CHAPTER 8

Cables and Connectors*

c0008

CHAPTER CONTENTS

This chapter has been written by three invited co-authors whom have addressed underwater connector selection from three distinct perspectives: the end-user, the manufacturer, and sales engineering. Our deepest thanks go to Kevin Hardy, President of Global Ocean Design, Cal Peters, Director of Engineering for Falmat and Brock Rosenthal, President and founder of Ocean Innovations. They have lectured on the subject of "cables and connectors" at numerous Oceans MTS/IEEE conference tutorials. (These tutorial presentation materials form the basis of this chapter. Additional information on this team is provided in the Acknowledgements section.)

The ROV Manual.

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s0010
8.1 Introduction

p0230 Underwater cables and connectors provide system flexibility, ease of service, and other design advantages for undersea equipment—including ROVs. The primary purpose of underwater cables and connectors is to provide a conductive path, without leakage, in a pressure-resistant or pressure-tolerant package. Cables and connectors allow for simple system configuration (Figure 8.1).

p0235 Underwater connectors are used to connect the umbilical to a tether management system (TMS), then from the TMS to the ROV. In addition, these items interconnect separate components on the ROV to form a functioning integrated system. Connectors enable these components to be disconnected for easy removal for servicing, repairs, or upgrades.

p0240 A mated connector pair forms a unique small pressure case. All pressure case design criteria then apply. A bulkhead connector becomes a mechanical part of a pressure hull and thus should be looked at critically.

p0245 It is important to the success of any subsea project that both end-users and manufacturers speak the same language from the beginning.

p0250 In this chapter, readers will:

o0230 1. Learn the language of underwater cables and connectors common to the underwater industry;
o0235 2. Learn a practical approach to specifying underwater cables and connectors for their specific application; and
o0240 3. Raise their understanding of what can be expected from cable and connector manufacturers.

f0010 **FIGURE 8.1**

Cable and connectors provide flexibility in electric power and signal distribution.

(Courtesy MacArtney.)

s0015 8.2 Definitions

p0270 It is important to speak with the same terminology as your supplier. Jargon can vary somewhat between different industries, such as offshore oil & gas and the military. Generally, common terms are universally understood between applications.

p0275 **The Basics**

p0280 Connectors are, initially, a mechanical problem. A mated connector pair functions as a small pressure case. All pressure case and seal maintenance rules thus apply. So our definitions will start with the housing.

u0010 *Plug* is the male body.

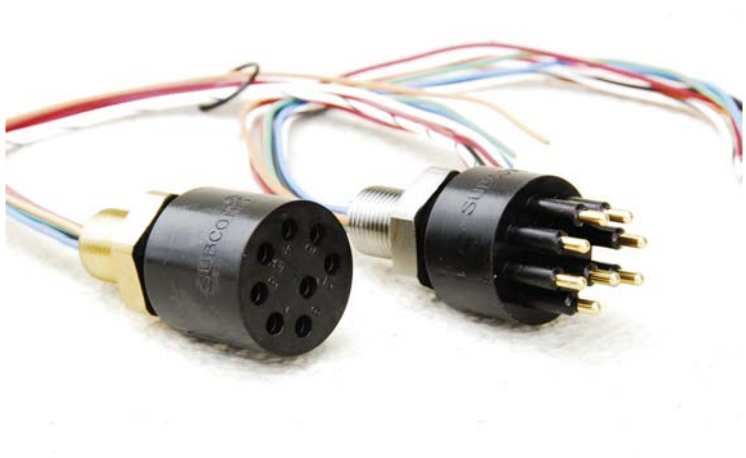
u0015 *Receptacle* is the female half.

p0295 Inside the mated housing are electrical *pins* and *sockets*. Most commonly, plugs have pins, and receptacles have sockets (Figure 8.2). Connector manufacturers typically have naming conventions for their connector configurations descending from general toward specific arrangement. As an example, a four-pin female micro connector can be any of several arrangements such as MCIL4F (micro connector in-line 4-pin female), MCBH4F (micro connector bulkhead 4-pin female), and MCPBOF4F (micro connector pressure-balanced oil-filled 4-pin female), MCDC4F (micro connector dummy connector 4-pin female). The same naming convention continues with low profile (LP), standard circular (SC), etc. As a general rule, it is best not to mix connector manufacturers' products for the same connector unit (e.g., Manufacturer A's male connector plugging into Manufacturer B's receptacle). When in doubt, check with the manufacturer for compatibility between connectors.

p0300 Connectors are broadly classified by:

u0020 • Connector type (i.e., electrical, optical, or optical/electric)
u0025 • Mating environment (i.e., dry mate, wet mate, or underwater mate)
u0030 • Voltage (e.g., low voltage, medium voltage, high voltage, or very-high voltage)
u0035 • Amps (i.e., low/medium/high current)
u0040 • Number of contacts (self-explanatory)
u0045 • Pressure rating (i.e., low/medium/high/extreme pressure).

p0335 *Bulkhead connectors* can attach to a pressure housing using o-rings to make the seal. A threaded post bulkhead connector screws into a tapped hole. A spot face (i.e., a smooth, flat or conformal



f0015 **FIGURE 8.2**

Bulkhead connector receptacle (left) and plug (right).

(Courtesy Ocean Innovations.)

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curved, accurately located surface) provides the sealing surface for the o-ring face seal. A threaded post bulkhead connector can also be mounted using a simple clearance through-hole and secured with a nut and washer on the interior side. A flange-mount bulkhead connector is attached to a pressure housing using machine screws that secure the connector. The screws pull the flange mount against the pressure housing, compressing the o-ring against a spot face on the pressure housing, and thereby making the watertight seal. Particular attention must be paid to avoid dissimilar materials and anaerobic corrosion.

p0340 **Threaded posttype connectors**

u0050 BCR, bulkhead connector receptacle
u0055 BCP, bulkhead connector plug

p0355 **Flange mount-type connectors** (Figure 8.3)

u0060 FCR, flange connector receptacle
u0065 FCP, flange connector plug

p0370 **Inserts** (Figure 8.4)

u0070 Fits inside connector shell
u0075 CIR, connector insert receptacle (sockets)
u0080 CIP, connector insert plug (pins)

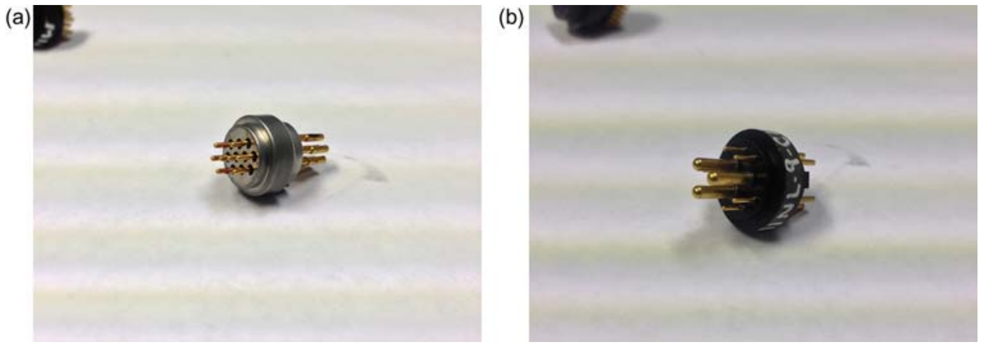
p0390 **In-line connectors or CCP/CCR, whip or pigtail** (Figure 8.5)

u0085 CCP, cable connector plug
u0090 CCR, cable connector receptacle

f0020 **FIGURE 8.3**

Flange mount bulkhead connectors.

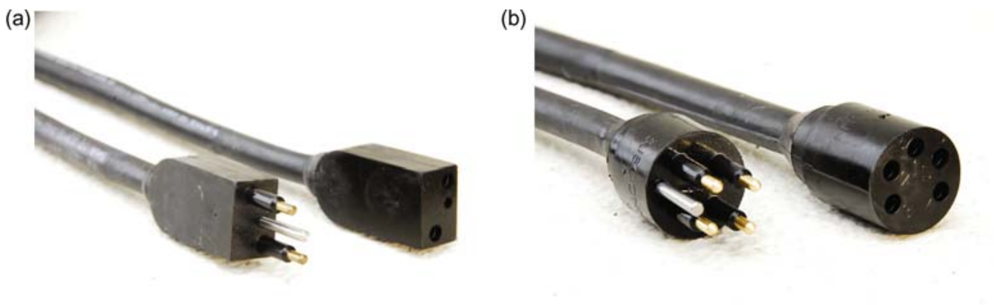
(Courtesy Ocean Innovations.)



f0025 **FIGURE 8.4**

(a) Metal body insert with glass seal of pins (left). (b) Molded epoxy body insert with pins (right). Note alignment key molded into base of insert.

(Courtesy SeaCon.)



f0030 **FIGURE 8.5**

(a) In-line rectangular body connectors (left). The rectangular body is also referred to as "low profile."
(b) In-line circular body connectors (right).

(Courtesy Ocean Innovations.)

p0405 **Dummy connectors and sealing caps**

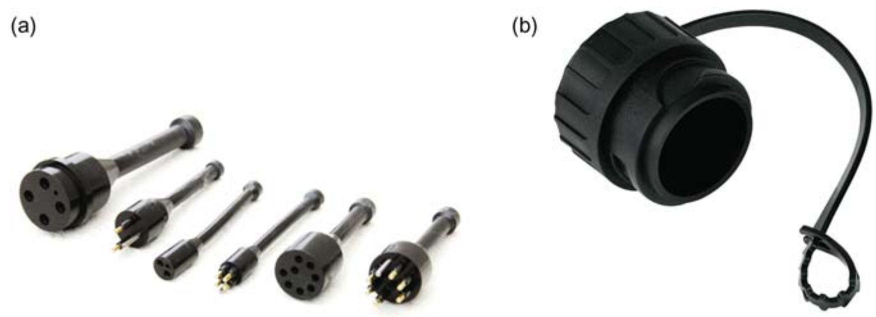
u0095 These keep electrical contacts clean when the connector is not mated.
u0100 *Dummy plugs* (Figure 8.6(a)) can be rated for medium depth or deepwater. Be sure the dummy plug is rated for the chosen application.
u0105 *Dust caps* are for surface use only (Figure 8.6(b)).

p0425 **Hermaphroditic connectors**

p0430 A hermaphroditic style connector (Figure 8.7) has both male pins and female sockets on each connector.

p0435 **Fiber-optic connectors** (Figure 8.8)

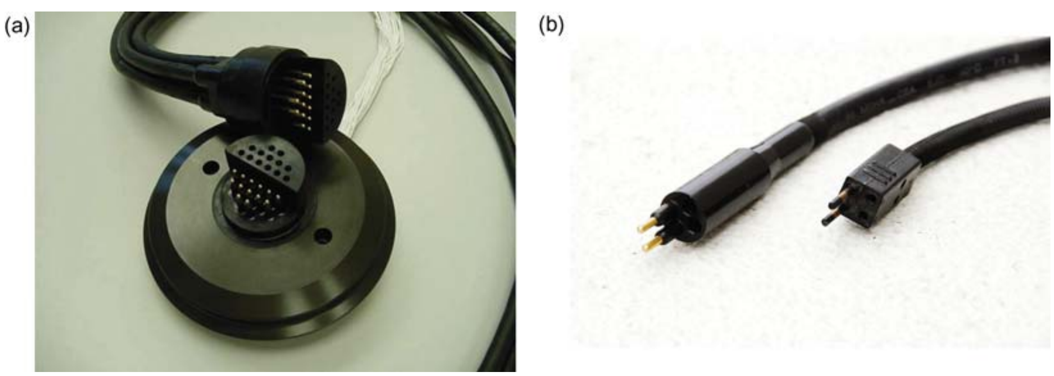
p0440 There are two approaches used in connecting two optical fibers in a connector: expanded beam optics and physical contact. The expanded beam process uses ball optics to transmit light across the medium.



f0035 **FIGURE 8.6**

(a) Circular dummy connectors (left). (b) A splash-proof dust cap (right).

(Courtesy Ocean Innovations.)



f0040 **FIGURE 8.7**

(a) A hermaphroditic style bulkhead connector and in-line connector (left). (b) Hermaphroditic style in-line connectors with circular and square bodies (right).

(Courtesy Ocean Innovations.)

Precise alignment is not required but the losses are higher. The physical contact approach utilizes polished optical fiber ends inside alignment ferrules. The mating faces must be held in contact to minimize losses, which are lower than the expanded beam approach.

p0445 **Hybrid connectors**

p0450 Hybrid connectors can provide contacts for power and data, as well as optical fiber passes.

p0455 **PBOF**

p0460 The pressure-balanced, oil-filled (PBOF) connector (Figure 8.9) provides the end-user with the flexibility of making and servicing his/her own cables. By running electrical conductors or optical fibers through an oil-filled hose, the connector is easily serviced without the need to destroy a cured connector. In addition, custom underwater cables are not needed and, if required, conductors can be reconfigured or replaced.

f0045 **FIGURE 8.8**

Fiber-optic connectors provide optical fiber passes with the ability for disconnect.

(Courtesy of GISMA.)

f0050 **FIGURE 8.9**

An example of a PBOF connector.

(Courtesy MacArtney.)

p0465 Some connectors incorporate a valve for oil filling and bleeding the connector interface. The mating PBOF bulkhead connector is then rated for open face pressure since the connector itself is at ambient pressure (i.e., little or no pressure differential across the connector). Other manufacturers have adapted a PBOF back shell to their standard line of rubber-molded connectors, as the one illustrated in Figure 8.9.

p0470 The plastic or rubber hose is slid over a hose barb fitting on the back of the connector and secured with a hose clamp. Then the tube is filled with oil. A second connector is installed on the opposite end in the same manner as the first, excess air is squeezed out, and the second connector is pressed into the oil-filled tube. A hose clamp secures the tube to the back of the second connector.

p0475 **Penetrators**

p0480 Penetrators (Figure 8.10) bring wires to the interior of the pressure housing but cannot be disconnected.

p0485 **Cable glands** (Figures 8.11 and 8.12)

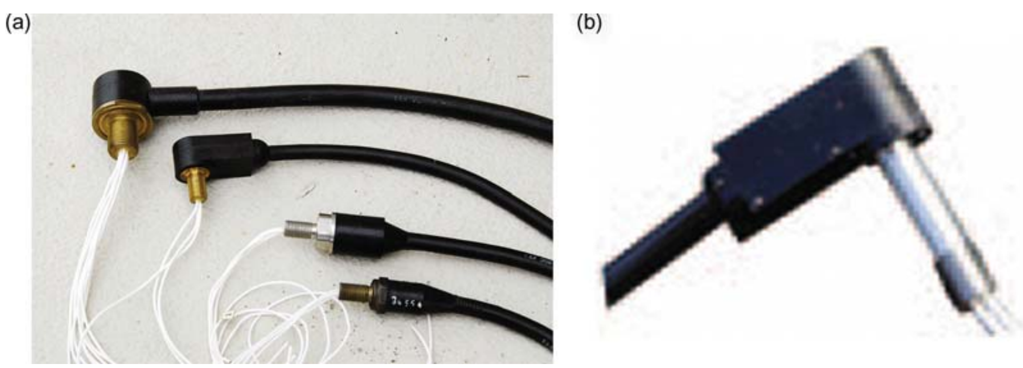
u0110 • Allows cable to enter an enclosure
u0115 • Splash proof.
u0120 • Not recommended for deep submerged use. Check with the manufacturer for depth recommendations.
u0125 • Not for dynamic applications where the cable will be flexed at the gland.

p0510 **Jumper**

p0515 A jumper (Figure 8.13) is a cable assembly with male to female connectors, much like a common household extension cord.

p0520 **Adapter cable**

p0525 An adapter cable (Figure 8.14) transitions from one connector type to another.



f0055 **FIGURE 8.10**

(a) Right angle and in-line penetrators with short threaded post for installation in threaded endcap (left).
(b) Right angle rubber molded with extended threaded post for use with internal draw-down nut (right).

