Opening Opportunities in Subsea Communications

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Abstract— **Subsea infrastructure for Oil & Gas Production and Ocean Science Cabled Observatories has increased in complexity as we seek greater depths, longer step-out distances and longer performance life, now up to 30 years. The capability of the sensors being developed for long term health management and environmental monitoring is leading to a significant increase in both bandwidth for communications and adaptive technology necessary for expansion into new systems and technologies for data transmission and communication conversions. This has in turn presented new challenges for controlling design, deployment and operational risk to support evolving communications and monitoring networks. As the methods and means of communication from systems and subsea equipment continue to evolve, new and unique product technologies are needed to provide effective solutions. Identified as Active Flying Leads (AFL), this new technology allows for the integration of subsea qualified connection systems to be used in communicating between various pieces of equipment. In some cases, communication protocols are converted using the AFL to avoid protocol conversion somewhere else in the system. This paper cites various case studies and the solutions that were developed to solve issues that are directly applicable to the Ocean Science and Offshore Energy markets.**

Keywords—Flying Lead; Electronics; Ethernet; Communications; Wet-Mate assembly; Subsea instrumentation; Subsea Data transmission; Subsea fiber optics

I. Introduction

In 2005, Teledyne Oil & Gas (TOG) began producing Ethernet flying leads. Early adoption of Ethernet by the Oceanographic market led to the development of this product by TOG. Around 2010, demands for Ethernet flying leads increased rapidly due to the standardization of subsea Ethernet by many Oil & Gas operators due to the need for an increase in data transmission. At this point it was apparent that the length limitation would eventually be an issue for the industry. At that time, the Ethernet flying lead length limit was 60 meters before communication broke down and was unusable. Teledyne developed a new cable capable of meeting industry performance specifications for Ethernet over a 100 meter length in a flying lead. Teledyne Oil & Gas partnered with an oil and gas operator and began to develop the technology to extend the reach of Subsea Ethernet through the use of optical fiber media conversion Prototypes proved that it was possible

Fig. 1. Teledyne Oil & Gas Nautilus Electrical Flying Lead (EFL)

to use Ethernet media converters to extend the length of Electrical Ethernet flying leads. This solution was appealing to the operator due to the decrease in complexity of the overall system. By eliminating length as a driver for determination of communication type and protocol used, the need for custom equipment is reduced, creating the ability to have a standard. After the development project was complete, and it was determined that further distance was feasible, the operator went on to plan future fields with the understanding that length limitation had been resolved.

Due to the changing requirements for subsea communications, Teledyne Oil and Gas began several iterations of technology gap assessments, eventually leading to the development of a new class of jumper technology referred to as the “Active Flying Lead” or AFL. Active Flying Leads build on the solid reliability of Electrical Flying Leads (EFL) to add functionality to a standard piece of subsea hardware with the addition of electrical components. The first AFL development was driven by a request for an Electrical Ethernet-based solution that would transmit longer than the currently available product. The limitation in length was due to the use of standard terrestrial Cat 5 cable inside of the pressure-balanced oil-filled hose. As this was not the environment that this cable was designed for, an in-specification performance was only achieved when the jumper length was less than 60 meters. To address this issue, Teledyne

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Oil & Gas created a custom Ethernet cable design to perform in-specification at 100 meter jumper lengths as determined by the ISO standard. This new cable was the first step towards the development of Active Flying Leads. Although this development represents a passive solution, without the creation of this cable, further developments of AFLs would not have been as attractive.

Additional customer feedback suggested that 100 meters may not always prove sufficient in length for some applications. Therefore, two additional development paths were conceived. The first path was the addition of Ethernet repeaters. Teledyne Oil and Gas designed and developed printed circuit boards using the most reliable components available to accept and rebroadcast the Ethernet signal. Other customers needed lengths just beyond 100 meters and believed that it would be difficult to deploy and may not be economical to use media converters. In response, Teledyne Oil & Gas created a smaller housing and provided a fully electrical option. This option limits the overall length available, but provides a solution at a cost more in line with the increase in length.

