E-8 AC Electrical Systems

Applies to AC systems on boats operating at frequencies of 50 or 60 Hz below 300 Volts. The standards apply to AC system on the boat as well as the shore power cord, but do not include AC systems on the dock.

Section E-8.4

Defines the technical terms used in E-8. All of these terms can be found in Blue Sea Systems' Technical Glossary.

Section E-8.5

Specifies general requirements of the AC system.

1. Shipboard AC systems must be consist of a system in which the grounded (white) and ungrounded conductors are connected in the same relation to all AC loads in the circuit.

2. The neutral system on shipboard systems must be grounded in the following manner:
Shorepower - When operating with shorepower, the neutral must not be grounded on the boat.

Transformer - The secondary neutral of an isolation transformer or polarization transformer shall be grounded at the secondary of an isolation or polarization transformer

Generator - When operating with generator power, the AC neutral must be grounded at the generator.
Inverter - When operating with inverter power, the AC neutral must be grounded at the inverter. When operating in the AC "pass-through" mode or as a battery charger, the AC neutral must be disconnected from the inverter ground.

The exception to this requirement is that for systems using an isolation transformer or polarization transformer, both the generator or inverter neutral and the transformer secondary neutrals may be grounded at the AC main grounding bus instead of at the generator, inverter, or transformer secondaries.

3. The main AC system grounding bus shall be connected to the engine negative terminal or the DC main negative bus on grounded DC systems, or the boat's DC grounding bus in installations using ungrounded DC electrical systems.

4. The AC safety ground wire (green) must be continuously connected with no means (switches of overcurrent protection devices) of breaking the connection.

5. If more than one shorepower source is used, their neutrals must remain isolated from each other.

6. On boats with multiple AC sources there must be a mechanism to insure that there is no possibility of one source being connected to another source. This mechanism must switch all normally current carrying lines and must switch in such a manner that the two sources cannot arc between each other or ever make contact. A means for disconnecting all power sources from the loads must also be located here.

The grounded neutral from a polarization transformer, isolation transformer, generator or inverter may be permanently connected to the same main AC grounding bus and is not required to be switched.

7. Energized parts of electrical equipment must be protected against accidental contact by the use of an enclosure, whose opening requires a tool. An enclosure that is normally intended for non-electrical equipment use should not be used for this purpose.

Section E-8.6

Specifies AC marking requirements

1. All switches and controls must be marked to indicate their function unless that function is obvious and whose misuse cannot create a hazardous situation.

2. All electrical equipment must have: a) manufacturer's identification b)a product identification or model number c) an AC electrical rating in volts and amperes or volts and watts d) phase and frequency, if applicable e) "Ignition Protected," if applicable. This must be identified by a marking such as "SAE J1171 Marine," "UL Marine-Ignition Protected," or "Ignition Protected."

Section E-8.7 specifies acceptable AC system voltages

1. Only the following voltages are accepted for use on boats:

120 volts AC, single phase;
240 volts AC, single phase;
120/240 volts AC, single phase;
120/240 volts AC, delta three phase; or
120/208 volts AC, Wye three phase.

Section E-8.8 defines the ambient temperature standards for 3 areas.

1. machinery spaces (engine rooms) is 50°C (122°F)
2. all other spaces is 30°C (86°F) (including shore power cables)

Section E-8.9 defines where ignition protected equipment is required

There are two areas where ignition protected devices are required: Gasoline compartments and LPG/CNG compartments. It should be noted that the intent in E-8.9 is not just to require ignition protected devices only in engine rooms and propane lockers, but in all compartments through which these substances pass.

1. All electrical devices installed in spaces containing gasoline powered machinery, or gasoline fuel tanks, or joints, or other connections between components of a gasoline system, must be ignition protected. The exception to this is when the electrical device is isolated from the gasoline fuel source. This section also describes the ways in which isolation from the gasoline fuel source can be achieved.

Gasoline fuel source isolation can be achieved if a bulkhead meeting the following is between the electrical components and the gasoline fuel source:

a) a bulkhead that separates the electrical component from the fuel source, and extend both vertically and horizontally the distance of the open space between the gasoline fuel source and the ignition source, and
b) resists a water level that is 12 inches (305 mm) high or one-third of the maximum height of the bulkhead, whichever is less, without seepage of more than one-quarter fluid ounce (7.5 cc) of fresh water per hour; and
c) has no opening higher than 12 inches (305 mm) or one-third the maximum height of the bulkhead, whichever is less, unless the opening is used for the passage of conductors, piping, ventilation ducts, mechanical equipment, and similar items, or doors, hatches and access panels, and the maximum annular space around each item or door, hatch, or access panel must not be more than 6 mm (one-quarter inch).

