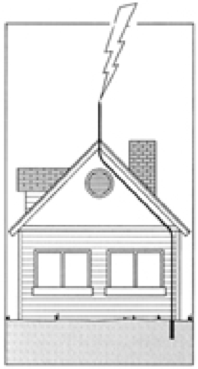
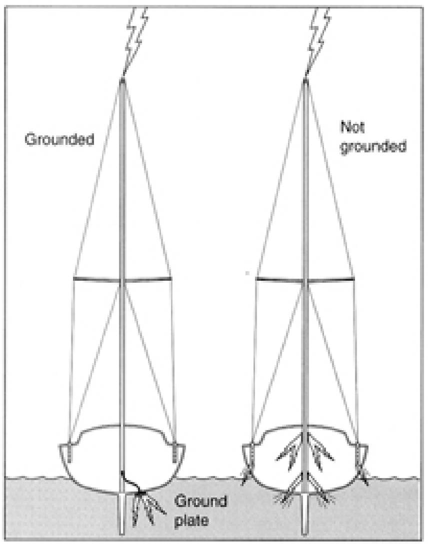
LIGHTNING PROTECTION



Despite the low risk, statistically, of being struck by lightning, getting caught out on the water in an electrical storm can be a frightening event. Fortunately, going below provides the crew substantial protection. It is the boat that is in greater peril. The best way to minimize the risk of damage is with a properly configured lightning-protection system.

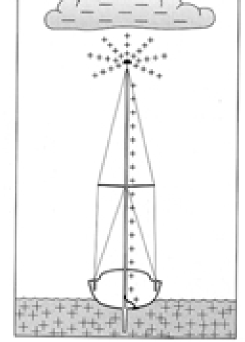
LIGHTNING ROD

The lightning rod was conceived in 1752 by Ben Franklin to protect wooden structures from fire by attracting the lightning strike and conducting it safely to ground. Lightning that would otherwise strike nearby finds the rod and its ground cable a lower resistance path to ground than another 100 feet (30 m) of air or the roof of a wooden building.



A sailboat with an aluminum mast already has a conductor sticking up in the air. The only thing necessary to make it a lightning rod is to give it a good ground, but the concept of *attracting* lightning makes some sailors reluctant to ground the mast. This logic is fundamentally flawed because, grounded or not, an aluminum mast is a better conductor than air and thus attractive to nearby lightning. When a hitchhiking strike reaches the bottom of an ungrounded mast, it generally fires through the hull to the water, often leaving holes big enough to sink an untended boat. It may also leap to other metal components in the boat, potentially passing through a crewmember.

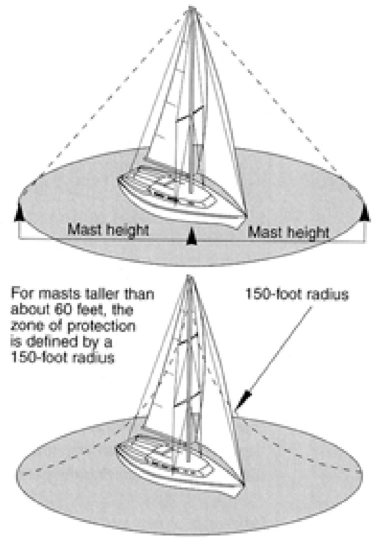
There is compelling evidence that grounding the mast lowers the incidence of damage or injury from a lightning strike, and no evidence that it increases the likelihood of being struck.

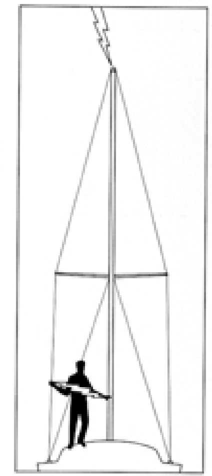


Some would have you believe that topping your mast with a pointed rod or a copper bottle brush will prevent a lightning strike. The theory is that the point or points of these static dissipators bleed off the charge from the grounded mast, thus lowering the voltage differential below what is required to "spark" lightning. Dissipators do bleed off static charge, but, to use a cliché, there is plenty more where that came from. Trying to bleed the ocean's charge into the air with a dissipator on your mast is like trying to lower the ocean's level with a soda straw. Ironically, because a dissipator ionizes the air around it, under some circumstances it could theoretically contribute to a lightning strike, although it is extremely doubtful that these units have any effect either way.

