Advancements in the Reduction of Size and Weight of Electrical and Optical Connectors for Extreme Environments

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Abstract:

SEA CON® have been working on many projects with the principle aim of reducing various key parameters, such as size and weight, of electrical and optical connectors for extreme environments, without major compromises on performance. This has primarily been for applications where space or weight is a limiting factor such as: smaller ROV's and AUV's; diver, swimmer or marine-mammal-deployable systems; low-profile surveillance systems; underwater lighting and security; use of lower cost and smaller operational vessels of opportunity and use of small-bore modular array systems. This technology is not limited to underwater applications but those in tactical and support environments including airborne, surface shipping and field applications subject to extreme operating conditions. This presentation highlights some leading examples of specific new technology related to the continuing trends towards miniaturization and weight reduction of electrical and optical connector components.

1. Introduction:

There are many factors driving the reduction of size and weight of electrical and optical connectors for extreme environments. Most of these are driven by particular and unique customer requirements although many are a result of a considered opinion of potential customer requirements.

Specific examples of these requirements are:

- Smaller host vehicles – as ROV, AUV or other systems become greatly reduced in size, or there is a reduction in available space due to increased vehicle complexity, the impact, both in size and weight of the connection elements of that system become more significant. There is a significant driver to not only reduce individual connection sizes but also minimize the number of connections for reliability reasons.

- Diver Systems – with an expectation for a reduction in diver or manned systems in favour of unmanned systems and operations, not occurring to the extent predicted so far, there is still a strong emphasis on not necessarily smaller equipment, as too small may prove too difficult for manual operation, but for weight reduction or increased density of electrical or optical functionality.

- Swimmer or marine-mammal-deployable systems – Similar to diver systems but with a specific emphasis on not only small size, but small mass and weight and simple operation.

- Low-profile surveillance systems – Required to be hidden or undetectable, EMI compliant, low mass, non-metal etc, but still operational in extremes of environments, including deepwater, sub-surface or buried.
- Underwater lighting and security – With the increasing emphasis on underwater lightings and security systems, smaller and lower cost connection systems assist with the economic viability of large-scale operations and systems.
- Lower cost and smaller Vessel-Of-Opportunity (VOOP) – Similarly with an emphasis on cost reduction, which can focus on the use of vehicles or vessels of opportunity rather than specialized and more expensive ocean-going vessels.
- Small bore modular arrays – An example of a single application in that a combination of the reasons above requires a slim-line small-bore modular array system, with net result requiring increased complexity but reduction in size and weight in water or air as part of an automatic deployable system.

2. Importance of Miniaturization

The importance in achieving a reduction in size and/or weight, without significant technical compromise is to offer a healthy choice of what we call 'enabling-technology' that can facilitate the future concepts, viabilities and practicalities of strategic system planning and implementation.

It is an important consideration and the purpose of this presentation is to highlight a significant amount of specific examples, the main drivers and an outline of the resulting hardware.

The hardware shown below is an example of the most basic form of dry-mateable and wet-plugable connectors. In both cases the technology is based on very simple rubber molded technology that has been around for many decades. However it has only been recently that even the functionality offered by these, the most basic underwater connector types has been able to be significantly increased as well as a reduction in size.

Figure 1 – Dry-Mateable Rubber Molded Connectors

Figure 2 – Wet-Plug Rubber Molded Connectors

3. Connector Classification

The main classifications of these connectors are as follows:

- Dry-mate underwater connectors – these can be electrical, optical or a combination of both, known as hybrids. They are coupled and uncoupled in the air or "dry" before deployment underwater or into a hostile environment.
- Wet-plug underwater connectors – these are electrical connectors that can be coupled and uncoupled underwater, typically to diver operating depths.
- Wet-mate underwater connectors – these can be electrical, optical or a combination of both, known as hybrids. They can be repeatedly coupled and uncoupled underwater at up to full ocean depths.
- Penetrators – these are permanent electrical or optical fixed "penetrations" enabling a "feed-through" of a section of the host system.
- Underwater switches – these offer huge advantages in providing the ability to isolate or connect circuits underwater. They can be used as part of low power trigger or relay circuitry or they can be manually operated or magnetically coupled. Recently they have been connectorized by the addition of a miniature wet-plug connector. They are small but easily operated manually, mechanically or by proximity.

