Enabling Technology: High Capacity Wet Mateable Optic Connection

Dave Jenkins, Matt Christiansen
SEACON Advanced Products, LLC
Bellville, Texas
djenkins@seaconworldwide.com, matt.christiansen@seacon-ap.com

***Abstract*— SEA CON® has raised the bar, with the recent introduction of a 8-48 channel Wet Mateable optic Connector (WMC). Based on the highly successful HydraLight wet mateable optic connector design, SEA CON's innovative design leverages the existing HydraLight components, and couples them with an existing multichannel insert, creating a high capacity, highly reliable optic wet mateable connector. This higher density WMC surely resets the bar for what is possible with undersea network architecture. The 24 channel version qualification is complete, with strong production interest from a number of market segments. This paper will provide a technical overview of this innovative product, and suggest possible applications. Key attributes include:**

- **Field proven sealing mechanism identical to the highly successful HydraLight design**
- **APC contacts, configurable up to a maximum of 48**
- **Combines HydraLight core design with multi-way insert from our successful G3 6 channel small form factor, wet mateable optic connector**
- **Synthetic mineral oil compensation fluid**
- **Fully compatible elastomers**
- **Oil filled and pressure balanced design**
- **Linear Latching and de-latching mechanism**
- **Standard SEACON® Precision MKII PBOF 13mm Hose interface**

This new product combines the highly desirable HydraLight wet mateable optic connector (over 3300 provided), with the multi-channel insert from our successful G3 downhole optical connector. A multi-channel optical insert allows each of the (up to) 8 HydraLight optical positions to be populated with a 6 way insert. This approach preserves the basic mechanics of the HydraLight, including the shells, seals and latching mechanism, and allows for a high density optical connection in a form factor identical to the current HydraLight connector. As is the case with the current HydraLight, the high capacity HydraLight can be equipped in either a ROV style, or a stab plate configuration. In addition, it may be configured with either oil filled hose, or hard cable.

This highly innovative new product will be introduced, characterized, and then examples of how it can be used in a number of system applications will be discussed. This high capacity optical WMC is a game changer, and has the ability to reshape what can and cannot be done with subsea optical connectivity.

I. Introduction

As anyone who has sat down and spent a few minutes trying to figure out how to bring two optical fibers together in the sea volume has discovered, the engineering challenge associated with the design of a wet mateable, optic connector is significant. While many novel designs have been tried, the major suppliers of wet mateable optic connectors have traditionally approached the mating of optical contacts subsea with a set of commercial optical contacts, packaged in two planar arrays. Joining the fiber pairs together has thus far been accomplished by joining the optical contact arrays using patented joined chamber technology, which effectively seals the coupled connectors together. This excludes debris during the fine alignment process, before opening up the oil filled interior to facilitate the coupling of the optical contacts in a benign, pressure balanced, and oil filled environment. Current contact transport mechanisms may differ somewhat from manufacturer to manufacturer, but the contact density is limited by the packaging of optical contacts in discrete fashion, all of which are brought together in the same contact plane.

While this approach can and does work, if the goal is to increase the capacity of the connector with additional optical circuits, a logical solution might be to grow this “contact mating plane” in diameter. This would result in an optical Wet Mateable Connector (WMC) of considerable size, in order to approach a contact density of say 36-48 channels. What has been done, is to step out of the box, change the paradigm, and incorporate a different, and highly innovative contact arrangement. This arrangement increases contact density in small groupings, while at the same time preserving the diameter of the basic WMC shell. This has the advantage of keeping the basic HydraLight shell size, sealing system, and latching mechanism (all of which are fully qualified) the same. This approach results in a WMC of the same form factor as the standard 8 channel, while offering up to 48 optical channels. As shown in Figure 1, and to readers familiar with the HydraLight WMC, the High Capacity WMC is identical in form factor to the HydraLight, with the exception of the header area, which now accommodate a greater number of exiting fibers [1].

