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Galvanic corrosion-proof underwater electrical interconnect

Abstract

A galvanic corrosion-proof underwater electrical interconnect comprising a plug assembly and a receptacle assembly. The plug assembly comprising a plug insert body having conductive terminals mounted within a plug shell, a coupling nut, a waterproof cable having wires connected to the conductive terminals, and a rubber overmold formed around a portion of the plug shell and cable forming a water-tight seal therebetween. The receptacle assembly comprises a first metal tubular member having a threaded portion to threadedly engage the coupling nut, a second metal tubular member separated from the first tubular member by a non-metallic outer body positioned around and between the tubular members, a receptacle insert having conductive terminals adapted to contact the plug conductive terminals. The plug shell, coupling nut and first metal tubular member are made of metal alloys having the same galvanic potential.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application claims the benefit of U.S. Provisional Application Ser. No. 63/326,015 filed on Mar. 31, 2022, entitled "Galvanic Corrosion-Proof Underwater Electrical Interconnect." Applicant incorporates by reference herein Application Ser. No. 63/326,015 in its entirety.

BACKGROUND OF THE INVENTION
1. Field of the Invention
(1) The present invention relates generally to underwater electrical interconnects, and more specifically to galvanic corrosion-proof and cathodic delamination-proof underwater electrical interconnects.
2. Description of the Related Art
(2) Salt water is highly conductive and causes any submerged exposed electrical component to short to ground. The purpose of an underwater electrical connector is to conduct needed electrical currents through the connector while at the same time sealing the connection to lower the risk of electrical leakage to ground. The typical underwater electrical connector is lined with synthetic rubber that blocks the ingress path of water while allowing a positive electrical connection. Additionally, such connectors may have a rubber overmold sealing the electrical cable to the connector plug.
(3) A common failure mechanism for bonds of elastomer to metal in a saltwater environment is cathodic delamination, which is the peeling and/or flaking away of the elastomer from the metal. Underwater electrical connector cathodic delamination of the rubber overmold sealing the electrical cable to the connector plug is induced by galvanic corrosion. Galvanic corrosion can occur when two different metals are located together in a liquid electrolyte such as saltwater. Essentially, one metal's molecules are drawn toward the other metal, leading to corrosion in only one of the two metals.
(4) In the past, electrically non-conductive coatings, epoxy- or ceramic-based, have been applied to the metal plug shell. These coatings have not been fully reliable due to issues of porosity, cracking at sharp edges, etc.
(5) One prior art approach to overcome the cathodic delamination problem has been to embed a plastic ring containing O-ring seals between the rubber overmold and the plug shell. This system limits the rubber overmold to lower temperature processes or else the O-ring seals will be heat damaged.
(6) A second prior art approach uses plastic shells to overcome galvanic corrosion. This system is structurally weak with high risk of fracture and subsequent system failure.
(7) A second problem often encountered by underwater electrical interconnects is galvanic corrosion between the electrical receptacle and associated mounting hardware and the underwater structure that the electrical receptacle is mounted to. Galvanic corrosion occurs when two dissimilar metals are immersed in a conductive solution and are electrically connected. One metal (the cathode) is protected, while the other (the anode) is corroded. The rate of attack on the anode is accelerated, compared to the rate when the metal is uncoupled.
(8) One approach at eliminating and/or reducing this problem has been to install a gasket between the receptacle shell and the underwater structure. This approach is ineffective due to only separating the galvanic couple by a small distance, while still bathed in the electrolyte (i.e., conductive solution). This approach also reduces the pressure sealing effectiveness of the system and mounting hardware, such as screws, can still be a direct link between the galvanic couples and the electrolyte.
(9) It would be desirable to have an underwater electrical interconnect that overcomes the issue of

cathodic delamination. It would also be desirable to have an underwater electrical interconnect that overcomes the issue of galvanic corrosion. Additionally, it would be desirable to have an underwater electrical interconnect that overcomes the issues of cathodic delamination and galvanic corrosion.

Description

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

(1) The invention is better understood by reading the detailed description of embodiments which follows and by examining the accompanying drawings, in which:

(2) FIGS. **1** and **2** are perspective views of an underwater electrical connector according to a preferred embodiment of the present invention, showing a plug assembly coupled to a receptacle assembly with a portion of the receptacle assembly cut away to show fastener details;

(3) FIG. **3** is an end view of the underwater electrical connector shown in FIGS. **1** and **2**, the view taken from an end of the plug assembly;

(4) FIG. **4** is an end view of the underwater electrical connector shown in FIGS. **1** and **2**, the view taken from an end of the receptacle assembly;

(5) FIG. **5** is a view taken along lines **5-5** of FIG. **4**;

(6) FIG. **6** is an enlarged view of the broken line portion of FIG. **1**;

(7) FIG. **7** is an enlarged view of the broken line portion of FIG. **5**;

(8) FIG. **8** is an end view of an underwater electrical connector similar to FIG. **4**;

(9) FIG. **9** is a view taken along lines **9-9** of FIG. **8**, showing the plug assembly uncoupled from the receptacle assembly;

(10) FIG. **10** is a view of another embodiment of the underwater electrical connector according to a preferred embodiment of the present invention, showing the plug assembly uncoupled from the receptacle assembly;

(11) FIG. **11** is a view of another embodiment of the underwater electrical connector according to a preferred embodiment of the present invention, showing the plug assembly uncoupled from the receptacle assembly; and

(12) FIG. **12** is a view of another embodiment of the underwater electrical connector according to a preferred embodiment of the present invention, showing the plug assembly uncoupled from the receptacle assembly.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

(13) It should be understood at the outset that although illustrative implementations of one or more embodiments are described below, the disclosed assemblies, systems and methods may be implemented using any number of techniques, whether currently known or not yet in existence. The disclosure should in no way be limited to the illustrative implementations, drawings, and techniques described below, but may be modified within the scope of the appended claims along with their full scope of equivalents.

