



ABYC E-2 July 2019

**Electrical Division Standard
Electrical Project Technical
Committee**

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ABYC reviews each standard at least every five years at which time it may be reaffirmed, revised, or withdrawn. ABYC welcomes any written comments on the standards and Technical information reports.

ABYC E-2

CATHODIC PROTECTION



Origin and Development

E-2, *Cathodic Protection* was first published in 1965 with revisions in 1971, 1973, 1981, 1996, 2001, 2008 and 2013. The July 2019 revision is the work of the Electrical Project Technical Committee.

Electrical Project Technical Committee

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This standard, which is the result of extended and careful consideration of available knowledge and experience on the subject, was developed under procedures accredited as meeting the criteria for American National Standards and is intended to provide minimum performance requirements. The Project Technical Committee that approved the standard was balanced to ensure that individuals from competent and concerned interests have had an opportunity to participate.

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Upon written request the Electrical PTC will render an interpretation of any requirement of the standard. The request for interpretation should be clear and unambiguous. Requests should be presented to the PTC in a manner in which they may be answered in a "Yes" or "No" fashion.

The committee reserves the right to reconsider any interpretation when or if additional information that might affect it becomes available to the PTC. Persons aggrieved by an interpretation may appeal to the Committee for reinterpretation.

Summary of Revisions

This list indicates revisions to the standard when compared with the previously published version. It is not intended to be used independently of the standard. It should be used for informational purposes and as a guide to the official requirements contained in this standard. It is the responsibility of the user to read and understand the complete standard.

The main changes in this revision of E-2, *Cathodic Protection* as compared with the previous edition dated 7/13, are:

- Scope and Purpose were combined
- Units of Measurement section was added
- Definition section was revised
- Cathodic bonding conductor requirements were revised
- Magnesium sacrificial anodes requirements were expanded
- Impressed current system requirements were clarified
- TABLE 1 was expanded with zinc reference cell potentials

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E-2 CATHODIC PROTECTION

Based on ABYC's assessment of the existing technology, and the problems associated with achieving the goals of the standard, ABYC recommends compliance for systems and associated equipment manufactured and/or installed after July 31, 2020.

2.1 SCOPE

This standard applies to the design, installation, and use of cathodic protection systems on boats with sacrificial anodes or impressed currents.

2.2 UNITS OF MEASURE

Values stated without parentheses are the requirement. Values in parentheses are explanatory or approximate.

2.3 REFERENCES

The following references form a part of this standard. Unless otherwise noted the latest version of referenced standards shall apply.

2.3.1 ABYC - American Boat & Yacht Council, Inc, 613 Third Street, Suite 10, Annapolis, MD 21403. Phone: (410) 990-4460. Fax: (410) 990-4466. Website: www.abycinc.org

[A-28, Galvanic Isolators](#)

[E-11, AC & DC Electrical Systems on Boats](#)

[TE-4, Lightning Protection](#)

2.3.2 ASTM - ASTM International 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959. Phone: (610)-832-9500. Fax: (610)-832-9555. Website: <https://www.astm.org>

ASTM B418 - *Standard Specification for Cast and Wrought Galvanic Zinc Anodes*

ASTM B605 - *Standard Specification for Electrodeposited Coatings of Tin-Nickel Alloy*

2.3.3 Military Specifications (MILSPEC) - A specification developed by the US Armed Forces. Obtain the referenced specifications from the Naval Publications and Form Center, 5801 Tabor Avenue, Philadelphia, PA 19120.

MIL-A-18001 - *Military Specification: Anodes, Sacrificial Zinc Alloy*

MIL-A-21412 - *Military Specification: Anodes, Corrosion Preventative, Magnesium Alloy, Cast or Extruded Shapes With Cast-In Cores*

2.4 DEFINITIONS

For the purpose of this standard the following definitions apply.

2.4.1 Active-Passive Metals - metals that exhibit two distinct corrosion potentials depending on the composition of the electrolyte, other environmental factors, and/or surface conditions of the metal itself. The austenitic (300-series) stainless steels are typical examples of active-passive metals.

2.4.2 Amphoteric - capable of reacting chemically in an acid or a base. Certain oxides of a few metals, including aluminum, tin, lead, and zinc, are amphoteric, which renders those metals more susceptible to corrosion in alkaline electrolytes than other metals.

2.4.3 Anode (Galvanic Anode) -

2.4.3.1 an electrode of a simple electrochemical cell at which metal ions pass into the electrolyte and the metal wastes away, or

2.4.3.2 an electrode of a galvanic cell which has a more negative corrosion potential than another electrode of the cell; or

2.4.3.3 an electrode of a supplied-current cell which is connected to the positive terminal of a DC current source (see Cathode).