CONE OF PROTECTION

Intuitively, a mast sticking up would seem to put you at greater risk during an electrical storm, not unlike standing beneath the only tree on a golf course. However, powerboaters are statistically at much greater personal risk. If your mast is grounded, it is actually your savior. When the mast is closer than the ground, lightning tends to divert to it. This results in a cone-shaped area that is essentially protected from lightning. This area is known as the cone of protection. It has a height and radius approximately equal to the mast height.

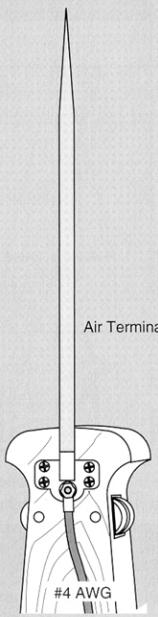




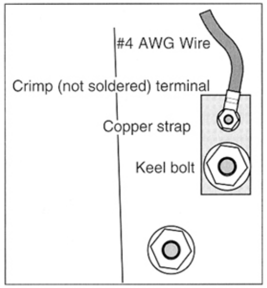
As long as the boat is entirely within the cone, there is little risk of anyone aboard being struck directly. However, you are still at risk if you are touching metal, and especially if you are bridging two metal components—the wheel and a stanchion, for example. And if the mast is poorly grounded, *side flashes*—a leap from the mast to other parts of the boat—can also cause injury. Even with a good ground, it is wise to stay well away from the mast during an electrical storm.

WOODEN MASTS

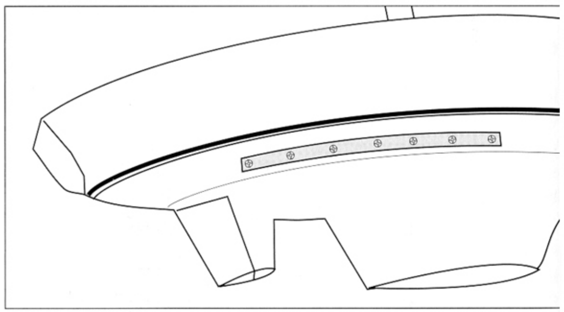
IF YOUR BOAT has a wooden mast, you need a metal lightning rod extending above everything at the masthead by at least 6 inches (15 cm) and connected to ground with #4 AWG wire. Without the metal rod, wooden masts struck by lightning tend to blow apart as the high resistance generates enough heat to instantly convert moisture in the wood to steam. A pointed dissipator, called an *air terminal*, makes a fine lightning rod.



GROUND

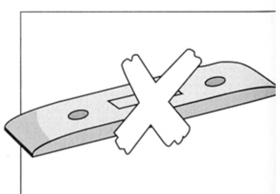


A metal keel makes an excellent ground for a lightning protection system. Bottom paint does not act as a significant barrier to a strike that has gotten this far in its quest to reach the water.

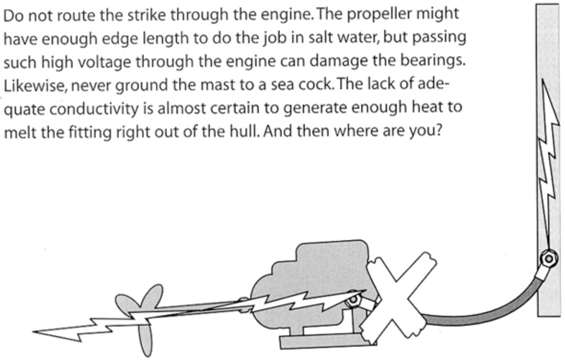


If your keel is encapsulated, a copper ground plate is needed. Lightning dissipates from the edge of the plate, so the perimeter of the plate should be at least 4 feet (1.2 m) if you sail in salt water. If there is any chance that you might sail in freshwater, the ground plate should have at least 24 feet (7.3 m) of sharp edge, usually accomplished by attaching a 12-foot (3.7 m) length of 1-inch (2.5 cm) copper strap fore and aft. Bronze bolts are preferred over stainless steel for bolting the plate to the hull and for cable attachment.