4. Connector Size Definition

For the purposes of this paper/presentation the following diagram will be used to provide an indication of key mated-connector dimensions wherever appropriate. The mated connector set is displayed as a conventional cylinder with a typical length and diameter, in inches, displayed to convey the idea of the overall size of the product. The example shown indicates a mated connector set with an overall length of 1 inch and a maximum diameter of 0.3".

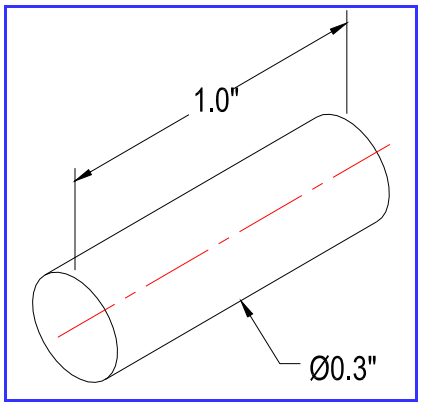

Figure 3 – Key Connector Dimensions

Photographs are shown wherever possible but in some case it has not been possible to show these and alternatively a solid-works drawing has been shown to give an indication of connector size.

5. Reduction in Size

Reduction in connector size can be achieved by several means, however it is important to understand the parameters that have the most significant impact on size and these are:

5.1 Voltage Rating

Voltage rating is defined by the quality of insulation between each of the current-carrying conductors and the external environment. Insulators have different properties and are defined by their dielectric strength and measured as insulation resistance. Miniaturization requires an effective reduction in conductor spacing and hence insulation dimensions and the consequent use of high dielectric properties insulating materials.

5.2 Current Rating

The current-rating of a conductor is defined by it's cross-sectional area. One of the greatest impacts on miniaturization is the ability to meet a reduction in conductor cross-sectional area. However the primary impact of this is a reduction in the steady state operating current and hence a balance is required to ensure the connector is suitable designed, rated and tested for a useful steady-state current.

5.3 Contact Density

The development of smaller contacts that can be efficiently and economically produced is an important consideration in conjunction with the development of the required production tooling and handling procedures as part of the production cycle, in order to achieve this. Examples are for the MicroMinicon design, contact spacing reduction of up to 66% was achieved by the development of new tooling.

5.4 Wasted space and material.

In traditional connectors, a lot of wasted space and material can be found. The miniaturization process requires removing all excess materials. The large areas of material are the result of O-ring grooves, retaining ring grooves and key/keyway requirements. Several techniques were adopted to meet this requirement enabling connectors to be produced that were not economically achievable 15 years ago.

5.5 O-Rings

Traditionally the industry has based O-ring selection on published charts and handbooks but the reality of miniaturization was the customization of a series of O-rings and tools to provide the required sealing. There were significant challenges in adapting the theoretical modeling of the new seals, but these were overcome to meet the practicalities of repeatable, high quality and high quantity production.

5.6 Key/Keyway Heights

New CNC active tools allowed the repeatable production of new concept key/keyways that enabled significant reduction on metal shell size.

5.7 Retaining Mechanism

The retaining mechanism needed to be smaller than anything commercially available. New tools and materials enabled viable alternatives that offered more space to maximize the insert face diameter, thus allowing higher contact densities.

5.8 Minimal Wall Thickness

All wall thickness have been reduced to their absolute minimum. Material choices have helped in this area. As an example titanium was chosen as the material for the shells so that wall sections could be thin and still retain strength for the design pressure ratings with the required 50% Factor of Safety in all calculations and computer models. Other materials can, and already have been used, but the choice of material does affect the mated pressure rating.

5.9 Aft End Technology.

One of the major hurdles to overcome was the wire termination and cable area. One examples was to load the inserts into the shells from the rear for easier termination and assembly. The rear loading was necessary to properly handle the small wires. These wires are as small as #28awg and some customer designs have required solid core wire. Reverse loading eliminates large service loops in the wire and minimized the size of the termination and overmold.

5.10 Mating Sequence

Proper mating sequence is essential to ensure that the pins and the connectors are not damaged during engagement. It is important to take this into account for the smaller connectors and this can work against size reduction so new methodologies needed to be developed.