(a) (Courtesy Ocean Innovations.) (b) (Courtesy MacArtney.)

f0060 **FIGURE 8.11**

Compression seal cable gland with strain relief.

(Courtesy Newmar.)

f0065 **FIGURE 8.12**

Compression cable gland, exploded view.

(Courtesy Conax Technologies.)

f0070 **FIGURE 8.13**

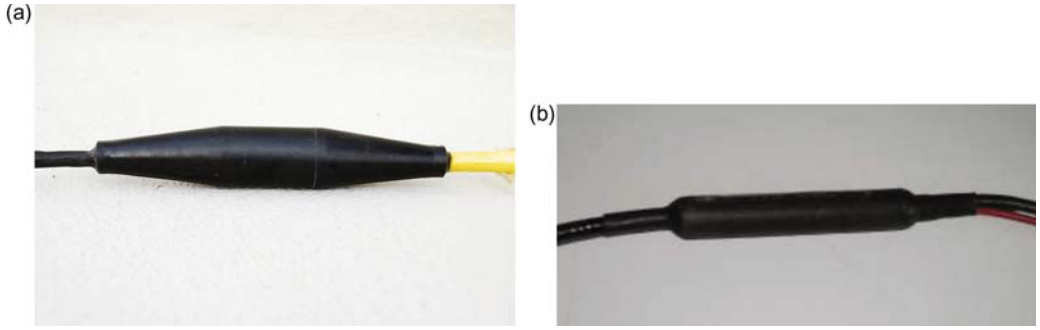
This jumper uses circular profile connectors on each end of an electrical cable.

(Courtesy Ocean Innovations.)

f0075 **FIGURE 8.14**

An adapter cable is a specialized double-ended jumper cable using different in-line connectors. A field installed cold splice is shown in the lower image.

(Courtesy Ocean Innovations.)



f0080 **FIGURE 8.15**

(a) A polyurethane-molded splice (left). (b) A vulcanized rubber-molded splice (right).

(Courtesy Ocean Innovations.)

p0530 **Barrel mold**

p0535 A barrel mold (Figure 8.15), a/k/a "Hot Dog" splice, is a cylindrical-shaped mold joining two or more cables together. There is very limited pull strength in a barrel mold joint.

p0540 **T-splice, Y-splice**

p0545 A T-splice and Y-splice are shown in Figures 8.16 and 8.17, respectively.

p0550 **Breakouts**

p0555 An example of breakouts is provided in Figure 8.18 where T-splices with short cables are terminated with in-line connectors for attachment to threaded post connectors intended for installation in separate pressure cases.

f0085 **FIGURE 8.16**

A T-splice of three cable segments (left).

(Courtesy Ocean Innovations.)

f0090 **FIGURE 8.17**

A Y-splice of three cable segments (right).

(Courtesy SeaCon.)

p0560 **Junction box**

p0565 A Junction Box, or “J-Box,” is a container for electrical connections. These may be enclosed within a 1 atm pressure proof housing or an oil-filled pressure compensated design operating at ambient pressure. Junction boxes (Figure 8.19) are used in place of hard-wired splices and Y-molds

f0095 **FIGURE 8.18**

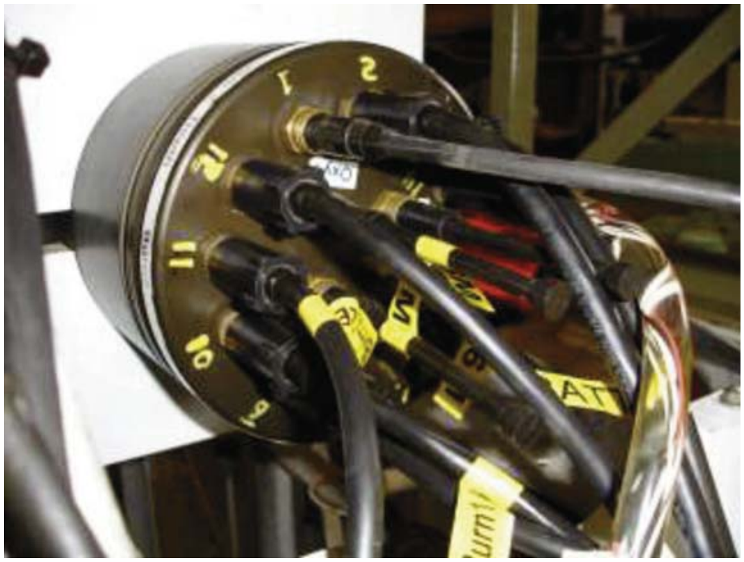
Main trunk cable with molded branches.

(Courtesy Ocean Innovations.)

because they are reconfigurable and easily serviced. They do, however, take up more space than a Y-mold.

p0570 **Field Installable Termination Assembly**

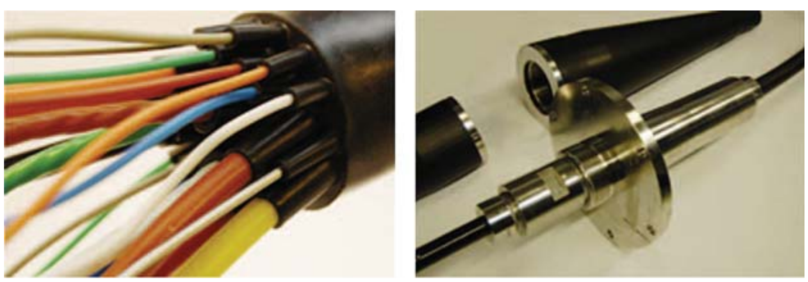
p0575 Unlike other termination assemblies, the field installable termination assembly (FITA) (Figure 8.20) can be assembled on site without the need for molding. The system joins two multi-conductor cables in a pressure compensated oil-filled environment. FITA terminations can be performed by trained operators on board, making it possible to repair broken cables without lengthy down time from sending the materials back for onshore repair.



f0100 **FIGURE 8.19**

An example of a junction box.

(Courtesy Ocean Innovations.)



f0105 **FIGURE 8.20**

FITA terminations.

(Courtesy MacArtney.)

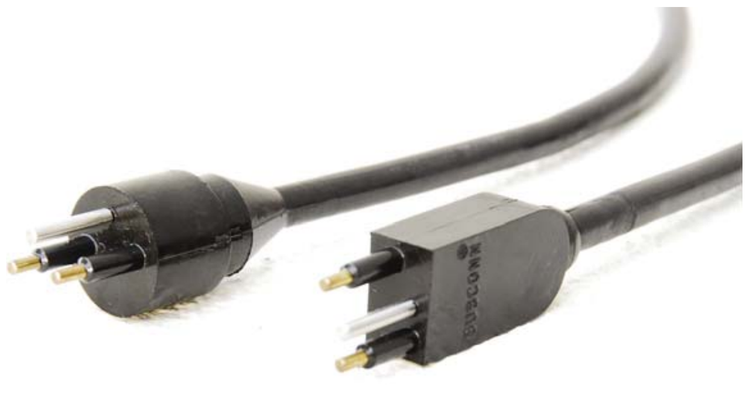
p0580 FITA terminations are often oil compensated, thus maintaining the same pressure inside the termination as outside. This allows operation at full ocean depth without the need for thick, heavy shells.

p0585 Because each conductor is isolated by an individual boot seal (should water ingress the oil-filled termination), it can still continue to operate fully flooded in saltwater. Boot seals have been successfully tested to 20,000 psi (1360 bar).

f0110 **FIGURE 8.21**

An epoxy or rubber insert (right) is soldered to wires, then overmolded with vulcanized rubber or polyurethane to produce the connector assembly (left).

(Courtesy Ocean Innovations.)



f0115 **FIGURE 8.22**

A stainless steel guide pin assures correct polarity alignment prior to mating.

(Courtesy Ocean Innovations.)

p0590 **Over-molding**

p0595 Over-molding (Figure 8.21) is a secondary molding operation.

p0600 **Guide pins**

p0605 Guide pins (Figure 8.22) are nonconducting pins used for alignment.

p0610 **Retaining devices**

u0130 Retaining devices include:

u0135 • Locking sleeves or lock collars (Figures 8.23 and 8.24)

u0140 • Straps (Figures 8.25 and 8.26)

p0630 **Strain reliefs**

p0635 Strain reliefs (Figures 8.27 and 8.28) transition the stress from the point where the cable meets the connector along a greater length of cable. These are also known as bending strain reliefs. Excessive flexing at the junction between the cable and connector is the most common failure mode of underwater connectors.

p0640 **Cable grips**

p0645 Cable grips transfer a load from the cable to another object (see Section 8.8.13).

p0650 **Strength ratings**

p0655 The following strength ratings apply to cables, terminations, cable grips, shackles, and handling equipment:

u0145 • BS, break strength or material yield

u0150 • SWL, safe working load

u0155 • Safety factor, BS/SWL and varies with application (e.g., manned versus unmanned)

f0120 **FIGURE 8.23**

(a) In-line locking sleeve pairs have matching internal and external threads and come in different sizes to fit different connector body sizes (left). (b) Locking sleeves may be color coded for circuit identification (right).

(Courtesy Ocean Innovations.)

f0125 **FIGURE 8.24**

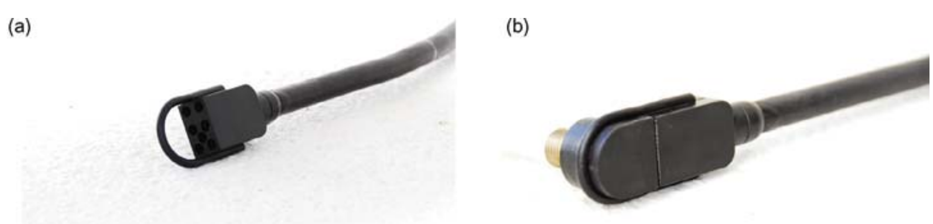
A single piece step locking sleeve (left) is installed before the connector is bonded to the cable. A snap ring locking sleeve (center and right) may be installed or replaced at any time. The snap ring may be subject to long-term corrosion.

(Courtesy Ocean Innovations.)

f0130 **FIGURE 8.25**

(a) Loose retaining strap (left). (b) Loose retaining strap installed (right).

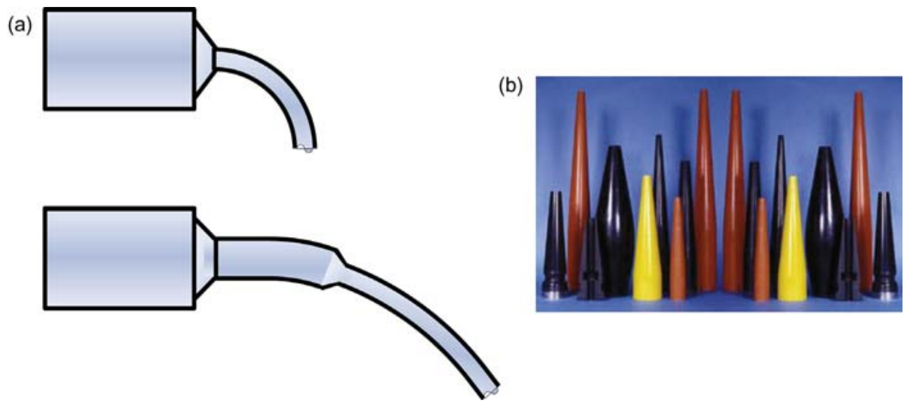
(Courtesy Ocean Innovations.)



f0135 **FIGURE 8.26**

(a) Molded in-place retaining strap (left). (b) Molded in-place retaining strap in use (right).

(Courtesy Ocean Innovations.)



f0140 **FIGURE 8.27**

(a) The molded connector (above left) has little strain relief and subsequently prone to wire breakage behind the connector body. The lower molded connector distributes the load over a greater length, resulting in longer service life (left). (b) Polyurethane-molded boot provides strain relief for any size cable (right).

(a) (Courtesy SeaTrepid.) (b) (Courtesy Ocean Innovations.)

f0145 **FIGURE 8.28**

Cable gland with strain relief.

(Courtesy Strantech.)

p0675 **Lubrication**

p0680 Lubrication is needed for o-rings and rubber surfaces. While opinions vary, the authors recommend the use of silicone grease such as Dow Corning DC-4 or DC-111 for the o-ring and 3M Food Grade Silicone Spray Lubricant for the connector body. Food grade silicone spray (Figure 8.29) is important as the propellants are noncorrosive.

p0685 **Dry versus wet mate connectors**

u0160 • Dry mate connectors must be mated in a dry environment before they are deployed.
u0165 • Underwater mateable/pluggable can be mated or demated underwater but with power off.

f0150 **FIGURE 8.29**

Dow Corning and 3M are well-known brands of silicone lubricants.

