Development, Testing and Track Record of Fiber-Optic Wet-Mate Connectors

Gary Brown, SEA CON® Advanced Products, La Mesa, California

Abstract

Underwater optical connectors enable subsea system designers to build modular subsea components and systems utilizing optical communication systems. These modular systems can be assembled on the seafloor, the optical connectors enabling connections and disconnections for installation and maintenance purposes or for future system expansion, particularly as part of installed underwater communication hubs to facilitate immediate or future expansion and connectivity. In anticipation of future applications requiring the large bandwidth, high speed and long step-out distances achievable from using optical communication systems, optical wet-mate connectors have been qualified for use to 23,000 feet (7,000m) and so far been used to over 9,900 feet (3,017m). This paper presents an overview of the development and testing, plus a summary of the track record, of a full range of wet-mate optical fiber connectors suitable for the offshore communication industries.

1. Subsea Optical Communication Systems

Underwater optical fiber and communication systems have been in use in the offshore and subsea oil and gas environs for many years now. The main advantages of such systems are now well known, for example:

- Significant increase in communication bandwidth
- Significant increase in speed of data transfer
- Significant increase in communication distances
- Immunity to electrical noise
- Potential cost reduction in subsea umbilical construction and installation by enabling the manufacture of smaller diameter umbilicals
- Well-known temperature dependant properties of optical fiber

It is however the use of wet-mate optical connectors that has enabled modular underwater installation and this combined with the advantages above have allowed a significant growth of the following:

- Increasing quantity, speed and sophistication of remote, distant underwater monitoring and control
- Significantly faster underwater seismic streamer array processing
- Next generation subsea Christmas tree and manifold systems
- Subsea separation, subsea processing and subsea production boosting systems
- Significantly longer step-out distances for remote well locations or subsea satellites
- Real-time assessment of reservoir performance and optimization
- Real-time health and status monitoring of subsea equipment for safety and to better understand equipment maintenance regimes

© 2002 SEA CON®/Brantner & Associates

- Greater opportunity to access large quantities of raw subsea data
- The use of high power transmission systems which rule out conventional electrical data communications due to Electro Magnetic Interference (EMI)
- The opening up of long distance (200km) shore to field opportunities

It is the advent of these newer technologies moving into the subsea environs and in deeper waters that have created not only the need for optical wet-mateable connector products but also the number and increasing diversity of them as well.

2. The Challenge of Wet-Mate Fiber Optic Connectors

As a very brief introduction to fiber optical communications, the principle of operation exploits the ability of light to travel efficiently within a very fine glass fiber. The glass fiber is essentially an optical wave-guide in which light stays trapped within the core by near total internal reflection between the core and it's outer cladding. The core consists of a 9µm diameter high refractive index glass material covered by a 125µm diameter lower refractive index cladding.

For comparison of size a human hair is 90µm diameter. The 125µm cladding may also be covered in a protective coating to a diameter of 250µm that subsequently may also be covered by a secondary coating to 900µm.

Table 1 identifies the main challenges of wet-mate fiber optic connector design and manufacture.

Number	Challenge
1	The alignment and coupling of these very fine 9µm diameter glass fibers underwater without any contamination across the optical faces
2	The alignment and coupling of these very fine 9µm diameter glass fibers underwater without high optical losses
3	The ability to operate underwater for long periods of time underwater without discernable degradation

Table 1 – The Challenges of Fiber-Optic Wet-Mate Connectors

3. Specifications for Optical Wet-Mate Connectors

The demand for optical applications is increasing and not only are the quantity of optical system products increasing but so too is the variety and complexity of the many and varied applications required. These in turn affect the customer's requirement for optical wet-mateable connectors.

These varied technical and commercial requirements include but are not limited to those extremes identified in Table 2. These points all have an impact on product design, development, cost, qualification and availability:

Parameter	Specifications
Lifetime	• Long term (25 years plus), • Short term (months only)
Optical Losses	• As low as possible (≤ 0.5dB) • ≤ 2dB
Size	• As small as possible • Don't care

Table 2 – Diversity of Customer Requirements (continued)