Sintered bronze plates designed for grounding radios are a poor choice for conducting lightning to ground. They are less effective than solid copper at dissipating the charge of a strike, and reportedly they tend to explode when heat from the strike turns trapped water to steam.



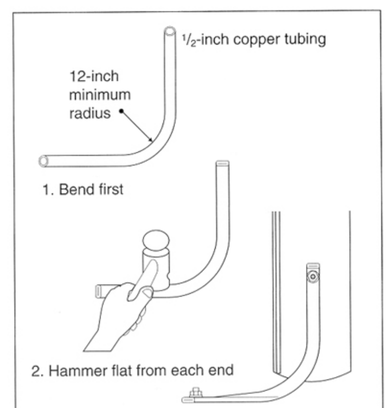
Do not route the strike through the engine. The propeller might have enough edge length to do the job in salt water, but passing such high voltage through the engine can damage the bearings. Likewise, never ground the mast to a sea cock. The lack of adequate conductivity is almost certain to generate enough heat to melt the fitting right out of the hull. And then where are you?



DIRECTING THE CHARGE

Connect the mast to the underwater ground with #4 AWG or larger cable. Because lightning travels on the surface of the conductor, solid copper strap is an even better choice. I like 1/2-inch copper tubing (water pipe), first radiused then flattened.

Lightning doesn't like to change direction, so conductors should lead as straight as possible to the ground. If a turn is required, give it a radius of 12 inches (30 cm) or more. Even if your mast sits directly on the keel, perfect the electrical connection with a copper strap from the mast to a keel bolt.



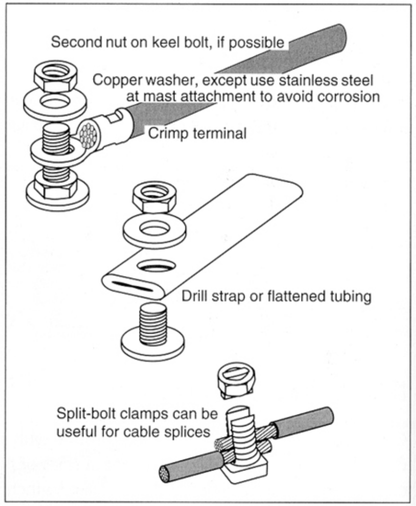
FRESHWATER SAILORS BEWARE

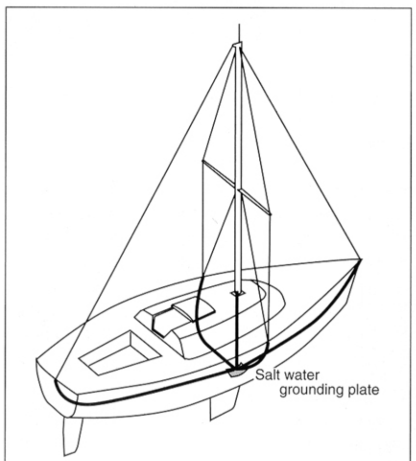
ACCORDING TO A Florida Sea Grant study, only one boat in ten struck by lightning in salt water suffered damage (excluding electronics) when the mast was grounded. In freshwater, six in ten suffered some kind of hull damage. Given the poorer conductivity of freshwater, this disparity is almost certainly due to inadequate grounding. To improve the odds, freshwater sailors should always choose a grounding plate to maximize the edge length. A 12-feet-by-1-inch plate is six times as effective at dissipating a strike as a square plate with the same area (1 square foot).

CONNECTIONS

The electrical connections must be perfect. The current flow in a lightning strike ranges from around 20,000 to nearly 400,000 amps, so a 1-ohm resistance can cause a 400,000-volt difference (I x R) from one side of the connection to the other. The result is enough heat to vaporize metal, and the resistance may encourage dangerous side flashes.