The boards then went through extensive qualification testing in which zero frame loss was achieved, and accelerated life testing for over 18 months at extended temperatures up to 95 °C. These developments were made with reliability as a core focus and designed to work in the challenging environment. The atmospheric subsea housing was designed to mount the electronic components in a manner that did not require any additional subsea mounting at the jumper level or special care considerations. The housing was limited in diameter to that of the bend restrictor used on the EFL's. These repeaters can be added at 100 meter increments to increase the length of the Ethernet jumper. One repeater can be added at the midpoint of a flying lead to extend the Ethernet reach to 200 meters and two repeaters can be used to reach up to 300 meters. The addition of an Ethernet repeater to a standard Ethernet flying lead is referred to as the Extended Ethernet Flying Lead (E^2FL), which is also capable of handling and retransmitting Power over Ethernet (POE) if required.

The next focus of Active Flying Lead development is the introduction of Controlled Area Network (CAN) bus repeaters. CAN bus, originally developed for the automotive industry, has been used for subsea sensing systems for many years. Through the Subsea Instrumentation Interface Standardization (SIIS) group, the use of "fault tolerant" CAN bus has been chosen as the standard. This CAN bus protocol uses an 8 volt differential signal to cross the copper lines. When only one sensor on a long length of cable is required, the capacitance of the system is too large for the communications to function properly. Through the use of patented circuitry design, Teledyne Oil and Gas has developed the ability to repeat the CAN signal. This repeated signal effectively removes the capacitance from the system and allows for longer transmission distances. There are several options available to increase the distance. The first is to simply double the available distance by

Fig. 2. AFL with CAN bus Extender

repeating the signal. The second option is to repeat the signal as high speed CAN bus and then repeat again at the normal CAN bus speed. With the addition of these circuit boards, CAN bus flying leads can reach distances of 1500 meters or longer. The canister housing for the CAN bus system is based on the housing design used for the Ethernet Repeater and is therefore prequalified.

Active Flying Leads technology allows for the integration of subsea qualified equipment for use in communicating between various pieces of equipment and in some cases, converting from different methods of communication that the equipment utilizes. The newest addition to the family of products is the Electrical to Optical Flying Lead (EOFL). The EOFL converts a fiber optic signal through a hybrid fiber optic wet-mate connector and produces an electrical Ethernet signal through a 12-way electrical connector on the other end. The conversion from optical to electrical is accomplished in a compact 1-atmosphere internal pressure chamber that is rated to an exposure of up to 10,000 PSI external pressure. This new technology may be used in place of more complex equipment such as secondary nodes and junction boxes or distribution manifolds, allowing a simplified infrastructure at reduced cost and risk. The AFLs are retrievable with a Remotely Operated Vehicle (ROV) for maintenance and upgrades if necessary; allowing for further operational cost savings. They can also be used to get sensitive equipment or experiments further from nodes or the shore than legacy technology allowed. Previous limits on experiment/instrument step-out distance from the Science Instrumentation Interface Module (SIIM) and Node modules have raised concerns that these structures may influence the behavior of sea life, prohibiting observation of these creatures in a truly natural environment unobstructed by artificial elements.