Or

the electrical component is :

a) lower than the gasoline fuel source and a means is provided to prevent gasoline fuel and gasoline fuel vapors that may leak from the gasoline fuel sources from becoming exposed to the electrical component, or
b) is higher than the gasoline fuel source and a deck or other enclosure is between it and the gasoline fuel source, or
c) the distance between the electrical component and the gasoline fuel source is at least two feet, and the space is open to the atmosphere. The "atmospheric opening" must be at least 15 square inches per 1 net cubic feet of compartment volume.

2. If LPG or CNG is provided on the boat, all electrical potential sources of ignition located in compartments containing LPG/CNG appliances, cylinders, fittings, valves or regulators must be ignition protected. The exception to this is boats with LPG/CNG systems installed in accordance with ABYC A-1, Marine Liquefied Petroleum Gas (LPG) Systems, or ABYC A-22, Marine Compressed Natural Gas (CNG) Systems, and stoves that comply with ABYC A-3, Galley Stoves
3. electrical devices in the following compartments that would otherwise be considered LPG/CNG compartments are excepted:
1. Accommodation spaces
2. Open compartments having at least 15 square inches (968 mm2) of open area per cubic foot (0.03 m3) of net compartment volume exposed to the atmosphere outside of the craft

Section E-8.10 defines the requirements for AC Reverse Polarity devices

120 Volt AC shore power systems on boats must be equipped with reverse polarity indicators that emit a

continuous audible or visual signal when the hot (black) and neutral (white) conductors are reversed on the line side of the indicator. These devices must provide at least 25,000 Ohms of resistance between current-carrying conductors (hot and neutral) and the safety green wire in order to avoid becoming a path for galvanic current. This usually takes the form of a resistor in one leg of the reverse polarity indicating LED.

Reverse polarity indication is not required if:
No load in the circuit requires polarization for proper operation
All branch circuits have over-current protection in both hot and neutral conductors
A polarization or isolation transformers is installed that that establishes the polarity on the boat

E-8.11 defines the type and location of AC overcurrent protection devices (OPD's)

The first part of E-8.11 discusses OPD ratings, stating they must "temperature rating and demand load characteristics consistent with the protected circuit and their location in the boat, i.e. machinery space or other space". This is general statement refers to the issues of time-current (or "trip") characteristics and temperature deratings. If one wanted to be very thorough in the interpretation of this statement, one would also need to correlate the various performance requirements of the standards that ABYC specifies for OPD's. These are:

1. UL 489, Molded Case Circuit Protectors For Circuit Breaker Enclosures, or
2. UL 1077, Supplementary Protectors For Use In Electrical Equipment, or
3. UL 1133, Boat Circuit Breakers

It is important to point out that E-8.11 does not require the OPD to be UL Listed. It only requires that the OPD "meets the requirements" of one of these UL Standards.

See Blue Sea Systems' Technical Appendix "Selecting an OPD" for more specific time-current characteristic and temperature deratings information.

E-8.11 does state the following specifics about the OPD's in AC circuits: (It should be noted, however, that these do not address the more complex issues alluded to in the "consistent with the protected circuit" statement discussed above.)

1. The AC voltage rating of an OPD must be greater than or equal to the nominal AC voltage of the circuit in which it is installed.
2. The current rating of the OPD cannot exceed the current carrying capacity of the smallest wire in the circuit to be protected. Current carrying capacities are defined in two different ABYC tables that takes into account flexible/non-flexible cables, insulation type, amperage and number of conductors in the wire bundle. An OPD 50% greater than the wire current carrying capacity is allowed if there is no standard OPD current rating at the wire current carrying capacity.
3. Must be manually resettable and trip-free
4. Must be capable of an interrupting capacity in required in ABYC E.8.11 Table I. This information is also available in Blue Sea Systems' "Interrupt Capacity Table" in the Technical Appendix. OPD's that are integral to electrical devices are exempt from this requirement. Further ABYC wording in the section states that "Generator circuit breaker ampere interrupting capacity (rms) must be selected considering available transient short circuit current (first half cycle)." This can be interpreted as follows:

The interrupting capacity needs to be sufficiently high so as to able to open the circuit breaker without damaging it. During a short circuit the generator is capable of supplying considerably more current than its rating, five to seven times, would be a typical design rule. This means that a 10 Kw generator at 240 V would be rated to supply about 42 amps, however for a short time, a half cycle, the current could approach 300 amps. This is not typically a problem since circuit breakers commonly available have interrupt ratings of 3,000 amps. This would imply that commonly available breakers could be used with generators of up to 100Kw or 420 amps at 240V. As the breaker rating increases the interrupt capacity normally does as well so one would typically not need to consider this in breaker selection.

Transformers

E-8.11.4 specifies circuit protection for transformer circuits. It specifies the following for these circuits:

If there is an isolation transformer on board it must have a circuit breaker in the primary circuit that is rated at, or below, the maximum current rating of the primary circuit. This circuit breaker must simultaneously open the hot and neutral conductors and be rated no larger that 125% of the current rating of the primary. This circuit breaker in the primary transformer circuit also does the job of protecting the transformer secondary circuit, but

only for 120 volt or 240 volt systems, not for 120/240 volt systems.

If the transformer secondary circuit supplies 120/240 voltage, then it too must have a circuit breaker that simultaneously opens all ungrounded conductors. This circuit breaker must be rated no larger that 125% of the current rating of the secondary.

The neutral conductor on the secondary side must be grounded at the transformer. In other words, the ship's ground is run to the transformer and the neutral, ship's ground and the transformer enclosure must be connected together at the transformer.

Branch Circuits

A branch circuit is a circuit that is on the non-line side of a main OPD. Branch circuit protection requirements are these:

Each ungrounded (hot) conductor of a branch circuit must have overcurrent protection at the point of connection to the panelboard bus. OPD's used for this purpose must be rated not to exceed the current rating of the smallest conductor between the OPD and the load. If there is not a standard current rating of the OPD equal to 100 percent of the allowable current for the conductor in Table V, the next larger standard current rating may be used, if it does not exceed 150 percent of the current allowed by Table II or Table V.

On 120 volt, single-phase systems, branch circuit breakers have to simultaneously open both current carrying conductors unless the AC system has a polarity indicator or a transformer. Fuses cannot be used for this application.

E-8.11 also states that if branch circuits contain two or more ungrounded current carrying conductors protected by fuses, means shall be provided to disconnect all energized legs of the circuit simultaneously or remove all fuses from the circuit simultaneously..

The simultaneous trip requirement is also specified for branch circuits containing two or more ungrounded current carrying conductors protected by a circuit breaker. This applies in applications where fuses are utilized in conjunction with circuit breakers to achieve the circuit's required AIC.

AC Motors

Each motor installation, and each motor of a motor operated device, must be individually protected by an overcurrent or thermal protection device unless it is a motor that will not overheat under locked rotor conditions.

AC OPD Location Requirements

Each ungrounded (hot) current carrying conductor must be protected by a circuit breaker or fuse. Notice that this does not exempt the neutral leg circuit breaker requirement in power feeder conductors that requires simultaneous trip circuit breakers 120 VAC single phase power feeder hot and neutral conductors.

A circuit breaker or fuse shall be placed at the source of power for each circuit or conductor. If this is impractical it may be placed within seven inches (178 mm) of the source of power for each circuit or conductor, measured along the conductor. If this is impractical it can be placed within 40 inches (102 cm) of the source of power for each circuit or conductor, measured along the conductor, if the conductor is contained throughout its entire distance between the source of power and the required circuit breaker or fuse in a sheath or enclosure such as a junction box, control box, or enclosed panel. This 40" rule cannot be used on power-feeder conductors from AC generators, inverters and shore power.

Simultaneous trip circuit breakers must be provided in power feeder conductors as follows:

120 volt AC, single phase - ungrounded and grounded conductors (white),
240 volt AC, single phase - both ungrounded conductors,
120/240 volt AC, single phase - both ungrounded conductors,
120/240 volt AC, delta three phase - all ungrounded conductors,
120/208 volt AC, Wye three phase - all ungrounded conductors.

