Current and Future Wet-Mate Connector Technology Developments for Scientific Seabed Observatory Applications

Howard Painter
John Flynn
Ocean Design, Inc. (ODI)
1026 North Williamson Blvd
Daytona Beach, FL 32114 USA

***Abstract* - This paper will review wet-mate connector technologies being deployed by current cabled seabed observatory projects as well as look forward to technologies under development to further enable connectivity of observatories. The goals of these new technologies include increasing bandwidth, system voltage and operating depth as well as reducing complexity.**

Wet-mate connector technology has been an essential enabling technology for the establishment of permanent cabled seabed observatories. Projects such as MARS (Monterey Accelerated Research System), VENUS (Victoria Experimental Network Under the Sea), ALOHA (A Long-term Oligotrophic Habitat Assessment) and NEPTUNE (North-East Experimental Network Under the Sea) are using a range of technologies and system architectures to meet the specific project requirements and constraints. Wet-mate connectors provide subsea serviceable connections between the backbone cable-to-shore and the observatory or node. At the node, wet-mate connectors allow for the regular interchange of scientific packages. This paper will provide a summary of the connector technologies used in the observatories mentioned above. This includes the unique development of a high voltage (10 kVDC) connector, adaptation of the standard Nautilus connector to transmit 100Base-T Ethernet and development of a compact medium voltage hybrid electric/optic connection system for deployment in >5,000 meters of water.

There are several technologies under development that can further enable connectivity of an observatory.

High Circuit Density Wet-Mate Optical Connector - The next generation of the I-CONN wet-mateable optical connector will support 12 and 24 circuits in a single, compact connector. This will enable greater bandwidth at a reduced cost per circuit. This increase in available circuits has the potential of enabling the use of passive optical devices that are being developed by other subsea industries.

1000Base-T Ethernet Capable Connectors - The development of connectors and their associated components continues to be driven by the requirements for greater bandwidth. Based on the experience gained in developing the 100Base-T systems, a design for a 1000Base-T system is currently under evaluation. This technology would facilitate the local deployment at the node of instruments such as high-definition TV without the need for dedicated fiber-optic connectors. It could also be used in conjunction with electric-to-optical converters and optical cables to provide long extensions from a node to smaller science experiment clusters.

Medium Voltage Nautilus - The development of high-power and high voltage connectors continues, with rising multi-industry demands for increased currents and voltages. Higher voltage ratings on standard Nautilus connectors will allow for longer cables and greater power delivery for systems using a simplified architecture such as employed on VENUS and ALOHA. This would eliminate the need for more complex power conversion systems in the node and the associated high voltage connection systems.

I. Introduction

Permanent cabled seabed observatories currently under development offer the revolutionary advantages of providing continuous real-time scientific data directly to shore and the ability to interchange experimental packages remotely. The system typically consists of a shore station, backbone cable, subsea node and individual science experiments. Wet-mateable connectors are essential for installation, maintenance and reconfiguration of components of the systems.

The shore station is the termination point of the backbone cable. It provides a network control center, data management and archiving system as well as connection with the Internet. The Internet connection allows the science investigator to access the experiments from their desk tops.

The backbone cable provides electrical power and high bandwidth optical communication to the node. At the subsea termination of the backbone cable, the optical and electrical elements are separated into optical and electrical jumpers with wet-mateable connectors. The electrical jumpers provide power up to 10 kVDC while the optical jumper transmits data up to 20 gigabit per second. Remotely operated vehicles (ROVs) are used to connect the jumpers from the cable to the node.

The node converts the high voltage to low voltage for powering the node electronics and science ports. The optical signal is converted to 100 Base-T Ethernet signal. The node's science ports consist of electrical wet-mate connection ports with combined Ethernet and low voltage power.

1-4244-0115-1/06/$20.00 ©2006 IEEE

The retrievable experiment packages are connected to the node by jumpers of up to 70 meters in length. There can be multiple instruments on each experimental package.

