Extending Ethernet Reach for Instruments Used in Subsea Observatories

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***Abstract*— Due to the increased use of subsea instruments for scientific research that generate large quantities of data, higher data transmission bandwidths are a necessity for subsea communications in these systems. Furthermore, there is a desire to locate scientific equipment relatively far away from the node in order to minimize the influence of the disrupted environment to the measurement being investigated. Through the ODI product line, Teledyne has developed solutions for extending the reach of conventional electrical Ethernet, while maintaining an electrical Ethernet wet-mate interface to customer equipment. With these new technologies, Ethernet step outs of up to 10 km are achievable.**

Keywords*— *extended, Ethernet, communications, bandwidth

I. Introduction

Since 2005, Teledyne has offered subsea electrical Ethernet jumpers, utilizing terrestrial CAT-5e and CAT 6 cable within the pressure balanced oil filled (PBOF) hose. As the terrestrial cable is not optimized for this environment, the performance of the subsea jumper was limited to about 70 meters instead of the 100 meters that terrestrial cable is rated for. This de-rated performance was partially due to the characteristics of the cable itself in the subsea environment, coupled with a reduction in performance due to the inherent geometry of the electrical wet-mate connector. Ethernet wires require twisting for as long of a distance as possible to minimize cross talk in the system.

With subsea architectures moving towards electrical Ethernet as a standard for communications, providing Ethernet solutions in excess of the 70 meter benchmark is desired. In response to this industry need, solutions are being developed to extend the reach of Ethernet up to 10 kilometers. Point-to-point electrical Ethernet jumpers have been engineered to provide 100 meter capability. To address the range of 100 meters to 300 meters, an extended solution using integral signal repeaters has been developed and qualified for subsea use. For lengths in excess of 300 meters, a method of extending Ethernet utilizing electrical to optical conversion of the Ethernet signals integral to the electrical connector on either side of the jumper using robust subsea qualified components has been developed. These three technologies are highlighted in Figure 1.

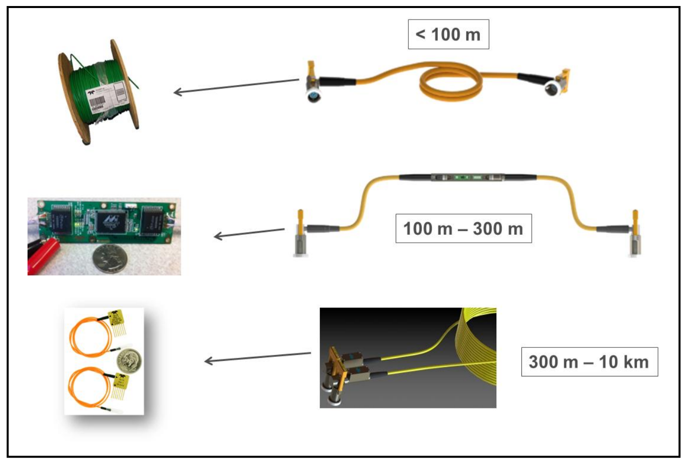


Fig. 1. Three technologies for Ethernet data transmission

These new approaches can save the costs associated with optical infrastructure in an electrical Ethernet based subsea architecture with long step outs to instruments, while enjoying the benefits of increased high bandwidth data transmission distances normally offered only by optical data transmission.

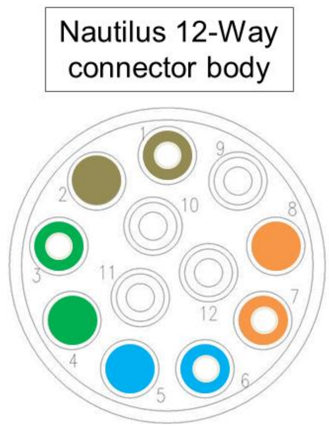
II. Lengthening Standard Ethernet to 100 Meters

In order to reach the 100 meter performance capability of Ethernet wiring, a custom cable was designed and constructed which is optimized for the subsea environment. Studies were also conducted to determine the optimum pin configuration at the wet-mate connector interface in order to minimize crosstalk at the connector. The result of this effort is a subsea rated Ethernet jumper which is capable of 100 meter performance with excellent conformance to ISO/IEC 11801 (IEEE 802.3) specifications. These Ethernet jumpers can also carry power capable of powering instruments (620 VAC/3 A) along with the communications signals.