Parameter	Specifications
Cost	• Must be inexpensive • Don't care but not exorbitant
Material	• Non-corrosive metal body materials • Non-metallic body materials
Configuration	• ROV, AUV, Diver, Stab-plate
ROV Handle	• T-bar, H-handle, Fishtail-handle • ISO 13628-8 Design & Operation of ROV Interfaces on subsea production systems
Temperature	• Low temperature only, High temperature only • Wide operational temperature
Channels	• Single channel only • Between 4 and 8 channels • As many as possible
Termination	• Cable termination, Hose termination • Strength member termination
Testing	• Fit for purpose • Extensive test program to meet operational requirements • Test to extremes

Table 2 (continued) – Diversity of Customer Requirements

In each case these requirements are assessed for compatibility with current products in an attempt to standardize product elements. In many cases there are technical, physical or commercial constraints that require alternative solutions, especially when the quantities are significant and the costs can be justified. Over the last few years this increasing trend from customers has led to the development of a family of several different wet-mateable optical products that are proving very successful. This has resulted in the availability of this range of products, thus allowing more technical and commercial choice of field proven products for the end-user.

4. Optical Wet-Mate Connectors

These requirements have led to the development of the following range of optical wet-mateable connectors:

(1) HydraStar
- 8-channel electro/optical - Qualified
- 14-channel electro/optical - Prototype

(2) HydraLight
- 8-channel optical, military version - Qualified
- 8-channel optical, ROV version - Qualified

(3) MicroStar
- 4-channel optical only connector for tree/wellhead applications - Prototype

(4) S-Series
- 4-channel optical only, modular optics - Prototype

(5) Photon
- 4-channel optical only, modular optics - Qualified

5. HydraStar

5.1 Introduction

The 8-channel HydraStar is the backbone of the wet-mate optical connector product range. It is a hybrid (electro/optical) connector that has proven itself as a rugged and reliable design. Following the successful conclusion of a very rigorous qualification test program, the HydraStar now has an impressive accumulation of field data with over 2.1 million accumulated operating hours over the last 4 years.

The HydraStar connector, as a hybrid, offers a combination of up to 8 electrical and/or optical circuits with a high degree of integrity. Whilst it has been used mostly for combined electrical and optical applications, it is also ideal for pure optical applications. The connector is simple with few moving parts and offers robust operational and optical performance. Figure 1 shows several HydraStars and parking positions installed on an optical junction box.

Figure 1 –HydraStar Optical Connectors & Optical Junction Box

5.2 Testing & Track Record

The connector underwent significant and rigorous testing with emphasis on the three original criteria regarding the challenges of fiber-optic wet-mate connectors i.e. the alignment and coupling of these very fine 9µm diameter glass fibers: (1) underwater without any contamination across the optical faces, (2) underwater without high optical losses and (3) to operate underwater for long periods of time without discernable degradation.

The first two were easily confirmed by extensive testing and backed up by subsequent experience in the field while the third relates to success and track record in the field.

(a) Testing. The testing included the following:

- **Optical Parameters:**
  - Insertion Loss (IL) is the light power lost through the connection. The average optical attenuation measured during qualification was -0.28dB with a standard deviation of 0.06dB.

  - Back Reflection (BR) is the amount of light reflected back to the source from the connection interface. Back reflection needs to be kept to a minimum in laser powered single-mode systems, in all cases it was measured less than the test target of –45dB.
- **Electrical Parameters**
  - Insulation Resistance (IR) measures the 'quality' of insulation between each electrical contact element and any other adjacent conducting element. The test target was >1Gigohm (10^9ohms) and in all cases the electrical IR measured exceeded this.
  - Contact Resistance (CR) measures the resistance through each connector electrical contact. In all cases the measured contact resistance was less than the design parameter of 0.1ohm.
- **Deep Ocean Environment Pressure Cycling.** The test chamber used chlorinated filtered natural seawater held at a temperature of 32°-35°F (0°-1.6°C) during the pressure cycling between 0psi and 10,000psi (0bar to 690bar). Test connectors were cycled hundreds of times at various test pressures and pressure cycling.
- **Sand/Silt Testing.** Extensive mating/de-mating testing of the connectors inside a turbid sand, silt and seawater environment was completed. This verified the ability of the two front connector seals to prevent particulate contamination from entering the connector and internal pressure compensation fluid from escaping.