6. Reduction in Weight

The availability of new metallic and non-metallic materials have allowed other advances in connector design not related directly to achieving miniaturization. As it turns out connector changes will tend towards miniaturization rather than the other way around but some material changes have tended to also produce a reduction in connector weight underwater. Typical changes have been the use of:

6.1 Metals

Titanium, which is lightweight, strong, less dense (but expensive) is the main alternative material of use, however research and development with alternative materials, with lighter, stronger and less expensive aims (example Shape Memory Alloys plus others) is on-going.

6.2 Non-Metals

The use of non-metals eliminates any cathodic de-lamination issues , they are very light and neutrally buoyant, underwater and non-magnetic. Examples are: PEEK (high quality, expensive, good mechanical strength); GRE (extensive use and experience, inexpensive, good mechanical strength); Delrin or Acetal (not as durable, easy to machine, inexpensive).

7. Dry-Mate Electrical Connectors

7.1 Introduction

Dry-mate electrical connectors have been around for many decades. The rubber-molded variants were and remain predominant with typical key dimensions of 1" in diameter. These are being replaced by many smaller units such as; the miniature Rubber-Molded versions and the Hummer series of connectors.

7.2 Rubber Molded

The standard rubber molded connectors consist of an in-line neoprene connector mated to a glass reinforced epoxy bulkhead connector.

The standard single pin versions are in fact quite small with a diameter of Ø0.31", however increased functionality requirements offer 3,4 or 6 contacts with a diameter of Ø0.75 and Ø1.08" for 12 contact connectors.

The first reduction initiatives came in the form of the Miniature Rubber Molded series of connectors, which offered size reductions from Ø0.75" to Ø0.37" for 4 contacts and from Ø1.08" to Ø0.56" for 11 contacts, with the same 600VDC rating but a reduction in interface wire size from #16awg to #22awg.

Figure 4 – Rubber Molded Connectors

7.3 Hummer

(a) Standard Hummer

The standard Hummer is a recent development in direct response to the ever-increasing requirement for smaller and higher density connectors. It is a miniature configuration that incorporates the proven characteristics of existing SEA CON® designs.

Figure 5 – Hummer (12-Way) Connector

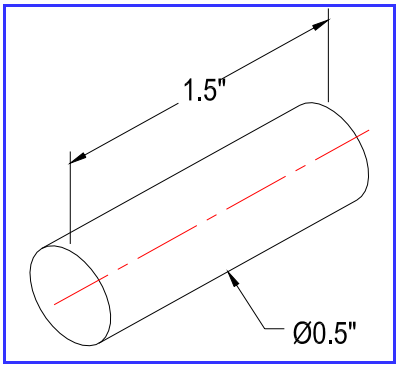

Figure 6 – Hummer (12-Way) Connector Size

The bulkhead half consists of a metal shell with molded glass-reinforced epoxy inserts, whilst the cable half is molded in neoprene to standard or custom cable lengths, with a metal coupling ring.

Available in 2 to 28 contact configurations, the diameter sizes are Ø0.37" for 2-contacts, Ø0.50" for 12-contacts and Ø0.62" for 28 contacts. This is achieved with a voltage rating of 300VDC with interface wire size to #28awg and complements a total low-cost solution.

(b) PEEK Hummer

The Hummer is also available with PEEK shells and coupling rings instead of the more traditional metal shells.
The main advantage of PEEK is that it offers a non-metallic alternative to metal shells for light-weight and non-magnetic underwater applications. The main disadvantages of PEEK are: that it is more expensive than even some of the more exotic metals; it is not as rugged as the metal versions and the pressure rating is reduced due to the lower tensile strength of the PEEK.

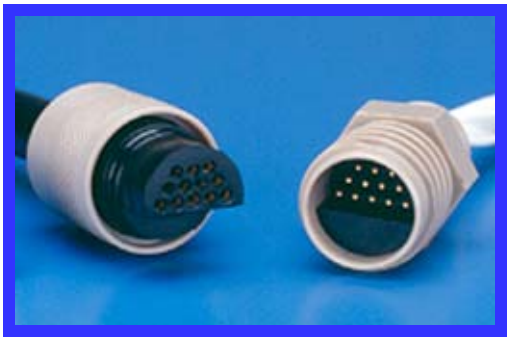

Figure 7 – PEEK (12-Way) Hummer

7.4 MicroMinicon™

(a) General Range

The MicroMinicon was developed for the same reasons as the Hummer, to produce a smaller, higher density dry-mateable connector. The MicroMinicon has other advantages offering a high-integrity miniature product to the highest possible specifications.

