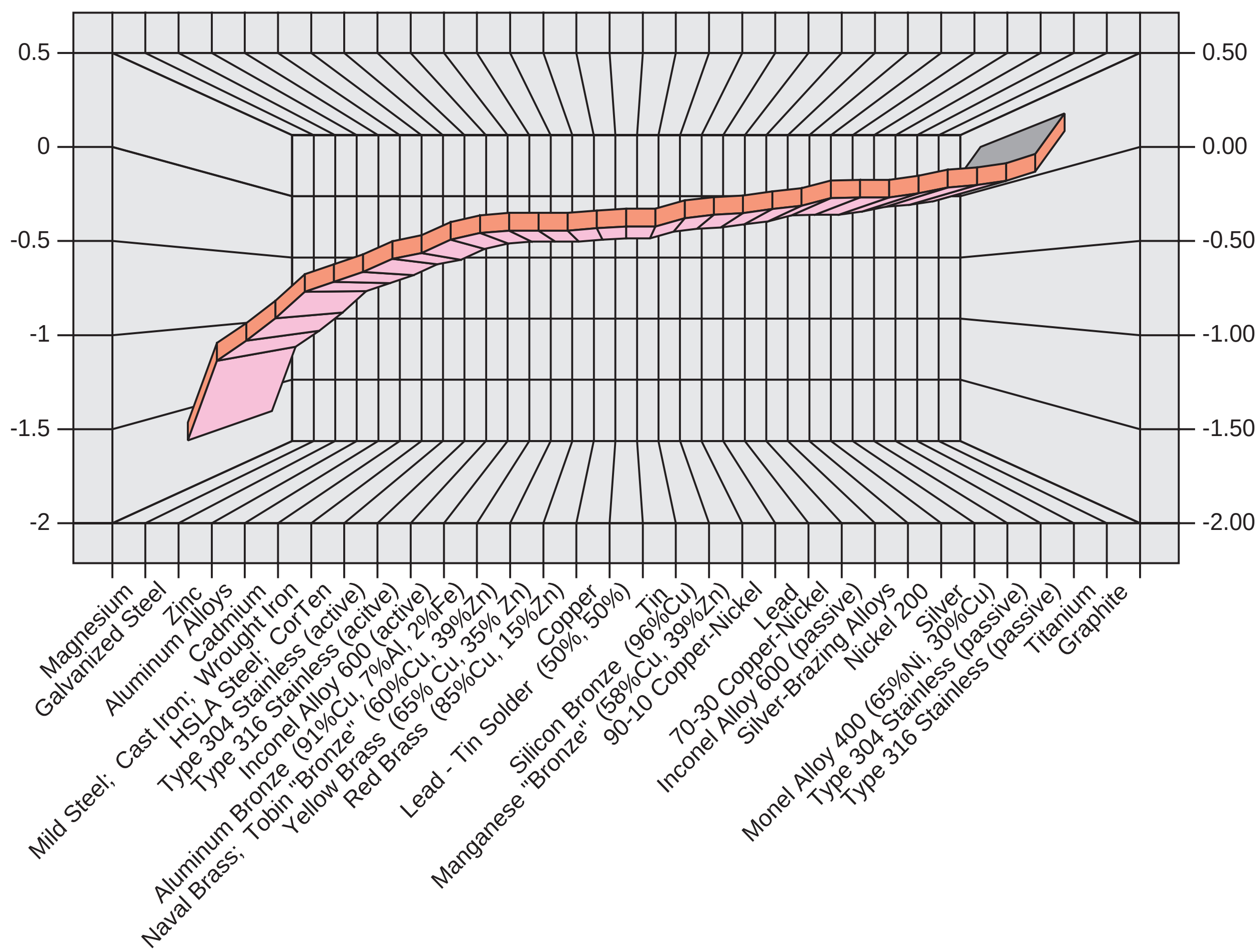
Metal Boat Quarterly

Corrosion, Zincs & Bonding

Average Voltage in Seawater



Summer 1998

Special Edition: Corrosion

The Metal Boat Society

6251 Goodhew Road
Sedro-Woolley, Wa. 98284

The Metal Boat Society is a volunteer, nonprofit organization open to anyone sharing its dedication to the international promotion of metal-hulled boats. Founded in October 1987, the Society's membership is based in the US, Canada, and abroad.

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The Metal Boat Quarterly

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Membership in the Metal Boat Society <u>includes</u> receiving the Metal Boat Quarterly.

Corrosion, Zincs & Bonding

Summer 1998 *Special Edition*

This little booklet, along with the previous Summer Special Edition, "Marine Metals Reference," is part of a larger work, the *Guide to Marine Metals*.

The material presented here attends to the modern trend toward more and more complex boats. Opinions are expressed, but enough information is given to provide the reader with his or her own judgment. My goal with these MBQ Special Editions has been to provide a clearly presented, simple and concise resource for use by boat designers, boat builders, and boat owners.

The illustrations on the front and back covers are the galvanic series—important charts to keep in the forefront of your decisions about metals.

As boaters, one of our main concerns is with the preservation of our boats and the various metal parts on them. Toward this end, it is essential that we develop a working knowledge of the different metals and how they react to being immersed in sea water together. Not only do we need to know what metals will tolerate other metals, or what combinations will be successful, but we also need to know about electricity and metals in salt water.

Throw metals and electricity into salt water and you have an interesting potential for trouble. The basic rules for preventing Galvanic Corrosion by appropriate use of zincs or bonding are treated thoroughly here, and then summarized in a brief table for reference.

The mess one can get into through ignorance of the marine metals and their correct uses is often beyond belief. A badly corroded piece may be what keeps your boat afloat. If it goes, so goes the boat! Foreknowledge and vigilance are essential.

There is much difference of opinion regarding ***bonding***—the reasons to use it, and the reasons not to use it. *The main issues are not what one would expect!*

Questions concerning corrosion, zincs and bonding are therefore important enough to have an entire Special Edition devoted to the topic.

This chapter of the *Guide to Marine Metals* will be the part which goes out of date first, as new practices and new, more complex technologies press themselves upon us. It is based on my own experience and a fair bit of research, but I will be pleased to receive technical feedback from others.

I have tried to present a complete enough picture for readers at any level of involvement to be able to judge for themselves how to best protect themselves and their boats.

—Michael Kasten

Corrosion, Zincs & Bonding

Michael Kasten

Excerpted from a larger work-in-progress by Michael Kasten: the "Guide to Marine Metals." This is the chapter dealing with corrosion and the issues surrounding its prevention. It is presented here as a service to the Metal Boat Society, for use by members in order to make informed decisions during their boat building, repairing, designing, and most importantly, for safe sailing!

"Bonding? Not for me!"
—Giffy Full, hero.

Corrosion is a process of metal deterioration. There are two kinds of corrosion of significance to the use of metals on boats:

Mechanical corrosion is like the cavitation corrosion on the edge of propeller blades. It is like a selective erosion. Cavitation can also happen on the water-jacket side of the cylinder walls in a diesel engine due to high frequency vibration.

Chemical or solutional corrosion is due to presence of an electrolyte. An electrolyte is a solution that conducts electricity via electrically charged atoms, called ions. An ion is an atom that has either picked up an extra electron (negative ion) or has lost an electron (positive ion). Both mechanical and chemical corrosion occur at the surface of the metal, where it can interact with the surrounding sea water.

Metals have an inherent electrical charge, which serves to hold the molecules intact. The charge can vary a little; it can have a differing ***"potential"*** according to temperature, salinity, aeration, and pollution of the water. For most metals in sea water, the charge is negative. Graphite, Platinum, and Gold for example have a positive charge in ordinary sea water.

Take a look at the galvanic series charts on each cover of this issue to see the progression of differing potentials (voltages) from the less noble metals (more negative), through to the more noble metals (less negative).

When two metals of a different potential are connected to each other, and immersed in an electrolyte like sea water, the metals have their charges "equalized." The less noble metal, *stripped of its inherent protective charge,* is unable to prevent the chloride ions in the sea water from pulling metal away. This is ***electro-chemical*** corrosion.

Less noble metals are ***anodic***, or negative, and if connected, will sacrifice themselves to any more noble metal they are electrically in contact with while immersed in an electrolyte. The more noble metal is ***cathodic*** (either positive, or just less negative).

The less noble metal is the giver, and the more noble metal, the taker.

"Galvanic corrosion" is what happens when two dissimilar metals are immersed in an electrolyte, and are electrically *connected*. In this case, a galvanic "cell" is created. This is essentially a battery, and the current it produces can be measured, and even used. Corrosion of the more noble metal will be reduced at the expense of the less noble metal, which will corrode more rapidly.

Two dissimilar metals immersed in an electrolyte, and *not connected* to each other, will corrode at their own inherent natural rate. In this case, there will be no battery, and no enhanced level of either corrosion or protection.