  As the connectors are pressure compensated these tests were also successfully repeated with a 15psi (~1bar) overpressure inside both connector halves and again with a vacuum in both halves to verify that even with pressure differentials the seals work as designed with no evidence of leakage.
- **Low Temperature Testing.** The connectors were also subjected to low temperature testing to verify the low temperature capability of the two front connector seals. The connector is rated operationally down to 32°F (0°C) with a comfortable margin.
- **Inter-mateability.** During all testing of connector sets, the inter-mateability of each connector half with all other available connector halves was conducted. In all cases the average optical attenuation was in the order of -0.3dB. The connectors are therefore specified and rated independent of connector pairing.

The majority of this testing was conducted at the Naval Facilities Engineering Service Center (NFESC) in Port Hueneme, California in October 1998 but testing of the HydraStar continues to this day, especially to meet various specific and unique customer requirements and applications.

Additional testing by other third parties to further qualify and evaluate the connector has included hyperbaric testing, pressure cycling, shock testing and vibration testing. Figure 2 shows both halves of a HydraStar set.

(b) Track Record. Current reliability data is based on actual field data. A statistical analysis of the field data confirms the product's operational performance in the field. Only connectors delivered and either taking part in system integrations or operating in the field have been included within this information but the accumulated operating time is in excess of 2.1 million hours with a calculated MTBF of better than 700,000 hours with an 80% confidence level.

As the track record of this product progresses in the many different applications it is used in, so too does the confidence in meeting the third challenge; "to operate for long periods of time underwater without discernable degradation" and consequently in selecting it for use underwater and especially for long-term deepwater applications.

The HydraStar has now been used successfully to 9,900 feet (3,017m).

Figure 2 – HydraStar Electro/Optical Wet-Mateable Connector

6. HydraLight

6.1 Introduction

The first such derivative of the HydraStar was the smaller HydraLight. Direct customer advice was the catalyst that led to the development. The HydraLight is basically a downsized optical only HydraStar that incorporated the following additions:

- Smaller size
- Improved optical performance both Insertion Loss and Back Reflection
- Optical only (up to 8 channels)
- Addition of plug cover sleeve
- Stronger springs and enclosure of main springs
- Seawater compatible interior
- Standardized Omnitec MKII PBOF hose interface
- Enhanced elastomers for improved chemical compatibility
- Improved compensation fluid offering better water-absorption properties and increased dielectric strength

SEA CON® currently has two versions of the HydraLight:

1. Military stab-plate version
2. Oil & Gas ROV version

Both of these utilize identical operating principles and technical specifications to that of HydraStar. The military version being part of host sub-system for underwater Defense applications and the Oil & Gas ROV version being the direct optical-only HydraStar replacement for long-term applications as expected within the underwater oil and gas industry. Figure 3 shows an ROV HydraLight set.

Figure 3 – ROV HydraLight Optical Wet-Mateable Connector

6.2 Technical Changes

Removal of the electrics to make this an optical-only connector led to an immediate size reduction and the addition of a cover sleeve around the plug was incorporated. Enclosure of the receptacle spring was achieved efficiently within the ROV version. In addition the compensation oil and elastomers used were re-evaluated with the final findings indicating positive reasons for change. It was therefore decided to re-qualify the connector with synthetic compensation oil for reasons of improved lubricity, improved dielectric strength and improved water absorption properties. The elastomers were also changed to a particular compound of fluorosilicone, which has proved to be a robust alternative with a greater degree of compatibility with the types of chemicals used in the oil & gas industry.

An additional change was also incorporated on the ROV version for a seawater compatible interior. This was driven by a specific customer with a requirement to ensure in the unlikely event that the HydraLight became flooded; it would remain functional for a long period of time. Whilst this change was incorporated it necessitated the use of significantly more expensive internal piece -parts and thus had an impact on price.

6.3 Testing

The qualification testing of the HydraLight has been extensive and rigorous. Covered by two separate test programs, one for the stab-plate version for military use and the other for use within the oil and gas industry:

(a) Military Stab-Plate Version. The testing was conducted by third party personnel at Southwest Research Laboratories in San Antonio, Texas and included:

- Optical testing
- Over 440 mate/de-mate cycles in total
- Mate/de-mate cycles in clean seawater
- Mate/de-mate cycles in clean seawater to 9,800 feet (2,987m)
- Mate/de-mate cycles in sandy/silty seawater (to a pre-determined mix)
- Mechanical testing as part of host system

In all cases the testing showed good connector optical and mechanical performance within specifications throughout. Figure 4 shows the front ends of the military stab-plate version.