In most cases for subsea Ethernet communications, either a single Ethernet 100 Mbps (4 wire – 2 twisted pair) channel is used for communications, or dual redundant Ethernet 100

Mbps channels are used. In the later scenario, the second Ethernet channel is used as a redundant backup to the first, thus both channels are not required to communicate simultaneously. In both of these cases, 100 meter jumpers have been developed with full conformance to the performance specified in ISO/IEC 11801 (IEEE 802.3).

In order to minimize the effects of crosstalk on Ethernet transmission, studies have been undertaken to determine the optimum wet-mate connector pin configurations in a 12-way connector. The optimal geometry for either single or dual channel Ethernet configurations is shown in Figure 2 below.



Connector Pins	Colors	Function
1 & 2	Brown/Brown-white	Eth Ch 1 (Tx +/-)
5 & 6	Blue/Blue-white	Eth Ch 1 (Rx +/-)
3 & 4	Green/Green-white	Eth Ch 2 (Tx +/-)
7 & 8	Orange/Orange-white	Eth Ch 2 (Rx +/-)
9	NA	+ 24 VDC
10	NA	GND
11 & 12	NA	620 VAC

Fig. 2. 12-way pin configuration used for Ethernet jumper

It has been demonstrated that separating the Transmit (Tx) and Receive (Rx) pairs by a maximum amount in any one Ethernet channel reduces the crosstalk in that channel (for single channel transmission). In dual Ethernet channel configurations, the configuration above also provides the best crosstalk suppression for the matrix of crosstalk pairs.

III. 100 Meter Ethernet Jumper Testing Results

To date, several 100 meter Ethernet jumpers have been constructed and tested, all having similar performance which conforms to the ISO/IEC 11801 specification. These 100 meter jumpers have included both 12-way and 7-way Nautilus connectors. Qualification characterization testing included pressure application at 5000 psi while passing a single channel 100 Mbps Ethernet signal and an applied electrical power signal of 620 VAC and 3 A. The performance of the jumper was measured with a Fluke Cable Analyzer to ensure conformance to the ISO/IEC 11801 specification, but also Network Traffic was sent over the jumper using a SmartBits Analyzer. The network traffic test result demonstrated no frame errors (1 frame = 1024 bits) measured during the testing with the SmartBits and cable analysis conformance to the ISO/IEEE 11801 specification. Characteristic attenuation and crosstalk data obtained for a 100 meter Ethernet jumper is demonstrated in Figure 3.