Figure 8 – MicroMinicon Connector

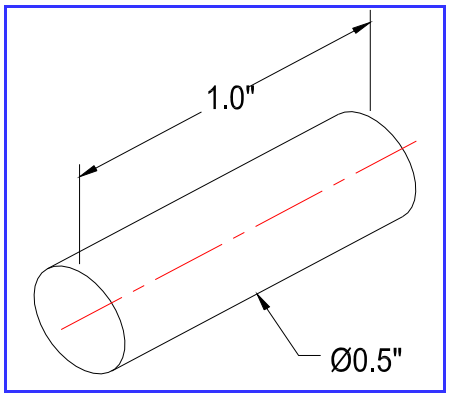

Figure 9 – MicroMinicon (8-Way) Size

It has been tested to MIL specifications and is also suitable for integration of optical fiber to make a hybrid dry-mateable connector. Additional advantages of the MicroMinicon over the Hummer series are: increased pressure rating; titanium metal shells; equalization valves for PBOF options and MIL testing. The smallest size configuration offers a diameter of Ø0.5" for 8 contacts of #28awg wire but the largest size and highest density offers 198 contacts of #22awg wire in the shell size diameter of Ø1.875".

(b) Special Miniature Push-Pull (12-Way) Version

The Push-Pull version of the MicroMinicon is a new specialized miniature version of the MicroMinicon. Made out of titanium it has been extensively tested for it's intended operation of

being able to be manually connected or disconnected quickly. It is suitable for very powerful applications such as: rapid surface connections, break away units, surface battle-space operations and most importantly for tactical operating equipment on the battlefield, where although underwater capability is not always required, operation within extreme operating environments is. The connector is very small, densely packed, with 12 #28awg conductors.

Figure 10 – Push-Pull MicroMinicon (12-Way)

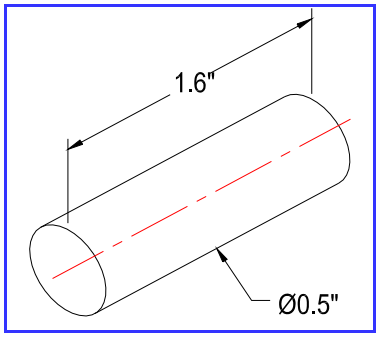

Figure 11 – Push-Pull MicroMinicon (12-Way) Size

7.5 Co-axial Dry-Mateable Connectors

The co-axial connector is a special application of a dry-mateable connector in that it offers a true impedance-matched connection that will function underwater. The connector has an excellent performance and specification with full pressure rating to 10,000psi and temperature range from –55ºC to +125ºC.

