When Lightning Strikes the Digital Boat

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Ensuring passenger safety in the event of a lightning strike has become far more complicated in the age of networked electronics and onboard control systems.

by James Cote

Above—*Lightning strikes and the damage they cause are unpredictable, but onboard electronics and control systems are particularly vulnerable. The wiring harness on this diesel auxiliary was destroyed when the catamaran it was on was struck by lightning.*

More than a decade of astonishing advances in marine electronics, connectivity, and digital communication has given today's boat owner previously unthinkable capacities to electronically monitor and control onboard systems and functions, ranging from engines, steering, stabilizers, and navigation to lighting, air-conditioning, security cameras, safety systems, water supply, and waste disposal. As cutting-edge electronic and digital communication technology has improved the operation, safety, and comfort of recreational boats, the wealth of new tools has simultaneously rendered many modern boaters completely dependent on digital display touch-screens, unseen electronic black boxes, and complex behind-the-scenes data/communication networks for the practical operation and basic seaworthiness of their vessels. This trend is accelerating (see the Rovings item “A Faster Network Standard,” in *Professional BoatBuilder* No. 190).

This complexity increases a boat’s fragility and is amplified by centralized data-transfer protocols, where every monitoring system, control system, power source, distribution panel, and electrical load is interconnected and controlled through now-ubiquitous touch-screen panels. These systems are vulnerable to even relatively minor lightning strikes, which could disable the underlying Ethernet or CAN bus networks, leaving an otherwise seaworthy vessel paralyzed, blind, deaf, and dumb, with her crew vulnerable, powerless, and at the mercy of the sea.

Now that we’ve created these highly complex cutting-edge boats that are quite vulnerable to lightning damage, how do we best protect them?

Let’s start by acknowledging that while no marine lightning protection system is perfect, boat owners can do more than just hope for the best, count on a timely rescue, and/or enhance the insurance coverage (now is always a good time to review your policy). A combination of old-school lightning protection methods, relatively new electronic overvoltage-protection devices, sensible wireless network practices, and conventional good seamanship can go a long way toward reducing the potentially crippling impact of a lightning strike on the systems of a modern connected boat.

Many of my colleagues say lightning strikes cannot be prevented, and lightning damage cannot be avoided. They are both right and wrong. A lightning strike cannot be prevented. If sufficient voltage is building in the atmosphere near your boat, she will be struck. However, with a properly designed and installed lightning protection system, most if not all the lightning energy can be diverted away from people, critical systems, and sensitive equipment.

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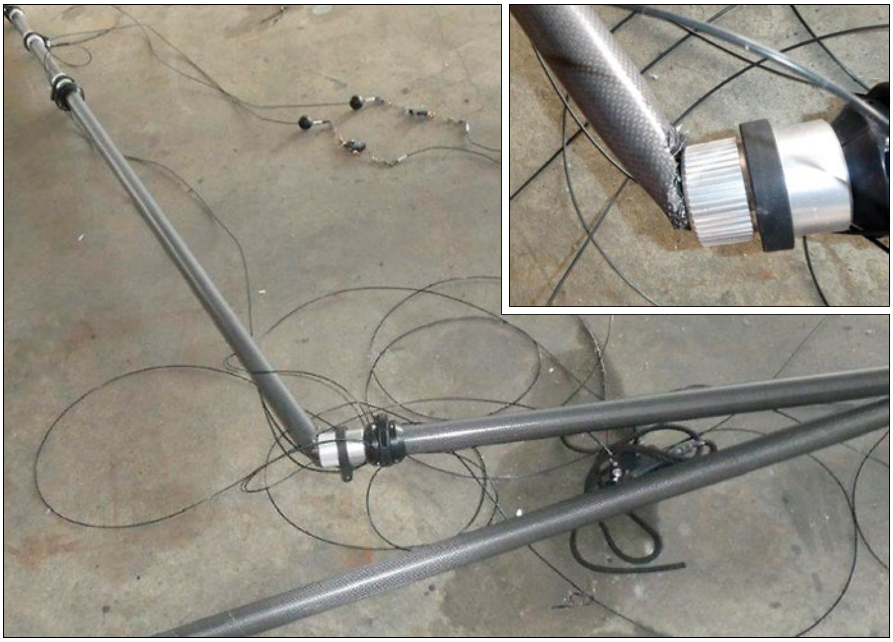
The clutter of navigation lights, VHF antennae, a loud hailer, radar, and satellite communications domes on this mast highlight how exposed the average modern yacht is to a lightning strike. Fortunately, this one also features a robust lightning rod installed higher than all the surrounding appendages.