Fig. 1. Upper Image: Standard 8 Channel HydraLight, and Lower Image: High Capacity (8-48 Channel) Wet Mateable Optic Connection, Showing Same Form Factor (Except for Headers)

The key enabling technology is a 6 Channel multi-way optical ferrule, with technology transferred from the G3. Additionally, the optical contacts utilized in this new technology are of the APC (Angled, Polished Contacts) design, which results in a significantly improved BR (Back Reflection) over contacts of a flat or domed polished design. Improved Back Reflection is a characteristic highly desired by the designers of distributed seabed sensing systems, which will be discussed below.

II. Brief History of Dry and Wet Mateable Subsea Connectors

Underwater cables have been in existence since at least the first successful transatlantic cable laying, in 1858. Subsea connectors appeared in the mid 1950's, driven by post war submarine technology needs, as well as an emerging offshore oil industry. Simple "dry mate" designs began to appear (connectors designed to be mated at the surface, and then taken subsea). These were of two basic types: rubber molded, interference-fit connectors with elastomeric bores that stretched and sealed over mating pins, and rigid-shell connectors whose mating parts sealed together via o-rings. Most of these early designs are still available today in roughly the same form factor.

In the early 1960's, electrical connectors designed for simple mating and demating underwater were introduced, and began to find their way into more complex system designs. Soon, designs were introduced that included oil filled and pressure balanced chambers, which greatly improved both functionality and reliability. As the advantages of fiber became known, subsea designers began thinking about how to package optical fiber in subsea systems, including long haul telecommunications systems. As system complexity grew, it became a further advantage to consider how one could assemble a complex, high bandwidth system on the seafloor. The advantages of subsea wet mateable optic connectivity then began to be incorporated in up front system design. In the 1990's, the first electrical wet mateable connectors appeared, followed within a few years by the first optical designs. SEA CON's® first foray into the wet mateable optic arena was with the HydraStar design. An improved, second generation design was introduced in 2000, called the HydraLight. Then, in response to market demand for a specialty down hole wet mateable optical connection, a highly innovative third generation design was introduced in 2010, called the G3. The G3 WMC is a low profile, 6 channel WMC for space restricted applications. Figure 2 illustrates the evolution of SEA CON® subsea connectors through to the latest optical design developments [2].

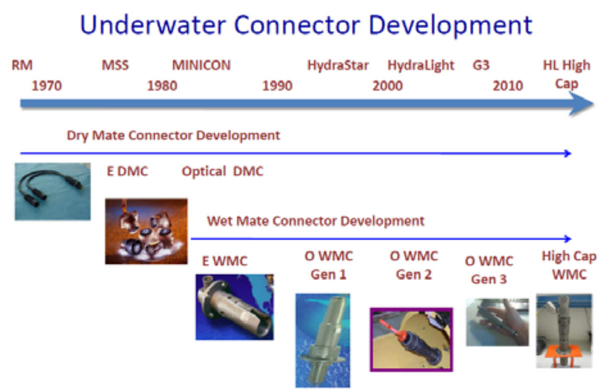

Fig. 2. SEA CON® Underwater Connector Development

In an attempt to visualize how additional optical capacity could be achieved with existing technologies, and not "reinventing the wheel", SEA CON® considered the combining of what is now the highly successful HydraLight wet mateable optical connector with the innovative, multi-way (6 channel) optical contact package of the G3 connector. This unique approach results in a high capacity optical connection, that utilizes the form factor, seals and latching mechanism of the now field proven HydraLight Wet Mateable Connector. This has created a High Capacity Optical WMC capable of up to 48 optical channels, depending on how many of the original optical pathways are configured with the multi-way contacts.