(Courtesy Ocean Innovations.)

u0170 • Wet mateable/pluggable can be mated or demated in a wet environment, such as on the deck of a ship, before they are submerged.

s0020 8.3 Applications and field requirements, writing specifications

p0705 Underwater system designers must answer the following questions in order to select the most appropriate connector for their application. The use of this selection criteria becomes the basis for the purchasing specification.

p0710 **Underwater connector selection criteria:**

o0245 **1.** Will the connector transfer power, signal, or both?
o0250 **2.** What is the expected deployment duration or system service life?

o0255 **3.** What is the expected operating service depth and design safety factor?
o0260 **4.** What are the expected environmental conditions? (cold, anaerobic, saline, etc.)
o0265 **5.** What is the available mounting space? Does it allow room for torque wrench installation?
o0270 **6.** Should the connector have seal or contact redundancy?
o0275 **7.** Must the connector mate to an existing system?
o0280 **8.** Must the connector retrofit to an existing installed connector?
o0285 **9.** Must the connector be underwater mateable? With power on?
o0290 **10.** Is the connector field serviceable? If so, what level of technician skill is necessary?
o0295 **11.** Are dissimilar materials present between the connector and housing (which may lead to unacceptable galvanic corrosion)?
o0300 **12.** Is the package designed to be handled in the field without danger of incidental damage to the connector?
o0305 **13.** What is the cable type to be wired and sealed to the connectors (i.e., twisted single pair, parallel bundle, coaxial, electromechanical (EM))? Are there construction fillers, jacket materials, molding, or other considerations?
o0310 **14.** Are there any MIL-SPEC requirements to be met? Are there any other special requirements to be met (i.e., fiber optic, neutrally buoyant, PBOF)?
o0315 **15.** Are locking sleeves or retaining straps an option?
o0320 **16.** Are there cost and delivery constraints?

p0795 Use of this checklist during the early design phase of a new underwater system will help the designer or program manager avoid predictable problems with these fundamental underwater system components. Work with the intended supplier as they want the project to be successful too. Retrofitting connectors on the backside of development and deployment can be a costly and complicated process.

s0025 8.4 Underwater connector design

p0800 A bulkhead connector passes electric signals or power across the pressure barrier. The bulkhead connector becomes an integral part of the pressure housing. Its selection is critical to mission success. A penetrator brings wires through without a demateable connector. A bulkhead connector does the same but provides the option of simple disconnect.

p0805 It is always a mechanical problem first; therefore, attention must first be paid to material selection. To avoid galvanic corrosion or delamination, match the housing and connector materials or select a nonmetallic body. Use of isolation washers has helped some designers mix materials, but there is still a potential for cathodic delamination. Material strength, cost, and availability are also important.

p0810 A mated in-line or bulkhead connector pair is itself a small pressure case. All pressure case design rules apply, including o-ring seal grooves. The *Parker O-Ring Handbook* (ORD-5700) is the unmatched, unquestioned authority on o-ring seal design. You would be aghast to find how many old connector designs fail to meet "*Parker spec*." See "References" at the end of this chapter to get a free copy of the *Parker O-Ring Handbook*.

p0815 *Metal shell* bodies use nonmetallic inserts or compression glass to electrically isolate pins from the body. The nonmetallic inserts may rely on an o-ring for sealing against open face pressure. This may require servicing at some point.

p0820 *Epoxy* connectors are a good choice for medium depth. Their greatest weakness is to side loading. A means of protecting the cable (attached to the epoxy connector) from being pulled, especially against side loads, is an important consideration. This may be as simple as black taping it to the ROV frame.

p0825 Electrical contacts are selected for power, considering the anticipated voltage and current requirements. The mechanical design should prevent the engagement of the pin and socket before the key−keyway engages. Sharp interior edges, such as on a keyway, should be recessed from any radial o-rings. Contacts passing through epoxy bulkhead connectors must be primed to assure good bonding for open face pressure.

p0830 Weaknesses in epoxy connectors include susceptibility to damage from side loads, flammability in the event of high-voltage shorting of pins, and exposed contacts inside the female receptacle. Water retained behind the radial seal of the male connector plug when vertical can drip onto the exposed pins as the plug is retracted.

s0030 8.5 COTs underwater connectors

p0835 Commercial-off-the-shelf (COTS) underwater connectors come in a wide variety of standard configurations for both electrical and fiber-optic conductors. These “standards” can be classified into the following generic categories:

p0840 **Rubber-molded connectors**

p0845 These are molded, typically in Neoprene, in a number of different configurations including straight, right angle, miniature, and others. They can be capable of high pressures and are typically low cost. They can be cleanly and inexpensively molded onto jacketed cables and are easy to use.

p0850 One of the oldest rubber-molded connector designs is known by the initials of its original manufacturer, Electro-Oceanic. EO connectors (Figure 8.30) are available from several manufacturers with 2−8 contacts and are rated to 10,000 psi (690 bar) or more. Electrical rating per contact is 115 V/6.5 A or 230 V/15 A.

p0855 A vent hole to the exterior in the electrical socket allows EO connectors to be mated or unmated at any depth, though not with power on. The male pins each have two circular contact bands on them. The male pins are flared at the tip and are oversized to the inside diameter of the female socket. This insures a wiping action and positive seal by forcing water through the length of the female socket and out the vent.

p0860 SubConns (manufactured by SubConn), Wet Cons (manufactured by SeaCon), or Wet Pluggables (manufactured by Teledyne Impulse) are among the most popular types of rubber-molded connectors (Figure 8.31). These are available with 1−25 contacts. The female receptacles have one or more rings molded into them that seal to the pins on the mating plug. Keep in mind, the more contacts, the more force required for mate/demate. Also, as the number of contacts increase, the outer pins are more susceptible to demating (loss of electrical connection) should the connector experience side loading. Variations of these connectors have been used to ocean trench depths.

f0155 **FIGURE 8.30**

Examples of EO-style connectors.

(Courtesy Ocean Innovations.)

f0160 **FIGURE 8.31**

Rubber-molded connectors are among the most popular of underwater connectors.

(Courtesy MacArtney.)

p0865 **Epoxy-molded connectors**

p0870 Rigid epoxy compounds add greater strength and dimensional control to molded connectors. These assemblies perform well at pressure and are moderately low priced. Some still call this style "Marsh Marine connectors," referring to the original manufacturer of these first commercial underwater connectors.

p0875 **Rubber molded to metal bodies**

p0880 By molding a rubber connector into a metal body, greater strength and stability are added to the product along with positive and stronger keying and locking. The connector is more robust and able to withstand more abusive environments. This configuration is often implemented as a metal-bodied bulkhead mating to a rubber-molded plug connector.

p0885 **Metal shells with molded inserts**

p0890 Molded connector inserts can be o-ring sealed into mating metal shells. This configuration offers secure o-ring sealing technology and isolation of the connector elements from the working environment. They are available in a wide variety of sizes and with a large range of inserts at moderate cost.

p0895 **Metal shells with glass-to-metal seal inserts**

p0900 Electrical contacts can be glass sealed into metal inserts for more demanding applications of pressure and temperature. In addition, they can withstand high open face pressures. Because elastomeric seals are not used, these connectors do not typically degrade over time, making them popular in military applications where long-term high reliability is crucial. Due to their tolerance to high temperature, glass-to-metal seal connectors are also common in down-hole applications. Due to the sophisticated manufacturing process, glass-to-metal seal connectors are moderately expensive.

p0905 **Fluid-filled underwater mateable**

p0910 This style of connector is typically a PBOF assembly incorporating redundant sealing barriers to the environment. This enables the connector to be wet mated by an ROV. Available in electric, optic, hybrid configurations and in high voltage and/or high amperage models, they are often used in offshore oil & gas installations as well as the nodes of ocean observatories. Fluid-filled underwater connectors are at the high end of the cost spectrum.

p0915 **Penetrators**

p0920 Where systems do not need to be rapidly disconnected, a penetrator may serve as a cable termination and interface to equipment modules. Penetrator construction follows roughly the same configurations as mentioned above for connectors.

s0035 8.5.1 Mated pairs

p0925 *Mated pairs* are the assembly created by combining matching halves of a connector combination. In hard shell connectors (both metallic and epoxy), there is an engagement sequence that is followed. An alignment mark assists with initial orientation. Following that, the engagement sequence should follow the pattern: Plug in Bore, Key aligns with Keyway, Pins and Sockets engage, Locking Sleeve installed, final tightening to set face seal.

p0930 **Retention**

p0935 Once mated, the connector pair should be sufficiently restrained to avoid inadvertent disconnect due to stresses on the cable and connector. Retention mechanisms range from simple friction devices to screwed collars and latches.

p0940 *Locking sleeves* are used to prevent the mated pair from accidental disconnection. Locking sleeves are made from Delrin, stainless steel, or glass-filled Nylon. Nylon 6/6 alone is hygroscopic and will swell with constant immersion in water, resulting in disengagement of the locking sleeve threads.

s0040 8.5.2 Advanced designs

s0045 *8.5.2.1 Recent trends and future developments*

p0945 **Miniaturization**

p0950 Introduction of smaller versions of many standard connectors and new designs for lower power electronic systems has been recently introduced (Figure 8.32).

p0955 **High-speed data connectors**

p0960 Specialized connectors are available for Ethernet communications with data rates of up to 1 GB/s (Figure 8.33).

p0965 **Smart connectors**

p0970 Three unique approaches to smart connectors may be seen with the Schilling SeaNet Connector, MBARI PUCK, and Integral Data Converters.

u0175 *Schilling SeaNet connector*

Concentric circular contacts allow this connector (Figures 8.34 and 8.35) to be rotated to change orientation so the cable exits in the desired direction during final assembly. The design is *not* intended for a rotary application in the manner of a slip ring. Internal indicator lights provide visual feedback of power and data status. The PBOF design makes it usable at any depth.

f0165 **FIGURE 8.32**

Micro connector series take up less space.

(Courtesy MacArtney.)

f0170 **FIGURE 8.33**

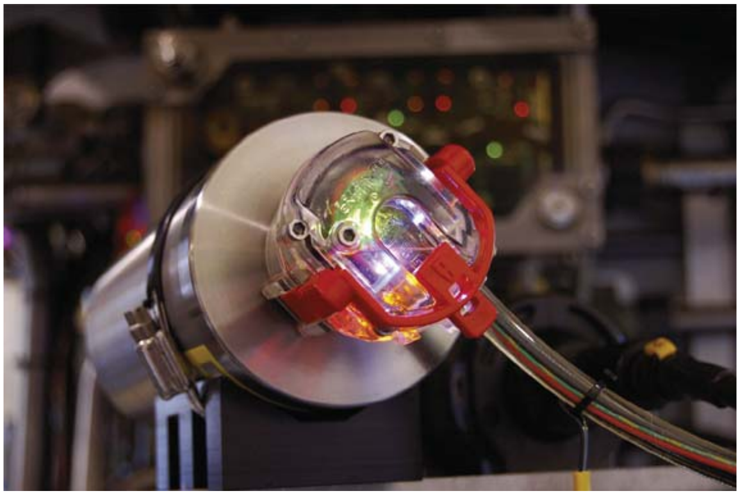
Example of a high-speed Ethernet data connector.

(Courtesy MacArtney.)

f0175 **FIGURE 8.34**

The Schilling SeaNet Connector installed on a manipulator.

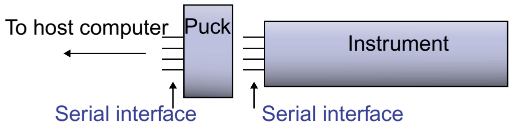
(Courtesy Schilling.)



f0180 **FIGURE 8.35**

Schilling SeaNet Connector indicator lights provide feedback on operation.

(Courtesy Schilling.)



f0185 **FIGURE 8.36**

MBARI PUCK schematic design.

(Courtesy MBARI.)

u0180 *MBARI PUCK*

Monterey Bay Aquarium Research Institute (MBARI) developed the Programmable Underwater Connector with Knowledge (PUCK). The MBARI PUCK (Figure 8.36) has the advantages of being a simple, small storage device and stores instrument-related information (e.g., unique ID, instrument driver, other metadata). Instrument information is automatically retrieved by the host computer when the puck and instrument are plugged into the host.

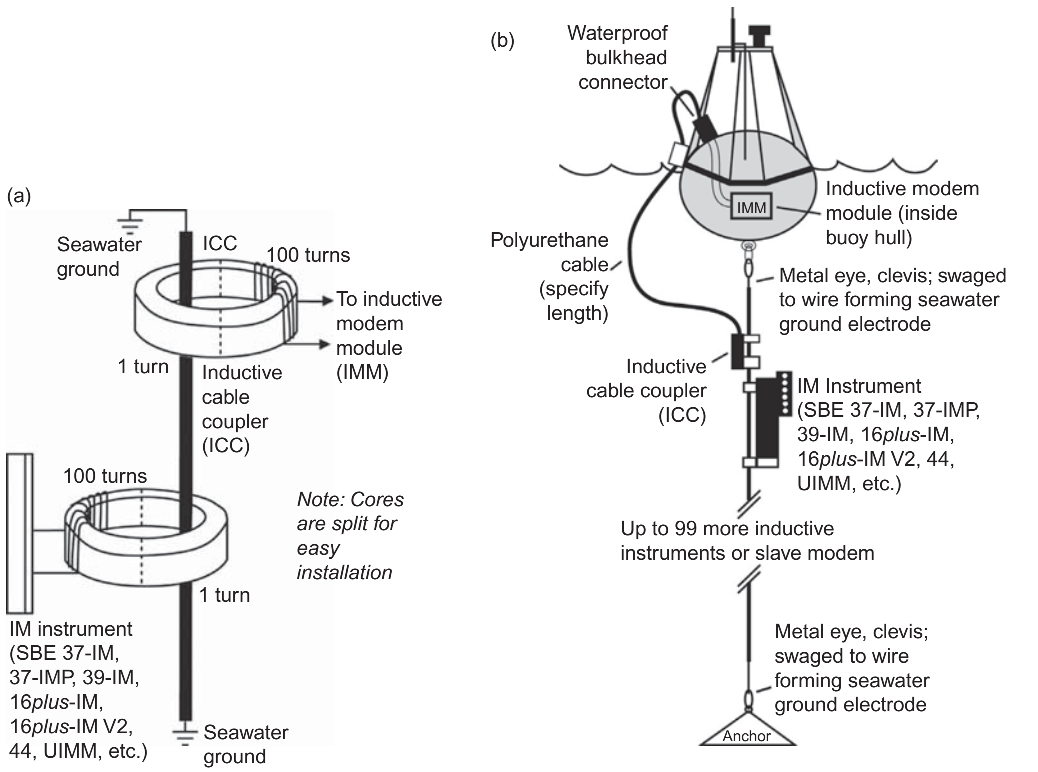
u0185 *Integral data converters*

Solid-state convertor electronics are pressure tolerant and can be built into a connector or a splice. The convertor transitions electric to optical, serial to Ethernet, or RS-232 to RS-485.

p1005 **Connectorless data transfer**

p1010 Data noncontact connections include:

u0190 • Inductively Coupled Modem
u0195 • BlueTooth (Wi-Fi)



f0190 **FIGURE 8.37**

(a) SeaBird inductively coupled modem detail (left). (b) SeaBird inductively coupled modem installed (right).

(Courtesy SeaBird Electronics.)

u0200 • Optical Infrared (IR)
u0205 • Acoustic Modems
u0210 • RF

u0215 *Inductively coupled modem*

An example of this design is the SeaBird inductively coupled modem (Figure 8.37). This device uses a plastic jacketed wire rope mooring cable to transmit data.

u0220 *Wi-Fi*

One design team at MBARI selected the 2.4 GHz RF (Wi-Fi) as its subsea communications device. The team modified and tested the Whip, Patch, and Helical antenna designs, selecting the whip as the most effective. The resultant system provided 9.8 Mbps over the few-centimeter gap between spheres underwater (Figure 8.38).

u0225 *Optical data transmission*

Using technology adapted from free space optics (Figure 8.39), underwater optical data transmission can achieve data rates of up to 100 mbps at distances up to 130 ft (40 m). Transmission range is highly dependent on water clarity, including turbidity and biomass.

f0195 **FIGURE 8.38**

MBARI tests bluetooth between glass spheres.

(Courtesy MBARI.)

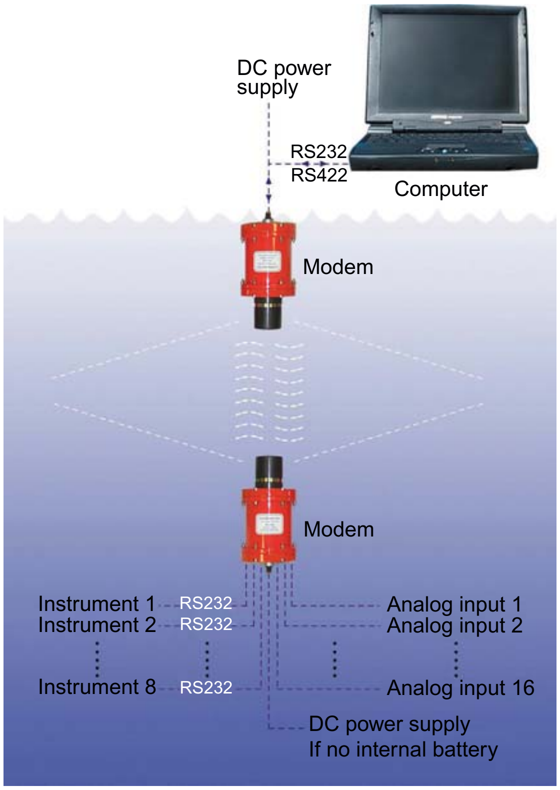
f0200 **FIGURE 8.39**

Ambalux Optical Data Transmission system in a test tank.