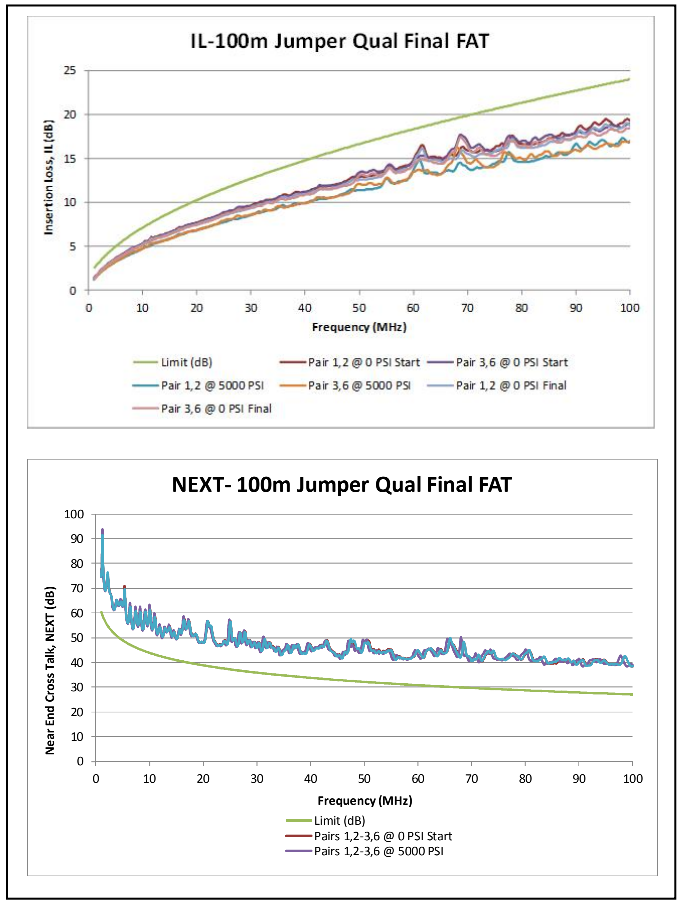


Fig. 3. Typical results for attenuation and crosstalk for a 100 meter Ethernet jumper, measured against specification limits set forth in ISO/IEC 11801

Further qualification testing to the 100 meter Ethernet jumpers included the following:

- Short term flooded back shell test – operation under pressure while back shell was flooded with seawater.
- Thermal cycling test – 5° C to + 60° C – monitored during the test to ensure no frame errors in network traffic and conformance to the ISO/IEC 11801 cable analysis specifications
- Jumper pull test (to simulate deployment loads) – applied 500 pound load to jumper – measured conformance to ISO/IEC 11801 specification before, during and after testing
- Jumper handling test – managed jumper on Figure 8 fixture at minimum hose bend radius. Measured

conformance to ISO/IEC 11801 specification before, during and after testing

- Mechanical shock and vibration testing – all three axes.
- Performed 5000 psi pressure test following shock and vibration test to ensure conformance to ISO/IEC 11801 specification at the conclusion of all testing.