(14) The following brief definition of terms shall apply throughout the application: The phrases “in one embodiment,” “according to one embodiment,” and the like generally mean that the particular feature, structure, or characteristic following the phrase may be included in at least one embodiment of the present invention, and may be included in more than one embodiment of the present invention (importantly, such phrases do not necessarily refer to the same embodiment); If the specification describes something as “exemplary” or an “example,” it should be understood that refers to a non-exclusive example; The terms “about” or “approximately” or the like, when used with a number, may mean that specific number, or alternatively, a range in proximity to the specific number, as understood by persons of skill in the field of the art; If the specification states a component or feature “may,” “can,” “could,” “should,” “would,” “preferably,” “possibly,”

“typically,” “optionally,” “for example,” “often,” or “might” (or other such language) be included or have a characteristic, that particular component or feature is not required to be included or to have the characteristic. Such component or feature may be optionally included in some embodiment, or it may be excluded.

(15) Embodiments of the invention will now be described with reference to the figures, in which like numerals reflect like elements throughout. The terminology used in the description presented herein is not intended to be interpreted in any restrictive or limited way, simply because it is being utilized in conjunction with the detailed description of certain specific embodiments of the invention. Furthermore, embodiments of the invention may include several novel features, no single one of which is solely responsible for its desirable attributes or which is essential to practicing the invention described herein.

(16) Perspective views of an underwater electrical connector according to one preferred embodiment of the present invention, generally referred to as **10**, are shown in FIGS. **1** and **2**. A plug assembly **20** is shown coupled to a receptacle assembly **60**. FIG. **3** is an end view of the underwater electrical connector **10** shown in FIGS. **1** and **2**, with the view taken from an end of the plug assembly **20** and FIG. **4** is an end view taken from an end of the receptacle assembly **60**. FIG. **5** is a cross-sectional view of the underwater electrical connector **10** taken along lines **5-5** of FIG. **4**. FIG. **9** is a view taken along lines **9-9** of FIG. **8** and shows the plug assembly **20** uncoupled from the receptacle assembly **60**.

(17) Referring to FIG. **5**, the plug assembly **20** includes a plurality of conductive terminals **22** mounted in a plug insert body **26** and the receptacle assembly **60** preferably has a similar number of conductive terminals **62** mounted in a receptacle insert body **66**. The plug insert body **26** and receptacle insert body **66** are primarily non-metallic, and more preferably made of polyetheretherketone (“PEEK”). PEEK is a high-performance engineering plastic with excellent mechanical strength and dimensional stability and has a proven track record in challenging environments. The plug insert body **26** and the receptacle insert body **66** may include a support member **28** (FIG. **5**) made of metal that is inserted into a mold when injection molding the insert bodies **26**, **66**. As shown in FIGS. **5** and **9**, the plug insert body **26** is mounted within a plug shell **24**. The illustrated embodiment includes twelve conductive terminals **22** in the plug assembly **20** and twelve conductive terminals **62** in the receptacle assembly **60** as shown in the end views of FIGS. **3** and **4**, respectively.

(18) It is to be understood that the number of conductive terminals **22**, **62** may be dependent on the number of required electrical connections. It is to be further understood that the conductive terminals **22**, **62** are spatially arranged in a pattern such that when the plug assembly **20** is coupled to the receptacle assembly **60**, there is one plug conductive terminal **22** that matingly contacts one receptacle conductive terminal **62**. Additionally, preferably each plug conductive terminal **22** has a single predetermined receptacle conductive terminal **62** to matingly contact when the plug assembly **20** is coupled to the receptacle assembly **60**. For example, with reference to FIGS. **3** and **4**, the contacts **22**, **62** are numbered **1** through **12** and like numbers will always contact each other when the assemblies **20** and **60** are coupled together. This can be achieved by spatially arranging the terminals **22**, **62** in a pattern or manner that only permits one orientation in order to couple the assemblies **20** and **60**. Additionally or alternatively, this may be achieved by requiring a specific orientation of the plug shell **24** relative to the first metal tubular member **72** as described below.

(19) Referring to FIGS. **5** and **9**, each receptacle conductive terminal **62** has a pin **62***p* and each plug conductive terminal **22** has a socket **22***s*. Preferably, the pins **62***p* extend axially outward from a forward face **66***f* of the receptacle insert body **66** and the sockets **22***s* are substantially flush with a forward face **26***f* of the plug insert body **26** as shown in FIG. **5**. When the plug assembly **20** is coupled to the receptacle assembly **60**, each pin **62***p* is received within and contacts a corresponding socket **22***s* to form an electrical connection.

(20) It is to be understood that the invention is not limited to pins and sockets but includes other

techniques of making an electrical connection as known in the art. One such example are spring-loaded contacts, also referred to as pogos, acting on pads. It is also to be understood that the pins could be on the plug conductive terminals **22** and the sockets on the receptacle conductive terminals **62**. Alternatively, there could be some combination of pins and sockets on the receptacle conductive terminals **62** and the opposite combination of pins and sockets on the plug conductive terminals **22** with each corresponding mating pair of terminals including one pin and one socket.