"Stray current corrosion" is when electric current escapes from its intended path, and uses our boat or our underwater fittings as its new path. Here we have a current straying from its intended path: a ***stray current.*** This is a much more severe kind of corrosion. Stray currents can cause very rapid metal loss, which is limited only by the amount of current available. If there is a direct short, the corrosion rate will be extraordinary.

"Electrolysis" describes all of the electro-chemical processes, including galvanic corrosion, stray current corrosion, and also is used to refer to electro-plating, removing hair from our legs, etc. *"Electrolysis"* is often used incorrectly to refer specifically to *"stray current corrosion"* where in fact, it can properly be used to refer to any kind of corrosion involving an electric current.

Strictly speaking, ***electrolysis*** means that chemical changes are being produced in an electrolyte by an electric current passing through the electrolyte. In the case of ***galvanic corrosion*** there is also an electric current—one that is created by the differing inherent charges of the dissimilar metals.

Areas of a metal fitting which are actively suffering from corrosion by one form or another of *electrolysis* will appear brightly eroded, as though freshly sand-blasted. Steel and aluminum will be a bright silvery color, for example. The same appearance will be the case for areas suffering from *cavitation corrosion.*

Sacrificial Zinc Anodes

Strictly from a *corrosion* point of view, every metal fitting below the waterline, whether it is bronze, monel, lead, copper, painted steel, galvanized steel or stainless will be best protected with its own separate ***zinc anode.***

Some zinc alloys perform better than others as anodes, and only those manufactured for use as sacrificial anodes should be used. ***ABYC recommends MIL-A-18001, or ASTM B-418 as a zinc specification.***

Magnesium is unsuitable as an anode in sea water; the voltages produced result in over-protection. Magnesium anodes are sometimes used successfully in fresh water, which has a higher electrical resistance. The presence of pollution can change fresh water into a better electrolyte where magnesium would no longer be usable.

The ***exposed surface area*** of the sacrificial anodes should be in proportion to the exposed surface area of the metal being protected. The exposed surface area is what's important, rather than the volume, or the weight of the piece.

Zinc anodes lose effectiveness with ***distance*** from the part being protected. A zinc should be located either directly on the protected metal fitting itself, or as close as is possible. A common rule of thumb is that there is zero protection at a distance of 50' and a continuous decline in protection up to that point.

The best method for attaching zinc anodes to any underwater fitting is by *welding*. This is the only really positive way to insure continued electrical contact. The zincs intended for welding onto underwater structures are cast around a steel bar. The ends of the steel bar are welded directly to the piece being protected.

If *bolting* is used, as is a more common practice on a non-metal boat, every effort should be made to assure *electrical continuity.* Zincs with a steel bar through them can be used here too by drilling the ends of the steel bar and bolting the bar to the fitting. The heavy copper paste used by electricians for coating electrical connections will work fairly well to preserve the connection under the bolt head. Brazing or soldering the bolted connection will also work well to assure a good electrical connection.

A good trick for attaching zincs that do not have a bar is to fuse a bolt or nut to the zinc anode by heating and melting the zinc locally with a torch until the fastener is effectively cast into the chunk of zinc.

If none of the above methods of attachment can be used, then *vigilance* is required to periodically renew the contact, tighten the bolt, and assure a good connection. The zinc will do no good if it is just hanging there.

Through-hull valves can be protected by installing a "tee" fitting directly to the valve just inside, and using one side of the tee to put in a *pencil zinc* like the ones used in an engine. A strainer should be provided, to catch the zinc flakes that slough off.

A shaft zinc should be removed at every haulout, and the shaft brightened with fine sandpaper to renew the connection.

If the zinc is in good condition, it might be too big for the job. If it is about half wasted, it is doing its job properly and should be replaced with a new zinc of the same size. If the zinc is used up completely, or nearly so, you may need a larger surface area of zinc, or a more frequent replacement interval.

If the zinc is not wasted at all, you either have a poor connection, or the zinc is too large for the application, and a smaller one should be used.

The same rule applies to any zinc on any other underwater fitting. Even a lead ballast keel should have sacrificial anodes, preferably more than one.

Zincs should not be forgotten on the inside of the boat, for protecting the salt water plumbing. Plug or pencil zincs are needed inside the water jacket of the engine. With fresh water cooling, plug zincs are also needed inside the salt water side of the heat exchanger.

Other places where salt water plumbing is likely to be found are pumps, heads, refrigeration heat exchangers, and some hot water heaters. All these will ideally have their own separate set of plug or pencil zincs for corrosion protection.

How Much Zinc?

The required amount of zinc can be estimated using general rules of thumb. However, due to differences in salinity, temperature, stray currents and other external influences, we usually only know the right amount of zinc by trial and error.

The ABYC has published guidelines for sizing the zincs on hulls of different materials. Briefly the guidelines state the following:

Recommended ranges of cathodic protection, relative to a Silver/Silver Chloride reference electrode, are as follows for hulls of different materials:

Aluminum	-900 to -1100 millivolts
Steel	-800 to -1050 millivolts
GRP	-550 to -900 millivolts
Wood	-550 to -600 millivolts

The overall negative potential should be kept within the range of prescribed values if possible. One millivolt is one thousandth of a volt. On wood and GRP vessels, it is assumed that the above readings will be in reference to the collective potential of the metals being protected.

Too much zinc is no good. The zinc develops a crust, gets fouled and quits working. Too much zinc may also cause overprotection. Overprotection on an aluminum hull, or an aluminum outdrive can be particularly destructive.

If an aluminum hull is overprotected (in excess of -1200 millivolts) the result may be alkali corrosion of the metal, and possible hydrogen blistering of the paint, known as "cathodic disbondment." Cathodic disbondment is the destruction of adhesion between a coating and its substrate due to the by-products of a cathodic reaction.

The ABYC recommends that all metal hull vessels utilizing shore power have a permanently installed hull potential meter and reference electrode.

On a hull of any material, a negative potential in excess of -1050 millivolts will result in some decrease in the effectiveness of antifouling paints.

If there is too little zinc, the zinc anodes will disappear too rapidly, after which the hull or other components will be unprotected until the zincs are replaced.

In general, increased water flow will increase the rate of depletion of zinc anodes. Also, increased salinity will increase the ability of the sea water to conduct electricity, and increased temperature will accelerate both processes.

How Do You Measure It?

The method recommended by the ABYC for sizing sacrificial anodes is to place the reference electrode (silver/silver chloride) in the water outside the hull near the item that is to be protected. Measure the voltage using a digital multimeter. Connect the negative terminal to the reference electrode. Connect the positive terminal to the metal part or bonded collection of parts that are to be protected, assuring that there is good contact.

Note the DMM reading.

Connect a sacrificial zinc anode or anodes of the proposed size to the metal part or bonded collection of parts that are to be protected.

Note the DMM reading.

*"Protection is adequate when the voltage measured is 200 millivolts **more negative** than the reading noted without the sacrificial zinc anodes."*

Further, it is noted that *"a cathodic protection system shall be capable of inducing and maintaining a minimum negative shift of 200 millivolts relative to the potential of the **least noble metal** being protected."*

Bonding...

What Is It?

In what has become common practice, the underwater metals on a boat may all be "bonded" together. In so doing, every metal fitting that is in contact with sea water is wired to every other such fitting. The accumulated potential of this whole mass of fittings is aimed at one large zinc anode. This practice is called ***"bonding"*** and is the subject of no small amount of controversy.

Bonding is defined by the ABYC as *"the electrical interconnection of metal objects in common contact with water, to the engine negative terminal, or its bus, and to the sacrificial anodes or impressed current system."*

ABYC recommends using a minimum of #8 AWG as the bonding conductor.

If bonding is to be introduced aboard a vessel, an insulated conductor should be used. Solid wire can be used, or if stranded wire, it should have very coarse strands. Finely stranded wire will deteriorate quickly in a marine environment. All marine wiring should be thoroughly pre-tinned to prevent corrosion.

It is common practice on fiberglass boats to use a non-insulated bare conductor. Wire or heavy foil are both used. That practice can hardly be recommended aboard a wood, metal, or ferrocement boat, where an insulated conductor must always be used.

For identification, ABYC recommends using green insulation or green with a yellow stripe.

The bonding circuit is usually in the bilge, and is therefore exposed to the corrosive effects of sea water. Vibration of the wire will have to be prevented. Soldered or brazed connections are preferred.

The current being carried is usually minute, and requires all the help it can get from each connection being as perfect as possible. Each bonding circuit or connection to a zinc anode should have ***a resistance of less than one ohm.***

One common failure point in a bonding system is the use of a shaft wiper to make the bonding connection to the propeller shaft. The idea is to have the shaft wiper work like the brushes in an electric motor.

