

**E-2 CATHODIC PROTECTION****Table of Contents**

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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, 2002.*

### 2.1 PURPOSE

This standard is a guide for the design, installation, and use of cathodic protection systems on boats.

### 2.2 SCOPE

This standard applies to the use of galvanic anodes and impressed current systems if installed on a boat.

### 2.3 REFERENCED ORGANIZATIONS

ABYC - American Boat & Yacht Council, Inc., 3069 Solomons Island Road, Edgewater, MD 21037-1416. Phone: (410) 956-1050. Fax: (410) 956-2737. Web site: www.abycinc.org.

### 2.4 DEFINITIONS

For the purpose of this standard the following definitions apply:

Amphoteric - Capable of reacting chemically with an acid or a base. Aluminum is amphoteric, and highly susceptible to corrosion when overprotected.

Anode (galvanic anode) - The electrode of an electrochemical cell with the more negative potential. The less noble metal of an electrolytic cell that tends to corrode.

Calcareous Coating or Deposit - A layer consisting of a mixture of calcium carbonate and magnesium hydroxide deposited on surfaces being cathodically protected because of the increased pH adjacent to the protected surface.

Cathode - The electrode of an electrochemical cell with the more positive potential. The more noble metal of an electrolytic cell that tends not to corrode.

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.

Cathodic Disbondment - The destruction of adhesion between a coating and its substrate by products of a cathodic reaction.

Cathodic Protection - Reduction or prevention of corrosion of a metal by making it cathodic by the use of sacrificial anodes or impressed currents.

Cell - Electrochemical system consisting of an anode and a cathode immersed in an electrolyte. The anode and cathode

may be separate metals or dissimilar areas on the same metal. The cell includes the external circuit that permits the flow of electrons between the anode and the cathode.

Corrosion - The deterioration of a metal, by chemical and electrochemical reaction with its environment.

Corrosion Controller - An automatic or manually operated device, in a controlled or regulated cathodic protection system, to regulate the flow of electric current for corrosion control.

Corrosion Monitor - An installed hull potential meter (voltmeter) capable of measuring the voltage difference between a reference electrode and a metal hull, or cathodic bonding system, when they are immersed in the same electrolyte.

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.

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

Dezincification - A corrosion phenomenon resulting in the selective removal of zinc from copper-zinc alloys. This is the most common form of de-alloying.

Dielectric Shield - In a cathodic protection system, an electrically non-conductive material, such as a coating, or plastic sheet, that is placed between an anode and an adjacent cathode to avoid current wastage and to improve current distribution to the cathode.

Driving Potential - The voltage difference between the anode and cathode of a couple.

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

Electrolysis - Chemical changes in a solution, or electrolyte, due to the passage of electric current.

**NOTE:** *This term is loosely applied to corrosion processes; however, since the term refers to solution phenomena not to corrosion, its use to indicate corrosion should be discouraged.*

Electrolyte - A liquid in which ions are capable of migrating. A liquid capable of conducting current. Solutions of acids, bases, and salts in water are electrolytes.

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

**Galvanic Couple** - A pair of dissimilar conductors, commonly metals, in electrical contact in electrolyte.

**Galvanic Current** - The electric current that flows between metals or conductive nonmetals in a galvanic couple.

**Galvanic Isolator** - A device installed in series with the (AC) grounding (green) conductor of the shore-power cable to effectively block low voltage DC galvanic current flow, but permits the passage of alternating current (AC) normally associated with the (AC) grounding (green) conductor.

**Galvanic Series** - A list of metals and alloys arranged in order of their potentials as measured in relation to a reference electrode when immersed in seawater. The table of potentials is arranged with the anodic or least noble metals at one end, and the cathodic or most noble metals at the other (see [TABLE I](#)).

**Half-cell (reference electrode)** - One electrode in an electrochemical cell used as a reference for measuring the potential of other metals.

**Hull Potential** - The composite potential (voltage) of the hull cathodic surfaces in an electrolyte as measured against a referenced electrode.

**Hydrogen Potential** - Over-voltage associated with the liberation of hydrogen gas.

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

**Ion** - An electrically charged atom or group of atoms. A form of current flow in liquids and wet wood.

**Mill Scale** - The heavy oxide layer formed during hot fabrication or heat treatment of metals. Mill scale is cathodic to the base metals.

**Noble** - The positive direction of electrode electrical potential relative to other material in the galvanic series.

**Open-circuit Potential** - The potential of an electrode measured with respect to a reference electrode or another electrode when no current flows to or from it.