Before discussing what constitutes a “properly designed and installed system,” we should clear up a common misconception. Although many marine insurance policies cover lightning damage to electronic and electrical gear (read your policy), the lightning protection systems as specified by the American Boat & Yacht Council (ABYC) and the National Fire Protection Association (NFPA) are not intended to protect such equipment. Indeed, ABYC and NFPA lightning protection tenets explicitly exclude protection of electronic and electrical equipment. For example, the ABYC “Lightning Protection Technical Information Report” (TE-4) states that its “primary objective is to decrease the risk to personnel and the risk of fire and sinking. Additional measures may be needed to harden electrical and electronics systems against lightning damage.” The NFPA “Standard for the Installation of Lightning Protection Systems” (NFPA 780) states that its purpose is the “safeguarding of persons and property from hazards arising from exposure to lightning” and “shall address lightning protection of the structure but not the equipment or installation requirements for electric generating, transmission and distribution.” So, in effect, if a lightning strike disables every system on board but the crew is not hurt, the boat is not on fire and does not sink, then the lightning protection system has worked perfectly.

The newest versions of the NFPA and ABYC standards both mention surge-protection devices (SPDs) as a means to protect electrical equipment from harmful overvoltage conditions including lightning-induced voltage spikes. SPDs are nonlinear, usually electronic semiconductor, devices used to clamp voltage surges. They have been around for a while and are almost always included in common 120V power strips, uninterruptible power supplies, household appliances, printers, etc. The most exciting advance in SPD technology for boaters is that the devices are now readily available for lower-voltage DC applications and in packages that can be easily retrofitted onto boats. Larger, higher-energy SPDs have also become available, as the National Electrical Code now requires them in new electrical-service-entrance installations. Expect to see more of these larger SPDs on docks and in marinas in the coming years.

Although lightning is a complicated phenomenon, basic lightning theory can be easily grasped by understanding a few simple concepts. For example, just as we can develop electrical static charges in our bodies by shuffling across a carpet, air masses can develop electrical static charges by shuffling through the atmosphere buffeted by updrafts, downdrafts, turbulence, hailstorms, and the like. Subsequently, a mass of air (e.g., a cloud) with an electrical charge can be suspended above the earth. Opposite charges attract, so the hovering charged cloud will pull oppositely charged electrical ions to the surface of the water directly under it. The force between these two masses of opposite electrical charges can be thought of as a sucking force working to bring the two masses together. If the two masses of charge are drawn close enough together, an electrical arcing event/high-discharge current occurs that neutralizes the voltage differential. It's like the arc between your finger and a nearby doorknob on a dry winter day but at much higher voltages.

If the voltage difference between the cloud and the water is insufficient to jump the air gap between them, then a lightning strike will not occur, just like the static charge from your finger will not arc to a doorknob from a foot (304mm) away. However, suppose your spouse or significant other is touching the doorknob while reaching over to give you a kiss? The spouse/other will bridge the gap between you and the doorknob and the static shock will be initiated (assuming your significant other is electrically conductive). Similarly, if an electrically conductive aluminum mast comes between the charged cloud and the oppositely charged water, the length of the air gap is reduced at that point, and the lightning current can now pass through the aluminum



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Left—*Carbon fiber appendages like this outrigger are conductive and just as vulnerable to lightning strikes as a wire antenna or mast.* ***Below***—*The wire coil is all that's left of this VHF antenna after it was struck by lightning.*

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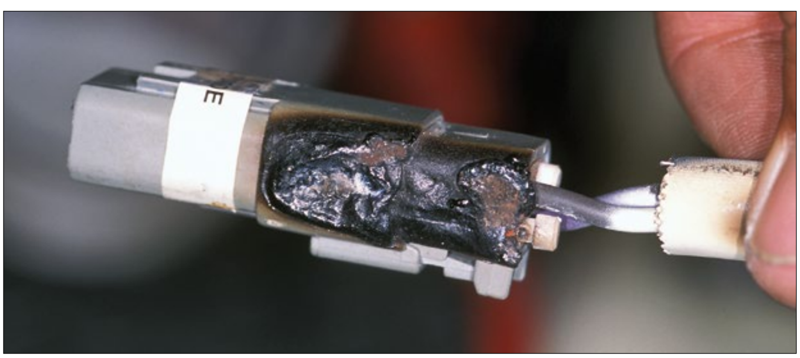

Above—*A melted wiring harness illustrates how vulnerable any electrical connection or component is to lightning damage if a boat is not well protected.* ***Right***—*This unpainted square copper plate on the hull bottom grounds the boat's lightning protection system and satisfies the ABYC guidelines.*

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shortcut (short circuit) to the water. A similar effect can occur with an aluminum fishing tower, outriggers, or VHF antenna connected with a vertical copper-wiring run, providing a short circuit path for the lightning current. The issue is compounded by the nature of the lightning strike itself. This question often arises: Is lightning direct current, alternating current, or radiofrequency (RF) energy? The answer is yes. A college professor once explained to me that your typical lightning bolt contains all frequencies from DC to daylight.