In practice however, the connection is compromised by the presence of any corrosion and by any oil film on the shaft. The currents involved are quite often too small to bridge this compromised path, and will ordinarily leave the shaft and propeller without protection.

A bonding wire connection to the engine block is not usually sufficient to assure connection to the shaft and propeller, and for the same reason: the oil film internally in the engine is a good insulator. Additionally, there may be a flexible shaft coupling which completely isolates the engine from the propeller shaft.

The ABYC recommends bonding together all the underwater metals if there is a DC electrical system aboard.

The ABYC position overall is that bonding provides:

I. Shock hazard protection
II. Lightning protection
III. Improved radio performance
IV. Protection from corrosion

People have come to expect boats to be bonded. That expectation has created pressure on builders to provide boats with bonding systems. This trend does not mean that bonding systems are necessary for corrosion protection, it only means that most people, and the ABYC, have come to expect bonding systems to be used.

The one overall compelling reason for bonding together the underwater metals on any boat is for the prevention of electrical shock to the people aboard.

If all the metal fittings, all the appliance and instrument cases, the engine, tanks, and the DC negative are all at the same potential, the hazard from being shocked by a faulty appliance is reduced. That is, provided that the connections were installed correctly, and provided that those connections are maintained.

One can still be shocked by touching one of the bonded components, and a positive DC wire or AC hot wire.

Bonding is widely used on fiberglass boats. Fiberglass is chemically nearly immune to corrosion, and is electrically non-conductive. Whether bonded or not, there is neither harm nor benefit to the boat hull structure itself.

As we will see here, it is not a necessity to bond the underwater fittings on a fiberglass boat just for the sake of corrosion protection, even though it is very commonly done. The fittings can be just as well or better protected from corrosion individually, each fitting having its own zinc anode.

Bonding can be used on a metal boat or on a ferrocement boat. Again, if only for the sake of corrosion protection, bonding is not necessary. Individual zincs will work fine to protect against corrosion.

On a metal boat, whether bonded or not bonded, each metal fitting, unless it is a directly welded part of the metal structure of the hull, should be fully isolated from the hull via paint, non-conductive isolators, and an adhesive caulking, the purpose of which is to prevent any moisture from penetrating the joint, and to prevent any possible electrical interaction between the hull and the fittings.

If bonded, the fittings on a hull of any material should be in electrical contact *only* with the bonding wire. A steel or aluminum (or ferrocement) hull will have its own zinc anodes, separate from those of the fittings.

On a wooden boat it is extremely difficult to recommended bonding of any sort, due to the extreme problems created for any wooden structures in proximity to the noble fittings. Consider the following:

In the galvanic couple created by bonding, the protected fittings are the cathodes and the remotely placed sacrificial zincs are the anodes. The water-soaked wood below the waterline is electrically conductive.

In the area around each of the noble metal fittings (the cathodes) highly alkaline *sodium hydroxide* is formed, and the wood is destroyed. A white fluff is formed that looks like small ice crystals or snow, and is very caustic. The lignin is stripped out of the cellular matrix of the wood leaving only soft spongy cellulose behind. Sodium hydroxide, where found, can on the surface be neutralized with vinegar, but the problem is not cured.

On a wooden boat, the system put aboard to protect the underwater metals *eats the boat instead!*

On any boat, a bonding system usually gets neglected or completely ignored, and the electrical continuity of the system is eventually lost. This is all too common, since the whole system is ordinarily routed through the boat's bilge.

With a series of questionable bonding connections, we don't really know how many of the fittings, if any, are still part of the system, unless we regularly go around and check with a meter. *How many times have you found yourself actually doing that?*

A bonding system is all too often improperly installed in the first place, using only crimped connections or some other mechanical connection. Every connection in a bonding system should be fully soldered. The currents are too small to bridge a corroded "contact only" connection. As mentioned, *one ohm* is the maximum recommended resistance, fitting to anode.

Aboard a boat that is bonded , there is the threat of serious rapid corrosion due to *stray currents* passing through the bonded together collection via the bonding wire.

Aboard a boat that is *not* bonded, if a fault develops in one place, it is relatively easy to isolate the cause, and the problem will not have had the chance to invade the rest of the underwater fittings.

Whether the metals used underwater are bonded together or not, the metals below the water line on any boat should be as close as possible to each other in the galvanic series.

One truth seems to emerge from the experience of the majority of boat survey and repair people: *Purely for the sake of preventing corrosion, it's hard to go wrong with an approach that gives each of the underwater metal fittings its own separate zinc anode, sized to the task.*

Bonding is very often an invitation to trouble. It is a scatter-gun approach to a series of problems, each of which may possibly be better addressed separately.

Why is bonding used?

Let us consider the following, which will address each of the main reasons one might use to justify bonding together the underwater metals on a boat...

The Case Against Bonding

Corrosion

The claim that bonding helps prevent corrosion is open to debate. Connecting all the underwater metals together will result in changing their inherent potentials, protecting the nobler metals, and rendering the least noble metals in the collection defenseless.

The intention is that the least noble metal in the collection will always be the zinc anodes at which the collection is aimed. The story changes however, if the zinc becomes consumed, falls off, or becomes poorly connected. If the zinc becomes depleted, the whole collection begins to feed on the next least noble member, which may possibly be an important structural part of the boat.

Bonding can work for corrosion protection, if the zincs are well maintained and properly sized, if the wiring is done correctly and remains intact, and if there are no other external influences such as from stray currents. Unfortunately, a bonding system provides a very convenient path for stray currents originating outside of the boat.

Stray currents can be induced by wiring the boat's electrical DC negative, or the AC shore power green ground wire, to the collection of underwater metals. Charlie Wing, in his excellent book, *Boatowner's Illustrated Handbook of Wiring,* correctly points out that bonding together the underwater metals will generally prevent corrosion due to stray currents from within the boat, but will tend to *cause* corrosion due to stray currents in the water outside the boat.

Stray current corrosion can exist, even in a perfectly bonded boat with healthy zincs, due to faulty marina wiring creating a potential difference in the water.

If a bonded boat is in the current path, the current will seek the path of least resistance. Most likely, if the bonding system is in good condition, the preferred path for the stray current will be through the boat's bonding wires, rather than through the water. Depending on the direction of the current, the zinc may be unable to do anything to prevent corrosion at the far end of the collection. Therefore, the recommendation is to have zincs at several locations.

On a boat that is *not* bonded, there is no such convenient path for the stray current.

One exception might be boat with a long exposed propeller shaft, where a potential difference may exist from one end to the other. The solution in that case will be to space shaft zincs along the exposed part of the shaft, as needed.

Stray Current

A boat without a connection to shore power can still be attacked by stray current corrosion.

Suppose our boat is in the "hot spot" between two other boats with a safety ground connection and an electrical fault, the current passing through the water can also partially pass through our boat on its way from the hot boat to the grounded boat. The metal fittings on our boat will then have a potential differential from one side or end of the boat to the other, and stray current corrosion will begin. Bonding cannot prevent this. Bonding is the *cause* of it.

On the other hand, if each metal fitting is electrically separate, and has its own zinc, there would be less opportunity for a stray current to pass *through* our boat on its way to ground.

If our boat is bonded, and we want to protect it from stray current corrosion, we can create a preferred path for the current in the water to get *around* our boat.

If we place a copper plate in the water on one end of a boat, and connect it to another copper plate on the other end of the boat, any current passing through will use the first pathway it encounters, and the boat will be bypassed.

In order to work in all directions, plates and conductors would have to also be arranged on both sides as well as below the boat. Any stray current will take the path through the net we have created, and the boat will be spared.

This "cage" around the boat is an extreme measure, but will work where there is no other choice. It can be an effective counter-measure for a *metal* boat which may not have bonded fittings, but which is being attacked by stray currents.

Stray electrical current can be measured by taking a test meter reading. A similar arrangement would be used: a plate in the water on one end or one side of our boat, and another plate in the water on the other side. Plates must be of the same material and about the same size. Moving the plates around will give an idea whether we are in a problem area of the marina.

Stray currents can be produced by faulty marina wiring, or faulty boat wiring, and can be extremely hazardous or fatal to a swimmer in the water. If you suspect trouble, your last choice (perhaps quite literally) will be to jump in to check it out!!

Excellent instructions for measuring stray currents can be found in *The 12 Volt Doctor's Practical Handbook,* by Edgar Beyn, and in *The Boatowner's Illustrated Handbook of Wiring,* by Charlie Wing.

Radio Ground Plane

Radio performance can be best improved via a generous ***"ground plane"*** which does not have to even *contact* the seawater. Only half of the radio antenna is above the water; the other half ***is*** the water. The water half is called the ***"counterpoise"*** or ground plane. An ideal radio counterpoise should provide a large area of metal *close to,* but not necessarily in contact with the water.