- 2.4.4 Anode Reaction - a type of electrochemical reaction in which metal passes into an electrolyte as ions leaving behind electrons and thus increasing the number of excess free electrons in the solid metal (see Cathode Reaction).
- 2.4.5 Anodic - less noble, having a relatively negative corrosion potential; pertaining to an electrochemical anode reaction (see Cathodic).
- 2.4.6 Anodic to - having a more negative corrosion potential than (see Cathodic to).
- 2.4.7 Anti-Fouling Coating - a coating applied to the hull and other underwater structures intended to prevent bio-fouling.
- 2.4.8 Barrier Coating - a coating applied to the wetted metal surfaces of the hull and other underwater metal structures that isolates the substrate from water and reduces the current required to provide cathodic protection.
- 2.4.9 Calcareous Coating or Deposit - a film consisting primarily of calcium carbonate and magnesium hydroxide which may be deposited on the cathodes of electrochemical cells in seawater and which reduces the current required to provide cathodic protection.
- 2.4.10 Cathode -
- 2.4.10.1 an electrode of a simple electrochemical cell at which excess free electrons in the metal are neutralized by an electrochemical reaction or
- 2.4.10.2 an electrode of a galvanic cell which has a more positive corrosion potential than another electrode of the cell or
- 2.4.10.3 an electrode of a supplied-current cell which is connected to the negative terminal of a DC current source (see Anode).
- 2.4.11 Cathode Reaction - A type of electrochemical reaction that consumes electrons and thus decreases the number of excess free electrons in the solid metal.
- 2.4.12 Cathodic - more noble, having a relatively positive corrosion potential; pertaining to an electrochemical cathode reaction (see Anodic).
- 2.4.13 Cathodic Bonding - the electrical interconnection of metal objects in common contact with water, to the engine negative terminal or its bus, and to the source of cathodic protection.
- 2.4.14 Cathodic Corrosion - corrosion of certain metals (such as aluminum) caused by excessive cathodic protection.
- 2.4.15 Cathodic Disbondment - a loss of adhesion between a coating and its substrate caused by products of a cathode reaction.
- 2.4.16 Cathodic Protection - reduction or prevention of corrosion of an immersed metal by making it a cathode of a galvanic or supplied-current (impressed-current) electrochemical cell.
- 2.4.17 Cathodic Protection Controller (Corrosion Controller) - an automatic or manually operated device, in a controlled cathodic protection system, to regulate the flow of cathodic protection current.
- 2.4.18 Cathodic to - having a more positive corrosion potential than (see Anodic to).
- 2.4.19 Cell (Electrochemical Cell) - an electric circuit consisting of two or more electrodes which are in contact with a common body of electrolyte and which are also connected electrically by direct contact or by a metallic link.
- 2.4.20 Conductor - a material capable of carrying electric current as a flow of free electrons (see Electrolyte).
- 2.4.21 Corrosion - the deterioration of or loss of metal by physical, chemical, or electrochemical reactions.
- 2.4.22 Corrosion Potential - the potential of an isolated metal in an electrolyte, relative to a reference electrode; also called rest potential, open circuit potential, freely corroding potential, and natural potential.

2.4.23 Couple - two dissimilar metals or alloys in electrical contact with each other that have different potentials and become anodes or cathodes when in common contact with an electrolyte. A couple may also be formed on the surface of the same metal.

2.4.24 Current Density - for corrosion purposes, the current per unit area of the anodes or cathodes expressed in milliamperes per square foot.

2.4.25 Dielectric Shield - in a cathodic protection system, an electrically nonconductive material, such as a coating or plastic sheet, that is placed around an anode to shield the hull from the effects of the strong electric fields at impressed current anodes and to improve current distribution to the cathode.

2.4.26 Dissimilar Metals - metals having different corrosion potentials, which therefore form a galvanic cell when electrically connected and in contact with a common body of electrolyte.

2.4.27 Driving Potential or Driving Voltage -

2.4.27.1 the open-circuit potential difference between the anodes and the cathodes of a simple or galvanic electrochemical cell, or

2.4.27.2 the open-circuit potential of the external current source of a supplied-current cell.

2.4.28 Electric Current - the movement of electrons through metals or of ions through electrolytes.

2.4.29 Electrically Connected - metallic objects in direct contact or connected by a metallic link, thus allowing electric current, as electrons, to flow between them.

2.4.30 Electrode - a conductive material, in an electrolyte, through which electrical current enters or leaves.

2.4.31 Electrolysis - the breakdown of an electrolyte resulting from current flowing in an electrochemical cell that includes that electrolyte, e.g., the breakdown of water into hydrogen and oxygen gases in a supplied-current electrochemical cell.

NOTE: The term "electrolysis" is often used loosely to describe corrosion in general, or the operation of supplied-current cells in particular. Its use in this respect is often confusing and is discouraged.

2.4.32 Electrolyte - a liquid (usually water) containing dissolved ions, capable of carrying electric current as the flow of those ions (see Conductor).

2.4.33 Galvanic Cell - an electrochemical cell consisting of two or more metals having different corrosion potentials, electrically connected and in contact with a common body of electrolyte (see Supplied-Current Cell, Simple Electrochemical Corrosion Cell).

2.4.34 Galvanic Corrosion - the corrosion that occurs at the anode(s) of a galvanic cell.

2.4.35 Galvanic Current - the electric current that flows between metals or conductive nonmetals in a galvanic cell.

2.4.36 Galvanic Isolator - a device installed in series with the grounding (green or green with yellow stripe) conductor of the shore power cable to block low voltage DC galvanic current flow, but permit the passage of alternating current (AC) normally associated with the (AC) grounding (green or green with yellow stripe) conductor.

2.4.37 Galvanic Series - a list of metals and alloys arranged in order of their corrosion potentials in a particular electrolyte relative to a reference electrode. The galvanic series of corrosion potentials is arranged with the negative, anodic, or least noble metals at one end, and the positive, cathodic, or most noble metals at the other (see [TABLE 1](#)).

2.4.38 Hull Potential - the composite potential of the electrically connected immersed metal parts of a hull, relative to a reference cell.

2.4.39 Hull Potential Monitor - a device capable of measuring and displaying the potential difference between a reference electrode and a metal hull or cathodic bonding system.