This paper will review the various approaches to seabed observatories and connection solutions required. The paper will also review enabling technologies currently under development.

II. System Architecture and connections system

The observatories distance from shore, water depth, data rates and installation scenarios all impact the final system architecture and connection system required. The following sections will describe the observatories under development and the associated connection solutions.

A. VENUS

University of Victoria's VENUS (Victoria Experimental Network Under the Sea) project located off of Vancouver is the first operational cable observatory using optical communications and wet-mateable connectivity. The maximum water depth is 400 meters and is located near shore allowing use of a low voltage power system.

The construction of the backbone cable that provides DC power and optical signal to the node is shown in Fig. 1. The backbone cable is terminated on the node base then distributed by jumpers consisting of penetrators connected via fluid-filled to a wet-mateable Nautilus connector and a Rolling-Seal optical connector as shown in Fig. 2. The retrievable node is installed on the node base prior to installation as shown in Fig. 3. The science ports, also seen in Fig. 3, provide power and Ethernet to the Science Instrument Interface Module (SIIM).

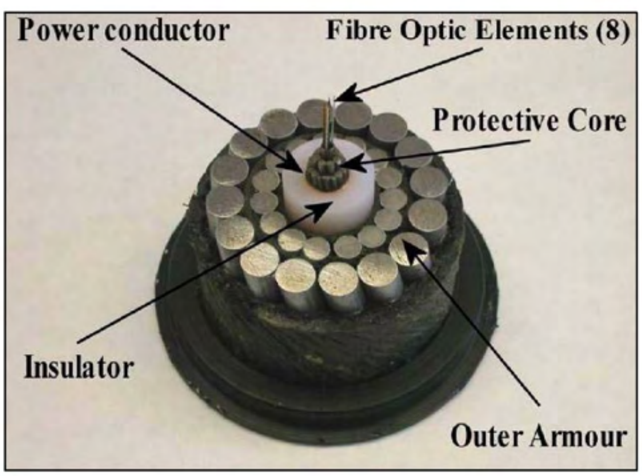

Figure 1. VENUS backbone cable provides DC power and optical communications to the node.

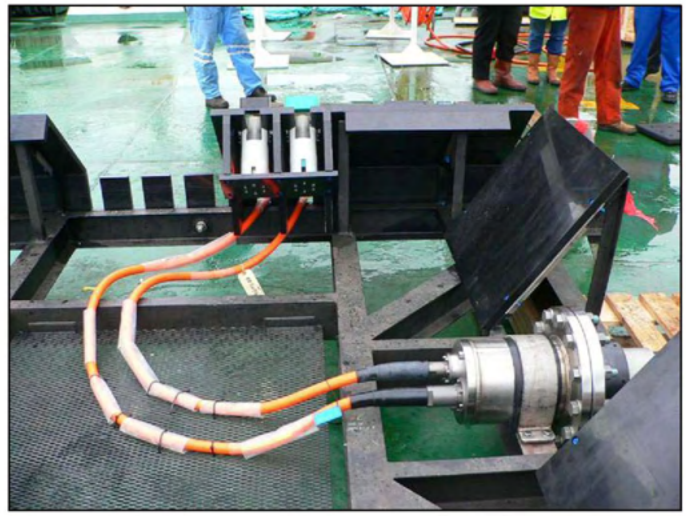

Figure 2. VENUS node base with cable terminated to optical and electrical flying ROV jumpers.

The SIIM is a retrievable multiple instrument platform deployed near the node and connected to the node by an ROV using a 70 meter jumper. The jumper consists of a flying ROV operated connector and a penetrator that is installed on the SIIM's electronic housing. Fig. 4 shows the deployment of SIIM.

The low-voltage system used on VENUS allowed for use of standard Nautilus connector for powering the node. A twelve-circuit Nautilus based jumper also provides Ethernet communication and power to the SIIM. Table 1 highlights the performance characteristics for the Nautilus connector. The Ethernet capabilities of the connector were originally developed for the MARS observatory. Reference [1] provides further details on the design and qualification of the connector's Ethernet capabilities.