Drill attachment holes in the ends of copper strap. Cable connections should be made with mechanically attached terminals—solder will melt. Be sure all connections are clean and tight, and use copper washers to increase the contact area—except use stainless steel washers on the mast connection to minimize corrosion. Coat the assembled connection with an anti-corrosion spray, and disassemble and clean it at least once a year to make sure it stays resistance-free. Periodically check the resistance from the mast to the ground plate with your ohmmeter.





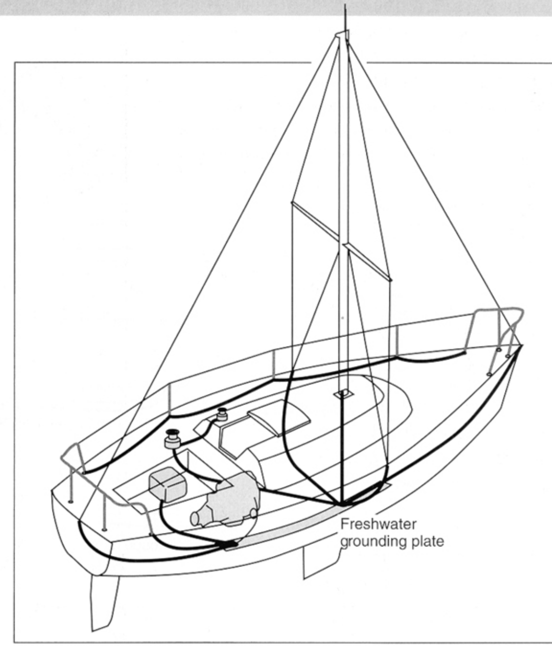
PARALLEL PATHS

Although an aluminum mast offers lower resistance than steel stays, a powerful strike may nevertheless induce current flow in stays and shrouds. To provide this current a safe path to ground, the chainplates should also be connected to the underwater ground. Here again, the route should be as direct as possible with only large radius changes of direction. You can use #6 AWG for these secondary grounding paths.

BONDING

The original idea behind bonding was to put all underwater fittings at the same potential to stop galvanic corrosion. Unfortunately, this type of bonding invites more-destructive stray-current corrosion. Bonding is still intended to put fittings at the same potential, but today the purpose is to prevent side flashes from voltage differences in the event of a lightning strike.

The rules for bonding are simple: bond all sizable metal components within 6 feet (1.8 m) of the mast or rigging to the mast ground, but do not bond any submerged metal (ground plate excepted).

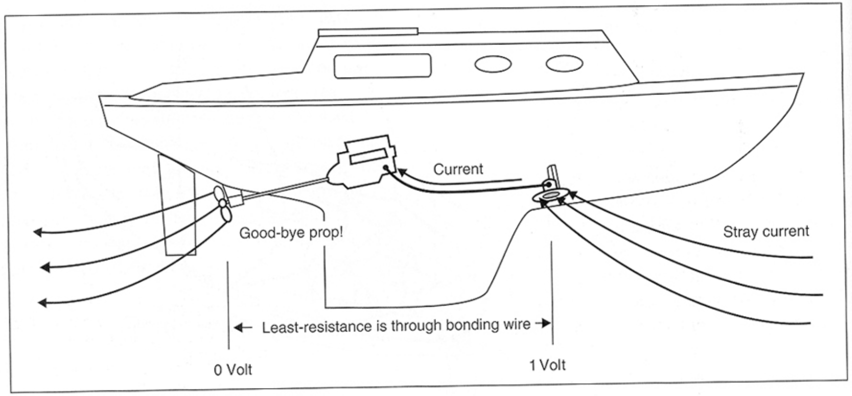


FOR LIGHTNING PROTECTION

During a lightning strike, when the mast has a potential of 30,000 volts and other metal components inside the boat are essentially at 0 volts, there is some risk of the lightning jumping to the lower potential. This is called a *side flash* and it is extremely dangerous to anyone in its path. To minimize this risk, give the charge a lower-resistance path by connecting all significant metal masses (e.g., tanks, stove, lifelines) within 6 feet (1.8 m) of the mast or rigging to the ground plate. Use #6 AWG wire (or larger), and connect each component to the ground with a dedicated wire.

