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Marine Grounding Systems

This is a revision of an article that was originally published in Practical Sailor. The author, Stan Honey, is a renowned sailor, navigator, and electrical engineer.

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> **ground** *n.* **12.** *Electricity* **A.** A large conducting body, such as the earth or an electric circuit connected to the earth, used as an arbitrary zero of potential.

In a normal house on land, grounding is simple. The grounding system includes the green grounding wire in the AC wiring system and serves the purpose of preventing shocks or electrocution. The ground connection is usually made by clamping to a metal water pipe, foundation rebar, or by driving long copper rods into the ground.

On a boat, things are considerably more complicated. In addition to the AC ground, we need DC ground or return lines, a lightning ground, and a RF ground or “counterpoise” for the radio antennas. Our first thought might be to simply make ground connections to metal thru-hulls, the propeller shaft, or other underwater metal. This underwater metal will be grounded by connection to the seawater to serve as our “water pipe”. Unfortunately, connections between these systems and underwater metal can give rise to electrolytic and galvanic corrosion problems. This article will discuss the requirements of each system, resolve the contradictions between the systems and propose a solution for a complete marine grounding system.

DC Ground

Every light or electrical device should be wired with its own DC return wire. Never use the mast, engine, or other metal object as part of the return circuit. The DC returns of all branch circuits should be tied to the negative bus of the DC distribution panel. In turn, the negative bus of the DC distribution panel should be connected to the engine negative terminal or its bus. The battery negative is also connected to the engine negative terminal or its bus. The key factor here is that the yacht's electrical system is connected to seawater ground at one point only, via the engine negative terminal or its bus. See figure one.

AC Ground

The best approach to avoid electrolytic corrosion induced via the green wire to the dock is an isolation transformer. A lighter and cheaper alternative is to install a Galvanic Isolator in the green wire, between the shore power cord socket on your boat, and the boat's AC panel. Also connect the grounding conductor (green) of the boat’s AC panel directly to the engine negative terminal or its bus. This meets ABYC recommendations.

Install an ELCI (Equipment Leakage Current Interrupter) within 10 feet of the shore power plug on the boat.

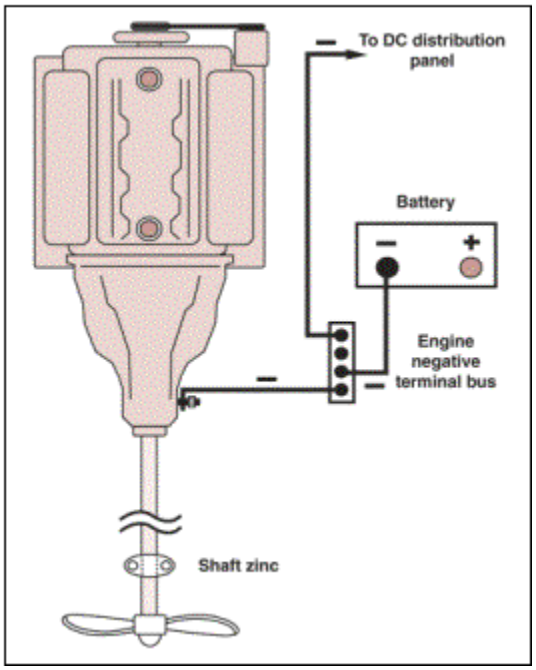
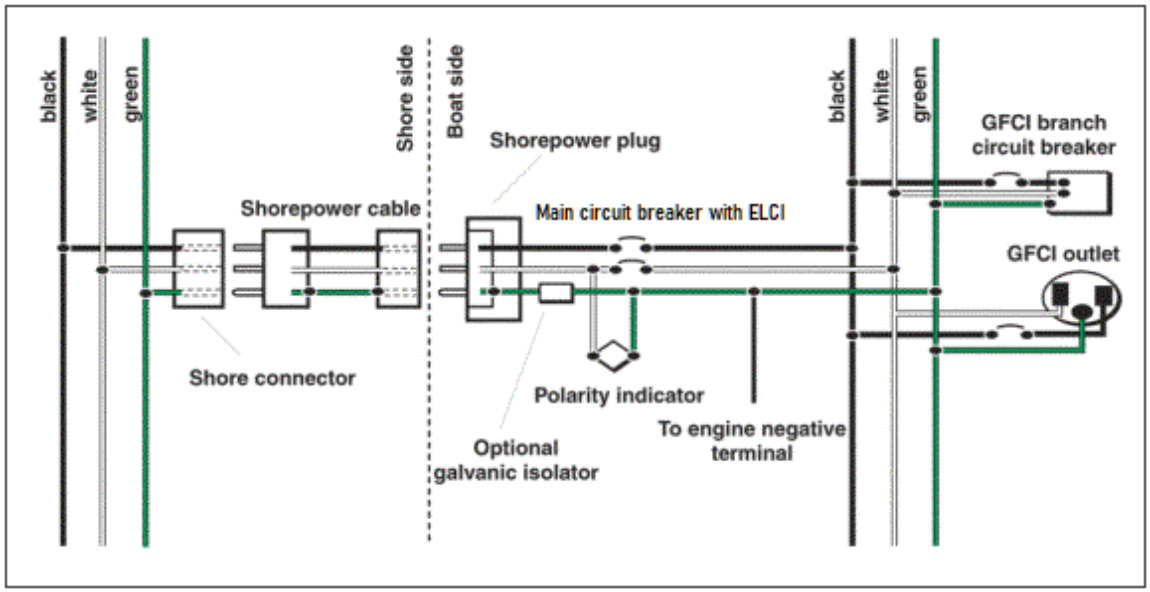