2.4.40 Impressed Current - direct current supplied by a device employing a power source external to the electrode system of a cathodic protection installation.

- 2.4.41 Ion - an atom or a chemically bonded group of atoms possessing a non-zero net electrical charge.
- 2.4.42 Noble - a descriptor applied to materials having corrosion potentials toward the positive end of the galvanic series.
- 2.4.43 Open-Circuit Potential - the voltage difference of an electrode measured with respect to a reference electrode or another electrode when no current flows to or from it.
- 2.4.44 Passive Film - a protective oxide film, formed either naturally or by chemical treatment, on certain active-passive metals like stainless steel alloys.
- 2.4.45 pH - a number indicating the concentration of hydrogen ions in a water solution. The pH scale runs from 0 (indicating acidity) through 7 (indicating neutrality) to 14 (indicating alkalinity).
- 2.4.46 Polarization -
- 2.4.46.1 a shift in the potential of an electrode of an electrochemical cell resulting from the flow of current in the cell, or
- 2.4.46.2 a gradual reduction in the amount of current required to maintain a desired potential on a cathodically protected metal surface, resulting from the formation of surface films and/or local changes in electrolyte composition.
- 2.4.47 Reference Electrode - an electrode of known standard potential used for measuring the potentials of other electrodes in the same body of electrolyte. Commonly used to measure hull potentials and the potentials of other underwater metal structures. The primary reference electrodes used in the marine industry are silver-silver-chloride (Ag/AgCl) and zinc (Zn).
- 2.4.48 Sacrificial Anode - a less noble metal intentionally electrically connected to and in contact with the same body of electrolyte as a more noble metal, for the purpose of protecting the more noble metal from corrosion.
- 2.4.49 Shaft Contactor - a device intended to make electrical contact to a rotating shaft (e.g., slip ring assemblies, shaft brushes, and shaft wipers).
- 2.4.50 Simple Corrosion Cell - an electrochemical cell in which the anodes and cathodes are located on the surface of a single metal object in contact with an electrolyte (see Galvanic Cell, Supplied-Current Cell).
- 2.4.51 Slip Rings - one or more continuous conducting rings that mate to shaft brushes to provide electrical contact to rotating, or otherwise moving, shafts in order to improve electrical contact to the cathodic bonding system.
- 2.4.52 Stray-Current Corrosion - corrosion resulting from an unintentionally or accidentally supplied current, DC or AC.
- 2.4.53 Substrate - the underlying base on which coatings are applied.
- 2.4.54 Supplied-Current Cell - an electrochemical cell in which an externally driven current source is interposed in the circuit. Impressed-current cathodic protection and stray-current corrosion are both examples of supplied-current cells (see Galvanic Cell, Simple Corrosion Cell).

2.5 GENERAL APPLICATION OF CATHODIC PROTECTION

- 2.5.1 A cathodic protection system shall be capable of inducing and maintaining a minimum negative shift of 200 mV relative to the corrosion potential of the least noble metal being protected.

NOTES:

1. The negative potential (e.g., -1050 mV as compared to silver/silver chloride reference electrode) that can be achieved by some corrosion control systems will result in some decrease in effectiveness of antifouling paints. Because the decrease in effectiveness increases with higher negative voltages, the negative potential should be kept as close to the optimum value as possible (see [TABLE 2](#)). A reference potential reading in excess of -1100 mV indicates excessive cathodic protection.
2. The need for a cathodic protection system for metal appendages on nonmetallic hulls may not be justified if the metals coupled are galvanically compatible (see [TABLE 2](#)); however, individual testing on a case by case basis may be necessary.

3. *Some propeller shafts and propulsion drives are intentionally isolated from the small craft's primary cathodic bonding system and should be individually protected with separate cathodic protection systems.*

2.5.2 **Hull-Mounted Metallic Trim Tabs**

2.5.2.1 On boats equipped with aluminum drive systems, metallic trim tabs shall be installed in accordance with the manufacturer's instructions, and may be isolated from the boat's cathodic bonding system to reduce the load on the boat's cathodic protection system.

2.5.2.2 Metallic trim tabs shall be electrically isolated from their electrically actuated mechanisms.

2.5.2.3 If a metallic trim tab system is connected to a boat's cathodic bonding system, the cathodic protection system's output rating shall be increased to provide the additional required protection.

2.5.2.4 An effective method of cathodic protection shall be provided to all components of a metallic trim tab assembly.

2.5.3 Immersed cathodic metal surfaces shall be favorably matched in anode to cathode area relationship.

NOTE: Coating of cathodic metal surfaces may be used to achieve the relationship.

2.5.4 **Coatings**

2.5.4.1 If antifouling coatings containing pigments that are galvanically incompatible with the substrate metal are used, then cathodic protection shall be maintained and a barrier coating shall be used between the antifouling coating and the substrate.

NOTE: Prior to the application of a barrier coating on metallic surfaces, the surface should be tested for the presence of soluble salts. If salts are present on a surface, they should be reduced to an acceptable level of three micrograms per square centimeter prior to the application of a barrier coating. Special solutions for the reduction of soluble salts, as well as test kits, are commercially available.

2.5.4.2 Coatings on surfaces shall be capable of tolerating alkali generated by the cathodic protection system.

2.5.5 **Anode Placement**

2.5.5.1 Anodes shall be mounted on a surface that cannot entrap gas bubbles.

2.5.5.2 Anodes shall be located so as not to disturb the flow of water past the propeller(s) or jet drive intakes and nozzle(s).