(21) With reference to FIG. **9**, the conductive terminals **22**, **62** have distal ends **22***d*, **62***d*, opposite the socket **22***s* and pin **62***p*, extending from the plug and receptacle insert bodies **26**, **66**, adapted for wires **14**, preferably insulated wires, to be connected, preferably by soldering, to the conductive terminals **22**, **62**. Although not shown, typically after the wires **14** have been soldered to the plug conductive terminals **22**, the voids between the plurality of wires **14** of the electrical cable **12** in a rear portion **24***r* of the plug shell **24** are filled with epoxy potting.

(22) In a preferred embodiment, the waterproof electrical cable **12** comprises the plurality of wires **14** that are connected to the distal end **22***d* of the plug conductive terminals **22**. Preferably, a rubber overmold **13** (FIG. **9**) is formed around the end of the waterproof cable **12** and the rear portion **24***r* of the plug shell **24** to form a water-tight seal.

(23) The receptacle assembly **60** includes an outer body **70** preferably non-metallic, and more preferably made of PEEK. The receptacle assembly **60** also includes first and second metal tubular members **72** and **74**, respectively. The first metal tubular member **72** has a forward portion **72***f* and a rear portion **72***r*. The forward portion **72***f* has a flat end surface **72***s* and exterior threads **72***t*. The second metal tubular member **74** has a forward portion **74***f* and a rear portion **74***r.*

(24) Preferably, the outer body **70** is molded around and contains the forward portion **74***f* of the second metal tubular member **74** and the rear portion **72***r* of the first metal tubular member **72** as shown in FIGS. **5** and **9**. The outer body **70** includes a gap-forming portion **70***g* between the opposing ends of the first and second metal tubular members **72** and **74** as shown in FIGS. **5**, **7** and **9**. A seal **76**, preferably a rubber seal, may be positioned between the gap-forming portion **70***g* and the receptacle insert body **66** as a redundant safety seal.

(25) As shown in FIG. **9**, the first metal tubular member **72** has an axial bore **73** for receiving the receptacle insert body **66**. The second metal tubular member **74** has a stepped axial bore **75** defining a shoulder **75***s*. The shoulder **75***s* forms a restriction to axial movement of the receptacle insert body **66** in the direction towards the rear end **74***r* of the second metal tubular member **74**. Additionally, an annular groove **73***g* may be formed in the axial bore **73** of the first metal tubular member **72** with the annular groove **73***g* adapted to receive a retaining ring **78** to prevent axial movement of the receptacle insert body **66** in the direction towards the forward end **72***f* of the first metal tubular member **72**.

(26) Still referring to FIG. **9**, the plug shell **24** has a stepped interior axial bore **25** defining a shoulder **25***s*. The shoulder **25***s* forms a restriction to axial movement of the plug insert body **26** in the direction towards a forward portion **24***f* of the plug shell **24**. As shown in FIGS. **5** and **9**, an annular interior groove **24***g* in the plug shell **24** is adapted to receive a seal **29** to form a seal between the plug shell **24** and the plug insert body **26**.

(27) In one embodiment, the plug shell **24** has a stepped exterior diameter **27** comprising a first shoulder **27***f* of increased diameter and a second shoulder **27***s* of reduced diameter as shown in FIG. **9**. Extending around the forward portion **24***f* of the plug shell **24** is a coupling nut **30** having an internally threaded portion **30***t*. An interior flange **30***f* is formed at a rear portion **30***r* of the coupling nut **30** as shown in FIG. **5**. The interior flange **30***f* is adjacent to the first shoulder **27***f* of the plug shell **24** which restricts forward movement of the coupling nut **30** with respect to the plug shell **24**. A retaining ring **32** received in a groove **26***g* of the plug shell **24** limits the rearward movement of the coupling nut **30** with respect to the plug shell **24**.

(28) The coupling nut **30** is adapted to rotate relative to the plug shell **24**. Preferably, the coupling nut **30** includes one or more gripping means **34** to facilitate rotating the coupling nut **30** as shown

in FIGS. **1-3**. The gripping means **34** may comprise one or more various surfaces and shapes. A few examples include, without limiting the invention, a plurality of longitudinal grooves or lines inscribed on the outer surface, a knurled outer surface, a recess or an outer shape adapted to be received by a tool or wrench, to name just a few.

(29) In a preferred embodiment, the pins **62***p* of the conductive terminals **62** are located rearward of the flat end surface **72***s* of the first metal tubular member **72**, and the forward face **26***f* of the plug insert body **26** is located adjacent to or slightly rearward of a forward end surface **24***s* of the plug shell **24** as shown in FIG. **9**. Preferably, the axial bore **73** in the forward portion **72***f* of the first metal tubular member **72** includes an orientation guide **80** (FIG. **9**) and the forward portion **24***f* of the plug shell **24** includes a complementary orientation guide **40** (FIG. **5**). The orientation guides **40** and **80** must engage one another in order for the forward portion **24***f* of the plug shell **24** to be received within the forward portion **72***f* of the first metal tubular member **72**. The guides **40**, **80** may be any of a variety of engaging shapes, sizes, quantities and/or angular positions that require one orientation in order for engagement to occur. Without limiting the invention, one example may be a tongue and groove.