III. High Capacity (8-48 Channels) Optical Wet Mateable Connector

A. Based On Proven HydraLight Design

The design of this connector borrows from the field proven interface and seal design of the HydraLight 8 Channel Wet Mateable connector. Over 3300 HydraLight connectors have been delivered, with the basic HydraLight design fully qualified to a demanding Oil-Gas (Norsk Hydro) specification in 2000. Increased contact density is achieved by combining the basic HydraLight contact approach (with 8 nominal optic pathways) with the multi-way ferrule design (6 channels) from the G3 Downhole wet-mateable connector. Using a 6 channel multi-way ferrule on each of the 8 basic HydraLight optic pathways results in as many as 8 x 6 = 48 optic channels in the same form factor occupied by the base 8 channel HydraLight connector. This allows passing 48 wet mateable channels through one wet connection, where previously 6 connector sets would have been required.

Fig. 3. Base Design: HydraLight WMC Form Factor and G3 WMC (Source of Multi-way Insert)

B. Reduced Risk Approach

By using the field proven sealing and latching mechanism of the highly successful HydraLight design, a significant technology risk reduction is achieved. In addition, the contact insert from a separately qualified product (G3) is used as the optical contact package, a further reduction in risk. .

C. APC Contacts for High Performance

As this product development is intended to support distributed sensing systems, whose optical components rely on superior optical back reflection, Angled Polished Contacts (APC) are used. APC contacts use an angled surface to reduce reflection across the ferrule interface surfaces, thereby improving distributed sensing performance.

Fig. 4. Angled Polished Optical Contacts

D. Compatible Materials and Fluids

The main seawater wetted components are made from Titanium. Elastomers are made from fluorosilicone or nitrile rubber. Exterior facing seals are made from a fluorosilicone compound, which are compatible with the wide variety of the fluids found in oil gas applications. Utilizing further the advantages of a proven design, the high capacity connector uses the same high performance synthetic mineral oil compensation fluid, as is employed in the HydraLight connector. This fluid offers improved lubricity and compensation characteristics, as well as the appropriate index matching for optic performance.

E. Pressure Balanced and Oil filled (PBOF) Design

As is common for deep water electrical and optical connectors, this connector relies on pressure balanced, oil filled chambers to bring the contacts together and achieve the optical interface.

F. Proven HydraLight Latching and De-latching Mechanism

In a further effort to reduce risk, the high capacity connector uses the same linear latching and de-latching mechanism as is used in the HydraLight WMC. This robust latching mechanism is now field tested and proven. In addition, the same ROV handle options traditionally offered for the HydraLight WMC can also be offered for the High Capacity connector.

G. SEACON® Precision Standard MKII PBOF 13mm Hose Interface

The High Capacity WMC includes the standard industry interfaces, which include a field proven, highly robust, 25 year PBOF hose system and MkII interface [3]. This dual sealed system is in broad use in the oil-gas industry.

Fig. 5. PBOF Hose System With Mk II Interface

IV. DESIGN, INNOVATION AND RISK

This innovative, lower risk approach takes advantage of two successful, qualified and field proven base technologies. The HydraLight design is now fully in service, qualified in 2000 to a demanding oil-gas specification. The G3 design optical wet mate connector is more recently qualified, and has now seen service in both land and sea downhole wells. The innovative combination of these two technologies into a high capacity wet mateable optical connector has the tremendous advantage of using a qualified and field proven sealing and latching system from the HydraLight WMC. It also uses the multi-way contact assembly from the G3 connector. In this way, a lower risk, high capacity approach is achieved, that does not rely on untested, new science. In addition to this lower risk approach, SEA CON® has configured this high capacity connector with APC (angled, polished contacts), which allows for an improved Back Reflection (BR). Utilizing an angled contact surface dramatically reduces the reflection across the face of the optical contact, which enhances optical performance in distributed sensing systems.