Figure 3. VENUS node installed on node base showing power input, signal input and four science ports.

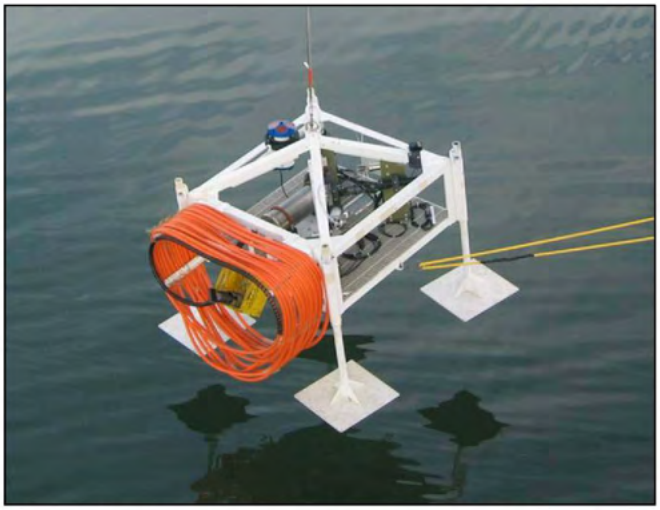

Figure 4. VENUS SIIM being deployed with coiled ROV jumper for connection to the node.

TABLE 1

PERFORMANCE CHARACTERISTICS OF THE NAUTILUS WET-MATE CONNECTOR

Operating Voltages (U_0)	1.8 kVAC or 3.3 kVDC
Amperage	30 Amps per Circuit
Number of Circuits	4,7,12
Contact Resistance	$\leq$ 0.1 Ohms per Circuit
Insulation Resistance	$\geq$ 10 Gigaohms @ 1kVDC
Operating Temperature	0 ^{0} Celsius – 50 ^{0} Celsius
Mate Life	>1000 Mates
Mate Force	$\leq$ 6 lbs per Circuit
Design Life	25 Years
Transmissivity	10/100BaseT CAT5e
Maximum Ethernet Length	~70 Meters

The optical connection from the backbone cable to the base is provided by Rolling-Seal optical connectors that were developed to provide high bandwidth, noise immune optical connections [2]. The Rolling-Seal connector supports up to 8 circuits comprised of either multi-mode or single-mode fiber-optic and/or electric. Table 2 highlights the performance characteristics of the Rolling-Seal connector shown in Fig. 5.

B. ALOHA

The University of Hawaii's ALOHA (A Long-term Oligotrophic Habitat Assessment) observatory is the deepest subsea observatory under development. It is located in 5200 meters of water 100 km north of Oahu. The system utilizes an existing telecommunication line that is no longer in service. The system architecture is similar to VENUS with respect to the nodes functions and science ports.

TABLE 2

PERFORMANCE CHARACTERISTICS OF THE ROLLING-SEAL CONNECTOR

Insertion Loss	$\leq$0.50 dB @1550 nanometers
Return Loss	$\leq$-30.0 dB @1550nanometers
Number of Circuits	8
Operating Temperature	0 ^{0} Celsius – 50 ^{0} Celsius
Mate Life	100 Mates
Mate/De-Mate Force	$\leq$ 80 pounds
Design Life	25 Years

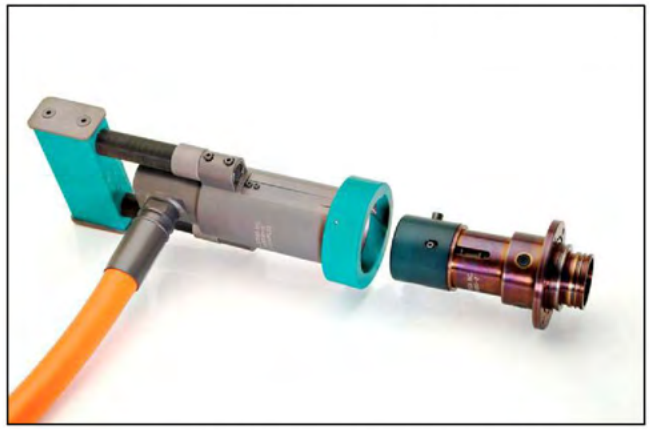

Figure 5. ROV operated Rolling-Seal connector.