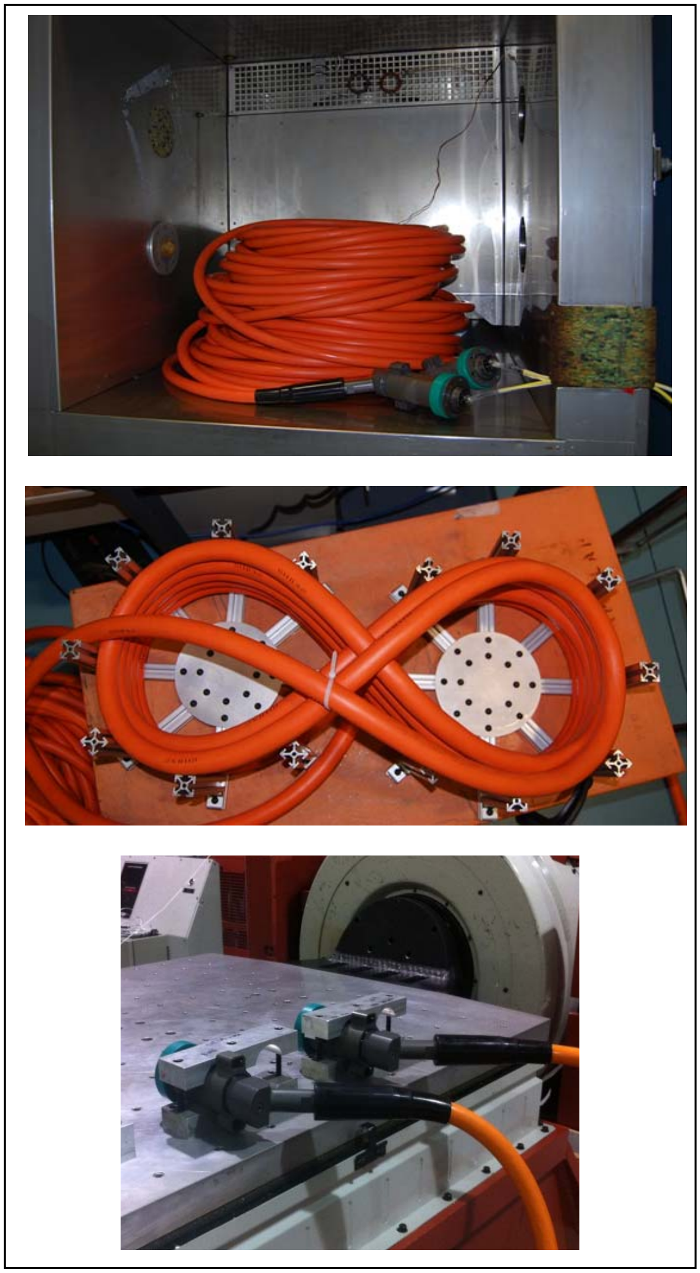


Fig. 4. 100 meter Ethernet jumper during Thermal testing (top), minimum bend radius testing (middle) and shock and vibration testing (bottom)

The testing as outlined above is focused on the interaction of the cable inside of the jumper, and Ethernet performance of the jumper under pressure.

IV. EXTENDING ETHERNET TO 300 METERS

In order to reach out beyond 100 meters with an electrical Ethernet solution, the Ethernet signal requires repeating in intervals not exceeding 100 meters each. This has been accomplished by design in the E^{2}FL – 300 (E^{2}FL = Extended Ethernet Flying Lead). The design utilizes a PBOF hose jumper, having integral electrical repeaters to receive and re-transmit the Ethernet signal over the next segment of cable within the PBOF hose. The design is offered with one repeater or two in a jumper. A single repeater system has a maximum length of 200 meters, while the dual repeater system has a maximum length of 300 meters.

During the assembly process, each 100 meter wire segment is tested with a Cable Analyzer to ensure conformance to ISO/IEC 11801 prior to integration within the PBOF hose assembly and integrating the repeaters. Once the jumper is fully assembled, a Cable Analyzer test is no longer possible due to the presence of the repeaters. The Cable Analyzer can only measure cables that are point-to-point, without any additional electronics present. Therefore, the constructed jumper is instead tested via network traffic testing for bit or frame error rate.

The E^{2}FL – 300 assembly supports 10/100 Mbps Ethernet protocols, the jumper is designed to carry a single Ethernet channel (2 twisted pairs). However, 1 Gbps data rates can also be supported. Each repeater board has a power requirement for 24 VDC and 2 Watts of power. The circuitry is designed such that the 24 VDC signal can be provided from one or both ends of the jumper to power the repeaters. The jumper also has the capability to pass higher voltage power (620 VAC, 3 A) while transmitting Ethernet signals.

The circuit boards used in the E^{2}FL – 300 jumper (power conversion board and repeater board) have been qualified to ISO 13628-6:2006 Q1 and Q2 testing prior to jumper level qualification. This testing included mechanical shock and vibration testing and temperature soak testing as outlined in the ISO 13628-6:2006 specification. Q1 testing is a test sequence that is performed at the circuit board level, while Q2 testing scrutinizes the circuit boards in their assembled package. The flowchart for both Q1 and Q2 testing is shown in Figure 5.