A. Design Specification

Although there are no known current industry standard specifications for underwater mateable connectors, a variety of organization specific requirements documents have been created by oil and gas operators and associated major equipment providers. These specifications form the main documents used in the initial development and qualification of underwater interconnect equipment. Additionally, there are industry working groups such as Subsea Fiber Optic Monitoring (SEAFOM), that are working on creating industry recommended practices for subsea interconnect systems. Recommendations through SEAFOM are currently being developed and should become available to the industry over the next several years. As more applications for underwater connectors are encountered, greater focus will be put on specification and qualifications. This is now seen in some of the major offshore developments that are using fiber optic connectors.

The SEA CON® high capacity (8-48 Channel) wet mateable optical connector has been developed with the following design ratings:

Table 1 Design Ratings

Description	Parameter
Design Life	25 years
Optical Performance – Single Mode	
Insertion Loss (IL) 1310nm & 1550nm	Better than -0.50 dB
Back Reflection (BR) 1310nm & 1550nm	Better than –45.0dB
Pressure Rating	
Operational Depth	7,000m (23,000 feet)
Header Differential Pressure Rating / Test	300 Bar (4351 psi) / 450 Bar (6729 psi)
Temperature Rating	
Operating	-5ºC to +45ºC (23ºF to +113ºF)
Storage	-40ºC to +60ºC (-40ºF to +140ºF)
Operational Ratings	
Minimum Number Mate/De-Mate Cycles	100
Maximum Mate / De-Mate Speed	0.3 meters per second (12 inches/second)
Latch	Linear Mate/De-Mate, positive visual indication
Maximum mate/de-mate force	M 622N (140 lbs), D 222N (50lbs).
Typical mate stroke length	121mm (4.8 inches)
Maximum Rotational / Angular / Radial misalignment	Rotational 10º / Angular 5º / Radial 6.4mm (0.25inches)
Maximum applied mating force	5000 N (1124 lbs.)
Chemical Compatibility	
Materials and components compatible with the following fluids:	Dow Corning DC200 Silicon Oil, Mineral Oil, Diesel, Castrol Brayco Micronic 864HT200 synthetic base hydraulic fluid, Marsten Bentley HW443 water based hydraulic fluid, Glycol, 50% Citric acid, 50% Acetic acid, Xylene, Methanol, Mono Ethylene Glycol (MEG), Water, Seawater

B. Qualification

Qualification of the high capacity WMC was successfully accomplished over 2011-2012 to the following parameters:

Table 2 Qualification Parameters

Parameter	Qualification Requirement
Optical Performance, Insertion Loss	Less than 0.5 dB, all channels
Optical Performance, Back Reflection	Less than -45 dB, all channels
Optical Performance, Crosstalk	Maximum -40 dB, any channel powered to all other channels
Bench Testing	100 mate/demate cycles, verify IL, BR and mate force every 10 mates
Drop Test (Flying lead connector)	Drop from 1 meter (3 drops per axis, 6 total, verify IL, BR)
Pressure Test	450 bar (6527 psi), 5 mate-demates, verify IL, BR)
Thermal Shock	+60C to 0C (5 cycles, verify IL, BR)
Thermal Shock	-20C to 0C (5 cycles, verify IL BR)
Mechanical Shock	Half sine 11ms at 30g, both mated and unmated, horizontal and vertical, verify IL, BR
Vibration	5-150hz, 5g, verify IL, BR
Mating Force, Dry	Less than 500N (5 cycles, verify IL, BR)
Mating Force, Turbid	Less than 500N (20 cycles, verify IL, BR)
Mating Force, ROV	Apply 5000N in connector axis, verify IL, BR
Maximum Misalignment	Maximum Of: Rotational: 10 degrees, Angular: 5 degrees, Radial: 0.25 inches
Life Testing	14 days at 10kpsi and 150F, Verify IL and BR daily

Fig. 6. High Capacity Wet Mateable Optic Connector During Pressure Testing

Fig 7. High Capacity Wet Mateable Optic Connector During Following Turbid Tank Testing