(Courtesy Ambalux.)

u0230 *Infrared*

Through an optical coupler, sapphire plate or borosilicate sphere, designers can utilize IR for data and control signal transfer. One example is the IRTrans Wi-Fi, which provides a USB, an RS-232, or an Ethernet interface. The system includes both an Infrared Transmitter and Receiver.



f0205 **FIGURE 8.40**

LinkQuest acoustic modem connection diagram.

(Courtesy LinkQuest.)

u0235 *Acoustic modems*

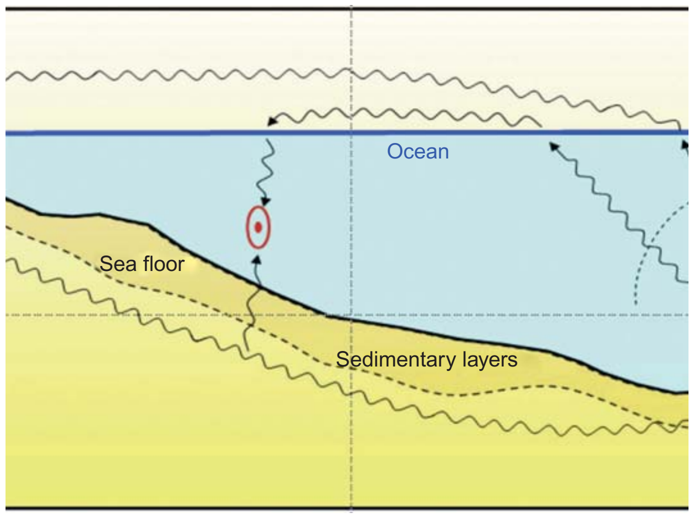
Acoustic modems (Figure 8.40) are commercially-available from several vendors, providing reliable and long-range data rates up to 38.4 kb/s. Characterization of the water path is needed for higher data rates. Changing environmental conditions may also affect data rates.

u0240 *Radio frequency*

Wireless Fiber Systems (WFS) has demonstrated RF systems (Figure 8.41) that provide data rates of up to10 Mb/s at very close ranges (1−2 m), decreasing to 10 bps at longer ranges. Longer ranges are possible in freshwater, or through a ground path. An air path is also possible under site-specific conditions. Unlike acoustical and optical communications, transmission through water is not affected by bubbles, thermal stratification, ambient noise or turbidity.

p1100 **Connectorless power transfer**

p1105 An Inductive Recharge System (Figure 8.42) developed by Florida Atlantic University (FAU) is up to 88% efficient, operating at 4.25 kHz. The unit can transfer up to 1000 W, 0−70 V, 0−30 A.



f0210 **FIGURE 8.41**

RF transmission occurs through water, ground, and air.

(Courtesy Wireless Fiber Systems.)

s0050 8.6 Reliability and quality control

p1110 A design starts with engineering, then proceeds to manufacturing. The two departments work together in the product development phase. Quality Control (QC) is an independent department that assures the part is made as it was designed. Quality is not added by the QC Department, only validated.

p1115 Production Quality Assurance (QA) involves mechanical tests including visual, dimensional, and pressure testing. Electrical tests are done where appropriate, including Hi-pot, conductivity, and Megger (see Section 8.9 below). They may also perform environmental tests such as shock, thermal, suspended material, and corrosion tests.

s0055 8.7 Field maintenance

p1120 With seals in general, "*Cleanliness is next to Godliness*." The wise technician will put together a field kit containing:

o0325 **1.** Spare o-rings (with replacement use chart)
o0330 **2.** Wood or plastic toothpicks or brass picks, as supplied by Parker Seal, for o-ring removal
o0335 **3.** Lint-free wipes
o0340 **4.** Isopropyl alcohol

f0215 **FIGURE 8.42**

(a) The FAU "Flying Plug" inductive recharge aystem (left). (b) The FAU Inductive Recharge system engaged (center). (c) WFS Inductive Power Link (right).

(a) and (b) (Courtesy FAU-OE.) (c) (Courtesy Ocean Innovations.)

o0345 **5.** Silicone grease
o0350 **6.** Silicone spray, food grade

p1155 When applying silicone grease to the o-ring, remember that grease does not seal. Go light.

p1160 Always carefully inspect o-rings and mating surfaces for defects.

p1165 Clean dirt off with soap and water (deionized or distilled). Alternatively use isopropyl (rubbing) alcohol. Use cotton swabs on female contacts. If contacts are tarnished, try using white vinegar.

Oxidation may be removed from male contacts by using #800 wet/dry emery paper cut in strips equal to or less than the width of the contact and rubbing lightly. For female contacts use a 0.22 caliber bore brush with nylon bristles.

p1170 **O-rings: inspection**

p1175 Carefully inspect o-rings before every use. O-rings on a bulkhead connector body only need to be checked when the connector is removed from the housing.

p1180 Remove the o-ring from the recessed groove where they may be inspected. Wooden toothpicks are a safe way to remove an o-ring without the fear of damaging the o-ring groove. Never use dental picks, awls, safety pins, or other steel objects for removing o-rings! These materials with higher hardness values can easily damage the surface of the groove, the o-ring, or both.

p1185 One at a time, run each o-ring between your fingers and feel for any dirt or foreign material. You should also feel a thin film of silicone lubricant on the o-ring. This provides lubricity for the o-ring to slide under pressure into its final sealing position and helps keep the o-ring flexible. If you feel dirt or grittiness, clean the o-ring. The surface should be smooth, continuous, and clean. If not, replace it with a new o-ring. "*When in doubt, throw it out.*"

p1190 Inspect for roundness. Some o-rings cold flow and flatten, reducing the compression needed for a good seal. Stretching the o-ring slightly can reveal nicks and cuts and indicate loss of elasticity as evidenced by lack of re-bound.

p1195 Carefully inspect the recessed groove as well. There should be no foreign material there. Dirt, hair, sand, salt crystals, or any material that is not silicone lube for the o-ring means you will need to clean both the o-ring and the groove. Remove any excess silicone grease as too much grease can prevent the o-ring from properly seating, resulting in a leak path.

p1200 **O-rings: cleaning**

p1205 For o-ring cleaning you will need lint-free wipes, such as Kimwipes, isopropyl alcohol, and Q-Tips. Holding the cloth in your hand, grab the o-ring and gently pull it through the cloth. Pull the entire loop through several times until all the foreign material has been removed and the silicone lubricant is gone. Once again inspect the o-ring under good lighting as described above, since imperfections, such as cuts or nicks, may be seen more easily without the silicone lubricant coating.

p1210 Using a Q-Tip or the lint-free cloth, thoroughly clean the recessed groove. Press the Q-Tip deeply into the groove to access corners and remove residual silicone.

p1215 After the groove has been cleaned, inspect for and remove any cotton fibers that may have been shed from the Q-Tip.

p1220 **O-rings: lubrication and installation**

p1225 Now you are ready to lubricate the o-rings. For this you will need pure silicone lubricant or silicone grease.

p1230 Put a small amount of silicone between your thumb and forefinger, then run the entire loop of the o-ring between your fingers several times. You need to coat the entire surface of the o-ring with a thin film of lubricant. The lubricant film should be thin, uniform, completely cover the o-ring and have a "wet" feel.

p1235 Place or stretch the o-ring back into its recessed groove and be sure it is well seated. Give the o-ring one last look for hair or other dirt that may have fallen on your work.

p1240 If you do not need to service an o-ring, it is best to leave it undisturbed. A sealed o-ring will remain so unless disturbed (such as cleaning).

s0060 8.8 Underwater cable design

p1245 ROVs require a cable to handle both electrical and mechanical functions. The EM cable transfers the mechanical loads, power, and/or communications between the ship and the vehicle. It must be possible to spool the EM cable out and in over and around sheaves and drums, be directed by a cable lay system, and operate in the intended environment. Interconnect cables inside the vehicle transfer power and signal between components.

p1250 It is important to know the operating environment the cable will be in: AU:2

- u0245 Depth
- u0250 Duration
- u0255 Temperature
- u0260 Salinity
- u0265 Suspended particulate matter
- u0270 Water chemistry
- u0275 Anaerobic condition
- u0280 Current profile

p1295 Some advanced ROVs carry their own power sources and only require a communication link to the surface vessel through an expendable fiber-optic microcable.

p1300 Most ROVs therefore have three general categories of cable to consider: umbilical cable, tether cable, and interconnect cable. Umbilical and tether cables are EM cables, containing the strength, power, and signal components. Interconnect cables seldom carry mechanical load and have only power and signal components in their construction.

p1305 The diameter of the cable is the dominant factor in overall vehicle drag. Therefore, minimizing cable diameter is an important part of ROV design and operation.

s0065 8.8.1 Umbilical and tether cables

p1310 The umbilical cable connects the ship to the ROV or TMS, while the tether cable connects the TMS to the ROV. The umbilical cable is generally steel jacketed, while the tether cable uses synthetic fibers to maintain neutral buoyancy. Use of a low-density jacket may help offset the negative weight of copper wire.

p1315 Initial cable design considerations include: (i) power requirements, (ii) signal requirements, and (iii) strength and weight requirements.

p1320 The power and signal requirements are usually the most important considerations because the cable's primary purpose is to transmit power to the ROV and return signals from it. However, the strength and weight are also important considerations. Therefore, a proper solution to designing an ROV cable requires a concurrent view at these multiple variables.

s0070 8.8.2 Power requirements

p1325 Transferring electrical *power* through a cable involves four factors:

- u0285 Voltage
- u0290 Phase

u0295 • Amps
u0300 • Duration

p1350 Transmitting electrical *signals* through a cable involves a different four factors:

u0305 • Frequency
u0310 • Bandwidth
u0315 • Impedance
u0320 • Capacitance

p1375 When determining the power ($P = IE$) a cable can transmit, it all comes down to amperes. The current capacity of a particular wire gauge does not reference volts. Thus, to increase power down a given size wire, a designer needs to step-up the voltage as current is fixed. For each ampere it is necessary to have enough material to conduct the power to the far end. Most conductors have resistance to electrical energy flow. This creates a voltage drop, and it is necessary to keep this value as small as possible to provide power to the source. Therefore, it is necessary to use material with as low a resistance as possible.

p1380 The most common material for providing power through a cable is copper. The most common form for electrical cable conductors in ROV cables is electrolytic tough pitch copper with a tin coating. Other coatings are available for special purposes, but most increase the resistance to electrical current. Oxidation of bare copper makes terminations more troublesome.

p1385 Another consideration is insulation on the conductors to contain the electrical energy. There are two general *insulation* families: thermoplastic and thermoset.

p1390 Thermoplastic is a material that repeatedly softens or melts when heated and hardens when cooled. Some examples are as follows:

u0325 – Polyethylene (PE)
u0330 – Polypropylene (PP)
u0335 – Polyvinyl chloride (PVC)
u0340 – Polyurethane (PUR)
u0345 – Nylon
u0350 – Fluorocarbons (Tefzel™ & Teflon™)

p1425 A Thermoset material reacts to heat, changing forever into its final molecular form.

p1430 Some examples are as follows:

u0355 – Cross-linked PE (XLPE)
u0360 – Chlorosulfonated PE (Hypalon™)
u0365 – Chlorinated rubber (Neoprene™)
u0370 – Ethylene propylene rubber (EPR)
u0375 – Ethylene propylene diene rubber (EPDM)
u0380 – Styrene butadiene rubber (SBR)

p1465 ROV cables usually use thermoplastic materials. They process easier than thermoset materials and thermoplastics cover a broad range. Thermoset materials require special processing equipment. However, because thermoplastics soften or melt with heat, it is important to know both the operating environment and the current requirements. The cable designer needs to look at all these parameters in choosing the proper material.

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p1470 The operating voltage is another consideration in the cable design. It is important to limit voltage stress on the insulation. If this is too high it can cause the insulation to fail and the electrical energy to exit the conductor before it reaches its objective, which can (to say the least) create a hazardous condition. Further, should the insulation breakdown (through damage or some other mechanism) and a ground fault develop, the flash grounding could produce an instantaneous high-temperature arching thus melting through all parts of the tether. This converts a tethered vehicle to an (expensive) untethered (and unpowered) floating/sinking vessel. This is not comical as it happens all too often. Therefore, it is important for the cable design to address the insulation voltage stress. Also, a separate conductor for an emergency ground is common as a safeguard in case there is a breakdown in the insulation.

s0075 8.8.3 Signal requirements

p1475 The signal requirements translate to attenuation losses. The signal, whether electrical or optical, attenuates through both the conductor and the insulator. This loss varies with both the signal transmission media and the frequency.

p1480 Signal transmission can be either analog or digital and either electrical or optical. The system usually dictates the signal transmission type. It is important for the cable designers to understand the media and as many parameters about the signal transmission as possible so they can select the proper conductor for the signals.

p1485 Copper conductors with thermoplastic insulation are also common for electrical signals, similar to power conductors. Signal transmission wires frequently require a shield from electromagnetic interference and radio frequency interference. Also, it is common to group the signal transmission wires separate from the power conductors.

p1490 As more fully explained in Chapter 13, there are both balanced and unbalanced electrical transmission schemes, and the system determines this requirement. Typical balanced lines are twisted pairs, and unbalanced lines are coaxial.

p1495 You can also transmit signals over optical fibers. Fiber optics come in various types:

u0385 – Multi-Mode
u0390 – 50/125
u0395 – 62.5/125
u0400 – Single-Mode
u0405 – Dispersion shifted
u0410 – Nondispersion shifted

p1530 The system requirements determine the optical fiber type. Some parameters to consider in any type fiber optic are as follows:

u0415 – Attenuation
u0420 – Bandwidth
u0425 – Wavelength

p1550 There are different ways to package the fiber optics in a cable: AU:3

u0430 – Loose-tube buffer
u0435 – Tight-buffer

p1565 The optical fibers can have either an individual buffer on each fiber optic, or they can have a common housing for all the optical fibers. The user will need to weigh the trade-off with the different approaches for the specific application because there is no single design that is correct for all applications.

p1570 Several standard cable design specification sheets follow throughout this section and are representative of state-of-the-art cables provided to the offshore industry by Falmat. A successful innovator in the ROV cable industry, they have been designing, manufacturing, and testing such cables for over 25 years.

s0080 8.8.4 Strength requirements

p1575 The strength member provides the mechanical link to the ROV. It usually has to support the cable weight, the ROV and any additional payload, and handle any dynamic loads. Also, the cable size can influence the load on the cable due to drag. Therefore, there are many variables to consider when choosing the cable strength.