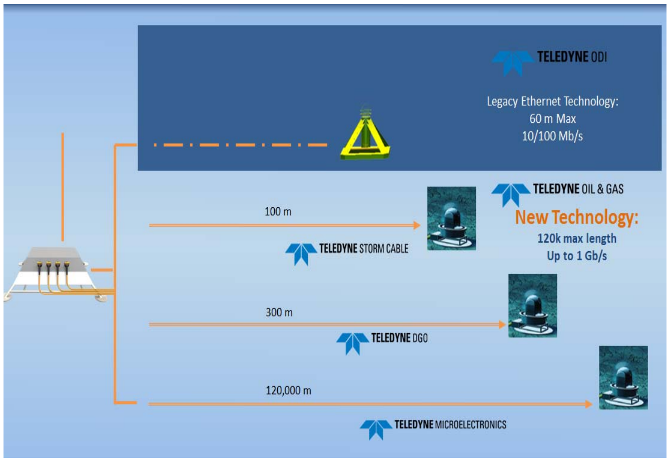

Fig. 3. Teledyne Innovation through Collaboration

II. Case Studies

A. Case Study 1

In 2010, Teledyne began a development project to demonstrate the ability to provide longer step outs than conventional Ethernet, via a conversion of the electrical Ethernet signal to an optical Ethernet signal and then back to an electrical Ethernet signal (E/O/E). A representation for this prototype jumper system is shown in Figure 4 below.

The prototype jumper included a 137 m segment of electrical/optical hybrid cable, and 8 meter segments for pressure-balanced, oil-filled (PBOF) hose containing electrical wiring (153 meters total length). The length of the hybrid cable could have easily been 10 km or greater, the 137 meters was chosen for testing logistics. In fact, once the jumper test was completed, the hybrid cable was replaced with a 25 km spool of optical fiber. The system demonstrated proper function in a bench top test with the fiber spool present. An electrical/optical hybrid cable was used in order to pass higher power electricity through the jumper along with the Ethernet signal. During this test 110 VAC, 5 amps of power were passed through the jumper. Gigabit Ethernet was presented to the electrical wet-mate connector on one end, transmitted through the PBOF into the Electro-optic media converter and

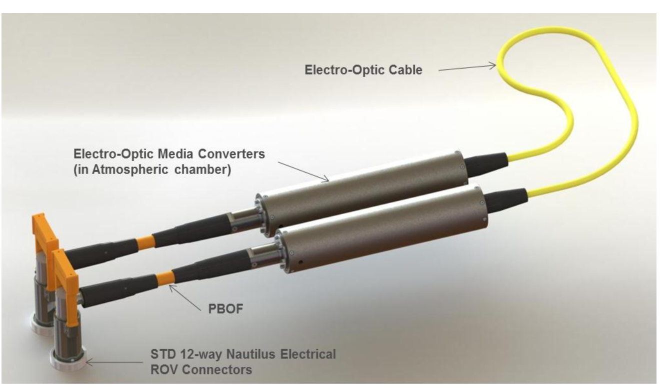

Fig. 4. Prototype of Dual Media Converter Flying Lead

then passed optically through the hybrid cable. This optical signal was converted back to electrical Ethernet on the opposite side, by a second media converter. This electrical signal was then passed through the second PBOF section to the second wet-mate connector. During prototype testing, Gigabit Ethernet was passed along with power in the jumper at 1000 psi and 10 °C. A total of four terabytes of data were transmitted during the test, error free. The figure below shows a representation of the prototype jumper. This was the first truly Active Flying Lead built and tested by Teledyne Oil & Gas.

B. Case Study 2

During system integration testing by a client, it was found that the new generation Multi-Phase Flow Meter (MPFM) would fail to function with the existing system configuration. It was then determined that the MPFM needed a 5 volt line operate properly. As this was found during the final stages of testing, there was very limited time available to redesign the Meter. This gave Teledyne Oil & Gas the opportunity to develop and produce a solution in just a few months. As the requirement for this was well defined, the component selection for the board was quick. With limited components needed, a complete board was designed in 2 weeks. The project depth requirement for this job was relatively shallow and allowed TOG to use standard Nautilus components that were already qualified. Through some simple modifications the project team was able to transform an existing design for an atmospheric housing into an atmospheric housing with circuit board mount. Once the design was finalized, it was tested and qualified within 3 months. The production units were completed just in time for deployments and kept the project on schedule.

This development showcases Teledyne's ability to quickly react to customer's needs and shows that integrated electronics are a viable solution to many challenges. This approach provided the lowest cost and quickest turnaround compared to all other solutions. It also provided a strong building block for future projects.