On a fiberglass or a wooden boat, copper screen or expanded copper sheet makes an ideal material for a ground plane, and can be located on the *inside* of the hull, below the waterline. On a fiberglass boat, it can even become part of the laminate. On a metal or a ferrocement hull, a radio *counterpoise* connection can be made directly to the metal hull, or in the case of a ferrocement hull, to the structural armature.

With a metal hull, even though the hull is thoroughly encased in epoxy paint, the zincs will serve as a radio *ground* (static discharge). The hull is already an adequate radio *counterpoise* even without the zincs.

We are referring to the radio transmitting counterpoise (ground plane), not the electrical negative. The counterpoise is connected to the shield of the antenna's coaxial cable, and to the chassis of the radio. The DC electrical negative wire is returned to the battery.

The DC negative and the counterpoise are often connected at the ground stud on the back of the radio. However, the electrical negative may be kept separate from the ground plane, if desired, via a "Ground Isolation Network." This is a circuit board available from SEA in Seattle, Washington, 206-771-2182. Part number ASY-1615-03 (as of 1995).

In this case a "floating ground" can be maintained, where neither the counterpoise nor the DC negative are in contact with the seawater. This is a valid consideration if our wish is to maintain a floating ground—one that is nowhere connected to the seawater. In this case, the counterpoise may foil our best efforts if it contacts the seawater. It would then provide a "leak" in our otherwise floating system.

According to the engineers at SEA, European radios, which are set up for a 24v. system, have essentially an isolation transformer inside to provide 12v. to the circuitry, and the counterpoise-to-electrical negative separation is maintained. They were quick to point out, though, that a connection to the water may help reduce static types of noise in a floating ground system. This might be simply achieved via a switch that could be closed when static is perceived to be a problem.

The point of these strategies, if used, would be to prevent the DC electrical system from interacting with the underwater metals, and would be pursued mainly in the interest of achieving the greatest degree of corrosion protection for those metals.

Lightning

In the US, out of the annual average of about 100 deaths due to lightning, 13 are aboard boats. If lightning is a hazard where the boat will be used, a plan must be developed to deal with the possibility of a strike.

In the Pacific Northwest, lightning is relatively rare. In Florida, though, strikes are measured in numbers annually per square mile, with some areas having more than ten!

The electrical potential built up before a strike may be over *100 million volts.* A lightning strike may carry something like *20 to 50 thousand amps,* and generate temperatures of some *55 thousand degrees.* Fortunately, it lasts only a fraction of a second.

It would seem undesirable, at best, to invite a lightning strike to preferentially pass through the interior of our boat.

A lightning protection system aboard a boat has a dual purpose:

1. It will primarily serve as a lightning ***prevention*** system, the purpose of which will be to continuously shed any charge built up by the boat, thereby rendering the boat "invisible" to lightning.

2. It will secondarily be asked to serve as a lightning ***strike protection*** system, to safely conduct a direct strike to ground.

The lightning protection system will therefore consist of a robust *"primary path"* which will be designed to safely conduct a direct strike to ground, and a series of *"secondary paths"* which will be designed to safely dissipate the accumulation of charge by the boat, and which will feed into the primary path.

The backbone, or primary path, will consist of three components:

1. An *air terminal* connected to:
2. A robust *conductor* leading vertically in a straight path to:
3. A *ground plate* immersed in the water.

The top-most end, or *air terminal,* should be a sharply pointed spike. Alternately, a wire "brush" type terminal can be placed at the masthead, with the bristles pointed upward. There are several claims that a single spike is more effective than a brush for dissipating the charge built up by the boat.

As a general rule, the spike, or brush, should be at least 6" higher than anything else nearby, and should project above everything within a 90° cone shaped zone extending downward from the spike in all directions. This cone shaped zone extends 45° from the vertical—half of the 90° cone—in all directions with the apex at the point of the spike.

From the spike point downward, this ***90° cone of protection*** spreads out, and should entirely enclose the boat. Inside the cone of protection there will be relative safety. This is the zone within which the charge will have been more or less dissipated, and lightning will be preferentially attracted to the spike.

In other words, lightning that would, in the absence of the lightning rod, strike within the region bounded by the conical surface is supposed to instead strike the cone apex. The apparent mechanism for this phenomenon is that the top of the lightning rod launches an upward-going discharge to meet the downward-going lightning stepped leader before other objects within the cone of protection can do so.

A larger 138° cone of protection is presumed to exist by lightning researcher Ewen M. Thomson via his analysis of lightning strikes to boats. His results are published in a paper entitled, ***A Critical Assessment of the US Code for Lightning Protection of Boats***, presented to an international conference of electrical engineers during May 1991.

It is critical that the *primary conductor* of the lightning protection system, which takes the path from the top-most end of the system to the water be as robust as it can be made, be as direct as possible, and use long radii, rather than sharp bends along the primary path to the grounding plate. The connections must offer low electrical resistance or the energy of a strike may instantly heat and melt the connection.

Ewen M. Thompson's research suggests that all conductors be a minimum of #4 AWG copper (21.2 mm^2 or 0.0329 in^2). Possibly as a result of his research, the new ABYC rule recommends *a minimum of a #4 AWG copper wire for the primary lightning protection system conductor, and a minimum of a #6 AWG copper wire for the secondary conductors. Tinned wire is recommended, as usual.*

A boat with a metal mast which is stepped on the keel will present an ideal situation. Here, the primary conductor may be the mast itself. An aluminum mast will be an excellent conductor, and will mainly require a substantial direct connection to the *air terminal* at the top, and to the *grounding plate* at the bottom.

With a wood mast, it may be necessary to rout a channel for a substantial copper conductor. A bronze sail track on a wood mast might be considered to be a substantial enough conductor, but it would have to be made continuous via mechanical, brazed or soldered connections. If used, it must have the same sectional area as a #4 AWG copper wire. In any case electrical continuity will have to be assured from the spike at the masthead to the copper ground plate in the water.

Other types of conductors need to be considered: Per the ABYC, a carbon fiber reinforced wood mast or a carbon fiber reinforced composite mast will ***not*** be treated as though it is a conductor. Stainless is ***not*** a good conductor. A stainless sail track will not usually be large enough to be adequate.

The ABYC states: *"every metal shroud and stay shall be connected from the chain plate directly to the ground plate or ground strip with a conductor equal to at least #6 AWG copper. Where the system consists of multiple shrouds, stays, and mast, they shall have an aggregate conductivity of no less than a #4 AWG copper conductor."*

A traditionally rigged vessel, having fully insulated shrouds due to serving and possibly the use of deadeyes and lanyards, will likely be a separate case.

The ABYC rule states: *"Large metal objects such as tanks, engines, deck winches, stoves, etc, within 6 feet of any lightning conductor shall be interconnected by means of a lightning conductor at least equal to #6 AWG copper."*

"To minimize flow of lightning discharge current through engine bearings, it may be preferable to bond engine blocks directly to the ground plate rather than to an intermediate point on the lightning protection system."

"To minimize side flashes and the induction of high voltage to the boat's wiring, lightning conductors in proximity to the boat's wiring shall not be routed in parallel to the boat's wiring."

The ABYC further states: *"a lightning system conductor shall not form an bend of less than 90° and it shall not have a bend radius less than 8 inches."*

For the *grounding plate*, an area of about one square foot is considered by the ABYC to be sufficient.

The grounding plates should be located as close to the base of the primary conductor as possible to minimize any horizontal runs in the primary conductor.

The edges of the external ground plate or strip need to be sharp, exposed, and not caulked or faired into the adjoining area. The ABYC suggests the use of a ***grounding strip,*** rather than a plate. The ABYC rule states:

"A grounding strip shall have a minimum thickness of 3/16 inch (5 mm), and a minimum width of 3/4 inch (19 mm). A strip approximately one inch (25 mm) wide and 12 feet long (3.7 m) has nearly six times the amount of edge area exposed to the water, which will improve the dissipation of charges.

"The grounding strip, if used, shall extend from a point directly below the lightning protection mast, toward the aft end of the boat, where a direct connection can be made to the boat's engine."

"An **equalization bus** on the inside of the boat, paralleling the grounding strip on the outside of the boat, may be used as the lightning ground conductor."

ABYC encourages use of two bolts at each end of the strip, extending between the external strip and the internal *"equalization bus,"* a metal strap inside the boat substantially parallel to the exterior lightning ground plate, and connected to the lightning ground plate at each end. Secondary lightning conductors can be connected to the *equalization bus.*

A grounding plate, if used instead, should be solid, rather than the sintered bronze type often used as radio grounds. The sponge-like structure of the sintered bronze plates may, in the event of a strike, allow the instant formation of steam, which could blow the plate apart, resulting in possible severe damage to the surrounding hull.