C. Failure Mode Effect and Criticality Analysis (FMECA)

An essential part of System Requirements Analysis is the rigorous analysis of new designs. As a part of this analysis, a formal Failure Mode Effect and Criticality Analysis (FMECA) for the High Capacity connector has been conducted. The analysis follows the methodology as described in MIL-STD-1629A, Procedures for Performing a Failure Modes, Effects and Criticality Analysis. This standard establishes the requirements and procedures to systematically evaluate and document failure modes and potential impacts on the function of subassemblies. Each potential failure is ranked by severity of its effect in order that corrective actions may be taken to eliminate or control those items identified as high risk. For this FMECA analysis, the connector subsystem (Plug and receptacle) was assessed in its main and sub functional components, resulting in 308 separate analyses. The analysis areas included:

- Flying Lead Connector Assembly
- Bulkhead Connector Assembly
- Male Flex Tube
- Fishtail Handle
- Header

Following the assessment regime of MIL-STD-1629A, a summary of these specific analyses is shown in Table 3:

Table 3 FMECA Assessment Distribution

		Severity		
Probability	**Catastrophic**	**Major**	**Marginal**	**Minor**
Frequent				
Reasonably Probable				0
Occasional			4	0
Remote		17	46	8
Extremely Unlikely	50	42	93	41

Table 4 FMECA Analysis Example Item

Top Level/ Bom	Part/Process Function Description	Failure Mode(s)	Failure Effect(s)	SAPL Part Nr	Sev	Failure Causes
F3.2	Midbody	Dmgd Seal Surface	Water ingress, contam. oil, degraded optical perf	A170-151	III	Oring surface, dmge

Table 4, Continued

Prob.	Prev.	Detect.	Action Rcmnd/Doc Ref	RespPersn/ Group	Schedule/ Date
D	Incoming insp, He leak test	He leak test during FAT	Process Doc Control FAT SAPL-FAT-1043)	SAPL Eng	Per sked

As a result of the FMECA analysis, a number of procedural steps were added to the Factory Acceptance Test. In addition, some design features were altered to make the particular dimension more robust.

V. Technology Gap Assessment, Applications, and Advantages

Technology Gap Assessments are normally conducted as a part of the product development of new products, and to ensure that a new product will indeed fit a legitimate system design requirement. This methodology was applied to the High Capacity Wet Mateable Connector, and how it could bring value to the industry. In such an assessment, one normally considers "Where We Are", vs "Where We Want to Be", and identifies a technology gap. The normal process would be:

1. Study the market and determine what is being asked for, or where an improvement can add value
2. Identify all areas of technology available
3. Identify the Gaps between where we are, and where we want to be. Consideration of commercial risk/return would normally be a part of this analysis.
4. Encourage/Develop products that close technology gaps, and introduce the desired products and services

A high capacity connector can add value to a number of emerging system functional designs, and industry arenas. System applications that can benefit from a higher capacity wet mateable connector include the following:

A. Fiber for Data Communications

Additional fiber circuits make possible additional new, or redundant pathways. If these additional circuits can be wet mateable, and can be achieved within the same package and form factor, this can reduce the footprint of the required hardware, and reduce upfront hardware expenditures. It is also true that multiplexing technologies such as CWDM (Coarse Wavelength Division Multiplexing), and DWDM (Dense Wavelength Division multiplexing) are available that can add extra channels (bandwidth) to an existing fiber. The system designer must balance the cost of the additional mux/demux equipment against the relatively modest cost of additional discrete fiber pathways. The system tradespace can now consider an additional column, which includes 48 optical circuits in one wet mateable connector, where before 6 wet mateable connectors were necessary.