2.5.5.3 Anodes shall be mounted so as not to disturb water flow near intakes and discharge fittings.

2.5.5.4 Sacrificial anodes and reference electrodes shall be installed to avoid areas marked for lifting slings and chocks.

2.5.6 All metals that are to receive cathodic protection from the cathodic protection system shall have a maximum resistance of one ohm to the cathodic bonding system anode.

NOTES:

1. *An electrical resistance greater than one ohm will degrade cathodic protection system performance.*
2. *Propeller shafts do not provide reliable electrical continuity to the boat's cathodic bonding system.*
3. *Resistance measurements should only be taken when the boat is out of the water.*
4. *Hull potential measurements using a reference electrode should be used to determine cathodic bonding system integrity when the boat is in the water.*
5. *Externally mounted hull anodes do not provide effective cathodic protection to the interior surfaces of seawater piping systems, seachests, and heat exchangers due to the restricted electrolyte path through the seawater in the narrow piping channels. Other means of protection from galvanic corrosion may be employed to protect these metals.*

2.5.7 Rudderposts shall be cathodically bonded by means of a flexible conductor positioned to allow full rudder movement without stressing the cathodic bonding conductor or its connection.

2.5.8 **Cathodic Bonding Conductors**

2.5.8.1 Cathodic bonding conductors shall be oil resistant, insulated, tinned, stranded copper wire, or uninsulated copper strip. Copper braid or copper tubing shall not be used for this purpose.

EXCEPTION: Bonding conductors used for submerged applications, such as outboard motors or outdrives, may be composed of manufacturer approved corrosion resistant materials, such as stainless steel cable.

2.5.8.1.1 Uninsulated copper strip, metal mounting hardware, and terminal hardware shall not be in direct contact with wood.

2.5.8.1.2 Connections to the uninsulated copper strip shall comply with [ABYC E-11, AC and DC Electrical Systems on Boats](#).

2.5.8.2 Wire, where used as a cathodic bonding conductor, shall be at least #8 AWG.

EXCEPTION: Wiring provided by engine and drive manufacturers contained on the engine/drive system.

2.5.8.3 Cathodic bonding conductors fabricated from a copper strip shall have a minimum thickness of 1/32 in (0.8 mm) if connections are thru-bolted and a minimum width of 0.5 in (13 mm), or

2.5.8.3.1 connections using machine screws shall have a minimum thickness sufficient to allow for the engagement of four threads at connections if drilled and tapped, and a minimum width of 0.5 in (13 mm).

2.5.8.4 Self tapping fasteners shall not be used at connections.

NOTE: These requirements are based on physical strength, the ability to make and maintain low resistance connections, and current ratings.

2.5.8.5 Insulated conductors shall be selected from [ABYC E-11, AC and DC Electrical Systems on Boats](#).

2.5.8.6 Insulated conductors shall be identified by the color green or green with yellow stripe(s).

2.5.9 Shaft contactors used to provide cathodic protection shall be constructed of materials that will not score the shaft at the shaft-to-brush contactor.

2.5.10 If the batteries are connected as a negative grounded system in accordance with [ABYC E-11, AC and DC Electrical Systems on Boats](#), a metal hull shall be connected directly to the engine negative terminal, and

2.5.10.1 the connection shall be made above the normal accumulation of bilge water, and

2.5.10.2 if a lightning protection system is installed on the boat, this conductor shall not be less than the equivalent of #6 AWG (see [ABYC TE-4, Lightning Protection](#)).

2.6 **GALVANIC ISOLATION**

2.6.1 If installed, galvanic isolators shall be installed in accordance with [ABYC A-28, Galvanic Isolators](#).

2.6.2 If installed, isolation transformers shall be installed in accordance with [ABYC E-11, AC and DC Systems on Boats](#).

NOTE: It is strongly recommended that any boat with a permanently installed shore power system be provided with galvanic isolation. Galvanic isolation may be achieved by use of a galvanic isolator, polarization transformer with galvanic isolator, or an isolation transformer. The electrical interconnection that occurs via shore power grounding conductor may result in the flow of galvanic current between the boat and dock structure or another boat. This can lead to excessive anode loss, or corrosion beyond the capacity of the boat's cathodic protection system.

2.7 SACRIFICIAL ANODES

2.7.1 If installed, the mass and exposed surface area of the anode(s) used to achieve cathodic protection (e.g., magnesium, zinc, aluminum,) shall be sufficient to provide continuous current output or capable of inducing and maintaining acceptable potential levels according to [E-2.5.1](#) for at least the period between inspections.

NOTES:

1. Inspections may be conducted at intervals suitable for the usage and location of the boat, generally annually (see [E-2 APPENDIX](#)).
2. Typical compositions of zinc, aluminum, and magnesium anodes appear in ABYC [E-2 APPENDIX](#). Zinc anodes require zinc of high quality with the most undesirable (critical) trace element being iron. The addition of cadmium and aluminum will permit an increase in the tolerance for iron. Zinc anodes have a natural potential approximately -1050 mV with reference to a silver/silver chloride reference electrode in seawater.
3. The fixed potential of sacrificial anodes provides their basic utility, but the available current depends upon the exposed surface and the necessary mass to maintain this current over a period of time.
4. Iron sacrificial anodes may be used to protect copper based metals in some piping, heat exchanger, and drive applications.
5. Anodes may be selected based upon location of the boat as follows:*

	SALT WATER	BRACKISH WATER	FRESH WATER
Zn	√		
Al	√	√	√
Mg			√

*This table is not a substitute for testing in accordance with this standard.