Figure 1. The boats electrical system should be connected to seawater at one point only, via the engine negative terminal or its bus.



An ELCI must be installed within 10 feet of the shore power plug. Ground fault circuit interrupters (GFCI) should be installed in each AC circuit. An ELCI or GFCI will disconnect power in the presence of ground currents, helping prevent an electrocution.

Lightning Grounds
Connect a 4 AWG battery cable from the base of your aluminum or carbon mast to the nearest keel bolt from external ballast. If you have internal ballast, you should install a lightning ground plate. One square foot is recommended for use in salt water; fresh water requires more. Do not rely on a thru-hull or a Dynaplate for use as a lightning ground.

Run additional 6 AWG wires from your keel bolt or ground plate to the upper shroud chainplates and to your headstay and backstay chainplates. If the backstay is interrupted with antenna insulators for your SSB it does not need to be grounded. Have each of the cables that are used for lightning ground wires lead as directly as possible to the same keel bolt, with any necessary bends being smooth and gradual.

Given that you have grounded your mast solidly to the ocean, your mast will be at the same electric potential as the ocean. There is no chance that you can dissipate the charge between the ocean and the atmosphere, so don't bother with a “bottle brush” static dissipater at the masthead. Static discharge wicks work well on aircraft to bring the aircraft to the charge of the surrounding air but don’t work on boats that are grounded to the ocean.

SSB Ground
Mount your automatic tuner as close to the backstay as possible, preferably just under the after deck. Run copper ground tape from the tuner and HF/SSB radio to the stern pulpit/lifelines, to the engine, and to a keel bolt. If the builder of your yacht had the foresight to bond into the hull a length of copper tape or an area of copper mesh, be sure to run a copper ground tape to this as well. Sintered bronze ground plates (e.g. Dynaplates) can be used as radio grounds in situations where the ballast or engine is unavailable or awkward to connect. If the ballast, engine, and lifelines are available, they generally make a high-performance ground.

Bonding and Electrolytic Corrosion Caused by DC current in the water
Do not bond any thru-hulls or other immersed metal that can be electrically isolated. Specifically, keep

your metal keel/ballast, your metal rudder shaft, your engine/prop, and thru-hulls electrically isolated, from each other, and from the engine.

It's worth understanding the reason. In some marinas there are DC electric currents running through the water caused by boats that are improperly wired. If your bits of immersed metal are bonded, the DC electric current that is passing through the water will take the lower resistance path offered by your boat in preference to the water near your boat, and the current will flow into one of your bits of metal, through your bonding wires, and then out another bit of metal. The anodic bit of metal or thru-hull that has the misfortune to be on the "out current" side of the current running through your bonding system will also become "out metal" and will be damaged.