**Passivation** - The formation of a protective oxide film, either naturally or by chemical treatment, on certain active-passive metals like stainless steels.

**pH** - An expression of hydrogen-ion activity, of both acidity and alkalinity, on a scale whose values run from 0 to 14 with 7 representing neutrality.

**Polarization** - The deviation from the open circuit potential of an electrode resulting from the passage of current, such as from anodes and impressed current systems.

**Reference Electrode** - A metal and metallic-salt (e.g., a silver/silver chloride half cell) mixture in solution that will develop and maintain an accurate reference potential to which the potential of other metals immersed in the same electrolyte may be compared.

**Sacrificial Anode** - A less noble metal intentionally connected to form a galvanic cell with a more noble metal for the purpose of protecting the more noble metal from corrosion.

**Shaft Brush** - A carbon or metalized graphite block that makes electrical contact to a rotating, or otherwise moving, shaft in order to improve electrical contact to the cathodic bonding system.

**Sliprings** - 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.

**Stray Current Corrosion** - Corrosion that results when a current from a battery or other external electrical (DC) source causes a metal in contact with an electrolyte to become anodic with respect to another metal in contact with the same electrolyte.

## 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 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 anti-fouling 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 II](#)). 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 non-metallic hulls may not be justified if the metals coupled are galvanically compatible (see [TABLE II](#)); however, individual testing on a case by case basis is necessary.*

2.5.2 Hull-mounted 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.

2.5.2.1 Trim tabs shall be electrically isolated from their electrically actuated mechanisms, in accordance with [ABYC E-9, Direct Current \(DC\) Electrical Systems on Boats](#).

2.5.2.2 If a stainless steel 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 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 shall not contain pigments that form galvanic couples with the substrate or coatings on substrate.

**NOTE: Anti-fouling paint manufacturer's recommended barrier coatings upon substrate can prevent metallic anti-fouling coatings from forming galvanic couples.**

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

#### 2.5.6 Anode Placement

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

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

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

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

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. A resistance as high as one ohm may degrade the cathodic protection system performance.

2. Propeller shafts do not provide reliable electrical continuity to the boat's cathodic bonding system.

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 insulated stranded copper wire, uninsulated copper strip, or copper tubing. Copper braid shall not be used for this purpose.

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

2.5.9.3 Cathodic bonding conductors fabricated from a copper strip shall have a minimum thickness of 1/32 inch (0.8 mm) and a minimum width of 1/2 inch (13 mm).

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

2.5.9.4 Insulated conductors shall be selected from Table V, [SAE Conductors](#); Table VII, [Conductors](#); and Table VIII, [Conductor Circular Mil Area and Stranding](#), in [ABYC E-9, Direct Current \(DC\) Electrical Systems on Boats](#).

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

2.5.9.6 Where the cathodic bonding system is used as a part of the lightning protection system, conductor type and size shall be as specified in [ABYC E-4, Lightning Protection](#).

#### 2.6 ELECTRICAL ISOLATION

##### 2.6.1 Isolation of Galvanic Currents

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

2.6.1.2 If installed, isolation transformers shall be installed in accordance with [ABYC E-8, Alternating Current \(AC\) Electrical Systems on Boats](#).

**NOTE: The electrical interconnection that occurs via shorepower cables from the dock may result in a galvanic couple 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. A galvanic isolator or isolation transformer can be used to break this couple.**

##### 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, etc.) shall be sufficient to provide continuous current output for at least the period between inspections (see ABYC E-2 APPENDIX, [E-2.Ap.3](#)).

**NOTES:**

1. *Typical compositions of zinc, aluminum, and magnesium anodes appear in ABYC E-2 APPENDIX (see E-2.Ap. [TABLE I](#)). 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.*

2. *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.*

2.7.2 Sacrificial anodes on a shaft shall be installed so as not to throw the shaft out of balance or 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 Only one current path shall be provided from each anode to the cathodic bonding system.

**NOTES:**

1. *Sacrificial anodes may be mounted directly on the metal to be protected.*

2. *Zinc galvanic anodes may be applied directly to aluminum, steel and non-metallic hulls without shielding.*

3. *Better current distribution will be obtained with a dielectric shield between the anodes and metals to be protected providing the anode is electrically connected to the metal being protected.*

2.7.4 Magnesium anodes shall not be directly coupled to the surface to be protected without dielectric shielding.

2.7.5 To prevent chemical attack of the hull material and paint directly above an anode due to gas generation, the width of the dielectric shield above the anode shall be increased. A minimum width of four inches (100 mm) should be provided (see [FIGURE 1](#)).