6. Sacrificial anodes may be mounted directly on the metal to be protected.
7. Zinc or aluminum sacrificial anodes may be applied directly to aluminum, steel, and nonmetallic hulls without shielding.

2.7.2 Sacrificial anodes on a shaft shall be installed so as not to restrict water flow to strut bearings.

NOTE: Collars applied to the propeller shaft of boats are usually adequate to protect the propellers and shafts of bronze and stainless steel.

2.7.3 Magnesium hull anodes installed on steel or aluminum hulls shall have a dielectric shield installed between the anode and the hull.

2.7.3.1 Magnesium sacrificial anodes shall not be used on vessels operating in seawater.

2.7.4 Each anode shall have a single point of connection to the bonding system.

2.8 IMPRESSED CURRENT SYSTEMS

2.8.1 If installed, the impressed current cathodic protection system installation shall be in accordance with the following:

2.8.1.1 If impressed current cathodic protection systems obtain power from the boat's battery system, provisions shall be made to maintain battery charge.

2.8.1.2 All electrical connections to the AC or DC electrical system shall be in accordance with [ABYC E-11, AC and DC Electrical Systems on Boats](#).

2.8.1.3 The cathodic protection controller of an impressed current system shall cut off, or reduce, impressed current to a hull potential level not to exceed the maximum level in [TABLE 2](#), if the lead to the reference electrode is shorted to ground or broken.

2.8.1.4 Hull anodes, reference electrodes, and other components that penetrate the hull below the water line shall be designed, constructed, and installed so that they will not loosen or fail structurally when subjected to the stresses and conditions normally imposed on the hull.

2.8.1.5 Hull anodes shall be designed and installed to prevent electrical leakage from anode electrical connections to internal metallic parts of the assembly so as to minimize stray current corrosion through contact with bilge water.

2.8.1.6 Impressed current cathodic protection systems shall be powered only from negatively grounded power sources.

NOTE: Vessels with isolated ground power sources may require the installation and maintenance of an additional power source for the impressed current cathodic protection system.

2.8.1.7 System controllers shall be installed at least three feet (one meter) from compasses and other magnetically sensitive equipment. Associated wiring shall be either twisted pair or shielded when in proximity to such equipment.

2.8.1.8 Impressed current anodes shall be separated from a metal hull by an insulating barrier extending beyond the edge of the anode a distance in accordance with [TABLE 3](#) (see [FIGURE 1](#)).

EXCEPTION: Combination anode/reference electrode assemblies mounted directly to the drive system.

2.8.1.9 The width of the dielectric shield above the anode shall be increased to a minimum width of four inches (102 mm) to prevent chemical attack of the hull material and paint directly above an anode due to gas generation (see [FIGURE 1](#)).

2.8.1.10 Impressed current anodes shall have the words "DO NOT PAINT" on a visible surface when installed.

NOTE: Anodes of any type are ineffective if painted.

2.8.1.11 Impressed current systems shall have a means to provide indication of overprotection or underprotection for each system.

2.9 CATHODIC PROTECTION OF ALUMINUM DRIVE UNITS AND OTHER METALLIC COMPONENTS MOUNTED ON NONMETALLIC HULLS

2.9.1 Aluminum drive units shall have a protective paint coating that is tenacious, resistant to erosion, and which provides a high resistance barrier between the aluminum and water.

NOTE: Aluminum is an amphoteric metal. Potentials more negative than -1200 mV can cause harmful overprotection such as alkali corrosion of aluminum and possible hydrogen blistering of paint, also known as cathodic disbondment.

2.9.1.1 Galvanically incompatible antifouling coatings, without a barrier coating, shall not be used.

2.9.2 Sterndrives, outboards, and other metallic components shall be protected with sacrificial anodes mounted on the aluminum lower units, and/or sacrificial anodes mounted on the hull and connected to the cathodic bonding system, and/or an impressed current system.

NOTES:

1. Aluminum lower units on sterndrive and outboard engines may require cathodic protection in addition to that supplied by the manufacturer when moored or used extensively in salt or brackish waters.
2. Cathodic protection supplied by the drive manufacturer may not be sufficient to provide protection to additional metallic components.
3. Boats equipped to use dockside power are subject to galvanic corrosion because the boat ground is electrically connected to the shore ground via the grounding conductor. An isolation transformer, a galvanic isolator, or polarization transformer with galvanic isolator in the grounding conductor may be used to reduce this problem (see [ABYC E-11, AC and DC Electrical Systems on Boats](#)).
4. Magnesium anodes should not be used in salt water since their negative potential is -1600 to -1630 mV. Aluminum is an amphoteric metal. Potentials more negative than -1200 mV can cause harmful overprotection such as alkali corrosion of aluminum and possible hydrogen blistering of paint, also known as cathodic disbondment.

2.10 CATHODIC PROTECTION OF ALUMINUM HULLS

2.10.1 If aluminum hulls are painted, they shall have a protective paint coating that is tenacious, resistant to erosion, and which provides a high resistance barrier between the aluminum and water.

NOTE: Aluminum is an amphoteric metal. Potentials more negative than -1200 mV can cause harmful overprotection such as alkali corrosion of aluminum and possible hydrogen blistering of paint, also known as cathodic disbondment.

2.10.2 Aluminum hulls normally stored in the water shall be protected with sacrificial anodes and/or impressed current cathodic protection (ICCP) systems mounted on the hull or underwater gear.

