Electrical Division Standard

Electrical Project Technical Committee

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, 2013 and 2019. The 2025 revision is the work of the 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.

ABYC's Project Technical Committee (PTC) meetings are open to the public. All inquiries regarding standards activity, interpretations, or meeting attendance should be directed to the ABYC Technical Department at comments@abycinc.org.

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Request for Interpretations

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 7/19, are:

- References were updated
- Cathodic protection wiring requirements were revised
- "If installed" clarifications were added
- Cathodic protection system requirements for carbon fiber reinforced hulls were added
- Editorial changes were made

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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, 2026.

2.1 SCOPE

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

> *NOTE: Installation of a component with integrated cathodic protection does not necessitate an additional cathodic protection system to be installed on a boat.*

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 and 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: www.astm.org

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

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*
MIL-A-24779 - *Military Specification: Anodes, Sacrificial Aluminum Alloy*

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, or surface conditions of the metal itself.

NOTES:

1. *A protective oxide film (i.e., passive film) can be formed either naturally or by chemical treatment, on certain active-passive metals such as stainless steel alloys.*
2. *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.

> *NOTE: 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 Antifouling Coating - a coating applied to the hull and other underwater structures intended to prevent bio-fouling.

2.4.7 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.

2.4.8 Cathode -

2.4.8.1 an electrode of a simple electrochemical cell at which excess free electrons in the metal are neutralized by an electrochemical reaction or

2.4.8.2 an electrode of a galvanic cell which has a more positive corrosion potential than another electrode of the cell or

2.4.8.3 an electrode of a supplied-current cell which is connected to the negative terminal of a DC current source (see anode).

2.4.9 Cathode Reaction - a type of electrochemical reaction that consumes electrons and thus decreases the number of excess free electrons in the solid metal.

2.4.10 Cathodic - more noble, having a relatively positive corrosion potential; pertaining to an electrochemical cathode reaction (see anodic).

2.4.11 Cathodic Bonding - the electrical interconnection of metal objects in common contact with water, to the grounding bus, and to the source of cathodic protection.

2.4.12 Cathodic Corrosion - corrosion of certain metals (such as aluminum) caused by excessive cathodic protection (i.e., overprotection).

2.4.13 Cathodic Disbondment - a loss of adhesion between a coating and its substrate caused by products of a cathode reaction.

2.4.14 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.

2.4.15 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.

2.4.16 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 metal link (e.g., cathodic bonding conductor).

2.4.17 Conductor - a material capable of carrying electric current as a flow of free electrons (see electrolyte).

2.4.18 Corrosion - the deterioration of or loss of metal by physical, chemical, or electrochemical reactions.

2.4.19 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.

2.4.20 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.

NOTE: A couple may also be formed on the surface of the same metal.

2.4.21 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.

2.4.22 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.

2.4.23 Driving Potential or Driving Voltage -

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

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

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

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

2.4.26 Electrode – an electrically conductive material, in an electrolyte, through which electrical current enters or leaves.

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

2.4.28 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 corrosion cell).

2.4.29 Galvanic Corrosion - the corrosion that occurs at the anode of a galvanic cell.

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

2.4.31 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.

2.4.32 Galvanic Series - a list of metals and their 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).

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

2.4.34 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.

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

2.4.36 Ion - an atom or a chemically bonded group of atoms possessing a non-zero net electrical charge.

2.4.37 Noble - a descriptor applied to materials having corrosion potentials toward the positive end of the galvanic series.

2.4.38 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.

2.4.39 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).

2.4.40 Polarization -

2.4.40.1 a shift in the potential of an electrode of an electrochemical cell resulting from the flow of current in the cell, or

2.4.40.2 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 or local changes in electrolyte composition.

2.4.41 Reference Electrode - an electrode of known standard potential used for measuring the potentials of other electrodes in the same body of electrolyte.

NOTE: Reference electrodes are commonly used to measure hull potentials and the potentials of other underwater metal structures. The most commonly used reference electrodes in the marine industry are silver-silver-chloride (Ag/AgCl) and zinc (Zn).

2.4.42 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.

2.4.43 Shaft Contactor - a device intended to make electrical contact to a rotating shaft (e.g., slip ring assemblies, shaft brushes, and shaft wipers).

2.4.44 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).

2.4.45 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.