From the backbone cable to the node, the 1,800 VDC electrical power and optical signal are combined into one connector. This connector is the Nautilus Rolling-Seal Hybrid (NRH). The NRH connector is a combination of the Nautilus connector and the Rolling-Seal connector providing up to 4 circuits of either multi-mode fiber, single-mode fiber or electrical circuits, as well as two 3 kilowatt electrical power circuits for a total of 6 circuits. Table 3 highlights the performance characteristic of the NRH connector shown in Fig. 6.

TABLE 3

PERFORMANCE CHARACTERISTICS OF THE NAUTILUS ROLLING-SEAL HYBRID (NRH) CONNECTOR

Operating Voltages (U_0)	1.8 kVAC & 3.3 kVDC for Nautilus 700 VAC & 1,000 VDC (Mated) for Rolling-Seal
Amperage	30 Amps per Nautilus Circuit 8 Amps per Rolling-Seal Circuit
Number of Circuits	2 Nautilus, 4 Rolling-Seal
Insulation Resistance	$\geq$ 10 Gigaohms @ 1kVDC
Insertion Loss	$\leq$0.50 dB @1550nm
Return Loss	$\leq$-30.0 dB @1550nm
Operating Temperature	0 ^{0} Celcius – 50 ^{0} Celsius
Mate Life	100 Mates

Figure 6. ROV operated NRH connector.

For the ALOHA project, the power from the backbone cable is carried through one of the power circuits and a sea earth return was used on the node. The four optical circuits were populated for primary TX and RX with a set of spares.

C. MARS

The Monterey Bay Aquatic Research Institutes (MBARI) MARS observatory (Monterey Accelerated Research System) is an experimental test bed for the development of cable observatory technology and science experiments.

The observatory is located in 1,300 meters of water 51 KM from shore in Monterey Bay, California. This distance of the offset and the development nature of the project led to the requirement for a 10 kVDC wet-mateable connector. To achieve this voltage rating, a larger Nautilus HP, originally developed for subsea pumping and renewable energy application, was adapted and qualified. Table 4 highlights the performance characteristic of the Nautilus HP connector.

The original development of both the Ethernet and high-voltage connectors was a cooperative effort between MBARI and Woods Hole Oceanographic Institute (WHOI), Alcatel Submarine Networks, Natronix/MariPro and ODI as described further in [1] & [3]. Reference [4] provides a discussion of the qualification testing conducted to verify the ability to meet the 25 year design life.

D. NEPTUNE

University of Victoria's NEPTUNE (North-East Experimental Network Under the Sea) is located off the coast of British Columbia in water depths up to 3,500 meters. The world's first regional cabled scientific observatory is the largest subsea network currently in development, with over 700 kilometers of electro-optical cable covering more than 12,000 square kilometers, supporting up to 10 separate nodes and 50 individual stations with 20 gigabit/second communication speeds from dual shore stations. This observatory will also use the system pioneered by the MARS observatory to supply high-voltage DC power and Ethernet-based communications architecture. In addition, hybrid extension ports based the NRH connector and penetrator technology developed for ALOHA will be used on the primary node. Smaller extension cable will then connect the node to primary junction boxes several kilometers away at scientific points of interest.

TABLE 4

PERFORMANCE CHARACTERISTICS OF THE NAUTILUS HP CONNECTOR

Operating Voltages (U_0)	5.0kVAC/ 10kVDC
Amperage	200 Amps
Number of Circuits	4
Insulation Resistance	≥ 10 Gigaohms @ 5kVDC
Leakage Current	≤ 50 nanoAmps
Partial Discharge	≤ 10 picoColumbs @ 7kVAC
Operating Temperature	0 ^{0}Celcius – 50 ^{0}Celcius
Mate Life	100 Mates
Mate/De-Mate Force	≤ 100 pounds
Design Life	25 Years

III. FUTURE CONNECTOR TECHNOLOGY

There are several technologies under development that will further enable the connectivity of future observatories.