NOTES:

1. Boats equipped to use dockside power are subject to galvanic corrosion because the boat ground is electrically connected to the shore ground via the grounding conductor. An isolation transformer, a galvanic isolator, or polarization transformer with galvanic isolator in the grounding conductor may be used to reduce this problem (see [E-11, AC and DC Electrical Systems on Boats](#), and [A-28, Galvanic Isolators](#)).
2. If magnesium anodes are used in salt water, the negative potential may exceed -1200 mV maximum recommended potential and create the conditions for cathodic corrosion.

2.10.3 When practical, underwater fittings, propeller shafts, propellers, and rudders fabricated of bronze or other metal alloys more noble than aluminum shall be electrically insulated from metallic contact with the hull and from internal metallic piping.

NOTE: Shafts or rudders may be cathodically protected separately by anodes directly attached to the metal that is to be protected.

2.10.4 Fasteners used for connections to aluminum hulls shall be 300 series stainless steel.

2.10.5 The hull shall not be used as a current carrying conductor (see [ABYC E-11, AC and DC Electrical Systems on Boats](#)).

2.11 CATHODIC PROTECTION OF STEEL HULLS

2.11.1 Steel hulls shall have a protective paint coating that is tenacious, resistant to erosion, and which provides a high resistance barrier between the steel and the water.

2.11.2 Steel hulls normally stored in the water shall be protected with sacrificial anodes mounted on the hull, or sacrificial anodes mounted on underwater gear, or an impressed current system.

NOTE: Boats equipped to use dockside AC electric power are subject to galvanic corrosion because the boat ground is electrically connected to the shore ground via the grounding conductor. An isolation transformer, a galvanic isolator, or polarization transformer with galvanic isolator in the grounding conductor may be used to reduce this problem (see [ABYC E-11, AC and DC Electrical Systems on Boats](#), and [ABYC A-28, Galvanic Isolators](#)).

2.11.3 When practical, underwater fittings, propeller shafts, propellers, and rudders fabricated of bronze or other metal alloys more noble than steel shall be electrically insulated from metallic contact with the hull and from internal metallic piping.

NOTE: Shafts or rudders may be cathodically protected separately by anodes directly attached to the metal that is to be protected.

2.12 HULL POTENTIAL MONITOR

2.12.1 A hull potential monitor shall have an internal resistance of not less than 20,000 ohms per volt, and be capable of measuring the voltage differences between a reference electrode and a metal hull or the underwater metal components connected to the boat's bonding system.

2.12.2 All vessels utilizing impressed current systems shall have a hull potential monitor and reference electrode permanently installed.

NOTE: A hull potential monitor should be considered for any boat that remains in the water for extended periods.

TABLE 1 - Galvanic Series of Metals in Sea Water with Reference to Silver/Silver Chloride and Zinc Reference Cells*

	Ag/AgCl REFERENCE CELL POTENTIAL (mVDC)	Zn REFERENCE CELL POTENTIAL (mVDC)
ANODIC OR LEAST NOBLE		
Magnesium and Magnesium Alloys	-1600 to -1630	-600 to -630
Zinc	-980 to -1030	-30 to +20
Aluminum Alloys	-760 to -1000	0 to +240
Cadmium	-700 to -730	+270 to +300
Mild Steel	-600 to -710	+290 to +400
Wrought Iron	-600 to -710	+290 to +400
Cast Iron	-600 to -710	+290 to +400
13% Chromium Stainless Steel, Type 410 (active in still water)	-460 to -580	+420 to +540
18-8 Stainless Steel, Type 304 (active in still water)	-460 to -580	+420 to +540
Ni-Resist	-460 to -580	+420 to +540
18-8, 3% Mo Stainless Steel, Type 316 (active in still water)	-430 to -540	+460 to +570
Inconel (78% Ni, 13.5% Cr, 6% Fe) (active in still water)	-350 to -460	+540 to +650
Aluminum Bronze (92% Cu, 8% Al)	-310 to -420	+570 to +690
Nibral (81.2% Cu, 4% Fe, 4.5% Ni, 9% Al, 1.3% Mg)	-310 to -420	+570 to +690
Naval Brass (60% Cu, 39% Zn)	-300 to -400	+600 to +700
Yellow Brass (65% Cu, 35% Zn)	-300 to -400	+600 to +700
Red Brass (85% Cu, 15% Zn)	-300 to -400	+600 to +700
Muntz Metal (60% Cu, 40% Zn)	-300 to -400	+600 to +700
Tin	-310 to -330	+670 to +690
Copper	-300 to -570	+430 to +700
50-50 Lead- Tin Solder	-280 to -370	+630 to +720
Admiralty Brass (71% Cu, 28% Zn, 1% Sn)	-280 to -360	+640 to +720
Aluminum Brass (76% Cu, 22% Zn, 2% Al)	-280 to -360	+640 to +720
Manganese Bronze (58.8% Cu, 39% Zn, 1% Sn, 1% Fe, 0.3% Mn)	-270 to -340	+660 to +730
Silicone Bronze (96% Cu Max, 0.80% Fe, 1.50% Zn, 2.00% Si, 0.75% Mn, 1.60% Sn)	-260 to -290	+710 to +740
Bronze-Composition G (88% Cu, 2% Zn, 10% Sn)	-240 to -310	+690 to +760
Bronze ASTM B62 (thru-hull) (85% Cu, 5% Pb, 5% Sn, 5% Zn)	-240 to -310	+690 to +760
Bronze Composition M (88% Cu, 3% Zn, 6.5% Sn, 1.5% Pb)	-240 to -310	+690 to +760
13% Chromium Stainless Steel, Type 410 (passive)	-260 to -350	+650 to +740
Copper Nickel (90% Cu, 10% Ni)	-210 to -280	+720 to +790
Copper Nickel (75% Cu, 20% Ni, 5% Zn)	-190 to -250	+750 to +810
Lead	-190 to -250	+750 to +810
Copper Nickel (70% Cu, 30% Ni)	-180 to -230	+770 to +820
Inconel (78% Ni, 13.5% Cr, 6% Fe) (passive)	-140 to -170	+830 to +860
Nickel 200	-100 to -200	+800 to +900
18-8 Stainless Steel, Type 304 (passive)	-50 to -100	+900 to +950
Monel 400, K-500 (70% Ni, 30% Cu)	-40 to -140	+860 to +960
Stainless Steel Propeller Shaft (ASTM 630:#17 & ASTM 564: # 19)	-30 to +130	+970 to +1130
18-8 Stainless Steel, Type 316 (passive) 3% Mo	0.0 to -100	+900 to +1000
Titanium	-50 to +60	+950 to +1060