Figure 4 – HydraLight - Stab-Plate Version

(b) Oil & Gas Version. The testing was conducted by SEA CON® personnel at Southwest Research Laboratories in San Antonio, Texas and included:

- **Optical Performance Measurements**

  Optical attenuation measurements were performed on each optical contact set, at 1310nm and 1550nm wavelengths and in both directions. A sample of over 3000 test measurements has yielded the following results:

  - Mean optical attenuation: -0.2dB
  - Single standard deviation: 0.1dB

  Optical back-reflection measurements were performed on each optical contact set, at 1310nm and 1550nm wavelengths and in both directions. A sample of over 3000 test measurements has yielded the following results:

  - Mean optical back-reflection: -50dB
  - Single standard deviation: 4dB

- **Helium Leak Test** – The qualification connectors successfully passed the 24-hour helium leak test
- **ROV Force Test** – This test verified a maximum applied ROV force of 5,000N.
- **Turbid Tank Test** – The connector was mated hundreds of times in cold 0°C and 4.5°C (32ºF to 40ºF) turbid sand, silt and seawater at ambient pressure.
- **Mechanical Shock Test** – The connector was subject to a shock of 30g for 11ms in the x, y and z planes.
- **Vibration Test –** The connector was subject to a double-sweep vibration profile on each of the x, y and z planes, including optical performance monitoring:
  - Displacement: 5 Hz to 25 Hz $\pm$ 2 mm
  - Acceleration: 25 Hz to 150 Hz, 5g
  - Sweep Rate: Maximum one octave per minute
- **Wet-Mate Test** – The connector was subject to intensive wet-mate testing including:

- Ambient, cold, freshwater - The connector was mated over two hundred times in ambient and cold 0°C and 4.5°C (32ºF to 40ºF) fresh water at ambient pressure
- Ambient, cold, turbid, seawater - The connector was mated over a hundred times in cold (0°C and 4.5°C) turbid sand, silt and seawater at ambient pressure

- **Partial-Mate Test** – In cold 0°C and 4.5°C (32ºF to 40ºF) seawater, the connector was partially separated, a minimum of 100mm and re-mated and then verified for optical performance a total of 10 times

  Hydrostatic Testing – The connector was subject to intense hydrostatic testing to the equivalent of 2,000 meters (6,500 feet).

Further to this additional testing was conducted to qualify the hose, hose termination and jumper assemblies as being suitable for use with optical fiber and an external Fiber Management System (FMS). These were completed by Bennex Omnitec in Norway and included:

<u>Hose and hose termination</u>

- Environmental stress tests - Hose absorption/compensation, ozone resistance, ultraviolet resistance and thermal shock
- Destructive testing - Tensile failure, burst pressure, crush resistance, outer sheath abrasion and hose kink testing

<u>Jumper assembly</u>

- Oscillating jumper test, jumper pull test, drop test, jumper handling simulation test
- Simulated deployment test

6.4 Track Record

Both versions of the HydraLight are now installed in the field but the sample population is still too small and too recent to calculate significant accumulated operating hours and MTBF.

Figure 5 – HydraLight - ROV Version, Flying Lead Half

7. MicroStar

7.1 Introduction

The second such derivative of the HydraStar was the smaller MicroStar. Direct requirements of the end-users were the catalyst that led to this development, however this involved a different and unique set of primary design constraints and subsequent issues as follows:

- Smaller size than both the HydraStar and HydraLight - 4-channel optical only, space constraints and new internal materials and techniques
- Higher temperature rating 121°C (250ºF) – Elastomers, compensation and expansion
- Chemical compatibility – Elastomers and fluids
- Subsea-tree/tubing-hangar interfaces including - Space constraints, stack-up tolerances, keying, installation, securing, compliance, sealing, mate/de-mate, lifecycle, water-venting

The MicroStar is basically a downsized optical only HydraStar/HydraLight that incorporated the lessons learned from the HydraStar and design improvements learned during the HydraLight development.

The operating principle and key technical specifications of the MicroStar are identical to that of the HydraStar and HydraLight.

Figure 6 show the prototype MicroStar plug half.

Figure 6 – MicroStar Plug Connector Half

7.2 Testing

Prototype testing and qualification testing is in progress. Initial testing will confirm the basic principles of the design and will be initially verified by the following:

- Optical testing - Insertion loss and back reflection
- Mechanical - Helium leak testing and mate/de-mate testing

After successful conclusion of the basic testing the connector will be issued to a third party for qualification whereby they will be simulating actual operating and interface conditions to verify that the connector remains within specification.