The ABYC states: *"An exterior grounding plate of copper, copper alloys, stainless steel, or aluminum may be provided by means of a plate which has an area of at least one square foot."*

Ewen Thompson's research indicates that in salt water, a grounding plate of one square foot in area may be sufficient, but that in fresh water, even two square feet or more may not be enough to provide a sufficiently low resistance in the event of a direct strike. Thompson argues in favor of a generous grounding *strip.*

If the grounding plate or strip is not large enough, the inevitable result will be that a lightning strike will seek additional pathways to ground, and the danger of ***side flashes*** will be dramatically increased, along with possible severe damage to the hull.

The grounding plate must not be painted, and therefore should not be integrated with the boat's corrosion protection system. If the grounding plate is attached to a zinc anode, the natural antifouling qualities of the copper will be eliminated, and the plate will quickly foul.

On a boat with an external ballast keel, the keel itself might seem like an ideal lightning ground. However, if an external ballast keel is used, a substantial area of the surface of the ballast would have to be kept bare in order to bleed off the gathering charge to help avoid a strike. That strategy would not be entirely practical even with a lead keel, since the exposed lead area will foul fairly quickly, especially if the lead keel is provided with zinc anodes for corrosion protection (as it should be). A coating of paint is too much insulation, not necessarily in the case of a strike, but in order to help prevent one.

Therefore, even if there is external lead ballast, it will be probably be preferred to use a copper plate or grounding strip, which, if it is *not* connected to zinc anodes, will provide its own anti-fouling.

The possibility of *"side flashes"* has been mentioned. Lightning strikes may involve side flashes to other metal objects. Side flashes are encouraged by an insufficient *path* to ground, or an insufficient *area* of the grounding plates. Side flashes can create a chain from one item to the next on the way to ground.

Side flashes are most prevalent in fresh water. In fact, Ewen Thompson's findings suggest that sideflashes are ***inevitable*** in fresh water, but they are much less likely in salt water, assuming that in both cases there is a lightning protection system aboard. His survey results show a much higher incidence of serious hull damage in fresh water than in salt water.

Thompson states, as does the ABYC that the actual *form factor* of the ground plate is important. A ground plate or strap with sharp corners or points will initiate streamers at a lower voltage and result in a lowering of ground resistance at a lower current than will a smooth or rounded plate.

To minimize the potential for side flashes, the *secondary protection system* involves all the metal objects aboard a boat which are larger than about one foot in any direction. These are to be connected to the lightening protection system *equalization bus* via the *secondary conductors.*

The ABYC states: *"Seacocks and through hull fittings, if connected to the lighting ground system shall **not** be connected to the main down-conductor. They shall instead be connected to the grounding strip or plate, or to the internal equalization bus."*

Connecting these many metal components to the lightning protection system will serve to equalize the built up potential among them and reduce the likelihood of a side flash.

The by-words for lightning conductors are robust, direct, and having no sharp bends.

The *bonding system* on any boat hardly qualifies. Neither is the bonding wire or strap adequate to handle the intense discharge during a direct strike.

We are faced with a problem here!

If the *bonding* system is asked to participate in the *lightning protection* system order to help prevent side flashes, the copper grounding plate will be stripped of its natural antifouling qualities.

A lightning strike involves a very rapid change in an electric current, generating a momentary, but very powerful magnetic field. This electro-magnetic pulse (EMP) can readily induce currents in adjacent wiring. Currents induced in wires by the EMP from a lightning strike may do some very weird things, such as fry every piece of electronics aboard.

A strike nearby or on another boat can fry the electronics aboard your boat without even requiring an electrical connection. A direct or nearby strike may have a radical and permanent influence on the compass, and may require that it be completely re-calibrated.

Strikes have been known to erase all the cassette tapes on a boat! Consider what would happen to other magnetic media, such as your hard drive! Sensitive electronics hardly stand a chance.

Lightning tends to prefer to run along the outside surface of objects. A logical approach might take advantage of this natural tendency. For lightning protection, airplanes use the strategy of external shielding to create a *Faraday Cage* around instruments.

The ABYC states: *"Wherever possible, electronic equipment should be enclosed in metal cabinets that are connected to the lightning grounding system. Surge suppression devices should be installed on all wiring entering or leaving electronic equipment."*

With a metal boat, the hull itself makes an excellent Faraday Cage and an excellent conductor. Still, it may not serve as an adequate lightning grounding surface due to the hull being completely enclosed within an epoxy skin. Even considering the zincs as ground plates, lightning protection will not be as intended, since the path to the zincs may not be straight, or the area may not be sufficient.

Ideally, on a metal boat there will be a pointed spike at the top of an aluminum mast, bolted to a #4 AWG copper jumper connected in a straight line from the mast to the grounding plate immediately below the mast. With this arrangement, a lightning strike can proceed unhindered in a straight path.

The ABYC states that aboard a metal boat, *"If there is electrical continuity between metal hulls and masts, or other metallic superstructures of adequate height, then no further protection against lightning is necessary."*

Primarily in order to have control over *stray currents,* it may seem most desirable aboard a boat of any material to be able to disengage a lightning protection system when the threat of a strike does not exist, particularly if the lightning protection system is elaborate. A bonding system, if present, may then be intentionally connected to the lightning ground network prior to an electrical storm.

Suggestion has been made that, in salt water, a robust (minimum #6 AWG) and directly routed *bonding system* may be kept separate from the *primary lightning protection system.* The rationale being that the salt water itself is sufficient as a conductor to allow the charges to be equalized. However, this may *not* be effective in fresh water, and there is no support for this strategy within the ABYC rules.

Aside from an external ballast keel, the propeller probably represents the largest underwater mass of bare metal, and consequently an excellent ground. It is therefore desirable for the engine block to be connected to the lightning grounding plate via a heavy and direct conductor. This should be done in order to reduce the potential for a side flash to the engine in the event of a direct strike and consequent damage to the engine.

Strictly for the sake of corrosion prevention, however, it may be desired to isolate the engine electrically from the underwater metals. In this case, it would be best to have the ability to selectively engage a lightning ground conductor during an electrical storm.

In an electrical storm we will be safest if we stay inside the boat, away from all metal parts, such as metal masts, shrouds, lifelines, engines, metal tanks, stoves, water pipes, faucets, sinks, electronic gear, inside ballast, spare anchors, or chain. We should especially stay away from any area ***between*** large metal parts.

Aboard a *metal* boat, the boat itself forms a protective Faraday Cage. The best strategy aboard a metal boat will be to encourage the hull itself to be integral with the primary conductor.

The ABYC notes that even if their new Lightning Protection Standard is employed, *complete protection from equipment damage or personal injury is not implied.* And that *a lightning protection system offers no protection when the boat is out of the water, and is not intended to afford protection if any part of the boat comes in contact with power lines.*

The ABYC further notes that *protection of persons and small craft from lightning is dependent on a combination of design and maintenance of equipment, and on personnel behavior. The ABYC guide is general in nature, and pointedly states that in view of the wide variation in structural design of boats, and the unpredictable nature of lightning, specific recommendations cannot be made to cover all cases.*

Needless to say, aboard a boat, any strike is to be considered dangerous. Protection requirements for a boat should be more stringent than those for buildings, since a failure of the protection system is more likely to result in personal injury aboard a boat. A failure rate which may be acceptable on buildings is clearly unacceptable on a boat in mid-ocean.

This discourse on lightning is not intended to recommend a specific approach. It is instead presented here simply to introduce the magnitude of the problem. Experts and standards bodies have not reached consensus on the subject. It is up to your own best judgment to choose what will work best board your own boat!

Good luck!

During an electrical storm, we had best observe Bre'r Fox' advice closely: *"Lay low, an' don't say nuffin."*

Summary

From the above, we can readily see that the corrosion problems aboard a boat are not optimally addressed by a *bonding system,* which in itself is not designed to adequately handle *lightning protection, radio grounding, or even corrosion due to stray currents.*

Clearly, if we are to employ a bonding system aboard our vessels, we must choose to do so on the basis of an informed rationale, rather than to expect the bonding system to perform duties for which it is inadequately suited.

The Case In Favor of Bonding

Shock Hazard

The shock hazard resulting from a person becoming the electrical pathway for a direct connection to the sea water is indisputable.

We can safely say that bonding ***does*** help prevent shock, and does so by bringing all the bonded together metals to the same electrical potential.

It becomes somewhat obvious that, for the sake of limiting liability, a boat builder will likely be convinced to use bonding, if only to prevent being the target of a suit alleging that the electrical system was improperly installed, and caused harm or death to an individual.

Faced with our blame-oriented legal system, one can hardly recommend against bonding. We must, however, understand the whole picture in order to assure that we do not become complacent and assume that we have cured all problems at once. It is rather the opposite... we may in fact have created a host of other unforeseen problems.