p1580 Mechanical strength of a cable must consider:

u0440 • (Anticipated) working load
u0445 • Maximum peak dynamic load
u0450 • Minimum bend radius/diameter
u0455 • Expected cycle-life performance

p1605 The cable design must also consider the handling system (see Chapter 9), including:

u0460 • Deployment/retrieval scheme
u0465 • Drums, sheaves, and level wind, which may have restrictive bend radii
u0470 • Heave/motion compensation

p1625 Steel is the most common strength member material for umbilical cables. This material is usually a carbon steel wire with a galvanizing coating on the outside to protect the steel from corrosion. This material's tensile strength, modulus, and abrasion resistance protect the cable from damage in service. Typically, an ROV umbilical will be double helix wrapped (in opposing directions) to balance torque under load, thereby reducing the umbilical's tendency to rotate as it is payed out and taken up.

p1630 Synthetic fibers, such as Kevlar™ from DuPont and Spectra™ (UHMWPE or ultra-high-molecular-weight polyethylene) from Honeywell can reduce weight. Synthetic fibers are frequently necessary in tether cables and also in umbilical cables for deepwater systems. Synthetic fiber strength members usually require an overmolded or woven outer jacket, such as Dacron™, for abrasion resistance. A synthetic strength member is generally more expensive than steel, but the weight difference is significant. In many cases, this is the only way to get to the necessary depth. For very deepwater applications, the in-water weight of a steel umbilical will be beyond the support steel's tensile strength required to support its own weight—much less the weight of the vehicle–TMS combination.

p1635 There are reasons to consider both strength member materials for different applications; these issues should be discussed with your cable manufacturer.

s0085 8.8.5 Construction

p1640 Designers must consider the mission requirements, including:

- u0475 Power, signal (copper or fiber), strength, water weight
- u0480 Torque balanced
- u0485 Cross talk (shielded conductor, twisted pairs)
- u0490 Need for neutral buoyancy
- u0495 Water blocked
- u0500 Flexing, including bend-over-sheave and minimum bend radius

p1675 If no COTS alternative is available, a designer has choices of how to proceed with a custom cable, including:

- u0505 Modifying a COTS cable
- u0510 Adapting a similar design
- u0515 Creating a completely custom design

p1695 Some alternative ways to modify a COTS cable include:

- u0520 Bundle multiple COTS cables together
- u0525 Add water blocking to increase the depth rating
- u0530 Add an overbraid strength member to support mechanical loads
- u0535 Add a flotation jacket to reduce water weight

p1720 The common ways to modify a similar design include:

- u0540 Minor modifications such as:
  - u0545 Improve electrical/mechanical performance
  - u0550 Different strength member and/or location
  - u0555 Add a flotation jacket to reduce cable weight in water
  - u0560 Create a completely custom design
- u0565 Designers can optimize cable performance by:
  - u0570 Using smaller AWG than standard COTS cable
  - u0575 Manufacture special performance components
  - u0580 Adjust weight and diameter to suit application
  - u0585 Use special materials to increase the operating temperature range
  - u0590 Use nonstandard twist rates to maximize flexibility

s0090 8.8.6 Cable design methodology

p1780 Designing a cable requires the engineer to identify the unique system requirements, including:

- u0595 Length or depth minimums
- u0600 Electrical or optical requirements
- u0605 Strength or dimensional limits
- u0610 Existing cable handling system restrictions, including bend radius
- u0615 Temperature and other environmental conditions

p1810 A designer should investigate all potential cable design solutions, including:

- u0620 Cable designs for similar applications
- u0625 Modify a similar application cable construction
- u0630 Modify a COTS cable
- u0635 Design a unique EOM cable specifically for the application
- u0640 Review the cable design solution to ensure it satisfies the requirements
- u0645 Manufacture a prototype and/or production cable design

p1845 As noted above, a custom cable design can provide variations in:

- u0650 conductor materials and strand numbers,
- u0655 insulation materials,
- u0660 jacket/sheath materials and construction, and
- u0665 the strength member.

s0095 8.8.7 Conductors

p1870 Conductors are the heart of the electrical cable (Figure 8.43). The most common wires are as follows:

- u0670 Copper
  - u0675 Tin-plated copper provides the best soldering and availability and is the most common material used in ROV cables.
  - u0680 Bare copper provides for lowest DC resistance at the termination, but surface oxidation creates problems with soldering, while availability is poorer.
  - u0685 Silver-plated copper is the best choice for higher temperature and signal frequency but comes at a higher cost and longer lead time
- u0690 Stranding (Figure 8.44)
  - u0695 Use solid wire for non-flexing applications only
  - u0700 Higher number of strands provides greater flexing

s0100 8.8.8 Insulation

p1910 As noted above, there are two families of insulation materials: thermoplastics and thermoset plastics. Materials vary on cost, operating temperature range, insulation value, and bonding ability (Figures 8.45 and 8.46).

s0105 8.8.9 Jacket/sheath

p1915 The *sheath* is the inner core wrapping that binds the cable assembly together prior to extruding the outer jacket. Materials widely used include:

- u0705 Polyolefin (PE and PP)
- u0710 Polyurethane
- u0715 Thermoplastic elastomer (TPE)

Copper Conductor Data

The conductors used by Falmat Wire meet the applicable requirements of ASTM specifications B-3, B-33, B-172, B-173, B-174, and B-286 and Federal Specification QQ-W-343.

The following data covers the more commonly used conductor constructions in the electrical electronics industry. Special constructions, not shown, are available or can be designed to meet specific requirements. It is suggested that the Falmat Wire product engineering department be contacted before a specification is finalized.

									D. C. Resistance 20°C[2]			
		Type	Diameter[4]		Area		Weight		Tin Coating[3]		Bare or Silver Coating	
AWG	Stranding	Stranding[1]	in.	mm.	circ. mils	sq. mm.	lbs./M'	kg./km.	ohms/M'	ohms/km.	ohms/M'	ohms/km.
32	7/40	Co or Bu	.0096	.254	100	.051	.21	.31	176	577	–@	–
30	Solid	–	.010	.254	100	.051	.30	.45	113	371	104	340
	7/38	Bu	.012	.305	112	.057	.35	.52	106	348	92.6	303
28	Solid	–	.01264	.321	159	.081	.48	.72	70.8	232	65.3	214
	7/36	Co	.015	.381	175	.089	.55	.82	67.5	221	59.3	194
27	Solid	–	.0142	.361	202	.102	.61	.91	55.6	182	51.4	169
	7/35	Co or Bu	.017	.432	220	.111	.69	1.04	53.8	176	–	–
26	Solid	–	.016	.404	253	.128	.77	1.14	44.5	146	41.0	135
	7/34	Co or Bu	.019	.483	278	.141	.87	1.29	42.5	139	37.3	122
	10/36	Bu	.0193	.490	250	.127	.78	1.15	47.3	155	40.4	133
	19/38	Bu or Co	.021	.533	304	.154	.97	1.44	38.9	128	34.1	112
24	Solid	–	.0201	.511	404	.205	1.22	1.82	27.2	89.2	25.7	84.2
	7/32	Co or Bu	.024	.610	448	.227	1.38	2.05	25.7	84.2	23.1	75.9
	16/36	Bu	.024	.610	400	.201	1.25	1.64	29.5	96.8	27.5	90.2
	19/36	Co or Bu	.025	.635	475	.241	1.48	2.20	24.9	81.7	21.8	71.6
22	Solid	–	.025	.643	643	.324	1.94	2.89	16.7	54.8	16.2	53.2
	7/30	Co or Bu	.030	.762	700	.355	2.19	3.26	16.6	54.4	14.8	48.6
	19/34	Bu or Eq	.0315	.800	754	.382	2.35	3.50	15.5	50.8	13.8	45.1
20	Solid	–	.032	.813	1,020	.519	3.10	4.61	10.5	34.4	10.1	33.2
	7/28	Co or Bu	.038	.965	1,111	.562	3.49	5.19	10.3	33.8	9.33	30.6
	10/30	Bu	.037	.940	1,000	.507	3.14	4.67	11.4	37.4	10.4	34.0
	19/32	Co, Bu or Eq	.040	1.02	1,216	.616	3.84	5.71	9.48	31.1	8.53	28.0
	26/34	Bu	.039	.940	1,032	.523	3.28	4.88	11.3	37.1	–	–
19	Solid	–	.0359	.912	1,290	.653	3.90	5.80	–	–	8.05	26.4
18	Solid	–	.0403	1.024	1,620	.823	4.92	7.32	6.77	22.2	6.39	21.0
	7/26	Co or Bu	.048	1.22	1,770	.897	5.55	8.26	6.45	21.2	5.55	19.2
	16/30	Bu	.0475	1.207	1,600	.810	5.01	7.45	7.15	23.4	6.48	21.3
	19/30	Co, Bu or Eq	.050	1.27	1,900	.963	5.95	8.85	6.10	20.0	5.46	17.9
	41/34	Bu	.049	1.244	1,627	.824	5.09	7.08	7.08	23.2	6.60	21.6
16	Solid	–	.0508	1.29	2,580	1.31	7.81	11.6	4.47	14.7	4.16	13.6
	19/29[4]	Bu or Eq	.057	1.45	2,426	1.23	7.52	11.2	4.82	15.8	4.27	14.0
	19/.0117	Bu	.0585	1.50	2,601	1.32	8.02	11.9	4.39	14.4	4.13	13.5
	26/30	Bu	.0606	1.54	2,600	1.32	8.15	12.1	4.39	14.4	3.99	13.1
	65/34	Bu	.060	1.52	2,581	1.31	8.20	11.9	4.47	14.7	4.16	13.6
14	Solid	–	.0641	1.63	4,110	2.08	12.4	18.5	2.68	8.79	2.52	8.28
	7/.0242	Bu	.073	1.85	4,100	2.08	12.7	18.9	–	–	2.61	8.56
	19/27[4]	Co, Eq or Un	.071	1.80	3,831	1.94	12.1	18.0	3.05	10.00	2.71	8.88
	19/.0147	Bu	.074	1.88	4,106	2.08	12.7	18.9	–	–	2.61	8.56
	41/30	Bu	.077	1.96	4,100	2.08	12.9	19.2	2.81	9.22	2.53	8.30
12	Solid	–	.0808	2.05	6,530	3.31	19.8	29.5	1.69	5.54	1.59	5.21
	7/.0305	Co	.092	2.34	6,512	3.30	20.2	30.1	–	–	1.64	5.38
	19/25[4]	Co, Eq or Un	.0905	2.299	6,088	3.08	19.4	28.9	1.87	6.13	1.70	5.59
	19/0185	Bu	.0925	2.35	6,503	3.30	20.2	30.1	–	–	1.64	5.25
	65/30	Bu	.094	2.388	6,500	3.29	20.8	31.1	1.82	5.97	1.64	5.25
10	Solid	–	.1019	2.588	10,380	5.26	31.4	46.8	–	–	1.00	3.28
	7/.0385	Co	.116	2.95	10,376	5.25	32.0	47.6	–	–	1.00	3.28
	19/.0234	Bu	.117	2.97	10,404	5.27	32.0	47.6	–	–	.98	3.21
	37/.0169	Co	.112	2.84	9,361	4.74	29.2	43.4	–	–	1.25	4.10
	105/30	Bu	.126	3.20	10,500	5.32	33.8	49.2	1.10	3.61	.99	3.24
8	7/.0486	Co	.146	3.71	16,534	8.38	50.1	74.5	–	–	.65	2.13
	19/.0295	Bu or Eq	.144	3.66	16,535	8.38	50.0	74.4	–	–	.65	2.13
	133/29	Ro 19x7/29	.169	4.293	16,983	8.61	54.0	80.4	.71	2.33	–	–
	168/30	Ro 7x24/30	.174	4.42	16,800	8.51	53.4	79.0	.70	2.30	–	–
6	19/.0374	Bu	.188	4.775	26,576	13.33	81.1	121	–	–	.40	1.30
	133/27	Ro 19x7/27	.213	5.41	26,818	13.60	84.1	125	.43	1.41	–	–
	266/30	Ro 7x38/30	.222	5.64	26,600	13.49	83.2	124	.44	1.44	–	–
4	133/25	Ro 19x7/25	.257	6.53	42,615	21.61	135	201	.29	.95	–	–
	420/30	Ro 7x60/30	.270	6.850	42,000	21.29	140	208	.28	.92	–	–
2	665/30	Ro 19x35/30	.338	8.59	66,500	33.72	213	317	.18	.59	–	–

[1]Bu—Bunched; Co—Concentric; Eq—Equilay; Ro—Rope; Un—Unilay

[2]Typical D.C. Resistance values for uninsulated wires. Multiply by 1.04 for typical values after insulation

[3]Values are for tinned, heavy tinned, prefused, overcoated or topcoated conductors

[4]Does not meet UL conductor stranding requirements.

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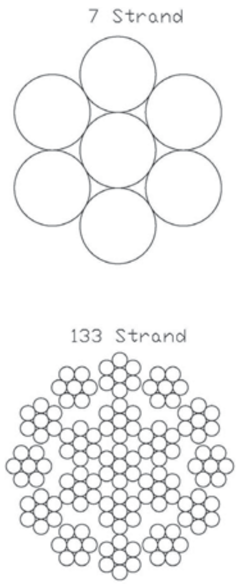
M5

f0220 **FIGURE 8.43**

Conductor size, resistance, and weight.

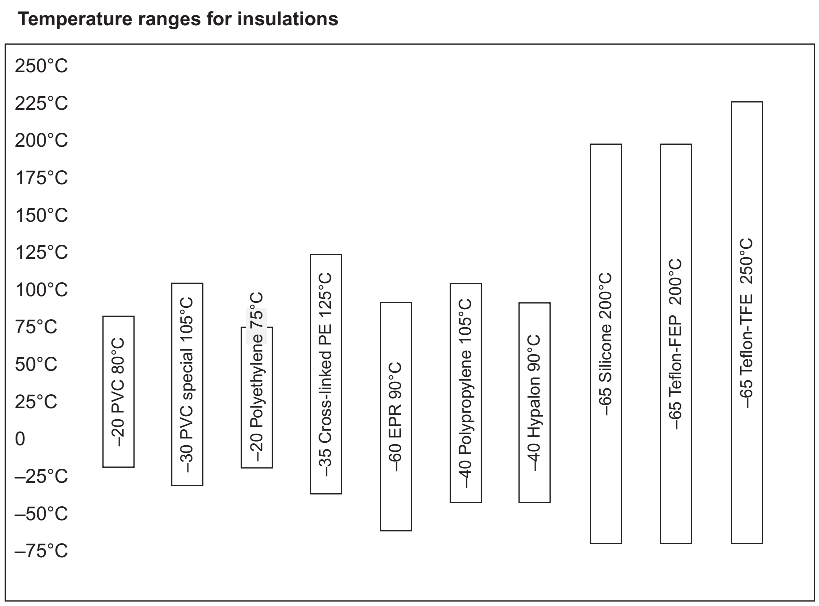
(Courtesy Falmat.)



f0225 **FIGURE 8.44**

Strand configurations.

(Courtesy Falmat.)



f0230 **FIGURE 8.45**

Operating temperatures ranges for various insulations.

(Courtesy Falmat.)