B. Fiber For Seabed Sensing Systems

Seabed (and sea volume) environmental conditions are now routinely tracked and recorded by a wide variety of environmental sensors. These sensors can be deployed in" point sensor" form, i.e. the sensor operates at the end of a fiber data link, or in the form of a new technology called "distributed sensing", where the fiber itself is the sensing element. With this new technology, the fiber itself can sense pressure, temperature and even seismic/acoustic information directly from the environment. Additional fiber pathways then become additional sensing elements, and having as many as 48 fiber sensing channels in one wet connection adds capacity to this kind of system, while keeping connection hardware costs down. An example of this kind of Distributed Sensing System, in this case a typical seabed seismic sensor for a Permanent Reservoir Monitoring (PRM) seismic application, is shown in Figure 8 [4].

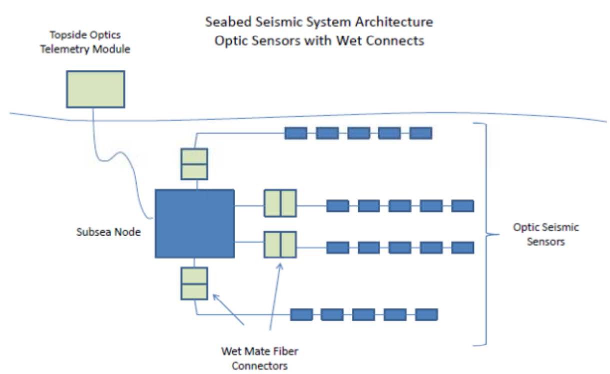

Fig. 8. Seabed Seismic System Architecture Using Optic Sensors and Wet Mate Connectors

C.Fiber for Production Oil Field Systems

For the typical oil collection platform, the subsea umbilical cable is configured from the platform, to an Umbilical Termination Head, and then to multiple manifolds. Currently, the architecture is limited to wet mateable connectors with 8 channels., because of the hardware that has been available. With a 8-48 channel Wet Mateable Connector available, harnesses that serve the multiple manifolds can be combined into a smaller distribution arrangement. Combining manifold harnesses can both reduce initial hardware expenditures, as well as operational expenditures.

D.Reduced Capital and Operational Expenditure

When the fiber pathways that are currently carried by 6 connectors can be reduced to one or two connectors, the impact on system capital expenditures can be significant. And from an operational point of view, if one or two ROV connections can be made instead of 6, the on station ROV operating time (and associated expenditure and risk) can be similarly reduced.

VI. Conclusion

The introduction of a High Capacity (8-48 channels) Wet Mateable Optical Connector has the potential to reshape subsea optical system design in a number of functional areas. System designers can now take advantage of a higher density wet optic connection, that can reduce up front hardware requirements, and simplify seabed networks. Simply put, the designer can take advantage of a greater numbers of fiber pathways at one distribution point. Both up front capital expenditures as well as recurring operational expenditures and risk can benefit from this approach. Further, the approach herein manages and reduces risk, by leveraging existing, qualified technologies, as opposed to beginning with a new design paradigm.

Acknowledgment

The authors wish to acknowledge the technical and manufacturing team that actually turned this product from an idea, into a working, wet mateable connection. As engineers, we sometimes forget that the concept for a new design is one thing, but the actual building of the device is another matter, and is frequently underestimated.

References

[1] M. Christiansen: Fiber Optic Connections in the Sea, Proceedings Underwater Intervention, New Orleans, La, 1999.

[2] G. Brown, M. Christiansen: Development, Testing and Track record of Multi-Way Optical Wet Mate Connectors for Deepwater Applications, Proceedings, OTC 2002

[3] D. Jenkins, S Thumbeck, (Utilizing Pressure Balanced Oil Filled (PBOF) Hose Cable Assemblies with Electric and Fiber Optic Connectors, MTS/IEEE Oceans, Quebec, Canada, Sept 2008.

[4] S. Thumbeck, “Underwater Connectors for Permanent Reservoir Monitoring (PRM) Systems ”, European Association of Geoscientists and Engineers Workshop on Permanent Reservoir Monitoring (PRM) Using Seismic Data, 28 February-3 March 2011, Trondheim, Norway