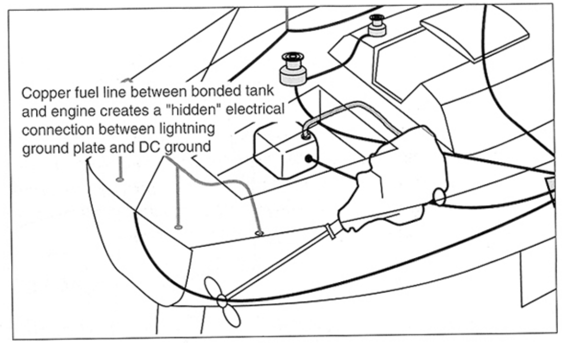
FOR CORROSION CONTROL

If underwater components are not galvanically identical, bonding them completes the circuit and *causes* corrosion (which must be controlled with zinc anodes). Bonding does protect underwater fittings from damage caused by onboard stray currents, but it invites damage from stray currents in the water, and "hot" marinas are today the rule rather than the exception. It is easy enough to avoid onboard stray currents with good wiring practices, but you have no control over stray currents in the water. *No good can come from bonding underwater metal components that are or could be otherwise isolated.*



ISOLATING

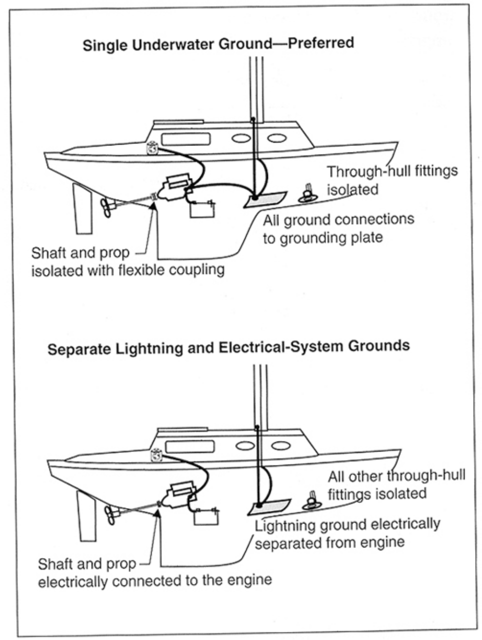
Metal through-hulls connected to rubber hose are already isolated. Likewise, the rudder shaft and/or fittings are normally isolated, but be sure components are not grounded some other way. For example, the rudder might be connected to the boat's central ground through steering cables and pedestal wiring. A fuel tank connected to the engine with metal fuel line is likewise electrically connected to the DC ground. In this latter case, bonding the tank for lightning protection provides a path for stray current to enter your boat at the ground plate and pass out at the prop (or vice versa).



Isolate bonded tanks by inserting a section of rubber hose in the fuel line. The propeller and shaft are easily isolated with a flexible coupling. (Note: A zinc collar is still required to protect the bronze prop if the shaft is steel.)

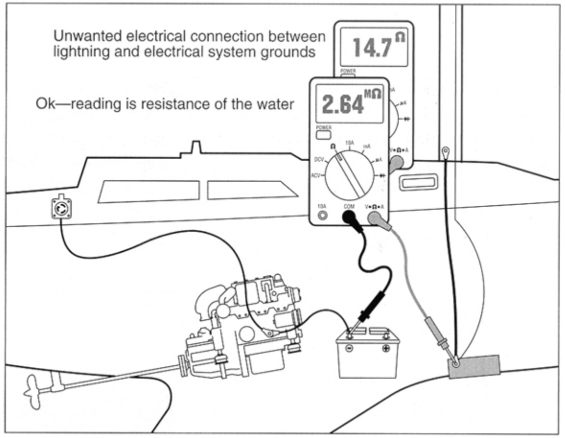
GROUNDING

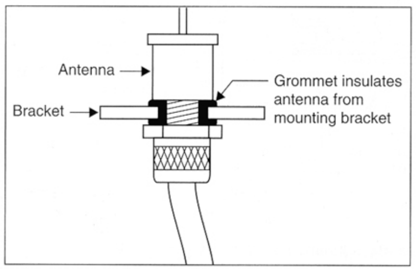
The general rule for corrosion control is to bond to a single underwater component. This eliminates any possibility of providing a circuit for stray current, and it also eliminates galvanic currents except between dissimilar metals in contact. The preferred configuration is to isolate the propeller shaft from the engine so the prop doesn't provide a ground, then use the lightning grounding plate for all ground connections. If the engine is not isolated, the necessity for ground near the base of the mast means you will have two bonded components in the water. Copper and bronze are close enough on the galvanic scale that significant galvanic corrosion is not likely, but stray current corrosion is a risk. The solution in this case is to keep the lightning ground electrically separated from the engine ground (for the DC and AC circuits).