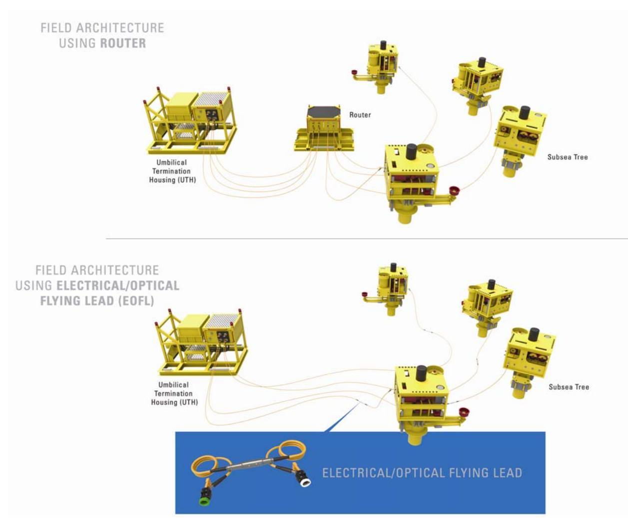

Fig. 5. Architectual change enabled by EOFL Development

C. Case Study 3

As the methods and means of communication from systems and subsea equipment continue to evolve, new and unique product technologies are needed to provide effective solutions. Teledyne has previously introduced solutions that extend Ethernet reach with use of repeaters integrated into the cable end connector, or flying lead, to significantly increase the limits of Ethernet transmission between subsea instruments. The client, a major Oil & Gas operator, required greater field architecture flexibility and a reduction in complexity to reduce total installation costs for a subsea field layout in the Gulf of Mexico. The client approached Teledyne Oil & Gas to develop a new product within the Active Flying Lead product line. The challenge, in this case, was to create a media converter that was compatible with multiple systems and can be contained in a small environment.

The Teledyne Oil & Gas technical team designed and qualified an Electrical Ethernet to Optical Flying Lead, which converts a fiber optic signal through a Nautilus Rolling Seal Hybrid connector fiber optic wet-mate connector and produces an electrical Ethernet signal through a 12-way Nautilus electrical connector on the other end. The EOFL allows up to one Gigabit per second data speeds over four twisted pairs to be converted to one single fiber. The conversion from optical to electrical is accomplished in a compact 1-atmosphere internal pressure chamber that is rated to an exposure of up to 10,000 psi external pressure. The circuit boards inside the chamber have been subjected to Accelerated Life Testing (test to failure) to validate the projected life expectancy.

The client considered the EOFL solution an optimal solution, even prior to qualification completion. After qualification and analysis, it was found that the concept did indeed change the field architecture and allowed for a total installed cost reduction.

The EOFL solution results in a simplified architecture, reducing the amount of complex equipment needed to complete the field. Having the technology capability of developing, packaging and qualifying various communications circuitry in a compact atmospheric canister has opened the door to the next evolution in subsea communication and a new class of products. Teledyne Oil & Gas retains the industry expertise to develop a total solution for subsea electronics integration and conversion to ensure that operators are preparing their subsea fields for the technologies that will arrive as future developments.

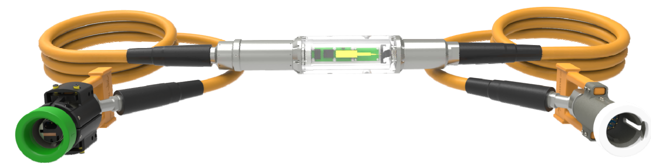

Fig. 6. Electrical/Optical Flying Lead (EOFL)

III. Industry Benefits

Active flying lead platforms, both qualified and under development, provide a foundation for the advancement of communication tools needed for the future of Oceanographic research. While the previous case studies focus on oil and gas issues, the oceanographic community can greatly benefit from the investments made in these adjacent applications. The needs of both industries are very similar. One could argue that the need for data is even larger for the oceanographic industry and that high reliability, cost controlled options are also very important.