Hastelloy C	-30 to +80	+970 to +1080
Stainless Steel Shafting (Bar) (UNS 20910)	-250 to +60	+750 to +1060
Platinum	+190 to +250	+1190 to +1250
Graphite	+200 to +300	+1200 to +1300
CATHODIC OR MOST NOBLE		

NOTES:

1. Metals and metal alloys are listed in the order of their potential in flowing sea water as determined in tests conducted by a nationally-recognized corrosion research laboratory. *Sea water flowing at 8 to 13 ft/sec (2.4 to 3.9 m/sec) except as noted; temperature range 50° to 80°F (10° to 26.7 °C).
2. The range shown does not include sacrificial aluminum anodes. Aluminum alloy sacrificial anodes are available that have a maximum corrosion potential of -1100 mV.
3. The galvanic series may be used to predict whether galvanic actions are likely between two metals. Other factors (e.g., area of the material, flow rate, composition of the electrolyte, crevices, the coupling of copper alloys with aluminum, etc) affect the relative corrosion rates in seawater (see [Ap 4](#) and [Ap 5](#)).

TABLE 2 - Recommended Range of Cathodic Protection Based on Ag/AgCl Reference Cell

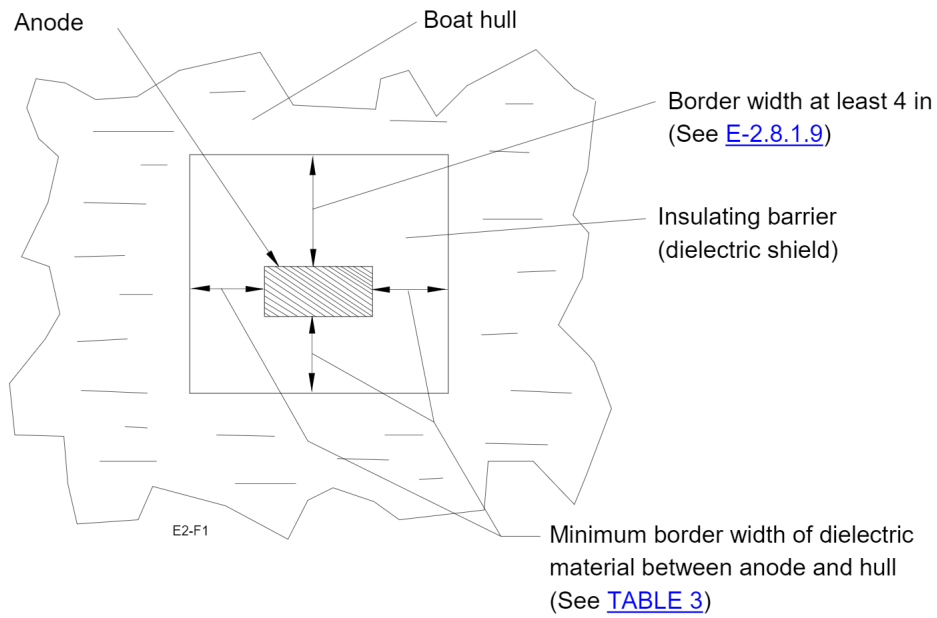
HULL MATERIAL	MILLIVOLT RANGE
Fiberglass	-550 to -1100
Wood	-550 to -600
Aluminum	-950 to -1100
Steel	-850 to -1100
Nonmetallic w/Aluminum Drives	-950 to -1100

NOTE: Exceeding -600 mV on a wooden boat may lead to significant damage to wetted wood surfaces in contact with the cathode.

TABLE 3 - Shielding of Impressed Current Anodes

MAXIMUM CURRENT OUTPUT OF ANODE	MINIMUM BORDER WIDTH OF DIELECTRIC MATERIAL BETWEEN ANODE AND METAL HULLS
MILLIAMPERE	INCHES
Below 350	1/2 (13 mm)
350-1500	3 (77 mm)
1501-5000	8 (205 mm)

FIGURE 1 - Dielectric Shielding For Impressed Current Anode



APPENDIX

Ap 1 Typical compositions of anodes are provided in the tables below.

Ap 2 In general, the use of several anodes in parallel, instead of one large anode, tends to provide better distribution of the protective current.

NOTE: The best current distribution will be obtained by remote mounting with the anode(s) positioned to be as equidistant as possible from the metals to be protected.