**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, provision 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-8](#),

[Alternating Current \(AC\) Electrical Systems on Boats](#), and [ABYC E-9, Direct Current \(DC\) Electrical Systems on Boats](#).

2.8.1.3 The controller of an impressed current cathodic protection system shall cut off, or reduce impressed current to a hull potential level not to exceed the maximum level in Table I, 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 used only on boats with negatively grounded or ungrounded electrical systems unless an independent source of power is provided that is negatively grounded.

2.8.1.7 System controllers shall be installed at least three feet (1m) 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 the hull by an insulating barrier extending beyond the edge of the anode a distance in accordance with TABLE II (see [FIGURE 1](#)).

2.8.1.9 To prevent chemical attack of the hull material and paint directly above an anode due to gas generation, the width of the dielectric shield above the anode shall be increased. A minimum width of four inches (100mm) should be provided (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.*

**2.9 CATHODIC PROTECTION OF ALUMINUM LOWER UNITS AND OTHER METALLIC COMPONENTS MOUNTED ON NON-METALLIC HULLS**

2.9.1 Aluminum lower 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, and a negative potential of over 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 anti-fouling 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, 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 stern drive 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-8, Alternating Current \(AC\) Electrical Systems on Boats](#), and [ABYC A-28, Galvanic Isolators](#).*

4. *Magnesium anodes should not be used in salt water since the negative potential is 1600 to 1630 mV (beyond 1200 mV maximum recommended for aluminum).*

**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, and a negative potential of over 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 shall be protected with sacrificial anodes mounted on the hull or underwater gear.

**NOTES:**

1. *While impressed current systems are capable of providing protection to aluminum vessels, they are not generally recommended because aluminum is amphoteric. A failure in the impressed current system can destroy the hull in a very short time.*

2. *A corrosion monitor may be installed to measure hull potential.*

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-8, Alternating Current \(AC\) Electrical Systems on Boats](#), and [ABYC A-28, Galvanic Isolators](#)).*

4. *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 An aluminum hull shall be connected directly to the engine negative terminal, and

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

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

**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 shall be protected with sacrificial anodes mounted on the hull, or sacrificial anodes mounted on underwater gear, or an impressed current system.

**NOTES:**

1. *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-8, Alternating Current \(AC\) Electrical Systems on Boats](#), and [ABYC A-28, Galvanic Isolators](#)).*

2. *A corrosion monitor may be installed to measure hull potential.*

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 All metal hull vessels utilizing shore power shall have an installed hull potential meter and reference electrode.

***NOTE: Hull potential meters should be considered for other metal hull vessels that remain in the water for extended periods.***

TABLE I - GALVANIC SERIES OF METALS IN SEA WATER WITH REFERENCE TO SILVER/SILVER CHLORIDE REFERENCE CELL [Sea water flowing at 8 to 13 ft./sec.(except as noted), temperature range 50°F (10°C) to 80°F (26.7°C)]