2.4.46 Stray-Current Corrosion - corrosion resulting from an unintentionally or accidentally supplied current, DC or AC.

NOTE: The term "electrolysis" is often incorrectly used to describe corrosion in general, or the operation of supplied-current cells in particular.

2.4.47 Substrate - the underlying base on which coatings are applied.

2.4.48 Supplied-Current Cell - an electrochemical cell in which an externally driven current source is interposed in the circuit.

NOTE: 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 If installed, 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 nonmetal hulls may not be justified if the couples 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 boat's primary cathodic bonding system and should be individually protected with separate cathodic protection systems.*
4. *Protection potentials more negative than -1200 mV can lead to harmful overprotection of certain metals, causing issues like cathodic corrosion, alkali corrosion, and potential hydrogen blistering of paint, also known as cathodic disbondment.*
5. *If not stated otherwise, all potentials mentioned in the standard are relative to an Ag/AgCl seawater electrode.*

2.5.2 Immersed cathodic metal surfaces shall have a favorable anode to cathode area ratio to ensure adequate protection.

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

2.5.3 ***Hull-Mounted Metal Trim Tabs***

2.5.3.1 On boats equipped with aluminum drive systems, metal 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.

2.5.3.2 Metal trim tabs shall be electrically isolated from their electrically actuated mechanisms.

2.5.3.3 If a metal 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.

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

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.

NOTES:
1. *Prior to the application of a barrier coating on metal 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. *If a galvanically incompatible antifouling coating is used, a breach of the barrier coating can result in corrosion damage to the metal hull.*

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 propellers or jet drive intakes and nozzles.

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 Each underwater metal component that is protected by a cathodic protection system shall be wired in parallel with a single connection to the cathodic bonding system.

NOTE: Bonding buses may be wired in series.

2.5.7 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 and drivetrains may not have reliable electrical continuity to the boat's cathodic bonding system.*
3. *Many shaft contactors do not meet the requirement of E-2.5.7.*
4. *Resistance measurements should only be taken when the boat is out of the water.*
5. *Hull potential measurements using a reference electrode should be used to determine cathodic bonding system integrity when the boat is in the water.*
6. *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.*

2.5.8 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.

2.5.9 ***Cathodic Bonding Conductors***

2.5.9.1 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.

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

2.5.9.1.2 Connections to the uninsulated copper strip shall comply with ABYC E-11, *AC and DC Electrical Systems on Boats*.

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

2.5.9.2.1 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 inches (13 mm).

2.5.9.3 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.

2.5.9.4 Wire, where used as a cathodic bonding conductor, shall be #8 AWG or larger.

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

2.5.9.5 Insulated conductors shall be selected from ABYC E-11, *AC and DC Electrical Systems on Boats*.

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

2.5.10 Shaft contactors used to provide cathodic protection shall be constructed of materials that will not score the shaft.

2.5.11 A cathodic bonding system shall be installed in accordance with ABYC E-11, *AC and DC Electrical Systems for Boats*.

NOTE: See ABYC E-11, AC and DC Electrical Systems for Boats*, diagrams for examples of DC grounding systems.*

2.5.12 If a cathodic bonding conductor is combined with a lightning conductor, this conductor shall not be less than the equivalent of #6 AWG (see ABYC E-11, *AC and DC Electrical Systems for Boats* and ABYC TE-4, *Lightning Protection*).

2.6 ***GALVANIC ISOLATION***

NOTE: It is 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 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.

2.6.1 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*.

2.7 ***SACRIFICIAL ANODES***

2.7.1 If installed, the mass and exposed surface area of the anodes 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 APPENDIX).*
2. *Typical compositions of zinc, aluminum, and magnesium anodes appear in 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. Aluminum anodes are sensitive to copper and iron impurities.*
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.*
*** Fresh water has different conductivity depending on mineral and pollution levels. Only Mg anodes offer adequate protection in most fresh water environments, while Al anodes may be required in high mineral / polluted fresh water to avoid overprotection.*

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 nonmetal 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 metal hulls shall have a dielectric shield of equal or greater surface area than the anode at the attachment point installed between the anode and the hull.

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

2.7.4 Each anode shall have a single point of connection to the cathodic 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 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 metal 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: boats 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.

EXCEPTION: Impressed current anodes with large inactive housing surfaces shall be permitted to be painted if it does not interfere with the functionality of the unit.