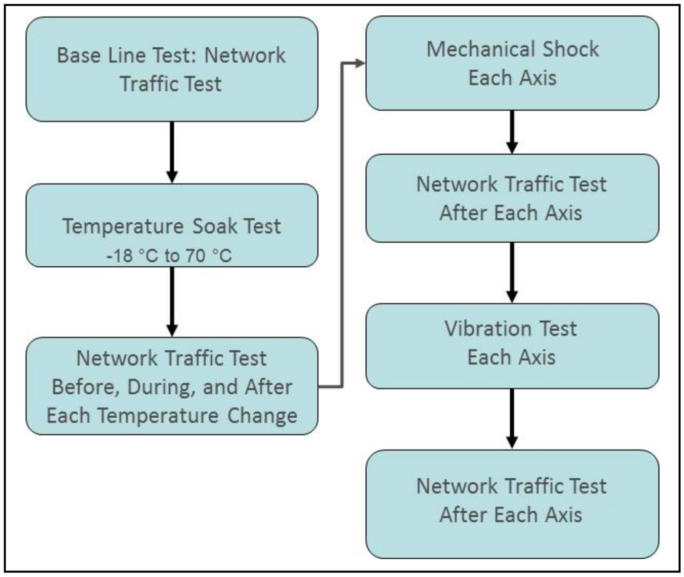


Fig. 5. ISO 13628-6:2006 as applied to E^2FL – 300 circuit boards

To ensure the reliability of the circuit boards used in the E^2FL – 300 jumper to a 30 year life, a reliability test plan has been developed for these circuit boards. The ALT (accelerated life testing) at the circuit board level entails subjecting 5 each of the circuit boards to long durations at three different elevated temperatures (15 circuit boards total at 55, 70 and 85 °C). Information regarding failures of these boards at the elevated temperatures will be used to determine the expected lifetime at the use condition temperature. Even with no failures, life models exist to estimate lifetime at lower temperatures. If any failures are witnessed during this testing, the model shown below in Figure 6 is employed. After spending 3000+ hours at each temperature, no boards had yet failed. At that point, the circuit boards subjected to 55 °C conditioning were elevated in temperature to 95 °C. The circuit boards at 70 and 85 °C continued to be tested at those temperatures. To date, all circuit boards have accumulated over 4000 hours with no failures. The boards at 95 °C have now logged over 1000 hours at with no failures.

In addition to this accelerated aging of the boards, jumper level ALT will be conducted on two jumpers for a period of 14 weeks at 70 °C, simulating 30 years at 2 °C. These jumpers will be removed periodically for inspection and functionality determination.

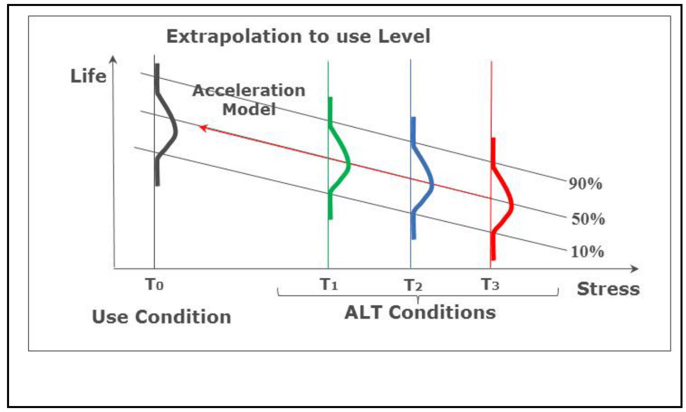


Fig. 6. Accelerated Life Modelling of Circuit Boards (E^2FL – 300 reliability testing)

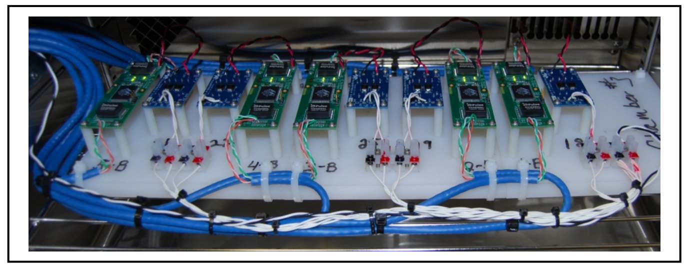


Fig. 7. ALT setup for circuit board testing at each exposure temperature

V. EXTEDNED ETHERNET DUAL MEDIA CONVERTER DEVELOPMENT PROJECT

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 8.

The prototype jumper included a 137 m segment of electrical/optical hybrid cable, and 8 meter segments for 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 A power was 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 then passed optically through the hybrid cable. This optical signal was converted back to electrical Gigabit 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 4 Tb of data was transmitted during the test, error free. Figure 9 below shows a representation of the prototype jumper.