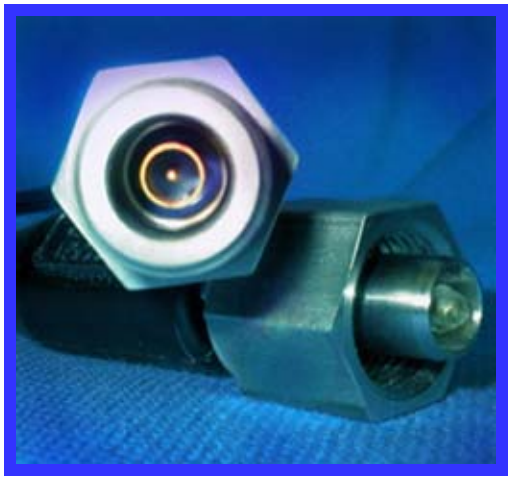

Figure 12 – Co-axial Connector

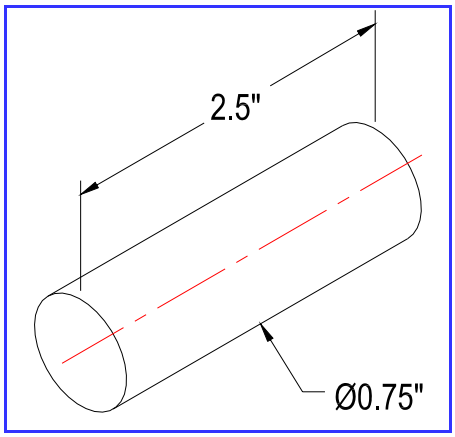

Figure 13 –Co-axial Connector Size

There are many configuration variants including the ability to produce hybrids that contain electrical contacts, optical contacts and co-axial contacts within a single connector insert, but the smallest is the single channel co-axial with a connector diameter of Ø0.75” and characteristic impedance of 50ohms.

7.6 Dry-Mate Electrical Size Comparison

Shown in Table 1 is a summary of the miniature dry-mate electrical connectors and how the diameters have decreased and functionality has increased. The arrows show the trends to smaller diameters.

Contacts	1 Contact	4 to 8 Contacts	11 to 14 Contacts	26 to 28 Contacts	198 Contacts
Rubber Molded	Ø0.31”	4 to 6 : Ø0.75”	12 : Ø1.08”		
Miniature Rubber Molded		4 : Ø0.31” 7 : Ø0.59”	11 : Ø0.56”		
Hummer		5 : Ø0.37”	12 : Ø0.50”	28 : Ø0.62”	
Micro Minicon		8 : Ø0.5”	12 : Ø0.50” 14 : Ø0.75”	26 : Ø0.88”	198 : Ø1.88”

Table 1 – Dry-Mate Electrical Size Comparison

8. Dry-Mate Optical Connectors

8.1 Introduction

Dry-mate optical underwater connector variants have also been around for over a dozen years. These are in the main metal shell variations based around the Minicon range of connectors, with new generations of products achieving increased functionality as well as decreasing diameters.

8.2 Single Channel Dry-Mate Optical Connector - Minicon

The smallest standard conventional dry-mate optical underwater connector is a Minicon F-size connector offering a single multi-mode or single-mode optical fiber with a typical diameter of Ø0.75”.

Figure 14 – Single-Channel Dry-Mate Optical Connector

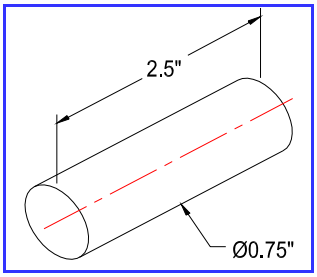

Figure 15 – Single-Channel Dry-Mate Optical Connector Size

Already a small connector with excellent optical performance along with a superb track record of operation. This design achieves these sizes using standard 2.5mm diameter optical ferrules. Further miniaturization of a single-channel connector to achieve the same optical performance is possible as shown in the next section.

8.3 Miniature 4-Contact Down-Hole Optical Dry-Mate Connector

The miniature 4-channel optical dry-mate underwater connector provides a very small package for the allowable functionality of 4 optical channels. It was designed to fit the space-constraints of down-hole oil and gas production instrumentation and offers a diameter of 0.82” with excellent optical performance.

Figure 17 – 4-Contact Optical Connector

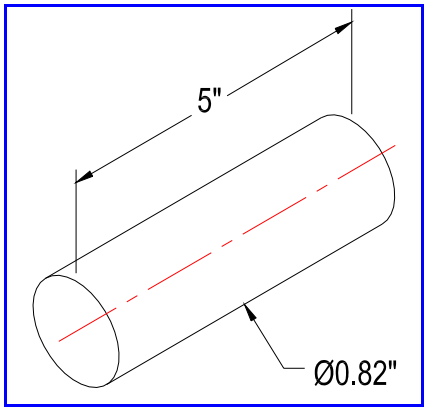

Figure 18 – 4-Contact Optical Connector Size

8.4 Miniature 12-Contact Insert

The ultra miniature 12-contact insert is the smallest highest density optical insert available. It offers an extremely small size and huge functionality without any compromise on optical performance.