(30) It is to be understood that when the orientation guides **40** and **80** are aligned for engagement, the sockets **22***s* are axially aligned with their corresponding pins **62***p*. As the plug shell **24** begins to enter the axial bore **73** of the first metal tubular member **72**, the exterior threads **72***t* of the first metal tubular member **72** come into contact with the coupling nut **30**. Rotation of the coupling nut **30** in one direction results in the engagement of the threaded portion **30***t* of the coupling nut **30** with the exterior threads **72***t* of the first metal tubular member **72**. As the coupling nut **30** is rotated and threaded onto the first metal tubular member **72**, the plug assembly **20** advances towards the receptacle assembly **60** until fully mated as shown in FIG. **5**. Additionally, engaged orientation guides **40**, **80** maintain the proper axial alignment and orientation of the pins **62***p* and sockets **22***s* during this coupling process while preventing any torsional stress.

(31) In a preferred embodiment, the second shoulder **27***s* of the plug body **24** includes an annular seal **42** received in a groove **44** and the axial bore **73** of the first metal tubular member **72** includes an annular seal **82** received in a groove **84**. As shown in FIG. **5**, in the coupled condition of the plug and receptacle assemblies **20** and **60**, the annular seals **42** and **82** form seals between the plug shell **24** and the first metal tubular member **72**.

(32) Referring to FIGS. **1** and **2**, a plurality of mounting hardware assemblies **100** are shown. In the illustrated embodiments, four mounting hardware assemblies **100** are shown but it is to be understood that a different number of assemblies **100** may be used within the scope of the present invention. As shown in FIG. **6**, the mounting hardware assembly **100** includes a fastener **102** such as a threaded screw made of metal having a head **102***h*. The outer body **70** includes a combination bore **70***b* and counterbore **70***c* for receiving each screw **102** as best shown in FIG. **9**. In a preferred embodiment, the outer body **70** also includes a circular recess **70***r* (FIG. **6**) around each bore **70***b* in a face **70***f* that abuts the structure S. The circular recess **70***r* is adapted to receive a seal **104**, such as an O-ring, as shown in FIG. **6**.

(33) Preferably, the outer body **70** additionally includes an annular groove **71** (FIG. **9**) in the face **70***f* around the second metal tubular member **74**. The annular groove **71** is adapted to receive a seal **106**, such as an O-ring, as shown in FIG. **9**. The structure S includes a hole for receiving the rear portion **74***r* of the second metal tubular member **74**.

(34) In a preferred embodiment, an annular groove **74***g* adapted to receive a seal **108** may be formed in the outer surface of the rear portion **74***r* of the second metal tubular member **74**, as shown in FIG. **9**. The seal **108** forms a seal between the structure S and the second metal tubular member **74**.

(35) It is to be understood that the preferred embodiments of the underwater electrical connector **10** is intended to be installed and connected when dry. The underwater structure S is preferably dry on the interior of the structure S. Preferably, the receptacle assembly **60** is installed to the underwater

structure S and the plug assembly **20** is connected to the receptacle assembly **60** prior to submerging the structure S underwater or in an electrolyte.

(36) Prior to mounting the receptacle assembly **60** to the structure S, the seal **108** is placed in the annular groove **74***g* of the second metal tubular member **74**, and the seals **104** and **106** are placed in the circular recesses **70***r* and the annular groove **71** of the outer body **70**. The threaded screws **102** are inserted in combination bores **70***b* and **70***c* and through corresponding screw holes in the structure S and secured to the structure S, typically via a threaded connection. With reference to FIGS. **6** and **9**, following securement to the structure S, a cap **110** having a cap head **110***h* and an outer annular groove **110***g* receiving a seal **112**, such as an O-ring, is inserted in the counterbore **70***c*. The seal **112** forms a watertight seal between the outer body **70** and the cap **110** preventing seawater W from access to the threaded screw **102**. Preferably, the length of the cap **110** is such that the cap head **110***h* extends out of the counterbore **70***c* to facilitate removal of the cap **110**, if needed. Preferably, the cap **110** is made of PEEK. Alternatively, the fastener cap **110** can be metal so long as it does not contact the fastener **102**.

(37) FIG. **10** shows another underwater electrical connector, referred to as reference number **210**, according to a preferred embodiment of the present invention. In this embodiment the plug assembly **20** is the same as for the underwater electrical connector **10** but the receptacle assembly **260** has been modified. It is to be understood that portions of the receptacle assembly **260** remain the same as the receptacle assembly **60** of the first embodiment. For example, the receptacle insert body **66** is the same, and will not be again described in detail.

(38) The receptacle assembly **260** includes an outer body **270**, preferably non-metallic and preferably made of PEEK. The receptacle assembly **260** also includes a metal tubular member **272** having a forward portion **272***f*, a medial portion **272***m*, and a rear portion **272***r*. The forward portion **272***f* has a flat end surface **272***s* and exterior threads **272***t*.

(39) As shown in FIG. **10**, the metal tubular member **272** has a stepped axial bore **275** defining a shoulder **275***s*. The receptacle insert body **66** is received in the stepped axial bore **275** from the forward portion **272***f* of the metal tubular member **272** and the shoulder **275***s* forms a restriction to axial movement of the receptacle insert body **66** in the direction towards the rear portion **272***r* of the metal tubular member **272**. Additionally, an annular groove **273***g* may be formed in the axial bore **275** of the metal tubular member **272** with the annular groove **273***g* adapted to receive a retaining ring **78** to prevent axial movement of the receptacle insert body **66** in the direction towards the forward end **272***f* of the metal tubular member **272**.