By installing a bonding system, we have most certainly lessened the shock hazard to individuals. The price we will pay as a result is that we may have:

I. Increased the likelihood of severe and unexpected corrosion, regardless of hull material.

II. In the case of a wooden boat, jeopardized the integrity of the wooden hull structure itself.

III. Falsely assumed that the bonding system provides an effective radio counterpoise.

IV. Falsely assumed that the bonding system is in any way adequate for lightning protection.

We can see that there is not a single solution to these separate problems, and that ideally they will be most adequately treated individually.

Bringing Aboard Shore Power

In the US, Shore-power is brought aboard a boat either as 110 volts AC or 220 volts AC at 60 cycles per second. In some cases, the voltage is 120 or 240. For 110/120 VAC, the three wires are a black hot wire, a white neutral wire, and a green safety ground wire. For 220/240 VAC, there are four wires: two hot wires, either both marked black, or one black and one red; the neutral wire is still white, and the safety ground is still green. Once aboard the boat, the green safety ground wire may be solid green, or green with a yellow stripe.

The green AC ground wire is a non-current carrying conductor provided to connect the exposed metallic non-current carrying enclosures on electrical equipment to ground.

The white AC neutral is a current carrying conductor, which is maintained at ground potential.

The black AC hot wire alternates above and below neutral potential. First the hot lead surges to 110v. positive, then surges equally to 110v. negative, and then back to positive. This cycle happens 60 times a second (in the US).

The green shore-power safety ground wire should be brought aboard and extended to serve the equipment that runs on shore-power. It is an important and valid safety feature!

If the AC hot wire contacts the case of some appliance, the green wire may then become a current carrying conductor. If we were to touch that appliance case at the same time as we touch a salt water plumbing fitting, we may become the preferred path for the current. This is the logic behind the ABYC recommendation that the green safety ground wire be extended to the bonded together collection of underwater metals, and that the white neutral wire be kept isolated.

The target for the green wire connection, per the ABYC manual, is the engine's negative terminal. This presumes that the boat does in fact have a bonding system, and that the engine is also bonded.

As may be the case on a wood boat, however, where a bonding system is not wanted, there might ***be*** no bonding system, and that option might not be available.

Above all, make dead sure there is no electrical connection of any kind between the AC white neutral and the boat's bonding system. There must likewise be no connection between the AC white neutral and the boat's DC negative.

If done properly, the connection between the AC green ground and the AC white neutral will be made in one place: onshore where a heavy copper grounding rod is driven into the ground at the point where the power departs from the shore. The green ground wire, per ABYC recommendations, is not to be connected to the neutral bus anywhere down-stream of that point.

The rule states explicitly:

"All exposed, electrically conductive, non current carrying parts of fixed AC electrical equipment and appliances intended to be grounded shall be connected to the grounding conductor. If any appliance has a neutral-to-ground bonding strap, it must be removed."

If incorrectly wired, the green safety and the white neutral might mistakenly be connected to each other inside the dockside AC supply box, defeating the shock protection on the dock itself.

If the green safety and the white neutral are mistakenly connected aboard the boat, the shock protection aboard the boat will be defeated.

If the black AC hot wire and the white AC neutral wire were to get reversed at the plug, we would have a live hot wire supplying full current into the neutral side of our system.

This is the logic behind the ABYC recommendation that there be a polarity indicator where the shore power comes aboard.

More than a few boats have been completely ruined by faulty electrical wiring, or had their fittings seriously wasted to the point of extreme structural danger, due to stray currents which were likely introduced by the AC shore power wiring polarities being reversed.

Strictly in terms of corrosion prevention, if we connect the green safety ground wire to the bonding system on a boat, we are inviting the possibility of serious stray current corrosion, since we have thereby connected our underwater fittings and zincs to any other boats' underwater metals and zincs in the marina which are similarly wired.

Any electrical fault on any one of those boats will immediately involve our boat. If an electrical fault on any boat wired this way ends up bleeding current into the water, a "hot spot" is created in the marina.

If the fault-boat uses up all its zincs, and our boat is close enough, the fault-boat will begin to use our zincs, since our zincs would be bonded to his zincs via our shore-power green safety ground.

An electrical fault of this kind has been known to kill swimmers near the hot spot by electrocution. Oddly enough, some people have expressed disbelief that this could even happen. What happens is that if a swimmer gets into the current path, a potential differential can be created between one part of the body and another, and sufficient current can pass through the body to be fatal. A recent case of this happening was in Seattle.

These hazards both to the boat and to the people aboard are the primary rationale for bringing the green grounding wire aboard. Having done so, however, we may have created a potentially destructive path for stray currents. Therefore, the ABYC recommendation of employing an *Isolation Transformer* or a *Galvanic Isolator* in the shore power line before it reaches the boat's AC distribution box onboard.

A *Galvanic Isolator* is a device installed onto the green ground wire of the shore power cable as it comes aboard to block low voltage DC galvanic currents but to permit the passage of AC currents if necessary. This alone will not prevent potentially severe damage due to the shore power polarity being reversed. Nor will it prevent potentially severe corrosion damage if your boat is wired with the correct polarity, but the neighboring boat is not.

Several kinds of "black box" devices are marketed to prevent another boat from using up our zincs. They may use diodes to allow current to flow only in one direction. They will still not prevent current from flowing in the "preferred" direction and remaining a danger to us or to swimmers. Additionally, if these devices are incorrectly wired, they may instead *encourage* corrosion, possibly quite severe.

Corrosion Prevention

How shall these kinds of disasters be prevented? There are essentially three possible avenues, each of which has several variations, along with their advantages and disadvantages; adherents and nay-sayers; believers and disbelievers.

Each of these choices must be studied on a per-boat basis, and the correct path chosen ***by the boat's owner*** for the vessel in question.

Briefly, the choices are:

I. Do not bring AC shore power aboard.

II. Bring AC aboard via a *Marine Grade Isolation Transformer,* but maintain a "floating ground" which does not connect the AC green grounding wire to the DC negative bus. ***This option creates a possible shock hazard to people aboard!***

III. Make use of a proper Marine Grade Isolation Transformer in the AC supply and *extend the green ground wire to the boat's bonding system* at the DC negative bus and therefore to the bonding system.

I. Case number one is the easiest choice. If we don't bring AC power aboard, the problem is simply solved. In small vessels, this is the obvious choice. It will eliminate a terrific expense, a huge liability, and will dramatically lessen the likelihood of severe stray current corrosion.

If this non-AC boat has a bonding system, however, stray currents from other boats or from faulty marina wiring can still prey on the vessel's underwater metals.

II. Case number two is perhaps inviting: if we bring AC power aboard via an Isolation Transformer, the stray current problem can be prevented by not connecting the shore-power green safety ground to our boats' bonding system.

Using this approach, we would take the green wire aboard only to serve the AC appliances, and take it back to shore via the shore power cord. Ideally, with this system a GFCI (Ground Fault Circuit Interrupter) will be used in all the on-board AC circuits, even if only brought aboard via an extension cord.

If the green ground wire is not tied to the boat's bonding system, an added bonus is that the AC and the DC systems will also be completely separated, which from a corrosion stand point should be desirable.

On a “simple boat,” without hot and cold running water, wet bar, electric range, microwave, deep freeze, television, or a *bonding system*, it seems likely that one may prefer to keep the AC green ground wire separate from the boat’s DC ground, regardless of the hull material with which the boat is built.

Aboard a relatively simple boat, which has brought AC power aboard only for charging the ship’s batteries, one may be tempted by this “floating ground” strategy. As we will soon see, the weak link in this strategy is often the boat’s battery charger; the very device which is the most likely reason for having AC power aboard in the first place.

It has been said many times by many people, “If we do not have the green ground wire attached to the boat’s bonding system, we will be at risk of shock.” ***This is absolutely true!***

It must also be realized that even if we ***do*** have the green AC ground wire extended to our bonding system, we are *still* at risk of receiving a shock by contact with an AC hot wire or a faulty AC circuit.

Shock Prevention

III. Choice number three involves the maximum shock prevention. Aboard a boat with complex systems which has an elaborate electrical system, we will have no choice—the ABYC recommendations will have to be followed.

*The AC power will have to be brought aboard through a proper **Marine Isolation Transformer,** and the AC green ground wire will have to be extended and attached to not only the AC neutral bus, but also to the boat’s bonding system at the DC negative bus.*

The ABYC recommendations will more or less make the onboard systems work the same as the onshore tools and appliances we are all used to. The AC green ground wire, and the bonding system, will have the same “ground potential” as the water.

The ABYC rule is quite specific in this regard. The AC green grounding wire is to be handled only as prescribed. In any case, a proper Marine Grade Isolation Transformer will provide for isolation of all three legs of the AC shore power, including isolation of the green ground wire.