8. Photon

8.1 Introduction

Specific customer specifications wanted less expensive, smaller and lower specification wet-mate optical connectors with customer studies indicating unit cost was a major factor in connector selection. The Photon connector is a different concept connector altogether, compared to the HydraStar. It draws on over 35 years of experience in underwater-mateable connector design and over 10 years specifically in underwater optical connector design.

The Photon is a patented modular concept device and can be easily configured from a single channel device through to any number of channels. The upper limit would be determined by the practicality of handling such a device. Figure 7 shows a prototype Photon connector set. In addition to it's modularity, the Photon has also been designed to fit the standard modular CM2000 electrical contacts to make a hybrid electro/optical connector. The prototype designed and built is a 4-channel device with the following specifications:

- Small, similar to electrical connector size
- Average optical insertion loss of –0.5dB with a single standard deviation of 0.25dB
- Mate/de-mate cycles of less than 50
- Qualified to 1,000m (3,200feet)

Figure 7 – 4-Channel Photon Optical Wet-mateable Connector

8.2 Testing

Prototype testing and qualification testing has been successfully completed. This included verification of the basic principles of the design and was verified by the following:

- Optical testing - Insertion loss and back reflection
- Mechanical - Mate/de-mate testing
- Hyperbaric testing

After successful conclusion of the basic testing the connector was issued to an independent third party to perform additional testing, including a statistical analysis of the insertion loss over about a dozen connector sets. The testing so far has involved over 400 mate cycles in both wet and dry conditions and the connectors have performed very well.

9. S-Series

9.1 Introduction

The S-series is the latest Optical Wet-Mate connector currently under development.

It was developed to fulfill a requirement for a small connector similar in size to the Photon but to a higher specification.

This was developed in a manner similar to the Photon and uses similar concepts.

It too is a patented modular concept device and can be easily configured from a single channel device through to any number of channels. The upper limit would be determined by the practicality of handling such a device.

The prototype designed and built is a 4-channel device with the following specifications:

- Small, similar to electrical connector size
- Optical insertion loss of less than 1dB
- Mate/de-mate cycles of less than 50

9.2 Testing

Currently the prototype is being assembled with testing to commence in September/October 2002. After successful conclusion of the basic testing the connector will then undergo a further series of testing to qualify as suitable for use.

Figure 8 shows a photograph of both halves of the S-4 connector set.

Figure 8 – S-4 Optical Wet-Mateable Connector Plug & Receptacle

10. Summary of SEA CON® Wet-Mate Optical Connectors and Applications

Table 3 summarizes the connectors in terms of testing, track record and main characteristics:

Connector	Testing	Track Record	Main Characteristics
HydraLight 8-channel optical, ROV version	• Qualified to 6,500 feet (2,000m) • Soon to be qualified to 23,000 feet (7,000m) • Compliance – Norsk Hydro, Statoil and Elf Exploration	• Connectors installed subsea	• 8-channel • Optical only • Highest specification • Highest integrity • Long-term applications • Ultra-Deepwater • Extreme Testing
HydraLight 8-channel optical, stab-plate version	• Qualified to 9,800 feet (2,9\7m)	• Field proven • Classified military project	• 8-channel • Optical only • Highest specification • Highest integrity • Long-term applications • Deepwater • Military applications
HydraStar 8-channel electro-optical (hybrid)	• Qualified to 23,000 feet (7,000m)	• Field proven • 9,900 feet (3,017m) • Over 2.1 million accumulated operating hours • MTBF of better than 700,000 hours	• 8-channels • Electro/Optical • High specification • High integrity • Long-term applications • Ultra-Deepwater • Extreme testing
MicroStar 4-channel optical	• Qualification in progress to 23,000 feet (7,000m)	• None	• 4-channel • Optical only • Highest specification • Highest integrity • Long-term applications • Ultra-Deepwater • Down-hole • Slim-line • 10,000psi (690 bar) • Enhanced temperature 121ºC (250º F)
S-Series 4-channel optical	• Prototype assembly in progress	• None	• Modular • Small • Low cost • Optical only • Medium-term applications • Littoral waters & deeper
Photon 4-channel optical	• Qualified to 3,200 feet (1,000m)	• Connectors delivered to customers but not operating in field	• Modular • Small • Low cost • Electro/Optical • Short-term applications • Littoral waters