(40) Preferably, the outer body **270** is molded around the medial portion **272***m* of the metal tubular member **272** and has a stepped exterior diameter **270***d* comprising a shoulder **270***s* between a reduced exterior diameter portion **270***r* and an increased exterior diameter portion **270***i*. Preferably, the reduced exterior diameter portion **270***r* is sized to be received in a receptacle opening in the structure S and the shoulder **270***s* is sized to abut against the outer surface of the structure S around the receptacle opening. Preferably, one or more seal rings **206**, **208** received in annular grooves **270***g* of the stepped exterior diameter **270***d* of the outer body **270** provide watertight seals between the outer body **270** and the structure S upon installation.

(41) Still referring to FIG. **10**, a washer **277**, preferably made of PEEK, is sized to fit onto the rear portion **272***r* of the metal tubular member **272** and abut the inner surface of the structure S around the receptacle opening. Preferably, the rear portion **272***r* of the metal tubular member **272** includes an exterior threaded portion **274***t* and a securing nut **278** threadedly engages the exterior threaded portion **274***t* and secures the receptacle assembly **260** to the structure S.

(42) It is to be understood that in the embodiment of FIG. **10** the metal tubular member **272** is isolated from and does not contact the structure S due to the PEEK outer body **270**. Additionally, the securing nut **278** is isolated from and does not contact the structure S due to the PEEK washer **277**.

(43) It is to be understood that the plug shell **24**, coupling nut **30** and metal tubular member **72**,

272, are made of metal alloys having the same galvanic potential.

(44) FIGS. **11** and **12** are views of two other embodiments of the underwater electrical connector. Similar to the embodiment shown in FIG. **10**, the plug assemblies **20** in FIGS. **11** and **12** are the same as for the underwater electrical connector **10** but the receptacle assemblies **360**, **460** has been modified. Only the major differences between the receptacle assemblies **360** and **460** with respect to the receptacle assemblies **60** (FIG. **9**) and **260** (FIG. **10**) will be described below. It is to be understood that a person of ordinary skill in the art will readily appreciate and understand the differences and how to implement each of the receptacle assemblies.

(45) The receptacle assembly **360** in FIG. **11** has a one piece metal tubular member **372** molded within an outer body **370**. The outer body **370** is preferably non-metallic and preferably formed of PEEK. Similar to the one piece metal tubular member **272** of FIG. **10**, the outer body **370** prevents the metal tubular member **372** from contacting the structure S. A plurality of mounting hardware assemblies **100** are provided in a manner similar to the embodiment shown in FIGS. **1-9**. As described above with respect to the receptacle assembly **60** shown in FIG. **9**, a couple of seals **106** and **108** form a fluid seal between the outer body **370** and the structure S around the metal tubular member **372**. Additionally, a seal **104** around each fastener **102** between the outer body **370** and the structure S and a cap **110** with a seal **112** received in a counterbore **70***c* similarly prevents the mounting hardware assemblies **100** from exposure to the seawater W.

(46) The receptacle assembly **460** in FIG. **12** has first and second metal tubular members **472** and **474** respectively, partially within an outer body **470**. Preferably, the outer body **470** is non-metallic and formed of PEEK. The outer body **470** may be molded around portions of the first and second metal tubular members **472** and **474**. The outer body **470** preferably includes a gap-forming portion **470***g* between the opposing ends of the first and second metal tubular members **472** and **474**. The gap-forming portion **470***g* of the outer body **470** prevents the first metal tubular member **472** from contacting the second metal tubular member **474**. A seal **476**, preferably a rubber seal, may be positioned between the gap-forming portion **470***g* and the receptacle insert body **66** as a redundant safety seal.

(47) The second metal tubular member **474** is allowed to contact the structure S although it is prevented from coming into contact with the seawater W. A washer **477**, which may be made of metal, may be sized to fit onto the second metal tubular member **474** and abut the inner surface of the structure S around the receptacle opening. The second metal tubular member **474** includes an exterior threaded portion **474***t*. A securing nut **478** threadedly engages the exterior threaded portion **474***t* and secures the receptacle assembly **460** to the structure S.

(48) Preferably, a seal ring **406** is received in an annular groove **470***r* of the outer body **470** to provide a watertight seal between the outer body **470** and the structure S upon installation. Additionally, the second metal tubular member **474** may have an annular groove **474***g* for receiving a seal ring **408** forming a seal between the structure S and the second metal tubular member **474**.

(49) In the preferred embodiments of the present invention, the receptacle assembly **60**, **260**, **360**, **460** is a plastic molded assembly containing metal components for mating to the plug assembly **20** and mounting to the structure S. Molded in metal inserts are not galvanically coupled from the seawater-exposed side to the interior of the structure S. The receptacle assembly **60**, **360** also segregates mounting hardware, typically fasteners **102** such as cap screws, from seawater W thus breaking a galvanic couple and the receptacle assembly **260**, **460** has the securing nut **278**, **478** contained within the watertight portion of the structure S.

(50) The plug assembly **20** uses only one metal alloy for the plug shell **24**, coupling nut **30** and retaining ring **32** and it is the same as the metal alloy of the mounting thread **72***t*, **272***t* and first metal tubular member **72**, **272**, **372**, **472** of the receptacle assembly **60**, **260**, **360**, **460**. This results in eliminating any galvanic couple between the metal components and therefore eliminates cathodic delamination of the over-molded rubber section **13**.

(51) The preferred embodiment of the present invention eliminates exposing dissimilar metals to

electrolyte (e.g., seawater). Doing so 100% eliminates both galvanic corrosion between the interconnect of the plug and receptacle assemblies **20** and **60**, **260**, **360**, **460** and the structure S it is mounted upon and cathodic delamination between the electrical cable rubber overmold **13** and the plug assembly **20**.