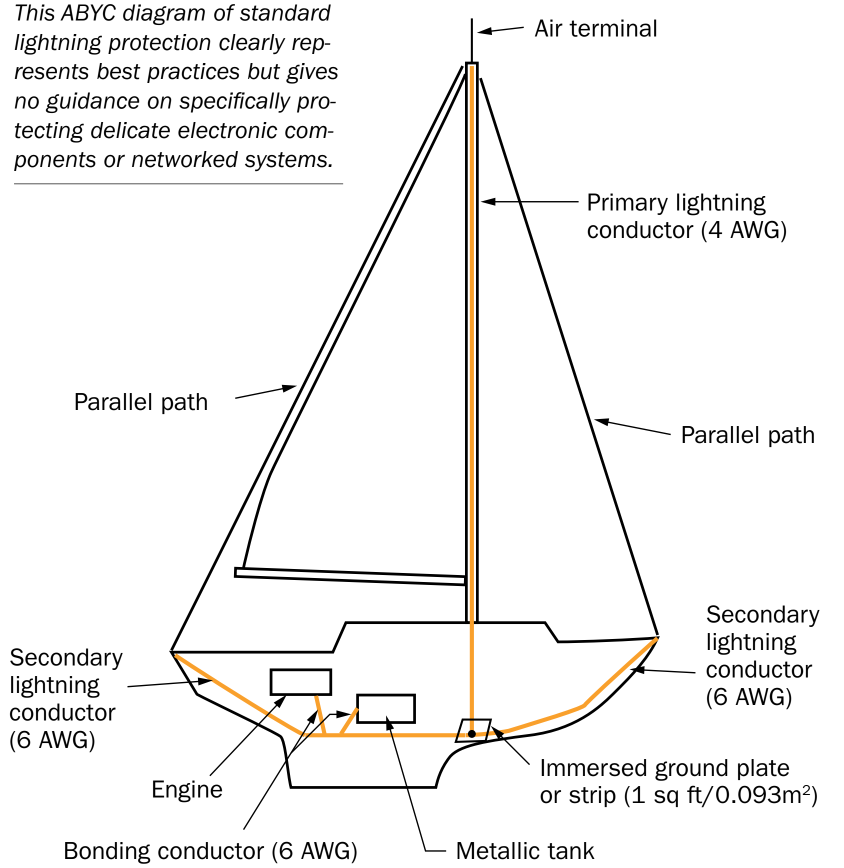
The key point in explaining how damage to so much equipment occurs during a lightning strike is that the wire to the VHF circuit, or a bonding wire to the tower, may not be able to carry all the lightning current being drawn through the boat to the water. Therefore, other parallel paths to earth can become energized, such as navigation light wiring, AC grounding conductors, metal pipework, CAN bus wiring, steering cables, etc. And if all the vessel's systems are connected to the same hub via data link cables, then dozens, if not hundreds, of parallel paths for the lightning current to ground can exist.

If all this sounds bleak, it is, especially if you are on an unprotected boat in a lightning-prone area. Those lightning protection naysayers who claim lightning strikes cannot be prevented are correct. As per ABYC TE-4: "When the conditions that create an electrical charge between clouds and the earth exist, there is nothing that can be done to prevent the lightning discharge. A boat can be struck in open water or while tied to the dock." There is no technology available today that has been proven to actively prevent a lightning strike, including those bottle brushes, fuzzy sticks, and metal umbrellas (if you have proof, please bring it to my attention). However, a properly designed, installed, and maintained lightning protection system can divert lightning energy away from people, combustibles, the hull, and even electronic equipment and wiring.

Conventional Lightning Protection

Old-school lightning protection theory hasn't really changed all that much since the days of Benjamin Franklin. He developed the lightning rod to prevent Farmer Brown's cow from being killed and his barn from burning down. Mr. Franklin's concept is easily transferred to marine applications. At its core the methodology is simple: install a metal lightning rod (air terminal) as the highest point on the structure, and connect heavy electrical wiring (down conductors) between the metal rod and a good grounding point. (See ABYC TE-4 or NFPA 780, Chapter 10 for details.) The air terminal attracts lightning to it rather than to your VHF antenna, and the down conductors provide an easy path for the lightning energy to get to earth, hopefully bypassing the boat's wiring. Larger boats, sailboats, catamarans, and those with challenging geometries might require more than one air terminal and/or multiple side-flash conductors to provide more routes for lightning energy to harmlessly pass to ground (go to abycinc.org to access ABYC TE-4, and nfpa.org to access NFPA 780, Chapter 10). Note that on metal-hulled boats, the hull and superstructure plating itself becomes the lightning conductor.