A. High Circuit Density

The next generation of the I-CONN wet-mateable optical connector will support 12 and 24 circuits in a single, compact connector. This will enable greater bandwidth at a reduced cost per circuit for distribution networks. This increase in available circuits also has the potential of enabling the use of passive optical devices that are being developed by other subsea industries or low power science experiments using batteries.

The multi-way I-CONN is based on the 2-circuit I-CONN shown in Fig. 7. The addition of a multi-contact ferrule provides the ability to package 12 or 24 fiber connection within the same space envelope.

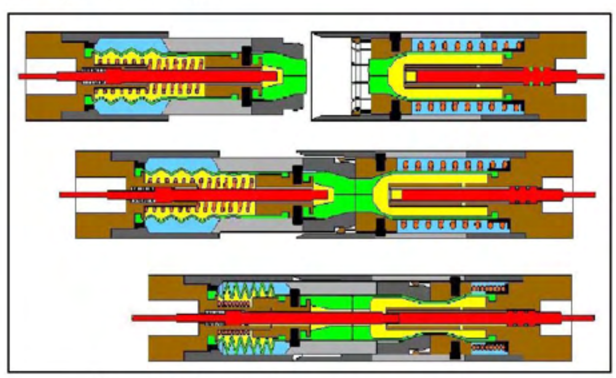

Figure 7. 2-Circuit I-Conn connector operations

Results from prototype testing indicate optical performance and repeatability are comparable to the current generation of optical connectors. Table 5 highlights the design characteristics of the multi-way I-CONN. Figure 8 shows a solid model of the connector.

B. 1000Base-T Ethernet Capable Connectors

The development of connectors and their associated components continues to be driven by the requirements for greater bandwidth. Based on the experience gained in developing the 100Base-T systems, a design for a 1000Base-T system is currently under evaluation. This technology would facilitate the local deployment at the node of instruments such as high-definition TV without the need for dedicated fiber- optic connectors. It could also be used in conjunction with electric-to-optical converters and optical cables to provide long extensions from a node to smaller science experiment clusters.

The goal of this development is to provide performance characteristic of the current generation Ethernet connector referenced above with an upgrade to 1000Base-T and harnesses assemblies with penetrators rated to greater than 3,500 meters of water. Qualification is scheduled to begin in Q1 of 2007.

TABLE 5

DESIGN CHARACTERISTICS OF MULTI-WAY I-CONN CONNECTOR

Insertion Loss	$\leq$0.50 dB @1550 nanometers
Return Loss	$\leq$-50.0 dB @1550nanometers
Number of Circuits	12-24
Operating Temperature	0^{0} Celsius – 50^{0} Celsius
Mate Life	100 Mates
Mate/De-Mate Force	$\leq$ 80 pounds
Design Life	25 Years