**NOTE: 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.**

(ANODIC OR LEAST NOBLE)	CORROSION-POTENTIAL RANGE IN MILLIVOLTS
Magnesium and Magnesium Alloys	-1600 to -1630
Zinc	-980 to -1030
Aluminum Alloys	-760 to -1000
Cadmium	-700 to -730
Mild Steel	-600 to -710
Wrought Iron	-600 to -710
Cast Iron	-600 to -710
13% Chromium Stainless Steel, Type 410 (active in still water)	-460 to -580
18-8 Stainless Steel, Type 304 (active in still water)	-460 to -580
Ni-Resist	-460 to -580
18-8, 3% Mo Stainless Steel, Type 316 (active in still water)	-430 to -540
Inconel (78%Ni, 13.5%Cr, 6%Fe) (active in still water)	-350 to -460
Aluminum Bronze (92% Cu, 8% Al)	-310 to -420
Nibral (81.2% Cu, 4% Fe, 4.5% Ni, 9% Al, 1.3% Mg)	-310 to -420
Naval Brass (60% Cu, 39% Zn)	-300 to -400
Yellow Brass (65% Cu, 35% Zn)	-300 to -400
Red Brass (85% Cu, 15% Zn)	-300 to -400
Muntz Metal (60% Cu, 40% Zn)	-300 to -400
Tin	-310 to -330
Copper	-300 to -570
50-50 Lead- Tin Solder	-280 to -370
Admiralty Brass (71% Cu, 28% Zn, 1% Sn)	-280 to -360
Aluminum Brass (76% Cu, 22% Zn, 2% Al)	-280 to -360
Manganese Bronze (58.8% Cu, 39% Zn, 1% Sn, 1% Fe, 0.3% Mn)	-270 to -340
Silicone Bronze (96% Cu Max, 0.80% Fe, 1.50% Zn, 2.00% Si, 0.75% Mn, 1.60% Sn)	-260 to -290
Bronze-Composition G (88% Cu, 2% Zn, 10% Sn)	-240 to -310
Bronze ASTM B62 (thru-hull)(85%Cu, 5%Pb, 5%Sn, 5%Zn)	-240 to -310
Bronze Composition M (88% Cu, 3% Sn, 6.5% Zn, 1.5% Pb)	-240 to -310
13% Chromium Stainless Steel, Type 410 (passive)	-260 to -350
Copper Nickel (90% Cu, 10% Ni)	-210 to -280
Copper Nickel (75% Cu, 20% Ni, 5% Zn)	-190 to -250
Lead	-190 to -250
Copper Nickel (70% Cu, 30% Ni)	-180 to -230
Inconel (78% Ni, 13.5% Cr, 6% Fe) (passive)	-140 to -170
Nickel 200	-100 to -200
18-8 Stainless Steel, Type 304 (passive)	-50 to -100
Monel 400, K-500 (70% Ni, 30% Cu)	-40 to -140
Stainless Steel Propeller Shaft (ASTM 630:#17 & ASTM 564: # 19)	-30 to +130
18-8 Stainless Steel, Type 316 (passive) 3% Mo	0.0 to -100
Titanium	-50 to +60
Hastelloy C	-30 to +80
Stainless Steel Shafting (Bar) (UNS 20910)	-250 to +60
Platinum	+190 to +250
Graphite	+200 to +300
(CATHODIC OR MOST NOBLE)	

†The range shown does not include sacrificial aluminum anodes. Aluminum alloy sacrificial anodes are available that have a maximum corrosion potential of -1100 mV.

**NOTE: 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 [E-2.Ap.5](#)).**

TABLE II - RECOMMENDED RANGE OF CATHODIC PROTECTION BASED ON AG/AGCL REFERENCE CELL

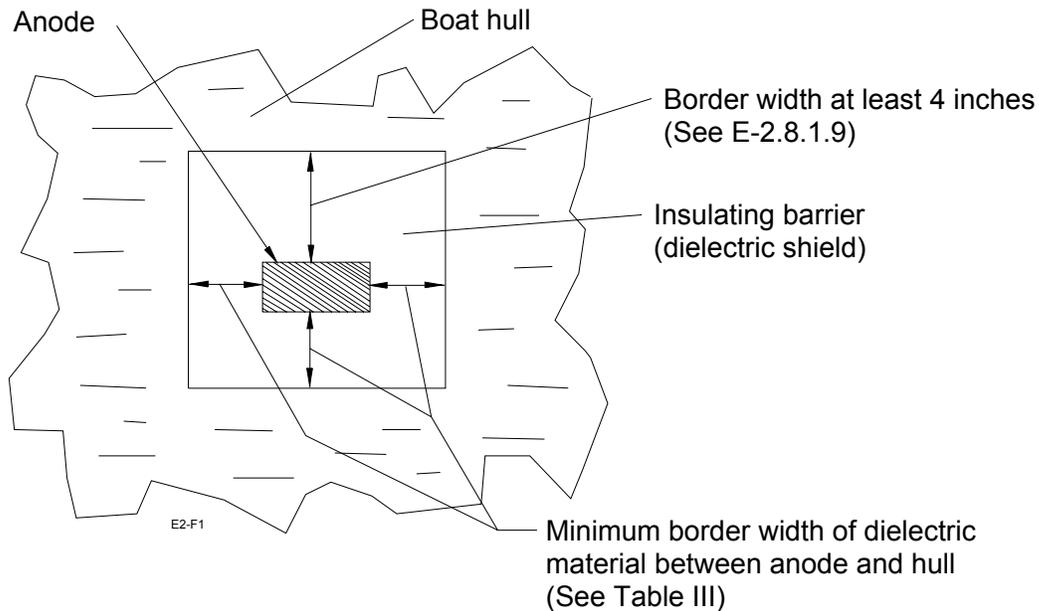
HULL MATERIAL	MILLIVOLT RANGE
Fiberglass	-550 to -900
Wood	-550 to -600
Aluminum	-900 to -1100
Steel	-800 to -1050
Non-metallic w/Aluminum Drives	-900 tp -1050

TABLE III – SHIELDING OF IMPRESSED CURRENT ANODES

SHIELDING OF IMPRESSED CURRENT ANODES	
Maximum Current Output of Anode	Minimum Border Width of Dielectric Material between Anode and Hull
Milliampere	Inches
Below 350	1/2*(13 mm)
1500	3* (77 mm)
5000	8 (205 mm)

\*The minimum shielding should be increased on metallic hulls.