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 METAL COMPONENTS MOUNTED ON NONMETAL HULLS*

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

> *NOTE: Aluminum is an amphoteric metal. Protection potentials more negative than -1200 mV can lead to harmful overprotection of certain metals, causing issues like cathodic corrosion, alkali corrosion, and potential 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.

> *NOTE: Use of coatings that are galvanically compatible with the substrate, rather than relying on a barrier coating, reduces risk of corrosion.*

2.9.2 Sterndrives, outboards, and other metal components shall be protected with sacrificial anodes mounted on the aluminum lower units, or sacrificial anodes mounted on the hull and connected to the cathodic bonding system, 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 metal components. Consult the sterndrive or outboard engine manufacturer before augmenting cathodic protection, as over-protection can be equally as harmful as under protection.*
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. Protection potentials more negative than -1200 mV can lead to harmful overprotection of certain metals, causing issues like cathodic corrosion, alkali corrosion, and potential 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 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. *Magnesium anodes should not be used in salt water since their negative potential is -1600 to -1630 mV.*
3. *Aluminum is an amphoteric metal. Protection potentials more negative than -1200 mV can lead to harmful overprotection of certain metals, causing issues like cathodic corrosion, alkali corrosion, and potential hydrogen blistering of paint, also known as cathodic disbondment.*

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 the hull and from internal metal piping.

NOTES:

1. *Shafts or rudders may be cathodically protected separately by anodes directly attached to the metal that is to be protected.*
2. *The underwater metals used with aluminum should be compatible with the aluminum alloy to minimize damage if the isolation between the two metals fails.*

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).Underwater fittings, propeller shafts, propellers, and rudders fabricated of bronze or other metal alloys more noble than steel should be electrically insulated from metal contact with the hull and from internal metal piping. Shafts or rudders may be cathodically protected separately by anodes directly attached to the metal that is to be protected.

2.12 *CATHODIC PROTECTION ON BOATS WITH CARBON FIBER REINFORCED HULLS*

2.12.1 Carbon fiber reinforced hulls shall have a protective coating that is durable, resistant to erosion, and provides a high electrical resistance barrier between the composite and the water.

NOTE: This requirement applies to both the exterior of the hull and the bilge area where water can accumulate.

2.12.2 All underwater metal components, including fittings (e.g., metal thru-hulls), fasteners, propeller shafts, propellers, and rudders made of metal alloys, shall be electrically insulated from the hull.

2.12.2.1 Anodes and their mounting hardware shall be electrically insulated from the hull.

NOTES to E-2.12:

1. *This section applies to composites that use carbon fiber alone as reinforcement or a blend of carbon fiber with other materials, such as fiberglass or aramid.*
2. *Carbon fiber (graphite) is cathodic (i.e., has a more positive potential) relative to metals typically used on boats.*
3. *Carbon fiber reinforced deck, mast-mounted equipment, and associated hardware, including fasteners, should be electrically insulated from the carbon reinforcement in the laminate. This minimizes the risk of electrochemical interaction between the carbon fiber and metals.*
4. *Shafts and rudders may be protected by anodes attached directly to the metal being protected.*
5. *Underwater metals may be protected using sacrificial anodes mounted on and electrically insulated from the hull, sacrificial anodes mounted on underwater gear, or an impressed current system.*
6. *Electrically insulating barriers may be required to prevent electrical equipment, including mounting hardware, from making direct contact with the carbon laminate. For equipment above the waterline, hardware, and devices without electrical connections—or those with electrically insulated connections—may be mounted directly onto the carbon fiber substrate if sealants, coatings, or adhesives effectively prevent water intrusion at the contact points.*
7. *Some rubber hoses can be electrically conductive due to the presence of lamp black (carbon) as a colorant. Silicone-based rubber hoses are less likely to be conductive. Care should be taken to prevent conductive rubber hoses from coming into contact with a carbon fiber reinforced hull.*

2.13 *HULL POTENTIAL MONITOR*

2.13.1 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.