Your zinc is only intended to protect against the modest galvanic potentials and therefore currents that are caused by the dissimilar metals that are immersed and electrically connected on your own boat. Your zinc is incapable of supplying enough galvanic potential to protect against substantial DC currents that may be flowing in the water.

Zincs and Protection from Galvanic Corrosion

Use zincs to protect against the galvanic currents that are set up by dissimilar metals on your boat that are immersed and that are in electric contact with one another. The most common example is your bronze propeller on a stainless shaft. The best protection is to put a zinc right on the shaft next to the propeller, or a zinc on the propeller nut. An isolated bronze thru-hull doesn't need protection so long as it is not in electrical contact with another piece of immersed dissimilar metal. If electrically isolated, high quality marine bronze is electrochemically stable in seawater. Nothing good can come from connecting wires to it. Note that bronze fittings and cannon from ancient shipwrecks last essentially forever underwater.

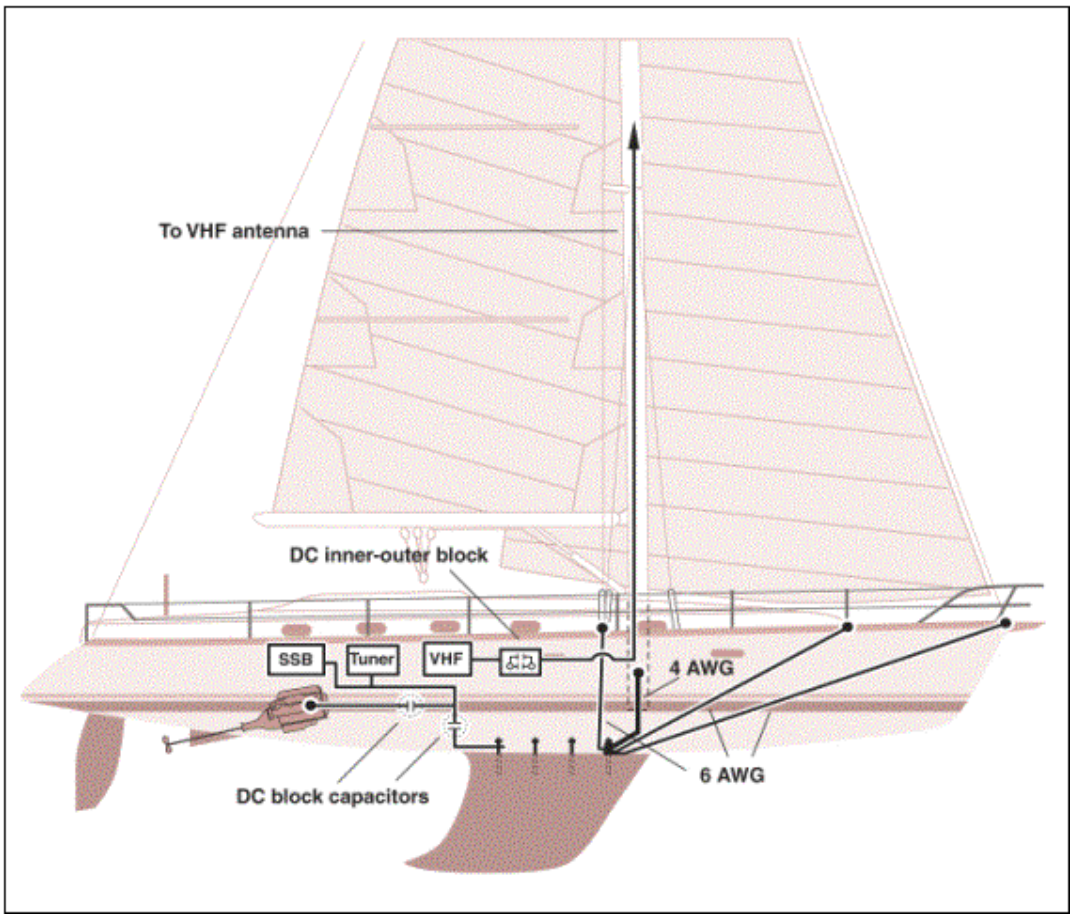


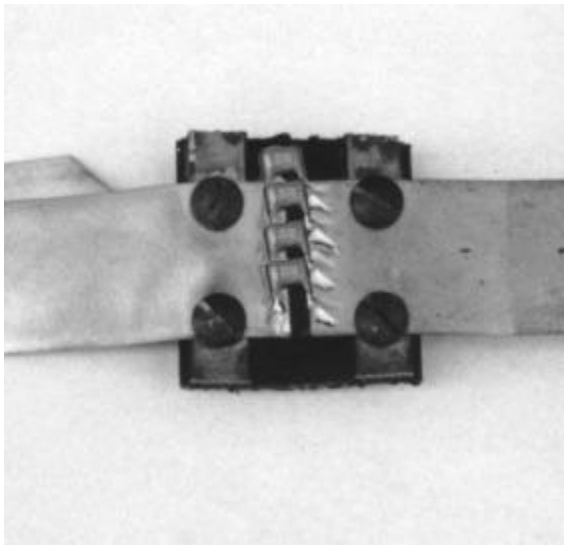
Figure 2. Lightning conductors are shown running from the external keel to the mast and standing rigging. Those conductors reduce damage from a lightning strike. Note that all RF ground connections to the keel are DC-blocked with capacitors to allow an RF ground but no DC current.

Stainless steel is a special case. Generally, it is a bad idea to use stainless steel underwater because it can pit. When it pits the "nobility" of the metal changes locally, and you end up with tiny galvanic couples that are made up of different parts of the same piece of metal and the pits grow deeper. One school of thought suggests that if you must use stainless steel underwater (e.g., you need its strength), then you should connect a nearby, immersed zinc to it; this protects the stainless steel from itself, reducing the rate of pitting. The electrochemistry of this assertion is compelling enough to recommend that you protect a stainless-steel rudder shaft with a zinc. This may be done by mounting a zinc on the hull near the rudder shaft, and electrically connect it (inside the hull) to the stainless rudder shaft. For the reasons described