the telecommunications industry that provides passive amplification without conversion to an electrical signal, and an appropriate choice of fiber, unrepeated distances of 200-300 km can be achieved. These distances will support one of the long-term goals of the tieback community;- tieback to shore.



EDFA Schematic

CAPEX Reduction for Umbilical Manufacture and Installation

As step-out distances increase and installations get ever deeper, the costs associated with ISU's grow in relation to the overall development capital expenditure. The unit length manufacturing cost for an ISU is dependent on the cross-sectional construction and the final diameter of the active elements drives the weight of armoring needed. Therefore, any reduction in the dimension of the umbilical internals can lead to a reduction in weight per unit length, which may lead to further cost reduction for installation.

As a case study, the original installation plan for the BP Amoco King's Peak field in the deep-water GOM called for dual-redundant electrical communication with a 16 mile (25 km) ISU linking the Kings Peak gathering manifold with the production vessel proposed for the King field. The water depth over most of the installation is in excess of 6,000 ft. The original umbilical design included separate twisted shielded pair conductors to each control module. The resultant ISU was too large to manufacture in one piece. This meant that the installation vessel specifications had to include a moon pool for launch and recovery of the termination assemblies and the central splice enclosure. At this point, the forecast development costs were becoming uneconomic, largely driven by the cost of manufacture and installation of the ISU.

BP Amoco's decision to replace the electrical communication lines with optical fibers in a hermetically welded steel tube resulted in a reduction in cross-section and in the amount of armoring needed. This led to a sufficient weight saving so that the ISU could be fabricated in one length. The installation could now be carried out by a less costly vessel as the moon pool was no longer a requirement.

Once the decision to use optical fiber communication was taken, an additional benefit was realized. BP Amoco were able to implement a real time interrogation of the PES SCRAMS system directly from the surface, simply by adding additional fibers in the existing fiber tubes and placing additional optical modems in the Subsea Control Modules. This decision did not affect the cross-section of the umbilical and the cost impact was limited to a few cents per foot for each additional fiber.

<u>EMI Noise Immunity To Support High-power Systems</u>

Electrical communication is at risk of data corruption from electromagnetic noise, such as that generated by high-voltage power lines and large electric motors. The growth in interest in subsea single and multiphase pumps for pressure boost and water re-injection, where extended step-outs require either assistance for fluid movement and/or environmentally friendly disposal of produced water from a subsea separator, has led to the development of a number of different pump/motor systems. Many of these motors are electrically driven and at powers in the 2-5 MW range.

In order to supply these levels of power, low-loss, high-voltage transmission lines need to be used. In addition, the motor control loop will often use a variable frequency power supply to provide motor speed control. Under these conditions, the power conductors and the motors become sources of high levels of electromagnetic interference.

Two options exist for electrical communication:

a) Shield the communication conductors from the noise source. This is costly in terms of umbilical construction and is not always successful.

b) Run a separate communication cable. Again, this is costly in terms of umbilical installation. The communication and power cables will need to be installed at least 1m apart. Difficulties may arise when trying to keep the communications cable shielded at the subsea termination.

Optical fiber is inherently noise immune. The fiber can be run in a stainless steel or copper carrier tube in the same umbilical as the high-power conductors, with no risk of data corruption through EMI.

Subsea installations of high-power pumps, including the Troll Pilot water injection pump and the Petrobras SBMS multiphase pump, have used all optical communication with wet-mate fiber-optic connectors and jumpers providing the modular installation necessary for these large systems.

Sensors and Sensor Support

As tieback technology continues to increase its level of sophistication with the installation of complex subsea systems, ever more sophisticated sensors with real time data access are needed as a fundamental component of any feedback loop control system. No longer are subsea sensors needed to just monitor valve position. Today's suite of sensors provide real time data on single and multiphase flow conditions, temperature and pressure, pipe erosion monitoring, level sensing, water cut, etc.

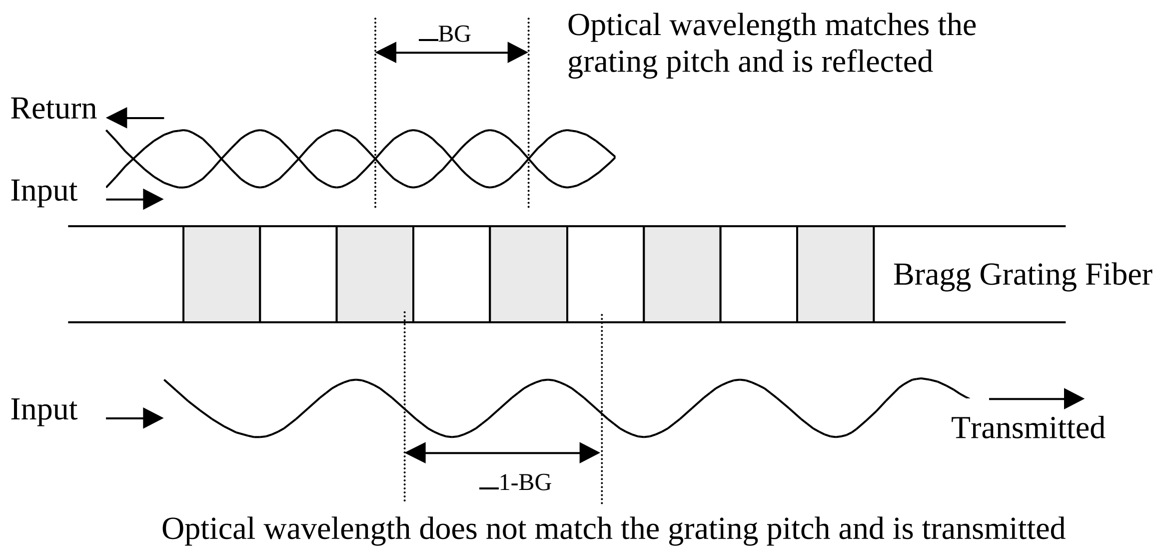
Optical fiber provides the high bandwidth communication backbone necessary for the implementation and best use of many of these sensors. This can allow the sensor control and diagnostic equipment to be located on the platform and have a number of passive sensor heads located in the extreme environment, either downhole or inside pipe-work. In addition, optical fiber is itself capable of sensing many of the measurements covered by the sensors listed above.