Table 3 – Optical Wet-Mate Type, Testing & Track Record Comparison

Table 4 summarizes the connectors in terms of relative cost, relative performance and relative lifecycle, demonstrating a conclusive coverage in cost and performance from low to high:

Optical Connector	Relative Cost	Relative Optical Performance	Relative Lifecycle (Mate Cycles)
HydraLight	High	Highest	Highest
HydraStar	Medium-High	High	High
MicroStar	Medium	High	Medium
S-Series	Medium-Low	Medium	Medium
Photon	Low	Medium	Low

Table 4 – Optical Wet-Mate Relative Cost, Optical Performance and Lifecycle Comparison

11. Operational Use of Optical Wet-Mate Connectors

Over the last few years it has been noted that there have been instances of problems with the operational use of wet-mate optical connectors. In each case we work with the customer in establishing the nature and solution to the problems. The findings have always been categorized into three main groups:

Application	Damage	Education
Suitability	Mechanical	Misuse
Location	Chemical	Incorrect operation
Installation	Misuse	Pre-deployment checking
Operation	Accident	Maintenance & equipment
Packaging & Shipping	Packaging & Shipping	Packaging & Shipping

Table 5 – Application, Damage & Education

The basic problem though is education, education about optics, wet-mate optical connectors, how to specify, how to apply, how to use, how to install, fiber-management including how to handle fibers. Whilst many operators would rather fit and forget, it is not always possible for a fluid-filled pressure compensated connector offering a new technology, without attention to some basic details that require some basic education and training. In all cases we now offer standard recommendations when dealing with optical wet-mate connectors:

Education	Application	Damage
• Application engineering	• Application engineering	• Recommended spare parts list
• Training courses	• Advice on location, installation & operation	• Storage of standard spares
• Introduction to basics of fiber optics	• Specification	• Storage of key replacement items
• Operation & Maintenance manual	• Recommendations for modification to suit application	• Fast repair turn-around

Table 6 – Application, Damage & Education Recommendations

Whilst the industry is starting to take notice of these recommendations it is still surprising how few end-users take notice.

12. Conclusion

Whilst an ultimate desire is for product standardization, we have responded to immediate needs by evolving and developing three wet-mateable optical connector products from the same family; the HydraStar, the MicroStar and the HydraLight plus the development of a new family of products, the S-Series and Photon. Also highlighted are the key elements identifying the relativity of these to: qualification testing, track record, cost, performance and lifecycle.

The requirement for underwater mateable optical connectors has grown considerably over the last few years and in combination with a fast growing and successful track record, is ensuring an increase in the quantity of qualified components available for use within the offshore and subsea oil and gas environs.

Acknowledgements

We thank E Niekrasz and D Stephens from Lockheed Martin for valuable discussions on the design and testing of the HydraStar, HydraLight, S-Series and Photon; Bennex Omnitec in Norway for their work on the optical jumper qualification; Sensa and Shell in the UK for their continued support on the qualification of the MicroStar and in particular we thank the dedicated SEA CON® Advanced Products team scattered around the world for their continued and dedicated efforts in achieving these outstanding results.

References

1. M Christiansen: "Fiber Optic Connections in the Sea" proceedings UWI '99, New Orleans
2. DJ Smith: *Reliability Maintainability and Risk,* 4th Edition, Butterworth Heinemann (1993)
3. DV Lindley & WF Scott: *New Cambridge Elementary Statistical Table,*" Cambridge University Press (1984)
4. G Brown, M Christiansen, D Stephens: "Development and Testing of the HydraStar connector" proceedings OTC 2000
5. G Brown, M Christiansen: "Development, Testing and Track Record of the Multi-Way Optical Wet-Mate Connectors for Deepwater Applications" proceedings OTC 2002
6. M Christiansen & G Brown: "Fiber Optic Terminations for Sub-Sea Applications" reprint Sea Technology
7. Norsk Hydro ASA, *Requirements to Subsea Mateable Electrical/Optical Connectors,* NHT-I52-00073 Rev 04H
8. Statoil ASA, *Requirements for wet mateable electrical and optical connectors and cable jumper assemblies,* RA-SN∅-00182 Rev 01
9. Elf Exploration *Specification for Subsea Mateable Electrical/Optical Connectors,* AO-32-2-011-LT-00-SN-005 Rev C