above, ensure that your metal rudder shaft is not electrically connected to anything else. Your stainless-steel propeller shaft will be protected from itself, by the same shaft zinc that protects the propeller from the stainless-steel shaft. In both cases the pits, if they appear, will appear where the stainless steel is not exposed to the water. Trouble areas are in the cutlass bearing, inside the rudder bearing, and any wet area just inside the top of the rudder.

Keep your metal keel/ballast electrically isolated from all other bits of metal. If you have an external iron or steel keel, however, mount a zinc directly on it to reduce the rate of corrosion. Leave lead keels/ballast isolated.

Inconsistencies in the Ground Rules

So now, you are annoyed with the inconsistencies. We said to leave all bits of immersed metal electrically isolated when we described electrolytic corrosion caused by DC currents running through the water, but then we said to connect wires and copper tape to your keel and engine for lightning and RF grounds. So, what to do?



To avoid making another DC ground to the engine via the HF/SSB radio copper ground strip, fasten the copper tape securely to an insulating piece of phenolic or to a terminal strip, cut a 1/10" gap across the tape, and solder several 0.15 uF ceramic capacitors across the gap.

RF ground: The RF ground needs to be a ground for RF signals only. It does not need to conduct DC, and as described in "Bonding and Electrolytic Corrosion..." above, you do not want to connect a DC ground connection to your keel.

The solution is to find a dry secure place along each of the copper RF ground tapes that run from your SSB tuner to your engine and to your keel. Fasten the tape securely to an insulating piece of G10 or to a terminal strip, cut a 1/10-inch gap across the tape, and solder several 0.15uF ceramic capacitors across the gap. These capacitors will be transparent to the RF, which will be happily grounded by the ground tape system, but they will block any DC currents from running through the RF ground system and will avoid any resulting susceptibility to electrolytic corrosion from DC current in the water. It is worth selecting the capacitors carefully because they may carry a significant amount of RF current. An acceptable choice of capacitors is listed at the end of this article.