NOMENCLATURE

(52) structure S seawater W underwater electrical connector **10** waterproof electrical cable **12** rubber overmold **13** wires **14** plug assembly **20** conductive terminals **22** distal ends **22***d* socket **22***s* plug shell **24** forward portion **24***f* interior groove **24***g* rear portion **24***r* forward end surface **24***s* stepped interior axial bore **25** shoulder **25***s* plug insert body **26** forward face **26***f* groove **26***g* rearward end **26***r* stepped exterior diameter **27** first shoulder **27***f* second shoulder **27***s* support member **28** seal **29** coupling nut **30** interior flange **30***f* rear portion **30***r* threaded portion **30***t* retaining ring **32** gripping means **34** complementary orientation guide **40** seal **42** groove **44** receptacle assembly **60** conductive terminals **62** distal ends **62***d* pin **62***p* receptacle insert body **66** forward face **66***f* outer body **70** bore **70***b* counterbore **70***c* face **70***f* gap-forming portion **70***g* circular recess **70***r* annular groove **71** first metal tubular member **72** forward portion **72***f* rear portion **72***r* flat end surface **72***s* exterior threads **72***t* axial bore **73** annular groove **73***g* second metal tubular member **74** forward portion **74***f* groove **74***g* rear portion **74***r* stepped axial bore **75** shoulder **75***s* seal **76** retaining ring **78** orientation guide **80** seal **82** groove **84** mounting hardware assembly **100** fastener **102** head **102***h* seal **104** seal **106** seal **108** cap **110** outer annular groove **110***g* cap head **110***h* seal **112** seal ring **206** seal ring **208** underwater electrical connector **210** receptacle assembly **260** outer body **270** stepped exterior diameter **270***d* annular grooves **270***g* increased exterior diameter portion **270***i* reduced exterior diameter portion **270***r* shoulder **270***s* metal tubular member **272** forward portion **272***f* medial portion **272***m* rear portion **272***r* end surface **272***s* exterior threads **272***t* annular groove **273***g* threaded portion **274***t* stepped axial bore **275** shoulder **275***s* washer **277** securing nut **278** receptacle assembly **360** outer body **370** metal tubular member **372** seal ring **406** seal ring **408** receptacle assembly **460** outer body **470** gap-forming portion **470***g* annular groove **470***r* first metal tubular member **472** second metal tubular member **474** annular groove **474***g* exterior threaded portion **474***t* seal **476** washer **477** securing nut **478**

(53) The foregoing disclosure and description of the invention are illustrative and explanatory thereof, and various changes in the size, shape and materials, as well as in the details of the illustrated construction, may be made without departing from the spirit of the invention. The present embodiment is, therefore, to be considered as merely illustrative and not restrictive, the scope of the invention being indicated by the claims rather than the foregoing description, and all changes which come within the meaning and range of equivalence of the claims are therefore intended to be embraced therein.

(54) While the invention has been described in detail above with reference to specific embodiments, it will be understood that modifications and alterations in the embodiments disclosed may be made by those practiced in the art without departing from the spirit and scope of the invention. All such modifications and alterations are intended to be covered. In addition, all publications cited herein are indicative of the level of skill in the art and are hereby incorporated by reference in their entirety as if each had been individually incorporated by reference and fully set forth.

Claims

1. A galvanic corrosion-proof underwater electrical interconnect comprising: a plug assembly (**20**) comprising: a plug shell (**24**); a plug insert body (**26**) mounted within the plug shell (**24**), the plug insert body (**26**) having a plurality of plug conductive terminals (**22**); a threaded coupling nut (**30**) extending around a forward portion (**24***f*) of the plug shell (**24**); and a waterproof electrical cable (**12**) having a plurality of wires (**14**) connected to the plurality of plug conductive terminals (**22**);

and a rubber overmold (**13**) formed around a rear portion (**24***r*) of the plug shell (**24**) and a portion of the waterproof electrical cable (**12**) forming a water-tight seal therebetween; and a receptacle assembly (**60**, **460**) comprising: a first metal tubular member (**72**, **472**) having a threaded forward portion (**72***f*) adapted to threadedly engage the threaded coupling nut (**30**); a second metal tubular member (**74**, **474**); a non-metallic outer body (**70**, **470**) positioned around a rear portion (**72***r*) of the first metal tubular member (**72**, **472**) and a forward portion (**74***f*) of the second metal tubular member (**74**, **474**), the outer body (**70**, **470**) having a gap-forming portion (**70***g*, **470***g*) between opposing ends of the first and second metal tubular members (**72**, **472** and **74**, **474**) preventing contact between the first and second tubular members (**72**, **472** and **74**, **474**); a receptacle insert body (**66**) mounted at least partially within one of the first and second tubular members (**72**, **472** and **74**, **474**) and having a plurality of receptacle conductive terminals (**62**), wherein the plurality of plug conductive terminals (**22**) are adapted to contact the plurality of receptacle conductive terminals (**62**) upon mating engagement of the plug assembly (**20**) to the receptacle assembly (**60**, **460**), wherein the plug shell (**24**), coupling nut (**30**) and first metal tubular member (**72**, **472**) are made of metal alloys having the same galvanic potential.

2. The underwater electrical interconnect of claim 1, wherein the outer body (**70**, **470**) is made of plastic.

3. The underwater electrical interconnect of claim 2, wherein the outer body (**70**, **470**) is molded around the rear portion (**72***r*) of the first metal tubular member (**72**, **472**) and the forward portion (**74***f*) of the second metal tubular member (**74**, **474**).