The Isolation Transformer

The ABYC defines an ***Isolation Transformer*** *as “a transformer installed in the shore power supply circuit on a boat to electrically isolate all AC system conductors, including the AC green grounding conductor on the boat from the AC system conductors of the shore power supply.*

If we are bringing AC shore power aboard to an electrical panel on a boat, a marine grade *Isolation Transformer* should ***always*** be used in the shore power circuit where it comes aboard, and before it reaches the AC distribution panel or any other device aboard.

The AC shore power current passes through the transformer’s primary windings only, and induces a current in the secondary windings, which supply the boat. Primary and secondary windings are insulated from each other, and a ground fault on the shore side will not involve our boat.

At its simplest form, a transformer consists of two coils of wire in close proximity but electrically isolated from each other, usually wrapped around a common metal core to contain the magnetic fields produced. If an alternating current is applied to one of the coils, it will *induce* a similar current in the other coil.

Most transformers are designed to step voltage up or down by having differing numbers of turns in the two coils. An *isolation transformer* has the same number of turns in each coil, serving only to ***isolate*** the boat from the shoreside power, but to give the same voltage.

An *Isolation Transformer* is used because the *shoreside* AC power is referenced to ground. If you are connected to the earth and you touch the "hot" lead of a normal *shoreside* AC service, you will get shocked.

The *isolation transformer* removes the ground reference from the ship's service. ***Neither*** of the two sides of an AC circuit on the boat is at ground potential. Therefore you must contact both sides of the *onboard* supply to shock yourself.

Provided that all three legs are isolated in the transformer, this also means that if the boat next to you is leaking current, it won't flow into your grounding system but rather take some other path to earth.

The question is not whether or not one should employ an *isolation transformer**—one should, if AC is brought aboard for any reason!*** The question rather concerns how exactly to connect the green safety ground wire across the isolation transformer, and then what to do with it within the boat.

The 1998 ABYC updates recommend three basic ways of connecting an isolation transformer on a 120 VAC shore power inlet. The three different methods illustrate three different ways which different manufacturers have developed for handling the green safety ground wire.

The ABYC diagrams must be thoroughly studied! The methods they present for wiring an isolation transformer assure that there is no continuity between the shore power green grounding wire and the boat's green grounding wire. Please see the ABYC address within the Bibliography on page 23.

A commonly suggested solution to the problem of screwed up boat or marina wiring is to make use of a Ground Fault Circuit Interrupter, which will shut down the power to a circuit in which a ground fault is sensed.

Theoretically, a GFI will work as a safety indicator. Practically, though, it is more likely that you will get mad at the thing and deep six it before long, if not immediately.

The US Coast Guard here in Port Townsend aboard the cutter *Point Bennett* made a valiant attempt to introduce a GFI at the dock box. They even re-wired part of the marina, but finally gave up on the GFI... They could not trace the ground fault.

The Battery Charger

The most usual, and the most unsuspected route for the green ground wire, and possibly the neutral leg of shore power to involve itself in a boat's under water metals is via the boat's battery charger. Many high quality marine battery chargers have an internal *isolation transformer* as part of the unit. Cheap marine chargers or automotive battery chargers might not.

If all three legs of the AC current are not properly isolated then there will be the possibility of a direct connection between your boat's ground and that of the entire power grid.

ABYC requires the use of isolation transformer type battery chargers to reduce shock hazard and to reduce the chance of possibly severe corrosion.

The Verdict?

On any kind of boat, we must each make our own choice. The choice is an individual one, and everyone will have their own preference.

On a wooden boat, the choice may be somewhat more clear cut. We'll need to choose between the perceived lesser of two evils:

I. Make an attempt to protect ourselves from the possible hazard of electrical shock by installing a bonding system, and connecting both the DC negative, and the AC green ground wire to it via an isolation transformer, or...

II. Protect the wooden hull structure from being attacked by the highly destructive alkaline conditions formed at the noble fittings by not installing a bonding system, and instead protect each underwater fitting with its own set of sacrificial zinc anodes, thereby also eliminating the potential for stray current corrosion of the underwater metals.

On any vessel, regardless of the choices made, if there is AC power aboard, there should be an isolation transformer, and the green grounding wire should be attached to the Isolation Transformer in the manner prescribed by the ABYC.

On a boat built of any material, there are no hard and fast answers provided here, only a snapshot of the issues at hand. The consequence is that you will likely arrive at a different conclusion than the next guy.

Simple is beautiful!

Corrosion Control Systems

Impressed Current Systems

The bonded together collection of metals are sometimes protected by an *"impressed current"* system.

An impressed current system uses *electronics* to monitor the state of underwater electrical currents, and impress a "reverse" current to neutralize the effects of electrolysis. The source of the current is usually the boat's battery.

Here, the underwater metals are bonded together and attached to the zinc anodes via an *electronic controller*. This controller continually senses the hull potential and compares it to a "reference anode." As needed, the controller adjusts the resistance of the connection to the zinc anode, thereby preventing over protection.

This kind of system is prone to all the same pitfalls of a bonded system, and further introduces the element of failure of the electronic control.

These devices need to be constantly monitored, to assure that they're still working.

In the event of an electronic failure which disconnects the zinc, the bonded together collection will begin use up the next piece of metal at the low end of the galvanic scale. This could be the propeller shaft, or the keel bolts...

In this case, we have hung the fate of the underwater metals, and possibly the entire boat, on the ever changing condition of our ship-board batteries; on the assumption that they will remain charged; on the assumption that the electronic impressed current gizmo that is monitoring the state of the underwater metals is actually functioning; that the gizmo was installed correctly to begin with; and that there are no parts of the bonded together collection of metals which have become separated from the system.

Impressed current systems are the subject of considerable debate. The vast majority of what is written or said in favor of these systems comes from the people selling the equipment—people who obviously have something to gain if you want one.

The fact is that an impressed current corrosion control system must be set up *perfectly* to work right; must be constantly monitored to assure that nothing goes wrong with the electronics; the connections; the electrical supply; the monitoring system; the warning system; the ship wiring; the ship-to-shore wiring, and so on. Unless we're willing to baby-sit the whole thing, it is worse than useless, since we will very likely have the false impression that it is working correctly.

Impressed current systems may find some use on very large vessels which have a full time crew who are trained to maintain the systems and who can monitor them continually. The average boat definitely does not fit that description!

Protection measures of *all* kinds are quite often destroyed by faulty marine wiring, both on board and in the marina.

If we mistakenly hook up an impressed current system on our boat *backwards*, it will actively protect everything else in the marina, using our boat's underwater metal as though it is a giant sacrificial zinc!

An impressed current system can not be recommended for a wooden boat, due to the formation of alkaline conditions under all the cathodic metal fittings, and the resulting destruction of the surrounding wood.

A further caution should be kept in mind regarding impressed current systems: We may become victims of one, even though we do not have one aboard our boat!

If we are in the "current field" in the water created by an impressed current system aboard another boat, or near metal pilings or other structures being protected by an impressed current system, our bonding wires may become the path of least resistance for the "stray current" created by the system.

Here, the metal on one side of our boat will be protected at the expense of the metal on the other side, as the current passes through.

All the cautions about bonding on boats of different construction materials apply equally to impressed current systems.

Some Notes Specific to Metal Boats

Aluminum

No small number of aluminum boats have been completely ruined by the incorrect installation of an *impressed current* system, or by one which has begun to malfunction.

As has been mentioned, aluminum is not able to tolerate being *over* protected. If an aluminum boat or any other type of boat with an aluminum outdrive gets *over* protected, the hull will become too cathodic; a charge that is too positive will have been created.

If overprotected, aluminum will corrode rapidly due to the formation of alkaline conditions next to the metal wherever there is insufficient flow to renew the natural Ph of the water.

The alkaline conditions created by overprotection can soften and blister any semi-porous paint job, creating an even more alkaline condition next to the metal under the partially intact paint.

It is for this same reason that magnesium anodes can not be recommended for an aluminum boat in salt water: the result is over-protection.

With regard to aluminum vessels and other vessels with aluminum out drives, the ABYC states:

" Aluminum vessels shall have a protective paint coating that provides a high resistance barrier between the aluminum and the water. Galvanically incompatible anti-fouling coatings shall not be used. Aluminum hulls shall be protected with sacrificial anodes mounted on the hull."

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

Steel

The ABYC does not invoke the same cautions with regard to *impressed current* systems aboard a steel vessel as with an aluminum vessel, as the danger of overprotection is not so severe. Still there is the danger of failure or malfunction of the impressed current system.

It is unlikely that an impressed current system on any small steel vessel will be satisfactory, as any such system will require constant monitoring.

The cautions we have observed with regard to bonding, lightning, shore power, etc. all apply.