TESTING FOR ISOLATION

Measure the resistance between the lightning ground terminal and the DC ground terminal. In salt water the meter should read around 200 kΩ per foot of underwater separation between the ground plate and the stern tube, about 2 MΩ per foot in freshwater. A low resistance reading reveals a connection between the two grounds. Disconnect one bonding cable at a time until the meter reading changes: the unwanted connection is through the just-disconnected component.





Often you will find that the connection is through the mast, usually due to contact between a masthead antenna bracket and the coax shield. You can break this connection by installing insulating grommets around the bracket mounting bolts or in the antenna-mount hole.

Radio equipment may also be grounded to the engine and other metal components in the boat. If it is also connected to the lightning ground plate—as it should be—this is another electrical connection between the lightning ground and the DC ground. We deal with this problem below.

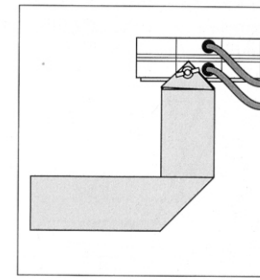
RF GROUND

SSB and ham radios need a good ground to provide the necessary counterpoise for transmission—like planting your feet to jump or throw. A good radio ground is a large mass of metal very close to but not necessarily touching seawater. This is usually accommodated by grounding the radio to the engine, other large metal components, and to the water through a ground plate. The lightning ground plate serves well.

RIBBON, NOT WIRE

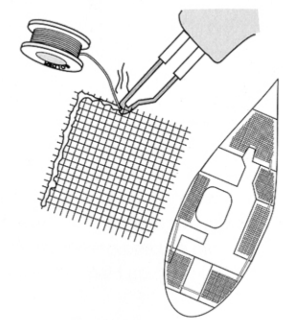
Radio grounds should be made with copper foil ribbon, not wire, because the current we want the conductor to carry is RF (radio frequency), not DC. RF currents travel on the surface of the conductor (lightning is also an RF event), so the more surface, the less the conductor impedes the RF current. This essentially means less of your radio's power is wasted in the ground system, so more is radiated from your antenna. That translates into longer range and clearer signals.

Use 3-inch-wide (7.6 cm) foil ribbon for the best RF ground connection. Fold the ends into a point for terminal attachment. Bend the foil around corners and obstacles as shown.