Figure 19 – Miniature 12-Contact Optical Dry-Mate Insert

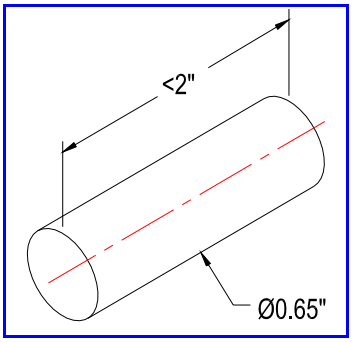

Figure 20 – Miniature 12-Contact Optical Dry-Mate Insert Size

9. Optical Penetrators

9.1 Single channel High Pressure Miniature Optical Penetrator

The single channel penetrator is a high integrity optical penetration suitable for pressure differentials of 10,000psi. Extensively tested and operating in the field in an application requiring very small space considerations for installation.

Figure 26 – Single-Channel Optical Penetrator

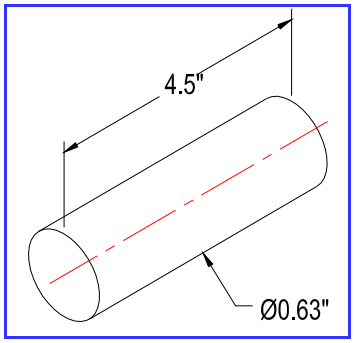

Figure 27 – Single-Channel Optical Penetrator Size

10. Dry-Mate Hybrid Connectors

10.1 Opti-Con Modular Hybrid Connector

The Opti-Con Modular Hybrid Connectors provide a range of commercial off-the-shelf (COTS) electro/optical dry-mateable connectors. They provide functionality of 4, 8,12 and 20 within a range of 4 shell sizes. The smallest a 4-channel version offers just over 1" in diameter but is able to be configured for electrical, optical or hybrid and offers significant cost-savings over any of the other range of dry-mateable products. This is achieved by economy of scale whilst still retaining small size and flexibility.

Figure 21 – Miniature 12-Contact Optical Dry-Mate Connector

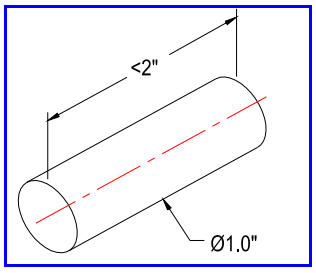

Figure 22 – Miniature 12-Contact Optical Dry-Mate Connector Size

10.2 Miniature 12-Contact Hybrid Insert

The ultra miniature 12-contact insert is the smallest highest density hybrid connector available. It offers an extremely small size and huge functionality without any compromise on optical performance, which is:

- Average optical insertion loss: 0.3dB
- Average optical back reflection: -40dB

With excellent electrical performance of:

- Insulation resistance of greater than 100Mohms
- Voltage rating of 600VDC.

Typical qualification tests carried out have been:

- Pressure testing
- Pressure cycling
- Operational temperature testing
- Storage and survival temperature testing
- Mate/De-mate testing
- Fluid compatibility testing

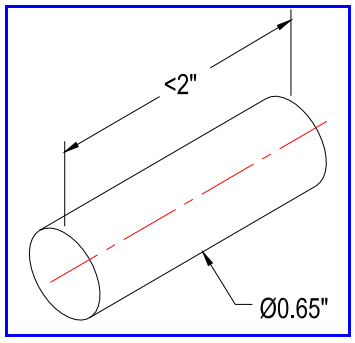

Figure 24 – Miniature 12-Contact Hybrid Size

Figure 23 – Miniature 12-Contact Hybrid (Pins)

Figure 25 – Miniature 12-Contact Hybrid (Sockets)

11. Wet-Mate Electrical Connectors

11.1 MicroWet-Con

The MicroWetcon is what is known as a wet-plugable connector. It is an inexpensive high-volume rubber molded connector based on the extremely popular and reliable Wet-Con series. It is smaller than the Wet-Con series with size reductions as follows:

Contacts	Wetcon Ø	MicroWetcon Ø
2	Ø1.00”	Ø0.61”
8	Ø1.25”	Ø0.61”

Table 2 – Wetcon OD versus MicroWetcon OD

Figure 28 – MicroWetcon (5-Way)

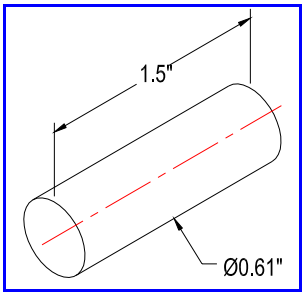

Figure 29 – MicroWetcon (5-Way) Size

The change in specification from a Wetcon to a MicroWetcon may appear significant but the reality is that they offer a practical, small and inexpensive instrumentation connector that suits a majority of applications.