Plastic Insulations

Property Considered	Cellular Polyethylene	High-Density Polyethylene	Low-Density Polyethylene	Nylon	Polypropylene	Polyurethane	PVC	Teflon
Acid Resistance	G to E	G to E	G to E	P to F	E	F	G to E	E
Abrasion Resistance	G	E	F to G	E	F to G	O	F to G	G to E
Alcohol Resistance	E	E	E	P	E	P	G to E	E
Alkali Resistance	G to E	G to E	G to E	E	E	F	G to E	E
Benzol (Aromatic Hydrocarbons) Resistance	P	P	P	G	P to F	P	P to F	E
Degreaser Solvents (Halogenated Hydrocarbons) Resistance	P	P	P	G	P	P	P to F	E
Electrical Properties	E	E	E	F	E	P to F	F to G	E
Flame Resistance	P	P	P	P	P	P	E	O
Gasoline, Kerosene (Aliphatic Hydrocarbons) Resistance	P to F	P to F	P to F	G	P to F	F	G to E	E
Heat Resistance	G to E	E	G	E	E	G	G to E	O
Low Temperature Flexibility	E	E	G to E	G	P	G	P to G	O
Nuclear Radiation Resistance	G	G	G	F to F	F	G	P to F	P to F
Oil Resistance	G to E	G to E	G to E	E	E	E	E	O
Oxidation Resistance	E	E	E	E	E	E	E	O
Ozone Resistance	E	E	E	E	E	E	E	E
Water Resistance	E	E	E	P to F	E	P	E	E
Weather—Sun Resistance	E	E	E	E	E	F to G	G to E	O

P=Poor F=Fair G=Good E=Excellent O=Outstanding
Above ratings are based on average performance of compounds. Any specific property can often be improved by the use of selective compounding.

f0235 **FIGURE 8.46**

Plastic insulation properties.

(Courtesy Falmat.)

p1935 The *jacket* is the outer, overall covering of the cable. It is snag and cut resistant and keeps the interior bundle from kinking and hockling. Materials widely used include:

u0720 — Polyurethane
u0725 — Polyolefin (PE and PP)
u0730 — Thermoplastic elastomer (TPE)

s0110 8.8.10 Strength member

p1955 The most common material used in *umbilical* construction is steel armor wire, including:

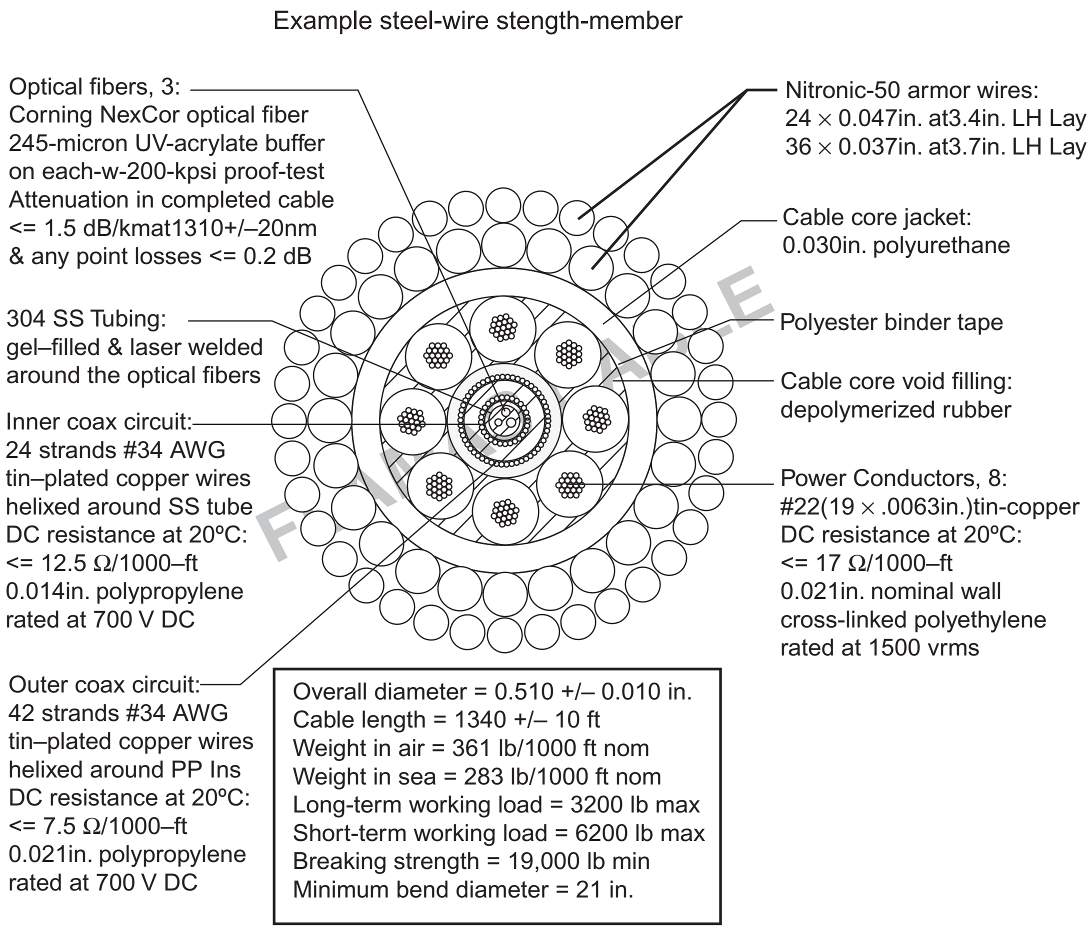
u0735 — Galvanized improved plow steel (GIPS)
u0740 — Galvanized extra improved plow steel (GEIPS)
u0745 — High-tensile alloys for greater corrosion resistance

p1975 The most common materials used for *tether* construction are synthetic yarns, including:

u0750 — Aramid fiber (Kevlar® and Twaron®)
u0755 — Liquid crystal polymer (Vectran®)
u0760 — PBO (Zylon®)

p1995 Examples of EM cable composite constructions include:

u0765 • Steel wire strength member (Figure 8.47)
u0770 • Synthetic strength member (Figure 8.48)



f0240 **FIGURE 8.47**

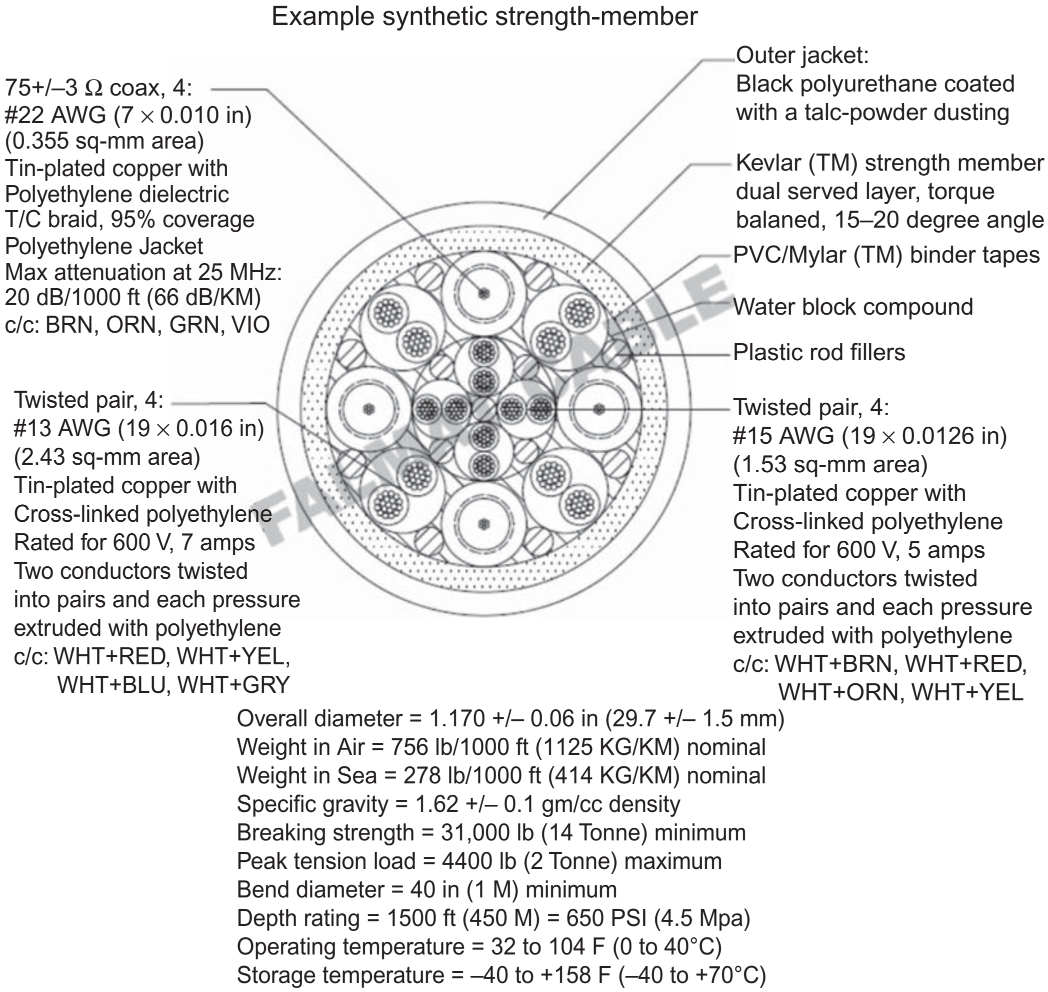
Steel wire strength member.

(Courtesy Falmat.)

- u0775 Near neutrally buoyant (Figure 8.49)
- u0780 Positively buoyant (floats) (Figure 8.50)
- u0785 Water-sampling tow-cable

p2025 Standard cables include:

- u0790 CAT-5, CAT-5e, CAT-6, etc.
- u0795 Coax components:
  - u0800 50 or 75 Ω characteristic impedance
  - u0805 30 or 20 pF per foot capacitance
  - u0810 MIL-SPEC Coaxes per MIL-C-17



f0245 **FIGURE 8.48**

Synthetic strength member.

(Courtesy Falmat.)

u0815 – Miniature, high-speed, low-loss Coaxes

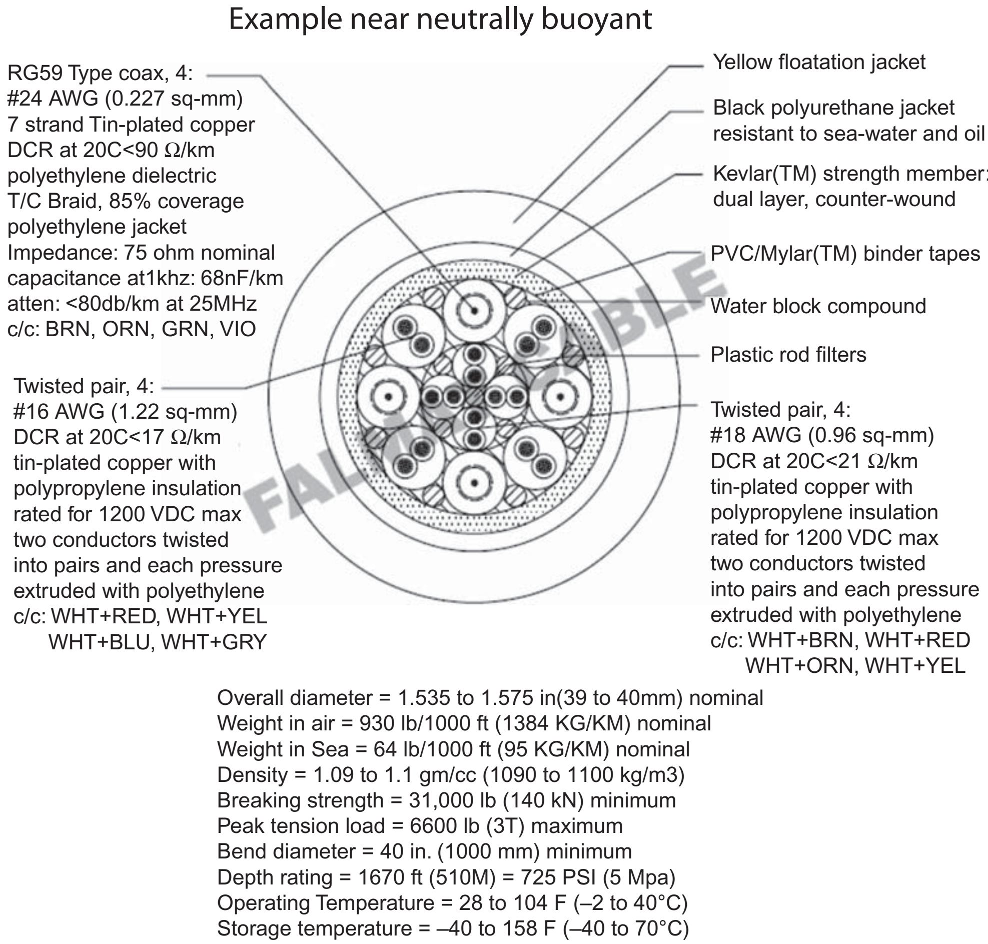
u0820 • RS-232, RS-422, RS-485, etc.

p2065 CAT-5 cable overview (Figure 8.51):

u0825 • Typically contains four pairs

u0830 – Note: Most applications use only two pairs

u0835 – However, Gigabit Ethernet uses all four pairs



f0250 **FIGURE 8.49**

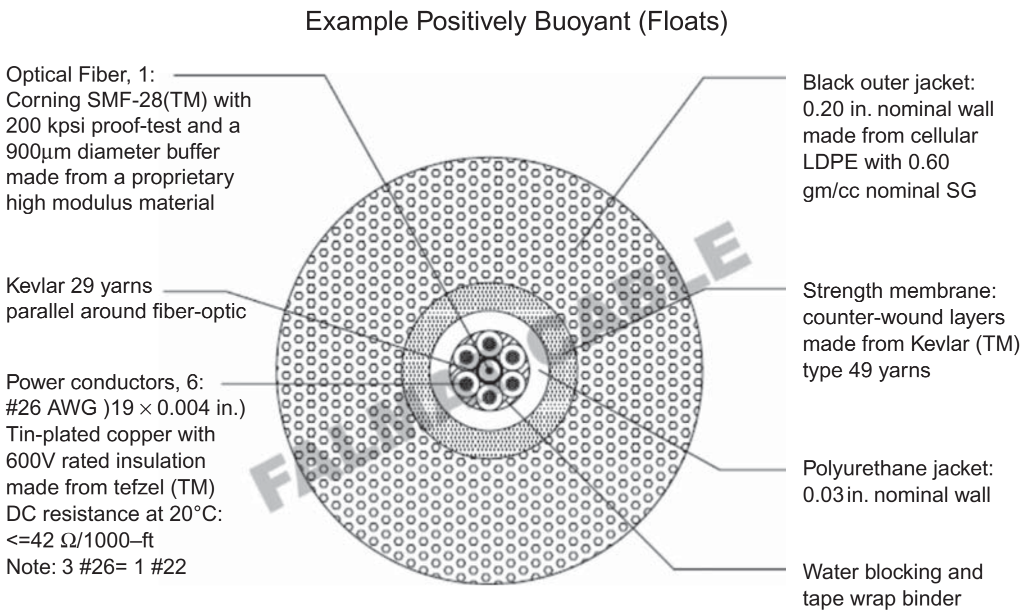
Near neutrally buoyant cable.