This ABYC diagram of standard lightning protection clearly represents best practices but gives no guidance on specifically protecting delicate electronic components or networked systems.



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Things can (and do) go terribly wrong when a lightning protection system is not properly installed; an incorrectly installed one may be worse than no system at all. Some common mistakes are: using the vessel's engine bed or bonding system as the lightning grounding point; installing the air terminal in the wrong location; neglecting to install side flash conductors;

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Left—*Lightning can jump from one conductive path to another even if they are not connected. That's what happened when a strike ran down the forestay and side-flashed to the wired deck switch at right.* ***Above***—*Hull damage, seen from the inside, resulted from lightning creating its own direct path to ground in a boat that was not wired to ABYC guidelines.*

strapping the lightning down conductors to the boat's electrical wiring; using propeller shaft brushes to carry lightning current; and not protecting the connections from corrosion. All these errors could result in lightning energy entering the boat's electrical systems, hull, or personnel on its way to earth, thereby perpetuating the myth that marine lightning protection systems don't work. But that's like putting in half of a burglar alarm system and then claiming that all burglar alarm systems do not work.

Remember that, technically speaking, as long as nobody is hurt and the boat does not sink or catch fire, the lightning protection system has worked perfectly. Back in the day, protection of the electrical and electronic equipment was merely a desirable cost-/time-saving benefit for the operator and the insurance carrier. But in the typical modern boat, a failure of the electronic systems can be life threatening. Consider a boat loaded with people caught in a storm without functioning electronically controlled engines, steering, radar, VHF radio, navigation lights, or GPS. It is easy to see how maintaining operational control of onboard electronics has become a safety of life at sea (SOLAS) issue.

Fortunately, the *properly installed* old-school protection system usually does a good job of diverting lightning energy away from the boat's wiring. However, if a lightning strike of several thousand amperes makes a direct hit on the boat's air terminal, or if one of the common installation mistakes comes into play, some or most of the lightning energy can enter the electrical system and data networks. And since everything is interconnected with wiring in the modern boat, everything can be affected. That is where the relatively new advances in surge protection technology can help.

SPDs

Surge-protection devices are defined as being overvoltage protection and are usually connected at the input electrical connections of a device or service entrance. They can be thought of as voltage fuses. If the incoming voltage is at normal levels or less, the SPD will behave as an open circuit, but if a voltage surge or spike occurs, the SPD is designed to short-circuit the overvoltage, hopefully keeping the voltage in the system within an acceptable range. The SPD works by converting the excess voltage to heat, sacrificing itself to protect the system. Note that if a second spike occurs, the sacrificed SPD may no longer be able to protect the system, hence the need to regularly check SPDs (many have indicator lights or flags to indicate viability or failure).

Because SPDs are now available in

various voltages, types, surge ratings, configurations, packages, etc. it is critical that the appropriate SPD be installed to protect onboard systems. A layperson should not casually purchase these devices online without careful thought and engineering oversight. Voltage rating, response time, energy dissipation, short circuit rating, and agency approvals are some of the factors that must be considered carefully in making the selection.

The actual installation of SPDs can be complicated and should be undertaken only by qualified marine electrical technicians from a reputable yard or service provider. They should install multiple SPDs as a coordinated system with overvoltage protection at the power sources, distribution panels, and the devices to be protected. Critical equipment and systems such as electronic engine controls, VHF radios, radars, GPS, alarm systems, and network hubs should all be protected. Additionally, SPDs should be installed where lightning can be expected to enter the vessel (e.g., the shore-power-service entrance and antennas). Section E-11.12 in the new edition of *ABYC Standards and Technical Information Reports for Small Craft* provides guidance for these installations.