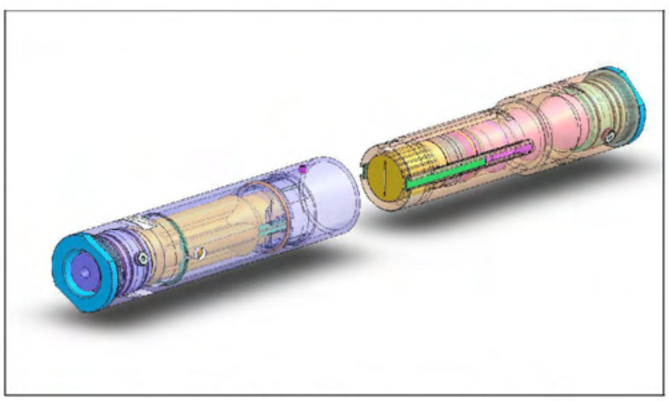

Figure 8 Multi-Way I-Conn connector solid model

TABLE 6

DESIGN CHARACTERISTICS OF THE MEDIUM VOLTAGE NAUTILUS WET-MATE CONNECTOR

Operating Voltages (U_0)	3.6 kVAC or 7.2 kVDC
Amperage	30 Amps per Circuit
Number of Circuits	4
Contact Resistance	$\leq$ 0.1 Ohms per Circuit
Insulation Resistance	$\geq$ 10 Gigaohms @ 1kVDC
Operating Temperature	0^{0} Celsius – 50^{0} Celsius
Mate Life	>1000 Mates
Mate Force	$\leq$ 6 lbs per Circuit
Design Life	25 Years

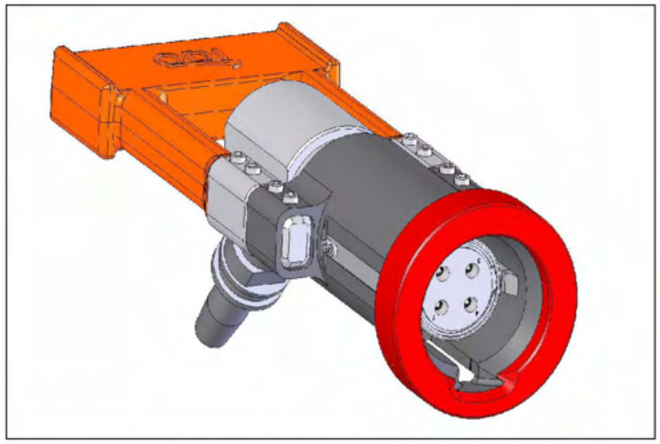

Figure 9 Nautilus Medium Voltage Solid Model

C. The development Medium Voltage Nautilus

The development of high-power and high voltage connectors continues, with rising multi-industry demands for increased currents and voltages. A medium voltage rating on standard Nautilus connectors allows for longer offset and greater power delivery for systems using a simplified architecture such as employed on VENUS and ALOHA. This would eliminate the need for more complex power conversion systems in the node and the associated high voltage connection systems.

The medium voltage Nautilus connector is actively being developed with funding from the subsea energy industry. The goal is to provide a cost-effective connector based primarily on standard high volume Nautilus components. Table 6 highlights the design characteristics of the medium voltage Nautilus connector. Figure 9 shows a solid model of the cable-end half of the connector.

IV. Conclusion

Wet-mate connector technology has become an integral part of the modern subsea observatory. This enables a system maintainable by an ROV, capable of high bandwidth transmissions and able to deliver a large amount of power to individual system components.

The Nautilus electrical connector, as well as the Rolling-Seal optical connectors, will enable scientists to gather reliable, accurate data on ocean events from the comfort of labs around the world. New enabling developments in connector technology will facilitate more creative solutions to future observatory architectures.

Acknowledgements

The photographs of the VENUS node shown in this paper are courtesy of the University of Victoria.

References

[1] S. Lerner, P. Fischer-Carne, A. Maffei, A. Round, F. Sonnichsen, "A Need for Underwater Ethernet Standards and Practices." IEEE Fourth International Workshop on Scientific Use of Submarine Cables and Related Technologies," 2006.

[2] J. Cairns, "Hybrid Wet-Mate Connectors: Writing the Next Chapter," Sea Technology Magazine, July 1997.

[3] S. Barlow, J. Flynn, W. Mudge, N. Shaheen, G. Waterworth, "The Evolution of ROV Wet-Mate Connecter Technology in Supplying High Bandwidth / High Power / Deep Water Solutions for the Scientific Ocean Observatory Market." IEEE Fourth International Workshop on Scientific Use of Submarine Cables and Related Technologies, 2006.

[4] G. Clark, H. Painter, P. Wright, "Subsea to Shore – Challenges and Solutions for Subsea Connections." Rio Oil & Gas Expo and Conference 2006 Annals, in press.