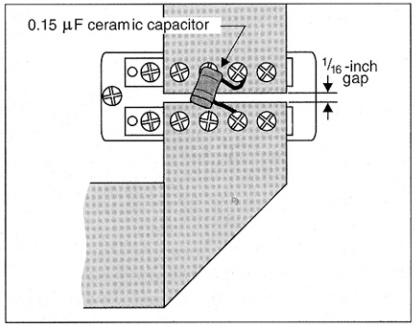
COPPER SCREEN

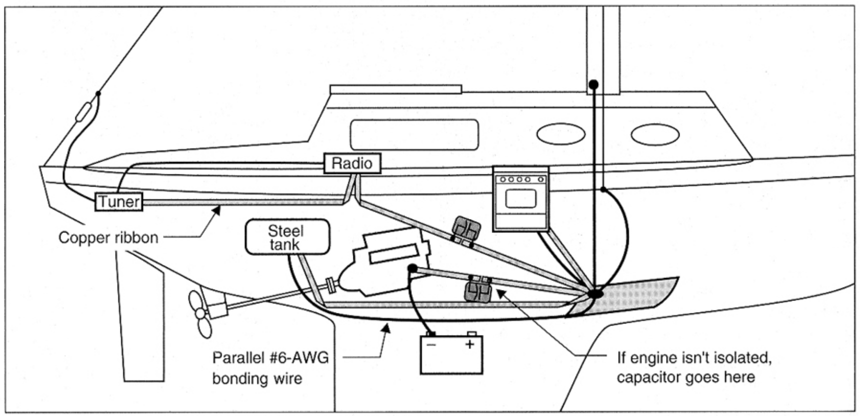
Today's automatic antenna tuners compensate for a less-than-perfect counterpoise, so few boats bother with "building" a counterpoise, relying instead on the metal masses already in the boat combined with a good "connection" to the ocean. Still, for the best radio installation, about 100 square feet (9.3 m²) of copper screening inside the hull can avoid a lot of transmission problems. Hardware stores sell copper screening for windows inexpensively, and it is easy to install in below-the-waterline lockers, covered with a layer of lightweight fiberglass cloth. However, because the wire in the screening is just woven together, corrosion may eventually degrade their electrical contact. Soldering two edges before installation avoids this problem. Join the various screen panels with 3-inch (7.6 cm) foil tape, also soldered.



STOPPING DIRECT CURRENT

Not only does the RF ground system not need to carry DC, but we don't want it to because that allows the flow of destructive stray current. This is easily prevented by cutting the foil ribbon leading to the ground plate and installing the ends on a double bus circuit block, leaving a gap of about $^{1}/_{16}$ inch. Now bridge the gap with a 0.15μF ceramic capacitor (available for under a buck from most electronics suppliers). You can solder the capacitor to the ribbon, or if the leads are long enough, simply capture them under an opposing pair of the terminal screws. The capacitor passes RF current but blocks DC.





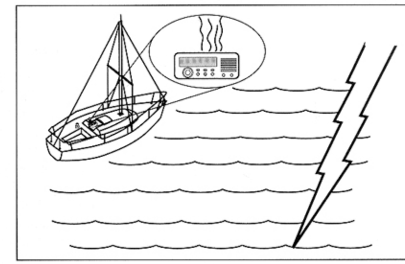
If other metal components bonded for lightning protection are also connected to the RF ground system, disconnect RF connections from the components to the radio and make them to the ground plate. Configured this way, a single capacitor will separate the DC ground from the RF ground. If your foil is thick enough—at least 9 mils (0.009 inches)—you can substitute the ribbon for the wire; otherwise connect the ribbon parallel to the #6 AWG bonding wire.

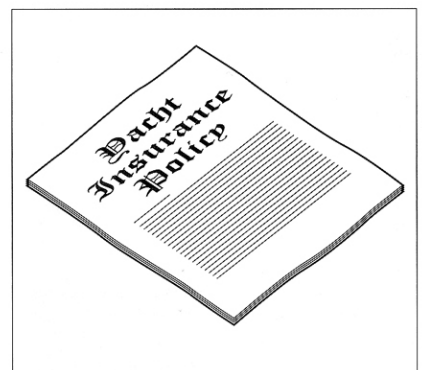
LIGHTNING AND ELECTRONICS

While a lightning-protection system can nearly eliminate personal risk and significantly reduce damage to the boat, it offers little if any protection for electronics. About half the boats struck by lightning experience damage to some or all of the electronics aboard.

THE FACTS

Like any moving current, lightning can induce current to flow in any conductor it passes near. Considering the enormous power of lightning, "near" might well be 100 yards or more. The closer and more powerful the strike, the more current that is induced. Such currents often exceed the capacity of the tiny, low-current components inside most electronics. Since electronics need not be connected to anything to be affected, disconnecting them does not prevent damage.





PROTECTIVE MEASURES

A surge protector in the supply line may provide protection for a limited range of lightning-induced power spikes. Twist all electronics power leads so induced currents will tend to cancel. All bonding wires should cross electrical wiring at 90 degrees to minimize the inductive effect of current flowing to ground. Grounding the chassis—the metal housing—protects internal circuits and components from directly induced currents. But despite every protective effort, if your boat is struck, your electronics have only one chance in two of not becoming toast. So the best protective measure is keeping your insurance paid up.