(Courtesy Falmat.)

u0840 • Pairs are unshielded twisted pairs
u0845 • Flexing cables need stranded conductors
u0850 • Shielded versions are rare in the United States
u0855 • Industrial versions are another variety.

s0115 8.8.11 Spare conductors

p2105 Custom cable construction often allows for the choice to either use "filler" strands or spare conductors to maintain a uniform circular cross-section. Fillers are cheaper, but spare wires can be used



Overall Diameter	= 0.65 inches nominal
Density	= 0.73 gm/cc nominal
Hardness	= 87 Shore A nominal
Breaking strength	= 5000 lbs minimum
Breaking strength	= 6000 lbs maximum
Peak tension load	= 1375 lbs maximum
Minimum bend diamete r	= 12 inches
Storage hub diameter	= 18 inches
Hydrostatic pressure	= 710 psig

f0255 **FIGURE 8.50**

Postively buoyant cable.

(Courtesy Falmat.)

for emergency field repairs and unforeseen system expansion requirements. However, the weight of these spare conductors must be considered in the neutral buoyancy equation for a vehicle's flying tether.

s0120 8.8.12 Interconnect cables

p2110 The preceding discussion on Power and Signal applies equally to interconnect cables.

p2115 Portable cords are often used underwater for power or signal cable. They are available in either thermoset or thermoplastic constructions. Thermoset rubber material hardens or "sets" under direct application of heat, called "curing," and once it sets, is not able to be resoftened by heating. Thermoset is a much more durable compound than thermoplastic.

Xtreme-Green “Xtreme-Cat”

Underwater Network Data/Power Cable

Homeland security, Oceanographic, Observation, and other extreme marine enviornments.

P/N	DESC.	Data Comp	Break Strength	Diameter	Wgt/1000’
FMXCAT51205K24	5C- 12AWG	Cat 5E -24awg (7)	2400 lbs	.700″	256 lbs
FMXCAT51207K24	7C- 12AWG	Cat 5E -24awg (7)	2400 lbs	.700″	297 lbs
FMXCAT51606K24	6C- 16AWG	Cat 5E -24awg (7)	2400 lbs	.564″	157 lbs
FMXCAT51610K24	10C-16AWG	Cat 5E -24awg (7)	2400 lbs	.564″	191 lbs
FMXCAT51812K12	12C-18AWG	Cat 5E -24awg (7)	1200 lbs	.500″	143 lbs
FMXCAT51806K12	6C- 18AWG	Cat 5E -24awg (7)	1200 lbs	.500″	110 lbs
FMXCAT52218K12	18C-22AWG	Cat 5E -24awg (7)	1200 lbs	.447″	120 lbs
FMXCAT52218	18C-22AWG	Cat 5E -24awg (7)	0	.433″	117 lbs
FMXCAT52824K8	24C-28AWG	Cat 5E -24awg (7)	800 lbs	.415″	90 lbs
FMXCAT52824	24C-28AWG	Cat 5E -24awg (7)	0	.400″	88 lbs
FMXCAT50000 *	N/A	Cat 5E -24awg (7)	0	.325″	47 lbs
FMXCAT50000K12 *	N/A	Cat 5E -24awg (7)	1200 lbs	.340″	52 lbs

** Cat 5 cable only, with rugged Xtreme-Green Polyurethane, no power conductors, or waterblock.*

Data Network/Power Composite Cable
Extreme ruggedness, Flexibility with waterblocked construction.
Designed for underwater use with high-speed network data, video, and sensor equipment.
Cables can be used for bottom-laid, vertical, winch systems, and ROV apllications.
Cat 5E 4pr stranded conductor. Meets or exceeds TIA 568-B. Suitable for 10Base-T and 100Base-T
Custom variations of these listed cables can be supplied with added break strengths, steel armor, additional jackets, or neutral buoyant constructions.

Xtrteme-Green Cables are designed for extreme enviornments with flexibility. These cables feature Falmat’s specially formulated “Xtreme-grade” polyurethane jacket for easier payout, tighter bends, and better tractor control with extremely low coefficient of friction. The Xtreme Green reduced diameter cable offers even smaller bend radius for tighter bends and smaller, portable, handling systems.

f0260 **FIGURE 8.51**

FalMat Xtreme Green CAT-5 cable.

(Courtesy Falmat.)

p2120 Thermoset cords include SO cable. From the basic SO cable to the specialized SOOW, these multiconductor cables are readily sourced from a number of manufacturers. The SOOW acronym stands for:

u0860 **S**ervice—All SO hybrids begin with this word.

u0865 **O**il resistance—The designation “SO” denotes a cable that is oil resistant.

u0870 **O**ther chemical resistance—The cable is impervious to additional chemicals such as acetone and diesel fuels.

u0875 **W**ater resistance—A heavy, yet flexible, nonporous casing keeps the cable interior dry. SOW cables are used to power mining applications, bulldozers, conveyors, temporary lighting, submersibles, pump applications, and more.

f0265 **FIGURE 8.52**

Open-End Spelter socket.

(Courtesy Crosby Group.)

p2145 The thermoset jackets are readily bonded to in secondary operations to add underwater connector terminations.

p2150 Another cable seeing increasing use in moderate depths is the AWM20233. Billed as a "Low Capacitance Communications/Instrumentation Cable," the outer jacket is polyurethane extruded over a copper braid shield. Inside are individual twisted pairs wrapped in aluminum/polyester foil with a stranded, tinned copper drain wire. Nylon rip cord filler provides cross-sectional bulk. End-users report success for yearlong durations at 2.5 miles (4 km).

p2155 Additional cable options may be known by your connector manufacturer. Ask their opinion, but use your own best judgment.

s0125 8.8.13 EM terminations and breakouts

p2160 *Mechanical strength terminations* are used to transition force from the winch to the umbilical and the umbilical to the TMS or to the tether of an ROV.

p2165 The termination type can influence the break strength of the cable. It is important to use similar terminations on each end of the cable. Do not rely on locking sleeves for transferring the load off a cable.

p2170 Two common field installable mechanical end-fitting/terminations are as follows:

u0880 • Spelter Socket
u0885 • Kellems Grip

s0130 *8.8.13.1 Socket or spelter socket*

p2185 A *Socket or Spelter Socket* uses molten zinc or epoxy poured in a socket to bond the splayed cable to the fitting (Figures 8.52–8.54). The *Spelter Socket* is suitable for steel strength members with

f0270 **FIGURE 8.53**

Spelter socket with wire splayed and technician pouring in epoxy binder.

(Courtesy Ocean Innovations.)

f0275 **FIGURE 8.54**

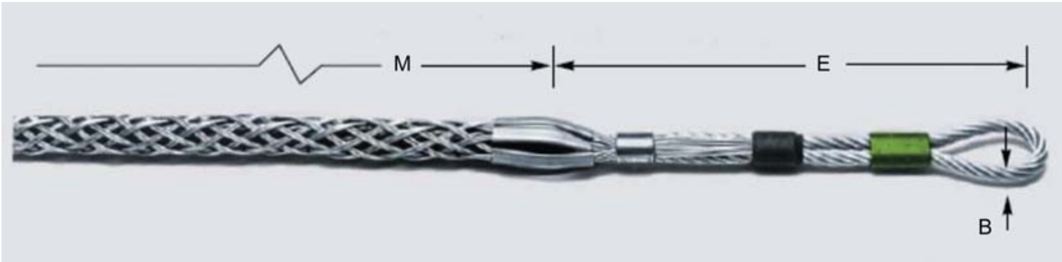
Pull test of spelter socket termination.

(Courtesy Ocean Innovations.)

high strength-efficiency and repeatability. It is also used for synthetic strength members, but it is about half as efficient and results are highly variable. Still, this is sometimes acceptable because synthetic strength members have higher break strength to working load ratios.

s0135 *8.8.13.2 Kellems grip*

p2190 A *Kellems Grip* is a woven "Chinese-finger grip": The harder you pull the tighter it gets. Among the highest strength models is the Hubbell Dua-Pull (Figure 8.55).



f0280 **FIGURE 8.55**

Hubbell Dua-Pull Kellems grip.

(Courtesy Hubbell.)

f0285 **FIGURE 8.56**

Yale grip.

(Courtesy Yale.)

s0140 *8.8.13.3 Lace-up grips*

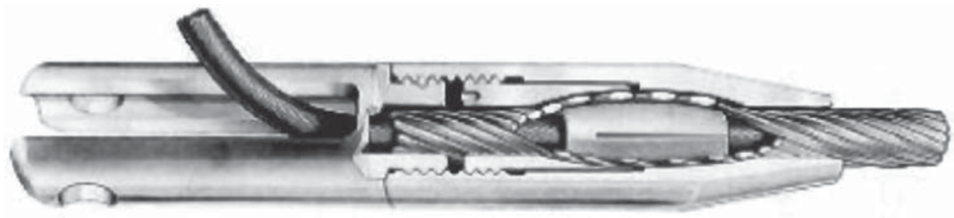
p2195 One example is the "*Yale Grip*," designed to allow easy installation mid-span by braiding four synthetic legs around the cable body (Figure 8.56).

s0145 *8.8.13.4 Helical termination*

p2200 A *Helical termination* uses gripping wires in a manner similar to the soft woven Yale Grip to bind the outside of a matching helix wire rope on a steel armored cable (Figures 8.57 and 8.58).

s0150 *8.8.13.5 Mechanical termination*

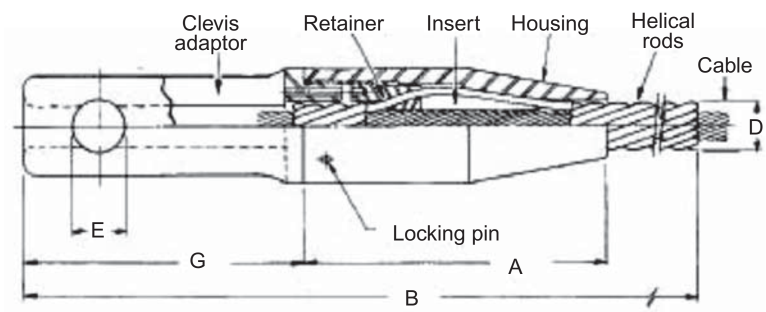
p2205 A *Mechanical termination* is an assembly using conical wedges to trap a splayed cable strength member inside a fitting (Figures 8.59 and 8.60).



f0290 **FIGURE 8.57**

A "torpedo" wedge helical termination.

(Courtesy Preformed Line Products.)



f0295 **FIGURE 8.58**

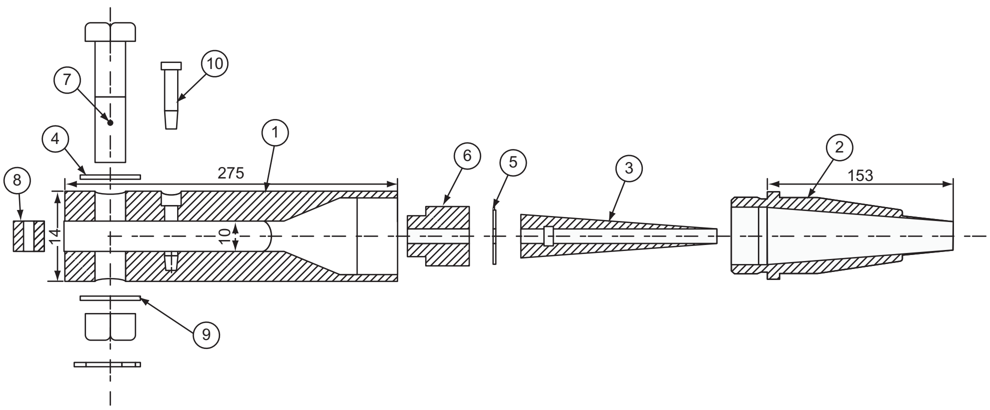
Helical strength termination.

(Courtesy Preformed Line Products.)

f0300 **FIGURE 8.59**

A conical wedge strain relief.

(Courtesy Ocean Innovations.)



f0305 **FIGURE 8.60**

A conical wedge strain relief cross-section.

(Courtesy Ocean Innovations.)

s0155 8.8.14 Bonding

s0160 *8.8.14.1 Vulcanized rubber splice*

p2210 The vulcanized rubber splice process requires specialized compression molding equipment that can apply elevated pressure, high temperature, over an extended time. Cable or connector manufacturers, generally not end-users, own such machines. The procedure, however, has been refined, tested, and found to produce good adhesion between the uncured thermosetting tapes and a number of polymer cable jackets.

s0165 *8.8.14.2 Transfer-molded rubber splice*

p2215 Transfer molding process creates molded joints by transferring an uncured compound onto a mold. Heat and pressure soften the compound, which then flows through the cavity and encapsulates the spliced cable, fusing to the cable jacket. When the part is cooled and removed, the result is a permanent, pressure proof reliable splice.

s0170 *8.8.14.3 Castable polyurethane resin splices*

p2220 A number of companies manufacturer quality castable polyurethane resin splice materials.

p2225 One of the most popular, 3M™ Scotchcast insulating polyurethane resins, have been used with great success in submerged applications. Mold forms are available for cylinder and Y-splices, providing a field-ready solution for cable splicing. The electrical and physical properties make them ideal for insulating and protecting electrical connections. Scotchcast 2130 provides excellent adhesion to a number of jacket materials including Neoprene, Hypalon, Nitrile/PVC, PVC, and polyurethane. A caution in assembly is the substrates must be completely clean and dry. In the case of synthetic jacket cables, it is necessary for the resin to be poured immediately after the surfaces are prepared.

p2230 Preformed Line Products offers their own version called "RD Encapsulant," a two-component polyurethane compound providing excellent moisture and electrical insulation protection for telecommunications cable splices.

p2235 Thomas & Betts produces a similar "Rezi-Con" polyurethane kit which includes the mold forms.

s0175 *8.8.14.4 Cold splice*

p2240 For decades, Scripps engineers and technicians have utilized a technique known as "cold splicing" to splice or repair underwater interconnect cables. This technique requires the use of three 3M products: Scotchkote electrical coating, Scotchfil electrical insulation putty, and Scotch 33 black tape. (3M deserves an award from the oceanographic industry for 33 tape alone.) Scripps engineer Frank Snodgrass, a pioneer in free vehicles, passed on this technique to his younger colleagues. Scotch black tapes have near universal loyalty at all US oceanographic institutions for their ability to stick and stretch under every conceivable condition at and under the sea.