4. The underwater electrical interconnect of claim 1, wherein upon installation of the receptacle assembly (**60**, **460**) to a structure (S) and immersing the structure (S) and receptacle assembly (**60**, **460**) in an electrolyte, the second metal tubular member (**74**, **474**) is not exposed to the electrolyte.

5. The underwater electrical interconnect of claim 1, further comprising a seal (**76**, **476**) positioned between the gap-forming portion (**70***g*, **470***g*) and the receptacle insert body (**66**) and forming a fluid-tight seal therebetween.

6. The underwater electrical interconnect of claim 1, further comprising: the outer body (**70**, **470**) having an annular groove (**71**, **470***r*) in a face (**70***f*) of the outer body (**70**, **470**); and a seal (**106**, **406**) received in the annular groove (**71**, **470***r*), wherein a portion of the second metal tubular member (**74**, **474**) is adapted to be received in a receptacle opening of a structure (S) prior to immersion of the structure (S) and the receptacle assembly (**60**) in an electrolyte, and the face (**70***f*) is adapted to abut an outer surface of the structure (S) around the receptacle opening with the seal (**106**, **406**) forming a fluid-tight seal between the outer surface around the receptacle opening and the outer body (**70**, **470**).

7. The underwater electrical interconnect of claim 6, wherein the second metal tubular member (**474**) has an exterior threaded portion (**474***t*) extending through the receptacle opening; and a securing nut (**478**) threadedly engages the exterior threaded portion (**474***t*) and secures the receptacle assembly (**460**) to the structure (S).

8. The underwater electrical interconnect of claim 6, wherein the second metal tubular member (**74**, **474**) is allowed to contact the structure (S).

9. The underwater electrical interconnect of claim 1, further comprising a mounting hardware assembly (**100**) for mounting the receptacle assembly (**60**) to a structure (S) prior to immersion in an electrolyte, the mounting hardware assembly (**100**) extending through the outer body (**70**) and sealed from exposure to the electrolyte, wherein upon installation of the receptacle assembly (**60**) to the structure (S), the first metal tubular member (**72**) is not in contact with and not galvanically coupled to the structure (S) and upon mating of the plug assembly (**20**) to the receptacle assembly (**60**), the plug shell (**24**), coupling nut (**30**) and first metal tubular member (**72**) are not galvanically coupled to the structure (S).

10. The underwater electrical interconnect of claim 9, wherein the mounting hardware assembly (**100**) comprises: a plurality of threaded screws (**102**) having screw heads (**102***h*) received in

counterbores (**70***c*) of the outer body (**70**); and a cap (**110**) with a seal (**112**) received in the counterbore (**70***c*) forming a watertight seal between the outer body (**70**) and the cap (**110**) preventing the electrolyte from contacting the threaded screws (**102**).
11. The underwater electrical interconnect of claim 10, wherein the caps (**110**) are made of plastic.
12. The underwater electrical interconnect of claim 1, wherein the receptacle insert body (**66**) and the plug insert body (**26**) are made of plastic.
13. A galvanic corrosion-proof underwater electrical interconnect comprising: a plug assembly (**20**) comprising: a plug shell (**24**); a plug insert body (**26**) mounted within the plug shell (**24**), the plug insert body (**26**) having a plurality of plug conductive terminals (**22**); a threaded coupling nut (**30**) extending around a forward portion (**24***f*) of the plug shell (**24**); and a waterproof electrical cable (**12**) having a plurality of wires (**14**) connected to the plurality of plug conductive terminals (**22**); and a rubber overmold (**13**) formed around a rear portion (**24***r*) of the plug shell (**24**) and a portion of the waterproof electrical cable (**12**) forming a water-tight seal therebetween; and a receptacle assembly (**260**, **360**) comprising: a metal tubular member (**272**, **372**) having a threaded forward portion (**272***f*) adapted to threadedly engage the threaded coupling nut (**30**); a receptacle insert body (**66**) mounted within the metal tubular member (**272**, **372**) and having a plurality of receptacle conductive terminals (**62**), wherein the plurality of plug conductive terminals (**22**) are adapted to contact the plurality of receptacle conductive terminals (**62**) upon mating engagement of the plug assembly (**20**) to the receptacle assembly (**260**, **360**); a non-metallic outer body (**270**, **370**) positioned around a portion of the metal tubular member (**272**, **372**), the outer body (**270**, **370**) having a stepped exterior diameter (**270***d*) comprising a shoulder (**270***s*) between a reduced exterior diameter portion (**270***r*) and an increased exterior diameter portion (**270***i*), wherein the reduced exterior diameter portion (**270***r*) is adapted to be received in a receptacle opening of a structure (S) and the shoulder (**270***s*) is adapted to abut an outer surface of the structure (S) around the receptacle opening, wherein the plug shell (**24**), coupling nut (**30**) and metal tubular member (**272**, **372**) are made of metal alloys having the same galvanic potential and the non-metallic outer body (**270**, **370**) prevents the metal tubular member (**272**, **372**) from contacting the structure (S).
14. The underwater electrical interconnect of claim 13, wherein the outer body (**270**, **370**) is made of plastic.
15. The underwater electrical interconnect of claim 13, wherein the outer body (**270**, **370**) is molded around a portion (**272***m*) of the metal tubular member (**272**, **372**).
16. The underwater electrical interconnect of claim 13, further comprising: the outer body (**270**, **370**) having an annular groove (**71**, **470***r*) in a face (**70***f*) of the outer body (**70**, **470**); and a seal ring (**206**, **106**) received in the annular groove (**71**) and forming a fluid-tight seal between the outer surface around the receptacle opening and the outer body (**270**, **370**).
17. The underwater electrical interconnect of claim 16, wherein the metal tubular member (**272**, **322**) does not contact the structure (S).
18. The underwater electrical interconnect of claim 17, further comprising: a non-metallic washer (**277**) positioned onto a rear portion (**272***r*) of the metal tubular member (**272**) and abutting an inner surface of the structure (S) around the receptacle opening, wherein the metal tubular member (**272**) has an exterior threaded portion (**274***t*) on the rear portion (**272***r*); and a securing nut (**278**) threadedly engages the exterior threaded portion (**274***t*) and secures the receptacle assembly (**260**) to the structure (S).
19. The underwater electrical interconnect of claim 13, further comprising a mounting hardware assembly (**100**) for mounting the receptacle assembly (**360**) to the structure (S) prior to immersion of the structure (S) and receptacle assembly (**360**) in an electrolyte, the mounting hardware assembly (**100**) extending through the outer body (**370**) and sealed from exposure to the electrolyte, wherein upon installation of the receptacle assembly (**360**) to the structure (S), the metal tubular member (**372**) is not in contact with and not galvanically coupled to the structure (S) and upon mating of the plug assembly (**20**) to the receptacle assembly (**360**), the plug shell (**24**), coupling nut