Parameter	Wetcon	MicroWetcon
Voltage	600VDC	300VDC
Pressure	20,000psi	10,000psi
Wire Size	#14, #16 or #18 awg	#18awg on 2-pin, #20awg on 8 pin

Table 2 – Wetcon OD versus MicroWetcon OD

11.2 CM2001/2mm High Pressure Version

The CM2001/2mm is a wet-mateable connector capable of repeatable mating and de-mating (up to a minimum of 100 cycles) underwater to it’s rated design pressure of 10,000psi (23,000feet).

It already has an excellent track record of operation and provides a voltage rating of 1,000VAC at 10Amps continuous current. There are two temperature versions, the standard 149ºF (65ºC) and a higher temperature product using a new elastomer rated to 200ºF (93ºC).

Figure 30 – CM2001/2mm

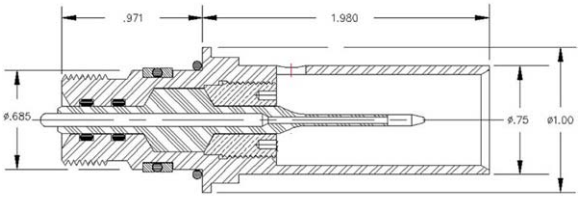

Figure 31 – CM2001/2mm High Pressure

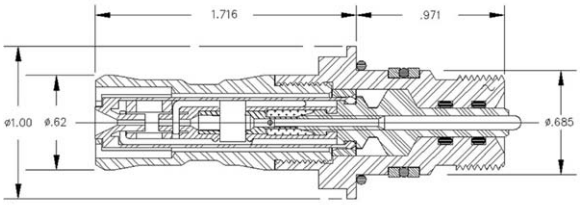

Figure 32 – CM2001/2mm High Pressure

The dimensioned drawings show how small the connector is with a maximum diameter of Ø1.0" and mated length of less than a few inches.

11.3 PEEK CM2004/2mm

A 4-channel PEEK version of the CM2000 was produced for a classified military program. The basis of the requirements was for an extremely light-weight, small, non-metallic connector. The results were achieved with excellent 4-channel functionality in a small physical size. The electrical performance characteristics of the PEEK version remain identical to the standard metal version, but the depth rating allows the ability to repeatedly wet-mate at depths of up to 11,500 feet.

Figure 33 – CM2004/2mm PEEK

The CM2004/2mm PEEK connector and termination offers a diameter of Ø1.5"version and less than seven inches in length. Whilst not a tiny connector it offers excellent versatility for it's weight, size and performance.

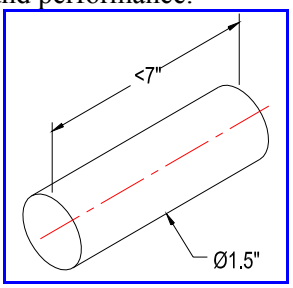

Figure 34 – CM2004/2mm PEEK

12. Wet-Mate Optical Connectors

12.1 S-Series, S-1 Optical Wet-Mate Connector

The S-series, 4-contact, known as the S-4 was designed and qualified as a small low cost, lower specification alternative to the high specification optical wet-mate connectors. It was designed with modular optical or electrical contacts. The S-1 is the modular single-channel version of it and makes for a small optical wet-mate. Shown in figures 35 and 36 is a preliminary version of the S-1 plug and receptacle indicating a diameter of approximately 1.6" at the largest cross-section, however initial research indicates this can also be further reduced.

Other versions of the optical wet-mate connector are also being looked at with a target diameter of less than 1" diameter.