p2245 The technique for a shielded two-conductor SOW cable follows:

o0355 **1.** Strip back the outer jacket from the end ½ in. for each conductor. The shield counts as one conductor, so strip 1½ in. on each cable end for the two-conductor shielded cable.
o0360 **2.** Clip out the cable bulk filler material, like jute.
o0365 **3.** Unbraid and twist shield wire into a multistrand conductor. Use a knife to scrape the surface clean of any rubber jacket residue on the last ¼ in. to improve solderability.
o0370 **4.** Cut the conductors so the three solder joints will be offset linearly from each other, that is so they are not located side-by-side. This prevents solder spikes from inadvertently pressing through the insulation under pressure and shorting to a neighboring solder joint. With the first cable end to be spliced, cut the shield ½ in. long. Cut one color conductor (i.e., black), to 1 in., and leave the last color conductor (white) a full 1½ in. long.
o0375 **5.** With the second cable end to be spliced, cut the conductor lengths the opposite, so the shortest in now the longest. Cut the one color conductor (i.e., white) ½ in. long. Cut the other color conductor (black), to 1 inch, and leave the shield a full 1½ inch long.
o0380 **6.** Strip each of the wires back ¼ in.. Use shrink tubing on the twisted shield wire as an insulation jacket. Use a heat gun to shrink it down tight on the shield wire.
o0385 **7.** Place approx. 5/8 in. long shrink tubing on wire pairs before soldering.
o0390 **8.** Solder the like color wires together. Perform a continuity check to be sure the conductors go where you expect them to, and not where they should not, by testing each pin to all others.
o0395 **9.** Center the shrink tubing over the solder joint and use a heat gun to shrink it.
o0400 **10.** (Optional) add a layer of Scotch 33 black tape over shrink tubing for a second layer of insulation if preferred.
o0405 **11.** Using isopropyl alcohol, clean the cable jackets 2 in. to either side of the splice. Similarly, clean the spliced wire jackets and heat shrink. Let dry.
o0410 **12.** Paint entire cleaned area liberally with Scotchkote. Let it flow into every nook and cranny. Do this over cardboard because it will drip off. Let dry completely. This is a primer that improves adhesion of the Scotchfil to the cable jacket.
o0415 **13.** Cut a 6 in. length of Scotchfil putty. Remove backing tape and stretch putty to ½ its original thickness. Wrap tape around joint, pulling to create an elastic affect, covering the entire splice

area and 1½ in. over each cable jacket end. Press and massage the Scotchfil to a roughly uniform diameter, slightly larger than the original cable diameter. The overall joint length is then approximately 5½ in. long.

o0420 **14.** Using Scotch 33 black tape, and starting ½ in. beyond the Scotchfil on the cable jacket, begin wrapping the black tape over the joint, pulling so as to create an elastic affect, and overlapping the tape 50% on each turn. When completely covered, cut the tape from the roll with a knife or scissors rather than pulling and breaking the tape. This keeps the bitter end from curling up.

o0425 **15.** Perform a final ohm sift to be sure the connections are still fine.

s0180 8.8.15 Cable design summary

p2325 A cable for an ROV is a special component because it is the primary link between the vehicle and the operator, providing power, signal, and handling strength. Thus, an ROV cable design must consider all these features.

p2330 The vehicle size, weight, and operating depth, as well as the vehicle motors, subsystems, and payload, all combine to determine the cable design, which is usually unique to the vehicle.

p2335 These brief descriptions of cable design considerations are just a starting point. Because each ROV has unique requirements, abilities, and limits, it is important to discuss your unique cable requirements with someone who has experience in this area.

s0185 8.9 Testing and troubleshooting

s0190 8.9.1 Electrical testing, troubleshooting, and predeployment checkout

p2340 Cables can get worn, broken, or damaged being moved, in transit, just stored, and in use over time. They should be inspected prior to deployment and possibly after recovery.

p2345 Common failure modes include:

u0890 Intermittent continuity
u0895 Open circuit
u0900 Delamination or debonding
u0905 Chemical contamination

p2370 At a minimum a *visual inspection* should be performed to identify breaks, cuts, kinking, or fraying.

s0195 8.9.2 Ohm sift or continuity test

p2375 An *Ohm sift*, or *Continuity test*, is used to verify conductivity of each conductor from end-to-end and to verify no-conduction (shorts) between the adjacent pins and the housing. This is referred to as "buzzing (or "*ringing*") out conductors." *DC resistance* precisely measures resistance in ohms of each conductor. Resistance changes with temperature and is typically specified at 20°C (68°F). Measurements at other temperatures must be converted to 20°C (68°F) for comparison.

s0200 8.9.3 MegOhm testing or insulation resistance

p2380 *MegOhm testing or insulation resistance (IR)* measures the insulation resistance between wire pairs AU:4 using a high voltage to verify resistance of the insulation to current flow. This is typically performed at 500 V DC for wire and cable. The values are typically specified in Mega (millions) ohms. This is referred to as "Meggered the cable." IR measurements are influenced by length, temperature, and time.

p2385 When interpreting measurements from IR equipment, operators must know:

p2390 IR versus length dependent

- u0910 IR is inversely proportional to length
  - u0915 Shorter lengths have proportionally higher IR
  - u0920 Longer lengths have proportionally less IR
- u0925 IR is typically specified in MegOhms/1000

p2415 IR versus temperature

- u0930 IR is inversely proportional to temperature
  - u0935 Measurements at higher temperature have lower IR
  - u0940 Measurements at lower temperature have higher IR
  - u0945 Rule-of-thumb is that IR halves or doubles each 10°C
- u0950 IR is typically specified at 15.6°C (60°F)
- u0955 It is important to log the temperature when recording IR measurements.

s0205 8.9.4 Hi-Pot or voltage withstand test

p2450 *Hi-Pot or voltage withstand* test is a high over-voltage DC test of a wire or cable insulation. It is typically run at 2× operating voltage +1000 V. The higher test voltage is run early in manufacture to verify quality of components. The lower MegOhm test voltage is acceptable at final acceptance. The Hi-Pot is generally derated further after installation.

s0210 8.9.5 A time-domain reflectometer

p2455 A time-domain reflectometer is a device to find the location of a break in a cable by sending a pulsed signal into the conductor and then examining the reflection of that pulse. Parallel wires will have the same time of reflection. A break will reflect the pulsed signal sooner, appearing like a shorter length. That length is the distance to the break. Spare conductors in cables may be available for field repair work.

p2460 Other electrical cable tests of potential interest include: capacitance, impedance, attenuation, cross talk, and skew.

s0215 8.9.6 Mechanical testing and troubleshooting

p2465 Mechanical parameters to be measured include the cable's:

- u0960 overall diameter and variance
- u0965 weight in air and/or seawater

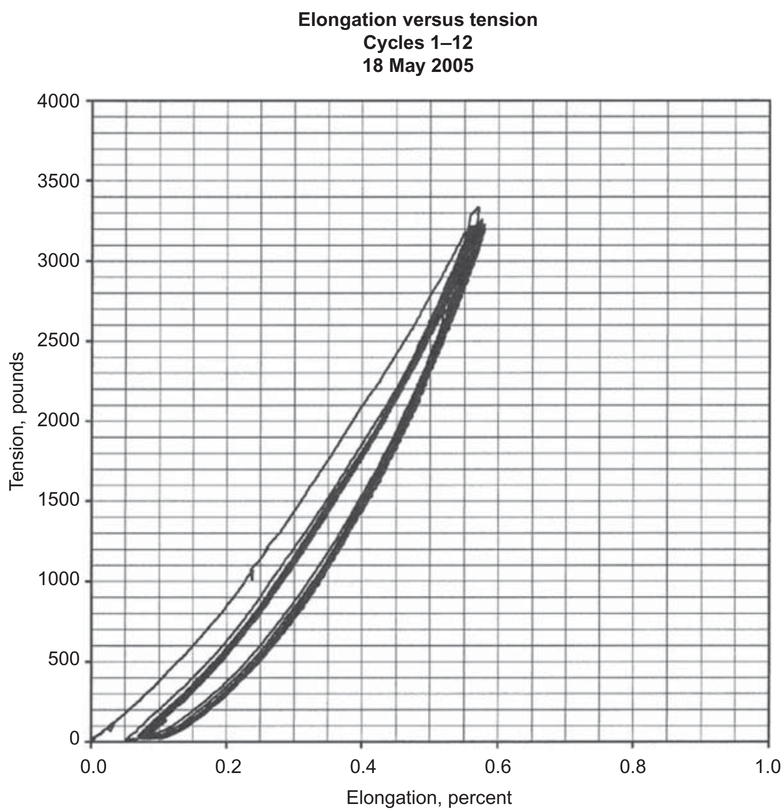
- u0970 break strength-with-field termination
- u0975 torque and rotation versus applied tension
- u0980 bending fatigue cycles simulating anticipated usage conditions including: load, sheave diameters, speed, temperature, etc.

p2495 Weight in air and seawater

- u0985 Weight in air is typically done on a 1-ft sample.
- u0990 Weight in seawater is usually calculated from the 1-ft sample weight and diameter.

p2510 More elaborate testing is possible, but exercise caution in interpreting results.
p2515 Additional mechanical testing may include: AU:5

- u0995 Elongation versus tension (Figure 8.61)
- u1000 Torque/rotation versus tension
- u1005 Ultimate break strength



f0310 **FIGURE 8.61**

Elongation versus tension of a Towed-Array Tow-Cable.

(Courtesy Falmat.)

s0220 8.10 TIPS from the field

p2535 Words to those who can learn from past suffering.

- u1010 Never use a connector if you do not need to. Use the KISS (Keep It Simple, Stupid) principle.
- u1015 Consider using connectors that have open face pressure ratings to match your operating depth in the event a connector-to-connector seal leaks.
- u1020 Do not mix-and-match connectors from different manufacturers unless there is a well-defined external specification such as a MIL-SPEC to fall back on, especially rigid epoxy or metal shell body connectors. Similar looking parts from different manufacturers parts cannot be guaranteed to be interchangeable, as one manufacturer cannot rationally guarantee the quality of another manufacturer's product. While there is more tolerance in rubber-molded connectors, as the outer body stretches to form a compression seal, there are many additional dimensions for pin length, pin diameter, pin pattern, and more that can make a critical difference. In a world of pointing fingers, the one who made the "buy" decision will be responsible not the manufacturers.
- u1025 The Parker O-ring Handbook (ORD-5700) is the bible of seal design. Anyone who says differently is playing with the devil. And the devil is in the details.
- u1030 Make sure your connector body material is compatible with your housing material. Dissimilar metals exposed to seawater form galvanic cells that will eat away one of the two, and both are important components of the pressure housing. A skirt, cup, or lip seal is one way to avoid creating a galvanic cell by isolating the bulkhead connector threaded post from exposure to seawater.
- u1035 Epoxy connectors are brittle and must be well protected from side loads and random impacts.
- u1040 Rubber-molded connectors and cable jackets can be seriously degraded if exposed to long-term heat, sunlight, or high o-zone levels. Inspect suspect connectors and cables carefully before reuse. There is a reason they call it a "bone yard."
- u1045 Do not mate or demate connectors with power "on" as arcing between contacts on demate will likely occur.
- u1050 Do not disconnect connectors by pulling on cables as it will stress (and probably break) the internal wire/connector joint. Do not wiggle epoxy or metal shell connectors back and forth when demating. You can get away with a little bit of this with rubber-molded pairs.
- u1055 Use a torque wrench to tighten bulkhead connectors to manufacturer specifications, especially epoxy bulkhead connectors. "Tink" is not a happy sound. Some experience is required as thread installation torques can vary with materials, cleanliness of the threads, thread tolerances, and thread lubrication.
- u1060 Do not use locking sleeves to mate connector halves.
- u1065 Locking sleeves should only be tightened by hand. Remember this point after the vehicle returns to the surface (with the resulting full temperature cycling of the connector/sleeve) only to find the sleeve is practically welded to the connector.
- u1070 Avoid sharp bends in cables. Know the "minimum bend radius" of your cables.
- u1075 Secure cables with black tape, zip ties, or other means to prevent strumming or movement created by an ROV in motion. Be careful using zip ties as they can bite into the cable jacket or cause sharp bend radii.
- u1080 Make sure mating connector halves are clean and properly lubricated.

- u1085 Do not apply grease excessively. A thin coat is needed for lubricity only. Grease has no shear strength and does not seal. Too much grease can prevent the o-ring from moving onto its optimum position and can even cause hydraulic fracturing of epoxy parts.
- u1090 Use only *food grade* silicone spray. Non-food grade has corrosive volatile propellants that cannot escape a sealed connector pair and can result in "dezincification of brass."
- u1095 Keep spares of critical connectors on hand.
- u1100 Do not use petroleum-based products, like WD-40, on rubber cables and connectors.
- u1105 Any accumulation of sand or mud in the female contact should be removed by flushing with clean freshwater, failure to do so could result in splaying of the contact and damage to the o-ring seal.
- u1110 Ensure that there are no angular loads on the bulkhead connector as this is a sure way to destroy a connector.

s0225 8.11 Summary

p2645 Underwater cables and connectors provide system flexibility, ease of service, and other design advantages for undersea equipment including ROVs. The primary purpose of underwater cables and connectors is to provide a conductive path without leakage in a pressure-resistant or pressure-tolerant package. They allow simple system reconfiguration.

p2650 A mated connector pair forms a unique small pressure case. All pressure case design criteria apply. A bulkhead connector or penetrator becomes a mechanical part of a pressure hull, and it should be looked at critically.

p2655 EM cable design is driven by the specific end-user application. Design criteria include: power, data, and strength.

p2660 Test EM cables both electrically and mechanically simulating the application field conditions. Use field terminations whenever possible. Exercise caution when interpreting results.

p2665 Feel free to discuss your requirements with the manufacturer and experience improved operational effectiveness by using the proper cable designed for your application.

References

p2670 1. *Parker O-ring Handbook (ORD-5700)* is available as a free download at <http://www.parker.com>. Enter "ORD-5700" in the Search box. The Handbook provides details on numerous groove designs, back-up rings, elastomer selection, machining tolerances and finishes, installation procedures, and everything else you might have ever wondered about o-rings. There are generic o-ring groove design charts, and information on how to finesse a design for a particular application. Parker is never wrong. Ever. AU:6

p2675 2. Bash, J., Ed., *Handbook of Oceanographic Winch, Wire and Cable Technology*, thrid ed., is available as a free download at <http://www.unols.org/publications/winch_wire_handbook__3rd_ed/index.html>.

p2680 3. Busby, R.F., *Remotely Operated Vehicles*, 1979, is available as a free download at <http://voluwww.archive.org/details/remotelyoperate00rfra>.

p2685 4. Busby, R.F., *Manned Submersibles*, 1976, is available as a free download at <http://archive.org/details/mannedsubmersibl00busb>. Chapter 7, "Power and Its Distribution," is still a relevant discussion of penetrators, connectors, cables, and junction boxes.

p2690 5. Wernli, R.L., *Operational Effectiveness of Unmanned Underwater Systems*, CD-ROM, this book contains details about unmanned systems, their expected performance, including full descriptions and specifications. The CD-ROM contains 700 pages with 390 photographs, charts, and diagrams. Available from the MTS at <https://www.mtsociety.org/shop/view.aspx?product_id = 3415&>.

p2695 6. Moore, S.W., Harry Bohm, Vickie Jensen, *Underwater Robotics: Science, Design & Fabrication* is written for advanced high school classes or college and university entry-level courses. The 850-page text is enhanced by hundreds of photos, illustrations, and diagrams of underwater vehicles. In addition, the textbook includes a discussion of subsea vehicle development, resource appendices, an extensive glossary, and a complex index. It is available at <https://www.mtsociety.org/shop/view.aspx?product_id = 3619&pType = 14&>.

p2700 7. *Teledyne Impulse*: Additional nomenclature may be found at <http://www.teledyneimpulse.com/download.aspx> and selecting "Glossary-Connector Terminology."

p2705 8. *Dummy's Guide to Marine Technology*, a useful description of technologies used beneath the sea, available at <o-vations.com/marinetech/index/html>.