(**30**) and metal tubular member (**372**) are not galvanically coupled to the structure (S).
20. The underwater electrical interconnect of claim 19, wherein the mounting hardware assembly (**100**) comprises: a plurality of threaded screws (**102**), each threaded screw (**102**) having a screw heads (**102**_h_) received in counterbores (**70**_c_) of the outer body (**370**); and a plurality of caps (**110**), each cap (**110**) having a seal (**112**) received in the counterbore (**70**_c_) forming a watertight seal between the outer body (**370**) and the cap (**110**) preventing the electrolyte from contacting the threaded screws (**102**).
21. The underwater electrical interconnect of claim 20, wherein the caps (**110**) are made of plastic.
22. The underwater electrical interconnect of claim 13, wherein the receptacle insert body (**66**) and the plug insert body (**26**) are made of plastic.
23. A galvanic corrosion-proof underwater electrical interconnect comprising: a plug assembly (**20**) comprising a plug shell (**24**), a coupling nut (**30**) rotatably connected to the plug shell (**24**), and a plug insert body (**26**) mounted within the plug shell (**24**); a receptacle assembly (**60**, **260**, **360**, **460**) adapted to be mounted to a structure (S), the receptacle assembly (**60**, **260**, **360**, **460**) comprising a first metal tubular member (**72**, **272**, **372**, **472**) having a forward portion (**72**_f_, **272**_f_) adapted to engage the coupling nut (**30**), a receptacle insert body (**66**) mounted at least partially within the first metal tubular member (**72**, **272**, **372**, **472**), and a non-metallic outer body (**70**, **270**, **370**, **470**) mounted on the first metal tubular member (**72**, **272**, **372**, **472**), wherein the non-metallic outer body (**70**, **270**, **370**, **470**) is positioned between the first metal tubular member (**72**, **272**, **372**, **472**) and the structure (S), and the first metal tubular member (**72**, **272**, **372**, **472**) is prevented from being in contact with the structure (S).
24. The underwater electrical interconnect of claim 23, wherein the plug shell (**24**), coupling nut (**30**) and first metal tubular member (**72**, **272**, **372**, **472**) are made of metal alloys having the same galvanic potential.
25. The underwater electrical interconnect of claim 24, wherein the non-metallic outer body (**70**, **270**, **370**, **470**) is molded around a portion (**72**_r_, **272**_m_) of the first metal tubular member (**72**, **272**, **372**, **472**).
26. The underwater electrical interconnect of claim 23, further comprising: a waterproof electrical cable (**12**) having a plurality of wires (**14**) connected to the plug insert body (**26**); and a rubber overmold (**13**) formed around a portion (**24**_r_) of the plug shell (**24**) and a portion of the waterproof electrical cable (**12**) forming a water-tight seal therebetween.
27. The underwater electrical interconnect of claim 23, further comprising a mounting hardware assembly (**100**) for mounting the receptacle assembly (**60**, **360**) to the structure (S) prior to immersion of the structure (S) and receptacle assembly (**60**, **360**) in an electrolyte, the mounting hardware assembly (**100**) extending through the outer body (**70**, **370**) and sealed from exposure to the electrolyte, wherein upon installation of the receptacle assembly (**60**, **360**) to the structure (S), the first metal tubular member (**72**, **372**) is not in contact with and not galvanically coupled to the structure (S) and upon mating of the plug assembly (**20**) to the receptacle assembly (**60**, **360**), the plug shell (**24**), coupling nut (**30**) and metal tubular member (**372**) are not galvanically coupled to the structure (S).
28. The underwater electrical interconnect of claim 27, wherein the mounting hardware assembly (**100**) comprises: a plurality of threaded screws (**102**), each threaded screw (**102**) having a screw head (**102**_h_) received in counterbores (**70**_c_) of the outer body (**370**); and a plurality of caps (**110**), each cap (**110**) having a seal (**112**) received in the counterbore (**70**_c_) forming a watertight seal between the outer body (**370**) and the cap (**110**) preventing the electrolyte from contacting the threaded screws (**102**).