FIGURE 1- DIELECTRIC SHIELDING FOR IMPRESSED CURRENT ANODE



E-2     **APPENDIX**

E-2.Ap.1       The information contained in this appendix is intended to provide practical procedures for the determination of the amount of cathodic protection needed on a boat. Typical compositions of anodes are provided.

E-2.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.**

E-2.Ap.3       **SACRIFICIAL ANODES - MEASUREMENT AND APPLICATION**

E-2.Ap.3.1      For the initial determination of the amount of sacrificial anodic material needed for protection of underwater metal, the following procedures may be used:

E-2.Ap.3.1.1    Place the reference electrode (silver/silver chloride) in the water outside the hull near the underwater unit that is to be protected.

E-2.Ap.3.1.2    Using a digital multimeter (DMM), measure the voltage by connecting the negative terminal of a DMM (preferably a very high impedance type) to the reference electrode, and the positive to the unit to be protected (make sure there is good contact with the metal).

E-2.Ap.3.1.3    Note the reading (e.g., should be -700 mV to -740 mV for aluminum die-castings relative to a silver/silver chloride reference electrode in seawater).

E-2.Ap.3.1.4    Place the sacrificial anode(s) in the water and electrically connect the anode(s) to the metal that is to be protected.

E-2.Ap.3.1.5    Note the reading on the DMM.

E-2.Ap.3.1.6    The sacrificial anode is working or is large enough when the voltage measured is 200 mV more negative than the reading noted in E-2.Ap.3.1.3 (e.g., approximately -900 mV to -940 mV relative to silver/silver chloride reference electrode for aluminum die castings).

E-2.Ap.3.2      Subsequent inspections of the anodes will determine whether there was sufficient or excessive anodic material provided. Adjustments may be made based on the experience gained through these inspections.

E-2.Ap.4       **IMPRESSED CURRENT PROTECTION - APPLICATION**

E-2.Ap.4.1      Impressed current systems for pleasure and light commercial vessels are available in two general types.

E-2.Ap. 4.1.1    Type One systems are generally designed to protect sterndrives/outboards and are limited to about 250 milliamps of protective current.

E-2.Ap. 4.1.2    Type Two systems are larger and generally designed to protect the entire vessel. Current output for these systems range to ten amps.

E-2.Ap.4.2      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.

E-2.Ap.4.3      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 have adjustable set points.

E-2.Ap.4.4      A Type Two system should include a corrosion monitor and output ammeter.

E-2.Ap.5       **FACTORS THAT AFFECT THE TYPE AND DEGREE OF CATHODIC PROTECTION REQUIRED.**

E-2.Ap.5.1      Water Velocity - Cathodic protection current requirements increase with water velocity past the hull. The current requirement can be as high as 30 times that required in still water.

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E-2.Ap.5.2 Boat Usage - More frequently operated vessels require more cathodic protection than vessels infrequently used.

E-2.Ap.5.3 Conductivity of the Water - As the conductivity increases, the rate of galvanic activity increases.

E-2.Ap.5.4 Salinity (Fresh and Seawater) - Current requirements increase with salinity but higher driving potentials are required in fresh water.

E-2.Ap.5.5 pH of the Water - As pH decreases (acid rain lakes), the corrosion rate increases.

E-2.Ap.5.6 Deterioration of Protective Coatings - Current requirements increase as protective coatings deteriorate.

E-2.Ap.6 ***Factors that affect the longevity and adequacy of anodes and system equipment***

E-2.Ap.6.1 Paint - Painted areas of anodes will not produce electrical current.

E-2.Ap.6.2 Loose Connections - Loose anode attachments or loose/corroded electrical connections will reduce or eliminate electrical current flow from the anode.

E-2.Ap.6.3 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.

E-2.Ap.6.4 Copper alloy electrical terminations, even if plated, shall not be in direct contact with aluminum.