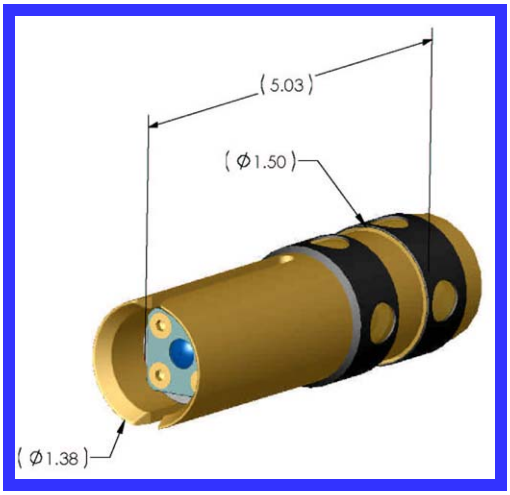

Figure 35 – S-1 Receptacle

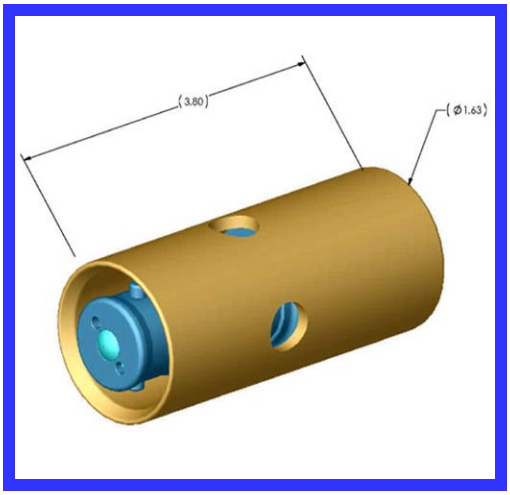

Figure 36 – S-1 Plug

13. Underwater Switches

13.1 Standard Switches

Underwater switches are available in many different varieties but we will focus on the smallest and the newest materials.

13.2 Miniature Proximity Switch

The miniature proximity switches are single-pole, double-throw and use magnets to open or close an electrical circuit. These offer a diameter of Ø0.75" and are available in stainless steel or titanium. Specific details are:

- 6,000psi rating, 1 Amp and 7 Amp power loads
- MIL-STD, meets NAVSEA requirements
- -65ºF to 400ºF
- Normally open or normally closed
- Magnet activated
- Proximity/sinking/sourcing/latching

Figure 37 – "VM" Series Proximity Switch

13.3 Miniature Limit Switches

The miniature limit switches are single-pole, double-throw and function due to a specified physical movement of an attached plunger. These offer a diameter of Ø0.75" and are available in stainless steel or titanium. Specific details are the same as the proximity switch but with a 0.4" stroke of plunger for the limit operation.

Figure 38 – "AU" Series Limit Switch

13.4 Plastic Limit Switches

The plastic limit switches are single-pole, double-throw and function due to a specified physical movement of an attached plunger. These have a slightly larger diameter than the standard limit-switch range at Ø0.935" but offer the advantages of non-magnetic and lightweight. Originally designed as a "push-to-talk" button. Specific details are:

- 500 feet rating
- 1 Amp and 7 Amp power loads
- Normally open or normally closed
- 0.3" stroke of plunger

Figure 39 – "AU PLS" Series Limit Switch

13.5 Modular Proximity Switch with Integral MicroWetcon Connector

The Modular Proximity switch offers a combination of two small items, the standard Ø0.75" diameter proximity switch and the 3-contact MicroWetcon underwater plugable connector which itself has a diameter of Ø0.61". These are integrated into an underwater plugable and interchangeable package using a steel re-inforced Neoprene mold. The combined product has the following specifications:

- 10,000psi rating
- MIL-STD
- Meets NAVSEA requirements
- -65ºF to 400ºF
- Normally open or normally closed
- Magnet activated
- Proximity/sinking/sourcing/latching

Figure 40 – Modular Proximity Switch

14. Summary

SEA CON® are without doubt the largest, the most diverse and the most experienced "underwater connector" company in the world. This has meant that, over the years, we have been able to significantly re-invest resources to work with customers in defining, developing and manufacturing their specific and latest requirements. This has led to a significant number of innovations and new products that has added to the diverseness of the product base. A key element of this has been at the forefront of initiatives to reduce connector size and use new materials and this we hope we have been able to demonstrate within this paper/presentation.

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