Lightning Ground. The lightning ground needs to be a direct connection to the keel or to a ground plate to handle currents due to lightning strikes. So how do we keep the keel or ground plate electrically isolated as required in "Bonding and Electrolytic Corrosion..." above?

The solution is to connect the keel or ground plate directly to the mast, but make sure the mast is not electrically connected to the boats DC ground system. If your steaming light, masthead light, tricolor, Windex light etc. are wired carefully and correctly, they each will have their own DC return wire; there should be no ground connection between their wiring and the mast itself. Make sure that this is the case. This should also be true of your masthead instruments. The unintended DC connection between mast and DC ground is typically made by the masthead VHF whip, which connects the shield of the coax to the bracket connected to the mast. That shield also connects to the VHF radio which is DC grounded by its power connection. The easiest solution is to insert what is called an "inner-outer DC block" into the coax. This RF device puts a capacitor in series with the center conductor, and another capacitor in series with the shield. This device is transparent to the VHF RF signals in the center conductor and shield but blocks any DC current in either the center conductor or shield. This device can be made by a good radio technician or purchased from radio supply houses. A few options are listed at the bottom of this article.

Note that VHF whips that are about 36 inches long and have a matching transformer in a small cylinder at the base do not require a ground/counterpoise connection to the mast. If you use one of these antennas, you can also break the DC connection by mounting the antenna on an insulator like a piece of G10. Shorter antennas like the 15- or 18-inch whips DO require a ground connection, i.e., the shield of the coax needs to be connected to your aluminum or carbon mast at the base of the whip. If you use one of these shorter antennas, and many race boats do, then you will need to install an inner-outer DC block in the coax to the radio or AIS antenna splitter to eliminate the undesirable DC connection between the mast and the electrical system ground.

Once the DC connection from the mast to the VHF is broken, check for any other connections with an ohmmeter, and straighten out any other wiring errors or unintended connections. If your metal fuel tank is also bonded to the lightning ground system (per ABYC) then make sure that it does not have DC connections either to the engine via the fuel line or to the electrical system via the fuel level sensor. A piece of approved rubber fuel hose in the fuel lines to the engine solves that connection, and a well-designed fuel level sensor will not make electrical contact with the tank.

When you're done, there will be heavy conductors running from the external keel or lightning ground plate to the mast, stays, and to the metal fuel tank, but there will be no DC connections from the keel or rig to the engine or to the yacht's electrical system. See figure 2.

Summary
By using capacitors to block DC connections in a few key areas, it is possible to have perfect ground systems for AC, DC, RF, lightning, and corrosion, and have a boat that is immune to stray DC currents that are traveling through the water caused by wiring problems on nearby boats.

In the old days, the technique of bonding everything together worked fine. The advantage of the "bond everything together" approach is that it makes your boat less sensitive to electrolytic corrosion that can result from faulty wiring on your own boat. The problem is, the "bond everything" approach leaves your boat defenseless to wiring errors in nearby boats, that cause DC currents to run through the water.

Today the technique of bonding everything together would still work fine if your boat spent all its time on the high seas, in remote anchorages, or in marinas in which all the nearby yachts are wired correctly. Having underwater metal bonded together in crowded marinas today, however, is asking for expensive trouble. As outlined above, it is avoidable trouble. It is possible, with careful wiring and a few capacitors, to have the best of all worlds, good RF and lightning grounds, ABYC approved DC and AC grounds, and security against electrolytic corrosion caused by DC currents in the water created by improperly wired nearby boats.

Sources:

Inner-Outer DC Blocks: The best choice is an IS-IE50LU-CO or IS-IE50LN-CO from Polyphaser, which also includes surge protection. They are no longer in production but are often available from Ebay. The units with a suffix U have standard SO239 connectors for conventional UHF marine coax connectors. The units with a suffix N have type N connectors for which adapters are widely available.

An Inmet 8048 is another alternative, also with N connectors, which can be purchased from various distributors.

Capacitors for use to block DC in SSB grounding tape: Digikey.com Ceramic capacitor, 0.15uF to 0.5 uF, 100v $0.90 each, examples include DigiKey part number: BC3212-ND, 445-175047-1-ND, or 445-174262-1-ND.