Any Metal Vessel

The ABYC recommends that: *"All metal hull vessels utilizing shore power shall have an installed hull potential meter and reference electrode. Hull potential meters are also recommended for all metal hull vessels that remain in the water for extended periods."*

"Underwater fittings, propeller shafts, propellers, and rudders fabricated of bronze or other metal alloys more noble then the hull material shall be electrically insulated from metallic contact with the hull and from internal metallic piping."

A marine grade *Isolation Transformer* should be installed on *any* vessel on which AC shore power is brought aboard.

A battery charger, or charger-inverter should be a true marine type having an internal *isolation transformer.*

The ABYC *presumes* that the metal hull itself will be bonded to the boat's DC negative bus bar via an attachment point on the engine, and therefore that the hull will be bonded to the other underwater metals which participate in the bonding system.

*Many metal boat builders choose instead to keep the hull completely isolated from the other underwater metals; to provide zincs for the hull; to protect other underwater metals separately with their own zinc anodes; and to do **without** a bonding system, per se.*

Welding Power Connections

The AWS Guide For Aluminum Hull Welding explains the correct way to make welding power lead connections to prevent electrolytic corrosion of a hull that's in the water.

The arc welding machine should be put aboard the boat being welded. The welding ground lead should be connected directly to the area of the welding being done. If the ground is connected some distance from the work being done, some current may flow through the water along-side the vessel.

A welding machine should be set up to avoid passing a current through the water to ground. The machine set up on one boat, and grounded to it should not be used to perform welding on another boat.

A welding ground lead should not be connected to a shoreside, or shore-power ground of any kind. Cables should be kept out of the water. It is essential that no welding current flows through the sea water to or away from the metal hull.

It is not recommended to weld on two ships simultaneously from the same welding machine, as both hulls would then be grounded to the same machine and any welding on one hull would allow a circuit to be completed through the other hull as well.

Cables should be of adequate size for the work being done, and all connections clean and tight.

Further Reading on Bonding and Electrical Wiring

Boatowners' Illustrated Handbook of Wiring, by Charlie Wing
International Marine, Camden, Maine

The 12 Volt Doctor's Practical Handbook, by Edgar J. Beyn
C. Plath, Annapolis, Maryland

The 12 Volt Bible for Boats, by Miner Brotherton
International Marine, Camden, Maine

Boatowner's Mechanical and Electrical Manual, by Nigel Calder
International Marine, Camden, Maine

Metal Corrosion in Boats, Second Edition, by Nigel Warren
International Marine, Camden, Maine

ABYC Standards and Recommended Practices for Small Craft,
ABYC, 3069 Solomons's Island Road, Edgewater, MD 21037

The first two books have the most to say about corrosion and bonding.
The other three books fill in a few areas not covered in the first two.
The ABYC book of standards may be available in your library—it's worth studying!

Preventing Galvanic Corrosion

* *Use metals below the water that are as close to each other as possible on the galvanic scale. Don't mix metals.*

* *Fasteners must always be more noble than the fitting they're used on.*

* *With a simple boat, or a wood boat of any kind, strictly for the sake of corrosion protection, it will be best to electrically isolate all underwater metal fittings from each other, and then.....*

* *Put a zinc on it. But don't put too much zinc on it! Weld the zinc on if possible, or bolt the zinc directly to the piece.*

* *Never paint a zinc anode!*

* *Painting the cathodic metals is beneficial.*

* *Never use graphite-bearing lubricants. Graphite is noble to almost everything!*

* *When bringing AC shore power aboard, it should always first pass through a true marine grade isolation transformer.*

* *Battery chargers must be an isolation transformer type.*

* *Use bonding if necessary, if you have a highly complicated electrical system, in order to reduce the electrical shock hazard.*

* *Do everything possible to avoid stray currents in the water, and to prevent them aboard.*

A few notes regarding the ABYC (American Boat and Yacht Council) standards are in order: The ABYC standard is not law. The ABYC states the following with regard to the use of the ABYC guidelines:

"All technical reports, practices and standards are advisory only. They are believed to represent, as of the date of publication, the consensus of knowledgeable persons, currently active in the field of small craft, on performance objectives which contribute to small boat safety. Their use is voluntary."

"As far as is practicable, these voluntary technical practices and engineering standards are stated in terms of performance and are not intended to preclude attainment of desired results by other means. These standards are of general applicability, and there may be instances in which the particular use, configuration , or other characteristics of a specific boat, or classes of boats, may result in special requirements differing from the generally applicable standards."

The ABYC standards are developed via a process of ABYC Technical Committee development; review by the ABYC Board of Directors; public review and feedback to the ABYC Technical Director; re-submission to the Technical Committee that authored the proposed standard; re-review by the ABYC Technical Board and the ABYC Board of Directors; and finally the proposed standard is published.

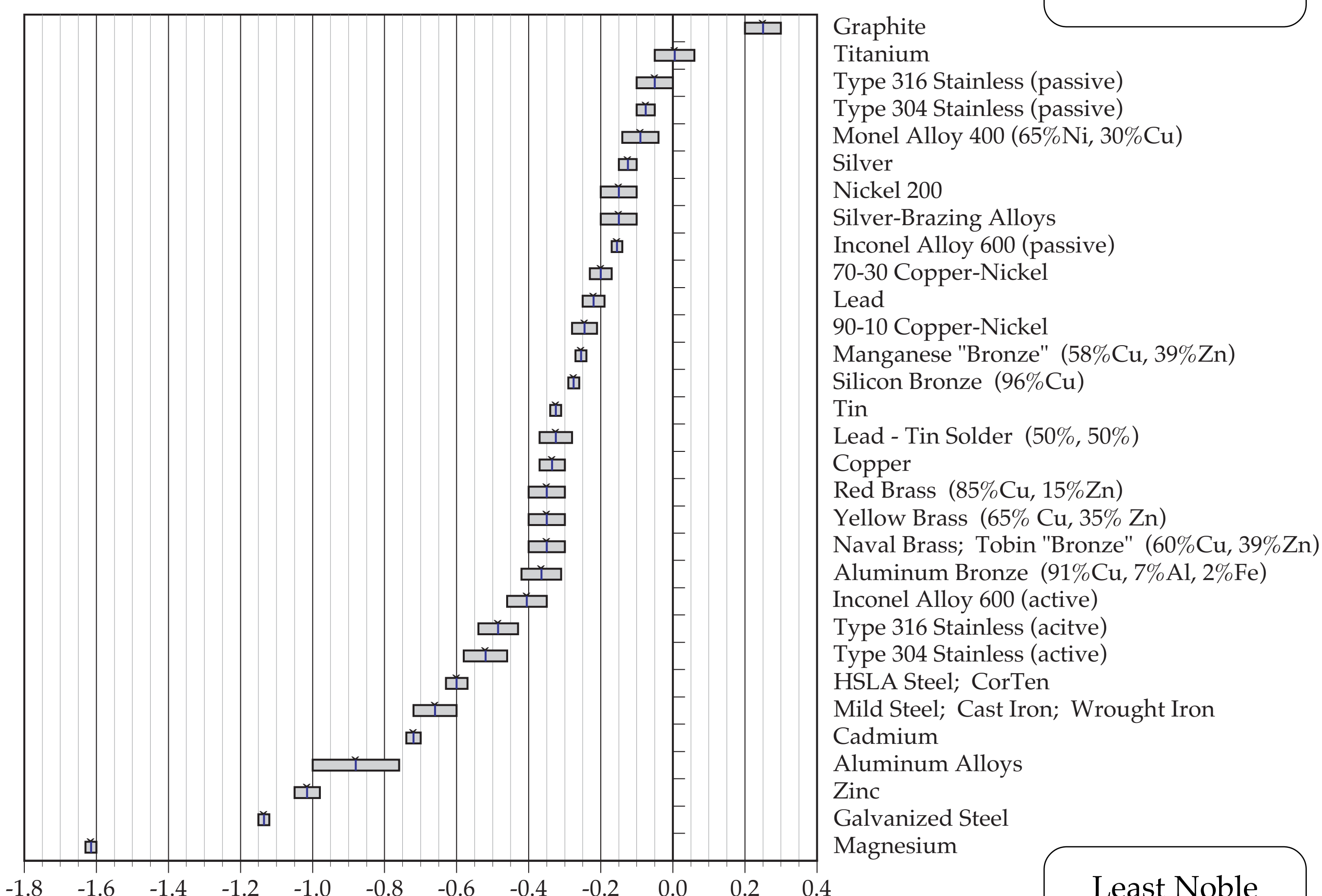
This process is quite rigorous. Nevertheless, as noted above, the ABYC standards are developed as a consensus among professionals in the boating industry, and are intentionally general in their applicability. The standards are expressed as minimums: *"They define the floors; the place to begin toward building a better, safer, or best way."*

Metal Boat Quarterly

The Galvanic Series

Average Voltage in Seawater

Most Noble
Cathodic



Least Noble
Anodic

Maximum Recommended Voltage Difference is 0.2 Volts

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