One sensor system already in place for a downhole pressure and temperature measurement is the FOWM (Fiber-Optic Well Monitoring) gauge system used by Shell on ETAP (Eastern Trough Area Project). The ten high temperature wells on the three fields Skua, Egret and Heron that make up Shell ETAP were not suitable for electronic gauge technology with temperatures in excess of 160º C. The FOWM system uses discrete optical pressure and temperature sensors, interrogated over a single fiber for each well set. A wet-mate, single channel, fiber-optic connector resides between the x-tree and tubing hanger, with additional wet-mate fiber-optic connectors and jumpers linking the x-tree to the umbilical termination assembly. The umbilical is fabricated in three sections linking each field and there are multi-circuit, wet-mate, fiber-optic connectors and optical jumpers linking each umbilical section. The sensor interrogation and diagnostics equipment, including the lasers and drive electronics, reside on the platform where easy servicing can be performed. Separate fibers link each well to the platform with spare fibers to each UTA and available through protected spare wet-mate fiber-optic connectors. The furthest well is >25 km from the Marnock platform, so the sensor signal traverses a round trip to the sensor in excess of 50 km. All of the optical sensors are read in real time and at the same time.

In its simplest form, optical fiber can be used as a distributed temperature sensor capable of measuring 30 km lengths with 1m measurement spacing and a temperature accuracy of 0.1º C. This technology is proving very useful in pipeline monitoring and pipeline heating programs, and even has a successful history of downhole distributed temperature measurement.

The addition of a "Bragg Grating" to the fiber converts that section of the fiber to a point sensor where any external effect which causes a change in length of the fiber grating, i.e. temperature, pressure, strain, etc., can be detected. A Bragg grating is a section of fiber encoded with a modulated transmission profile where the pitch on the modulation is equivalent to the optical signal wavelength passing through it. The grating is transparent to wavelengths that do not match the grating pitch. This allows gratings with different pitches to be added in series to a length of fiber creating a series of point sensors.

The sensor operates by having the parameter under test change the length of the grating by a small amount, thereby changing the pitch of the grating and the wavelength of a reflected signal. With a number of sensors in series on a fiber, they can all be read at the same time by illuminating the fiber with a white light source and monitoring (scanning) for the frequencies of the reflected signals.



Bragg Grating Schematic

There are a number of other discrete sensors that use optical measurement techniques and can be interrogated over an optical fiber. One of the largest potential uses of optical sensors is in high sensitivity passive geo-phones for use on the sea-floor or down-hole in the well for continuous production draw-down monitoring.

Fiscal Metering and Data Security

The growth in subsea tieback capability has led to the situation where complete developments for one Operator are run as a subsea tieback to a production facility owned and operated by a second Operator. Examples of this are the Shell ETAP development tied-back to the BP Marnock Platform, and Canyon Express in the GOM where ELF and Marathon have proposed subsea developments tied-back to a BP BP Amoco production facility. In these conditions, production and reservoir data has a real value and, as such, its security is of interest to the Operator.

Unlike electrical communication, which can be "read" by recording the electro-magnetic field generated around the conductor, optical fiber needs to be physically "tapped into" in order to be read and the power loss associated with this activity can easily be detected.

At least one program, Phillips "Little Dotty", installed in January 1997 in the Southern North Sea, uses optical fiber communication to a fiscal meter installed subsea and measuring Natural Gas production. The decision to use optical fiber was made for the bandwidth and data security benefits provided by optical communication.

Conclusion

With the current direction of the tieback community moving to support ever-deeper installations at increasing step-out distances. And with greater amounts of more sophisticated subsea equipment being installed, and running at higher voltages and needing more sophisticated feedback control, which in turn needs more sophisticated sensor systems……..

Optical fiber offers high bandwidth data communication in a noise immune format, which also offers high data integrity and security and is generally available to support unrepeated lengths >100 km, and can be configured for up to 300km.

Reliable, low-loss, wet-mate, fiber-optic and hybrid connectors (optical and electrical circuits in the same shell) and the necessary dry-mate connectors and jumper assemblies, have provided the means to carry out modular installation on a number of projects already subsea.

Fiber-optic sensors can provide a totally passive and environmentally robust alternative to many of the current range of electrical sensors. And in some cases, provide a means of easily carrying out a measurement which is difficult or impossible with existing electrical sensors such as distributed temperature measurement.

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