Ap 3 **IMPRESSED CURRENT PROTECTION - APPLICATION**

Ap 3.1 Impressed current cathodic protection devices are electronically controlled and should be used where cathodic protection is needed and where it is desired to eliminate the use of, or extend the life of, sacrificial anodes.

Ap 3.2 The devices use an external voltage source and an anode with a control to adjust the amount of current in the circuit. All the systems have automatic adjustment that senses the reference electrode voltage and automatically supplies the right amount of current to the anode to maintain the protection required. The controllers for larger systems may have adjustable set points.

Ap 4 **FACTORS THAT AFFECT THE TYPE AND DEGREE OF CATHODIC PROTECTION REQUIRED**

Ap 4.1 Water Velocity - cathodic protection current requirements increase with water velocity past the hull. The current requirement can be several times that required in still water. Uncontrolled sacrificial anodes do not have the capability to increase current output as water velocity increases.

Ap 4.2 Boat Usage - more frequently operated vessels require more cathodic protection than vessels infrequently used.

Ap 4.3 Conductivity of the Water - as the conductivity increases, the rate of galvanic activity increases.

Ap 4.4 Salinity (Fresh and Seawater) - current requirements increase with salinity but higher driving potentials are required in fresh water.

Ap 4.5 pH of the Water - as pH decreases (acid rain lakes), the corrosion rate increases.

Ap 4.6 Deterioration of Protective Coatings - current requirements increase as protective coatings deteriorate increasing exposed cathode surface area.

Ap 5 **FACTORS THAT AFFECT THE LONGEVITY AND ADEQUACY OF ANODES AND SYSTEM EQUIPMENT**

Ap 5.1 Paint - painted areas of anodes will not produce electrical current.

Ap 5.2 Loose Connections - loose anode attachments or loose/corroded electrical connections will reduce or eliminate electrical current flow from the anode.

Ap 5.3 Corrosion - corrosion at the point where the anode is bolted to the structure to be protected can inhibit electrical current flow. The use of a more noble core material in the anodes will assist in controlling this problem.

Ap 5.4 Copper alloy electrical terminations, even if plated, shall not be in direct contact with aluminum.

NOTE: When bolting plated copper electrical terminals to aluminum, use a conductive antioxidantizing aluminum paste formulated for aluminum/copper junctions. This paste is available from most commercial electrical supply houses.

Ap 5.5 Insufficient Mass/Surface Area - an anode that has sufficient surface area to produce the desired voltage initially may not have enough weight to sustain the current output for the duration of the time that the vessel remains in the water (i.e., time between haul-outs).

Ap 5.6 Impurities - impurities in the zinc anode alloy such as iron can seriously reduce or terminate their electrical current output.

Ap 5.7 Improper Anode Contact - metal foil antifouling systems must not come in contact with metals that are cathodically protected. This will render the antifouling properties of the foil useless, drastically reduce the protective voltage, cause rapid consumption of the anode, and lead to accelerated corrosion of normally protected metals.

Ap 5.8 Anode Composition - there are numerous anode compositions available. To ensure the best performance, customers should specify military specification anodes for zinc, aluminum, and magnesium.

Ap 5.9 Iron sacrificial anodes may be used to protect copper based metals in some piping, heat exchanger, and drive applications. Consult manufacturer for proper cathodic protection.

Ap TABLE 1A - Typical Composition of Zinc Anodes in Percentages or Range

	ASTM B418		MIL-A-18001	MINIMUM PURITY
	TYPE I	TYPE II		
Aluminum	0.1 - 0.4	0.005 max.	0.1 - 0.5	3.9 - 4.3
Cadmium	0.03 - 0.1	0.003 max.	0.025 - 0.15	0.002 max.
Copper	-	-	0.005 max.	0.1 max.
Iron	0.005 max.	0.0014 max.	0.005 max.	0.05 max.
Lead	0.003 max.	0.003 max.	0.006 max.	0.002 max.
Magnesium	-	-	-	0.005 - .02
Nickel	-	-	-	0.005 - .02
Silicon	-	-	0.125 max.	-
Tin	0.001 max.	0.001 max.	- -	0.001 max.
Zinc (remainder)	99.5 min	99.99 min	99.2 min	95.5 min

Ap TABLE 1B - Typical Composition of Aluminum Anodes in Percentages or Range
(ASTM B605)

Zinc (range)	5.0 - 6.0 %
Iron (maximum)	0.17 %
Copper (maximum)	0.02 %
Silicon (maximum)	0.10 %
Aluminum	Remainder

Ap TABLE 1C - Typical Composition of Magnesium Anode in Percentages or Range
(MIL-A-21412)

Aluminum (range)	5.0 - 7.0 %
Zinc (range)	2.0 - 4.0 %
Manganese (minimum)	0.15 %
Silicon (maximum)	0.30 %
Copper (maximum)	0.10 %
Iron (maximum)	0.003 %
Nickel (maximum)	0.003 %
Other (maximum)	0.30 %
Magnesium	Remainder

Ap TABLE 2 - Correction Factors for Reference Electrodes

HALF-CELL		POTENTIAL VOLT
Tenth Normal Calomel	TNCE	+0.333
Copper-Copper Sulfate	Cu/CuSO ₄	+0.316
Normal Calomel	NCE	+0.280
Saturated Calomel	SCE	+0.241
Silver/Silver Chloride	Ag/AgCl	+0.222
Standard Hydrogen Electrode	S.H.E.	0.000
Zinc	Zn	-0.778

NOTE: Potential values of reference electrodes refer to Standard Hydrogen Electrode (S.H.E.), the standard to which other more convenient references are related:

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