***NOTE: The use of an intermediate stainless steel washer may be used to separate the copper terminal from the aluminum surface.***

E-2.Ap.6.5 Insufficient Weight/Surface Area - An anode that has sufficient surface area to produce the desired voltage initially, may not have enough mass (weight) to sustain the current output for the duration of the time that the vessel remains in the water.

E-2.Ap.6.6 Impurities - Impurities in the anode such as iron can seriously reduce their output. Anodes should not be stored in steel bins or with other steel products. Particles of steel will adhere to the anodes forming cathodic cells on the anode surface which reduce output current and cause the anode to self-corrode.

E-2.Ap.6.7 Improper Anode Contact - Metal foil anti-fouling systems must not come in contact with metals that are cathodically protected. This will render the anti-fouling 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.

E-2.Ap.6.8 Anode Composition - There are numerous anode compositions available. To insure the best performance, customers should specify military specification anodes for zinc, aluminum, and magnesium.

E-2.Ap. TABLE I - TYPICAL COMPOSITION OF ANODES

E-2.Ap. TABLE I-A - TYPICAL COMPOSITION OF ZINC ANODES IN PERCENTAGES OR RANGE

	ASTM B418		MIL-A-18001	Minimum Purity
	Type I	Type II		
Aluminum	.1 - .4	.005 max.	.1 - .5	3.9 - 4.3
Cadmium	.03 - .1	.003 max.	.025 - .15	.002 max.
Copper	-	-	.005 max.	.1 max.
Iron	.005 max.	.0014 max.	.005 max.	.05 max.
Lead	.003 max.	.003 max.	.006 max.	.002 max.
Magnesium	-	-	-	.005 - .02
Nickel	-	-	-	.005 - .02
Silicon	-	-	.125 max.	-
Tin	.001 max.	.001 max.	--	.001 max.
Zinc (remainder)	99.5 min	99.99 min	99.2 min	95.5 min

E-2.Ap.TABLE I-B - TYPICAL COMPOSITION OF ALUMINUM ANODES IN PERCENTAGES OR RANGE  
(B605 ALLOY)

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

E-2.Ap.TABLE I-C - 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

E-2.Ap.TABLE II - CORRECTION FACTORS FOR REFERENCE ELECTRODES

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

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

E-2.Ap.TABLE II - CORRECTION FACTORS FOR REFERENCE ELECTRODES (cont.)

REFERENCE/SENSING ELECTRODES POTENTIAL IN SEAWATER COMPARED TO

Cu/CuSO4	Ag/AgCl	SCE	S.H.E.	Zn
+0.2	+0.3	+0.28	+0.52	+1.3
+0.1	+0.2	+0.18	+0.42	+1.2
0.0	+0.1	+0.08	+0.32	+1.1
-0.1	0.0	-0.02	+0.222	+1.0
-0.2	-0.1	-0.12	+0.12	+0.9
-0.3	-0.2	-0.22	+0.02	+0.8
-0.4	-0.3	-0.32	-0.08	+0.7
-0.5	-0.4	-0.42	-0.18	+0.6
-0.6	-0.5	-0.52	-0.28	+0.5
-0.7	-0.6	-0.62	-0.38	+0.4
-0.8	-0.7	-0.72	-0.48	+0.3
-0.9	-0.8	-0.82	-0.58	+0.2
-1.0	-0.9	-0.92	-0.68	+0.1
-1.1	-1.0	-1.02	-0.78	0.0
-1.2	-1.1	-1.12	-0.88	-0.1
-1.3	-1.2	-1.22	-0.98	-0.2
-1.4	-1.3	-1.32	-1.08	-0.3
-1.5	-1.4	-1.42	-1.18	-0.4
-1.6	-1.5	-1.52	-1.28	-0.5
-1.7	-1.6	-1.62	-1.38	-0.6
-1.8	-1.7	-1.72	-1.48	-0.7
-1.9	-1.8	-1.82	-1.58	-0.8
-2.0	-1.9	-1.92	-1.68	-0.9
-2.1	-2.0	-2.02	-1.78	-1.0

Converting Half-Cell Values (Example)

-0.700 volts Ag/AgCl  
+0.222 conversion factor  
- 0.478 volts S.H.E.

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*Origin and Development of ABYC E-2, Cathodic Protection.*

ABYC first published E-2 in 1965 with updates in 1971, 1973, 1981 and 1996. The July 2001 update is the work of the Electrical Project Technical Committee.

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