2.13.2 All boats 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 - Silver/Silver Chloride and Zinc Reference Electrodes

		Ag/AgCl REFERENCE ELECTRODE POTENTIAL (mV DC)	Zn REFERENCE ELECTRODE POTENTIAL (mV DC)
ANODIC	Magnesium and Magnesium Alloys	-160 to –1630	-600 to -630
OR LEAST	Zinc	-980 to –1030	-30 to +20
NOBLE	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
CATHODIC	Stainless Steel Shafting (Bar) (UNS 20910)	-250 to +60	+750 to +1060
OR MOST	Platinum	+190 to +250	+1190 to +1250
NOBLE	Graphite (Carbon Fiber)	+200 to +300	+1200 to +1300

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); temperature range 50° F to 80° F (10° C 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 Electrode

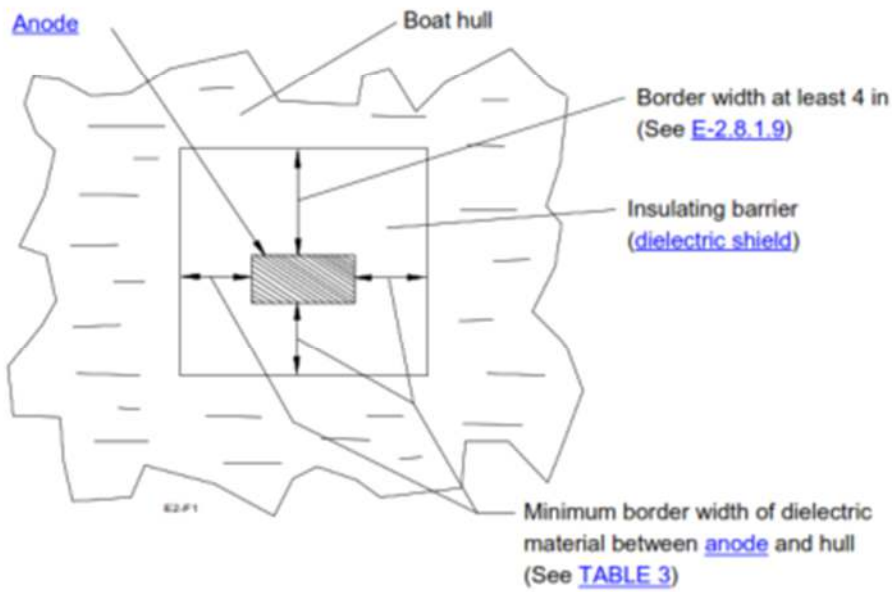
HULL MATERIAL	MILLIVOLT RANGE
Fiberglass	-550 to -1100
Wood	-550 to -600
Aluminum	-950 to -1100
Steel	-850 to -1100
Nonmetal with aluminum drives	-950 to -1100

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 (MM)
Below 350	1/2 (13 mm)
350-1500	3 (77 mm)
1501-5000	8 (204 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 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 RECOMMENDED CATHODIC PROTECTION***

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 boats require more cathodic protection than boats 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) - lower salinity in freshwater leads to higher resistivity which requires higher driving potentials.

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 If bolting plated copper electrical terminals to aluminum, antioxidizing paste suitable for aluminum/copper junctions should be used.

NOTE: If practicable, copper alloy electrical terminations, even if plated, should not be in direct contact with aluminum.

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

AP 5.6 Impurities - impurities in the zinc and aluminum anode alloys such as iron and copper can seriously reduce or terminate their electrical current output.

AP 5.7 Improper Anode Contact - metal foil antifouling systems should 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 exchangers and drive applications. Consult component manufacturer for proper cathodic protection.

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

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

AP TABLE 1B - Typical Composition of Aluminum Anodes in Percentages or Range (MIL-A-24779)

ELEMENT	CONVENTIONAL ALUMINUM	LOW VOLTAGE ALUMINUM
	WEIGHT (PERCENT)	WEIGHT (PERCENT)
Indium[1]	0.014 – 0.020	<0.005
Gallium[1]	<0.02	0.092 – 0.110
Zinc[1]	4.0 – 6.5	<0.15
Silicon	0.08 – 0.20	<0.10
Copper	<0.005	
Iron	<0.08	
Mercury	<0.0001	
Tin	<0.001	
Nickel	<0.005	
Magnesium	<0.010	
Manganese	<0.010	
Bismuth	<0.002	
Cadmium	<0.002	
Titanium	<0.002	
Lead	<0.002	
Boron	<0.001	
Aluminum[1]	Remainder	Remainder
NOTE: *1. Indium, gallium, zinc, and aluminum raw material purity should be a minimum 99.8% by weight.*		

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.

Silver/Silver Chloride Ag/AgCl electrodes are typically intended to be used in salt water and may not provide reliable readings in fresh and brackish water environments.

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