As you can probably tell from the language in this article, there is a bit of a Kabuki dance in the electrical engineering community over SPDs. While we recommend their use to help protect from damaging overvoltage conditions, we do not want the boating

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Surge-protection devices (SPDs) are available in myriad shapes, sizes, and specifications and should be installed by qualified marine electricians to protect electronics like control systems, critical navigational devices, and network hubs.

public to think that SPDs are a magic bullet that will prevent lightning damage. Article 242 of the NFPA's National Electrical Code covers SPDs in detail but describes them as overvoltage protection and does not specifically identify them as lightning protection devices (utility power issues and high-power switching can result in voltage surges). Despite this reticence, Chapter 4.20 of NFPA's Standard on Lightning Protection (NFPA 780) requires SPDs to be installed on all electrical-power-service entrances and communication systems. Paradoxically, this requirement has been written into a standard that ostensibly does not address protection of electrical systems. He who lives by the standard dies by the standard.

Likewise, the newest version of ABYC E-11 provides guidance for the installation of SPDs on boats (E11.12) but also disclaims their ability to provide protection against lightning damage when not included as part of a comprehensive lightning protection system. The latest version of the ABYC technical information report on lightning protection (TE-4, 2019) notes that SPDs can provide additional lightning protection.

Wiring Design, Wi-Fi, and Backup Devices

The third part of an effective lightning protection system is the thoughtful and effective design of the wiring and connections. For example, you should keep the general power and data wiring far away from the lightning down conductors, and never combine the lightning protection system with the DC grounding or cathodic bonding system (despite what is allowed in TE-4). A dedicated lightning grounding plate, or plates, should be installed with only a single connection between the plates and the cathodic protection system.

Consider segregating various portions of the electrical and data communication system from each other. As an example, I know of wind instrumentation that is a stand-alone solar-powered device communicating with the network via Wi-Fi. Obviously, if the instrument gets struck by lightning, it will have no effect on the rest of the system. Similarly, if your electronic system designer can isolate various components or systems through Wi-Fi, Bluetooth, or optical coupling, this could prevent wholescale system failure during a strike to a single component.

Finally, good seamanship is always the fallback solution to keeping the boat afloat and the crew safe. In this case, that includes having a backup VHF and GPS in a drawer as well as being able to configure a limp-home mode for your steering system and at least one of your engines in the event of electrical system failure. Having a contingency plan is good. Having a good plan would be even better.

Conclusions

So, what should be done when a boat is struck by lightning? After seeing that no one is seriously injured and the boat is not on fire, ensure that the boat is not taking on water or in imminent peril due to a compromised propulsion or control system. The next step is to check the functionality of all onboard systems, and get the boat to a safe harbor. On a boat equipped with properly designed and installed onboard systems, this may not be much of a problem. On the other hand, I know of one client who had to manually drop the anchor, manhandle the dinghy off the swim platform, and find a shoreside telephone to call for help. Owners should contact their insurance companies to evaluate if a claim should be initiated, but it is important for them to remember that whether they are expecting an insurance payout or not, they are still responsible for the boat. Most insurance policies expect owners to take every reasonable effort to mitigate further damage. The costs of these efforts are sometimes included in the coverage, assuming the damage meets the lightning damage deductible (read your policy).

Once safely in a harbor or service yard, all systems should be checked. Qualified engine, electronic, air-conditioning, and electrical technicians should test all the systems even if the insurance policy doesn't pay for it. The inspection should include electrical panels, float switches, fire alarms/suppression systems, battery chargers, tank senders, etc. Just walking through the boat turning on lights, air conditioners, and touch-screens is not a sufficient test. If the boat was equipped with SPDs, these should be inspected as well. If the SPD did its job, the $3,000 television may be okay, but the SPD could be toast.

A lightning strike does not necessarily mean that the boat will get all new, updated electronics, air-conditioning equipment, engine controls, and stabilizer. Most insurance companies willingly pay legitimate lightning-related damage, but unrelated damage typically is not covered, and making specious claims may raise a red flag.

There are boat owners who conclude that since even the best system cannot guarantee complete protection from a direct lightning strike, there's no point in installing one. Why not just bump up the insurance coverage and ride it out? That makes about as much sense to me as ramping up your auto insurance and then not wearing a seatbelt because it won't save you if

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Damage from a lightning strike can play havoc through a boat's electrical system. The overhead in this pilothouse was disassembled to reveal scorching damage along the wiring after a lightning strike.

your car gets run over by a tractor-trailer. Remember, a well-designed and properly installed lightning protection system can save the boat owner from much wasted time and heartache. In fact, with a very good system, the boat owner may not even know the strike had occurred.

Are not time and peace of mind the most important commodities that we can provide for boat owners? PBB

***About the Author**: James Cote is a marine electric and corrosion consultant, surveyor, and investigator at Cote Marine LLC, in Freeport and Port Saint Lucie, Florida.*

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ABYC TE-4: abycinc.org
NFPA 780, Chapter 10: nfpa.org