The Active Flying Lead products are organized into three specific classes of functionality offering multiple options for design gains:

- Active Flying Lead Extenders
- Active Flying Lead Converters
- Active Flying Lead Select

A. Active Flying Lead Extenders

AFL Extenders lengthen the reach of traditional flying leads with qualified integrated circuitry packaged in one or more atmospheric pressure canisters installed in-line with the PBOF hose. The first practical application was an Extended Ethernet Flying Lead, designed as a subsea repeater system to extend the operating range of a subsea Ethernet flying lead beyond the conventional 100 meter distance limit. The E^2FL designs are can also capable of transmitting power over Ethernet if required. This concept can be utilized with several other communication protocols. Ethernet is one of the most used communications protocols used in the oceanographic industry, the introduction of this repeater allows for experiments to be placed at medium distance from a node, (100-300 meters) without the large cost of integrating fiber optics.

B. Active Flying Lead Converters

AFL Converters offer a variety of electronic conversion options embedded into the qualified one atmosphere housing and integrated into the PBOF hose assembly. The capability of integrating ruggedized media converters and power converters into the flying lead allows for reduced complexity of field infrastructure and efficiencies in design for power and data transmission. Two practical illustrations of AFL Converter flying leads are the Electro-Optical Flying Lead and DC to DC power conversion flying lead (Fig 7). Both of these applications are directly applicable to the oceanographic industry. Many of the observatories currently in operation run on 400 VDC which allows for power to be transmitted long distances with limited line loss, however, most electronics do not operate on that high a voltage. This means at some point the voltage will need to be converted to match the equipment, currently handled by large bulky node. With an inline converter, this can be accomplished in proximity to the equipment, allowing for the right amount of power to be provided at longer distances than previously available. In some cases, multiple applications may need to be combined in one single flying lead. For instance, if a Fiber optic media converter is designed to run on 24 VDC but the only power available is 400 VDC, the solution is to add the DC to DC converter in line. The unit can convert fiber to electrical Ethernet and also provide the 400 VDC to the equipment.

C. *Active Flying Lead Select*

AFL Select allows other integrated electronics to provide functionality beyond communications and conversion. Examples of additional electronics options that can be introduced are thermistors, capacitors and resistors. The options are vast and based on utilizing the pre-qualified atmospheric housing designs and following the Teledyne Oil & Gas reliability qualification practices. Products in this category can solve several problems that may arise in a system. For instance, if the power line is too noisy for new equipment to operate, filters and surge protection can be added to the flying lead. New design opportunities are presenting themselves on a regular basis, and the options are relatively open to imagination. All these variations of the Active Flying Lead family can be combined and modified to provide a unique

Fig. 7. AFL Select

solution that can help to lower cost, complexity, and time to deployment all while increasing the reliability.

IV. Conclusion

The need for enhanced reliability, the ability to collect complete data and to confidently measure reliability is ever increasing. The introduction of Active Flying Leads provides a springboard towards solving future challenges in subsea data communication. As larger data transfers and longer distance requirements become the standard, it becomes paramount that operators, service companies, engineering organizations and technology suppliers work in symphony to develop the solutions to resolve tomorrow's challenges. Modern and emerging sensors and systems now demand greater data transmission capability in networking options. This trend will continue to grow in complexity as sensors and systems develop further. Subsea networks will, in turn, require modular connectivity using interconnect systems capable of supporting this high bandwidth availability. Just as sensors have become more reliable over time, interconnect systems have also evolved.

Active Flying Leads represent the innovative evolutionary technology of embedded functionality that allows for a change in field architecture design, lowering cost and increasing reliability while driving towards adopting industry standards in technology. A wide range of possibilities and custom functionality with Teledyne Oil & Gas reliability drives operational cost savings and lowers operational risk for the Ocean Science and Offshore Energy industries.