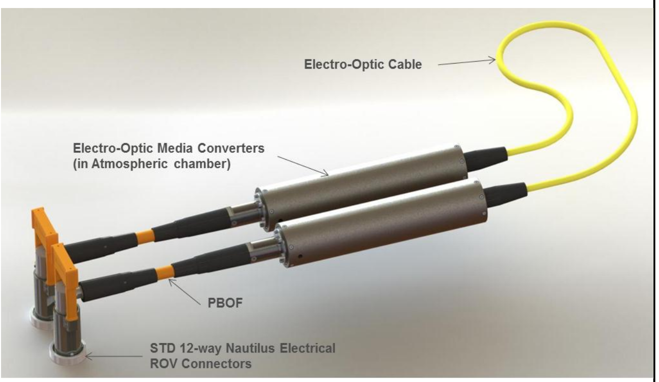


Fig. 8. Prototype of Dual media Converter jumper assembly

Fig. 9. Prototype of Dual media Converter jumper assembly

This prototype work helped to focus the development of the E/O media converter based version of the E^{2}FL – 10 k into a jumper design that is more deployment friendly.

VI. EXTENDING ETHERNET TO 10 KM

The prototype design that included the Electro-optic media converter has been redesigned to integrate the electronic housings onto each connector as shown in Figure 10. The E/O conversion now occurs in an atmospheric chamber in the back shell of the wet-mate connector. Also, in the compact package there exists a hybrid field assembled cable termination (FACT). This small form factor package has been designed to be managed readily via ROV, and does not contain the large canisters that the prototype design employed.

In this design, the choice of utilization of an optical or hybrid cable is dependent on whether low voltage DC power (5-48 VDC) for the media converters is available on only one or both sides of the jumper, and whether higher power (up to 620 VAC/3A) is required to be transmitted over the cable along with the optical Ethernet signal. Hybrid cables are significantly more expensive than optical only cables, but offer more capability in the jumper.

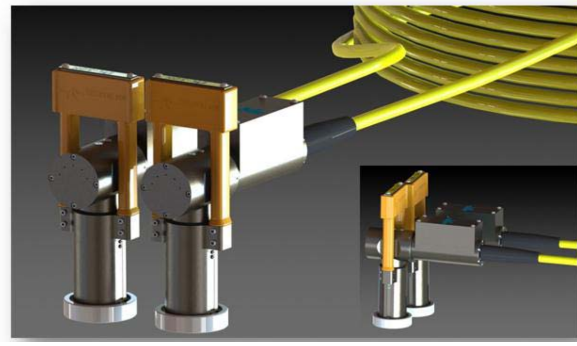


Fig. 10. E^{2}FL – 10k jumper assembly

The media converters used are miniature single mode transceivers, originally developed for aerospace use – requiring very high reliability. Additional reliability testing will be performed on these assemblies as the design progresses. Qualification testing of the E^{2}FL – 10 k design is planned for mid-2014.

VII. SUMMARY

Teledyne has developed solutions for extending the reach of conventional electrical Ethernet, while maintaining an electrical Ethernet wet-mate interface to customer equipment. With the new technologies, Ethernet step outs of up to 10 km are achievable. These new approaches can save the end user from having to include both electrical and optical control modules in their Ethernet based subsea architecture, while enjoying the benefits of increased high bandwidth data transmission distances normally offered only by optical data transmission.

The extended Ethernet solutions can be a cost effective alternative to optical data transmission, providing longer step outs than standard electrical Ethernet can provide. The offering for extended Ethernet now includes three options:

1) Up to 100 meter jumpers using point-to-point electrical Ethernet jumpers
2) For 100 meters up to 300 meter jumpers using integrated repeaters in PBOF jumper assemblies
3) From 300 meters up to 10 km jumpers using E/O converters to transmit optically but maintaining the electrical interface to customer equipment

These three options create methods to locate experimental subsea equipment far away from the node, thereby decreasing the influence of the node on the experiment.