If the location of the main shore power disconnect circuit breaker is in excess of three meters (10 feet) from the shore power inlet or the electrical attachment point of a permanently installed shore power cord, additional fuses or circuit breakers shall be provided within 10 feet (three meters) of the inlet or attachment point to the electrical system of the boat. Measurement is made along the conductors.

If fuses are used in addition to the main shore power disconnect circuit breaker, they must be rated so that the circuit breakers trip before the fuses open the circuit, in the event of overload. The ampere rating of the additional fuses or circuit breaker must not be greater than 125% of the rating of the main shore power disconnect circuit breaker. For 120 volt service, both the grounded and ungrounded current carrying conductors must have this additional overcurrent protection.

If required, overcurrent protection for power-feeder conductors from AC generators and inverters, shall be within 7 inches (180 mm) of the output connections or may be within 40 inches (1.0 meter) of the output connections if the unprotected insulated conductors are contained throughout their entire distance in a sheath or enclosure such as a conduit, junction box or enclosed panel.

E-8.12 discusses Ground Fault Protection

Before reading this discussion please read the definitions of GFP, GFCI and GFI in the Technical Glossary.

A reading of E8.12 would lead one to think that ABYC does not require that a ground fault protector be installed aboard a boat at all, however, buried in E-8.17 (AC Receptacles) is the statement that "If (a receptacle) installed in a head, galley, machinery space, or on a weather deck, the receptacle shall be protected by a Type A (nominal 5 milliamperes) Ground Fault Circuit Interrupter (GFCI)." This is an unfortunate separation of GFCI requirements in the Standards.

A ground fault protector (GFP) can only be used to protect equipment.

A ground fault circuit interrupter (GFCI) may be used on single-phase AC circuits to provide additional protection for personnel and equipment.

GFCI and GFP breakers must meet the requirements of Underwriters Laboratories standard UL 943, Ground Fault Circuit Interrupters, and the requirements of UL 489, Molded Case Circuit Protectors for Circuit Breaker Enclosures.

GFCI and GFP breakers may be installed as panelboard feeder breakers to protect all associated circuits or in individual branch circuits.

Single-pole GFCI and GFP breakers must only be used if the single-phase 120 volt system has a polarity indicator, or the system uses either a polarization transformer, or the system is 120/240 volts.

GFCI receptacle devices must meet the requirements of Underwriters Laboratories' standard UL 943, Ground Fault Circuit Interrupters, and the requirements of UL 498, Electrical Attachment Plugs and Receptacles.

GFCI receptacle devices may be installed as part of a convenience outlet installation either in single outlet applications or in multiple feed through installations. See ABYC E-8.17.8.
NOTE: Isolation transformer primary main breakers - GFP breakers may be installed as the main breaker on the primary side of isolation transformers. See E-8.23, Diagram 8 and Diagram 11. This GFP breaker will provide ground fault protection only for the primary winding of the transformer. Protection for circuits supplied by the secondary winding of the transformer may be provided in accordance with ABYC E-8.11.4, E-8.11.5, E-8.11.6.3, and E-8.12.4.

E-8.13 discusses the nature of grounds on AC equipment

Permanently installed AC electrical equipment used on boats must be designed so that the current carrying parts of the device are effectively insulated from all exposed electrically conductive parts. All exposed, electrically conductive, non-current carrying parts of permanently installed AC electrical equipment and appliances that are designed to be grounded must be connected to the grounding (green) conductor.

AC equipment that is built with a neutral to ground bonding strap must have the strap removed in order to comply with general requirement of E-8 that a boat has a neutral system grounded only at the appropriate shore, transformer, generator or inverter point, and no other.

Integral overcurrent protection may be provided.

E-8.14 specifies the details of AC system wiring

Wiring has to be rated at 600 volts and flexible cords must be rated at 300 volts. Wire and flexible cord temperature ratings have to be at least 140° F (60° C) dry. In engine spaces, where the standard temperature is 122° F (50° C) the wire insulation must be oil resistant and maximum operating temperature rated at 167°F

(75° C) dry.

Wires and flexible cords must meet the flame retardant and moisture resistant requirements of UL 83, Thermoplastic-Insulated Wires and Cables and the requirements of the applicable standards of Underwriters Laboratories Inc.

Wire insulation must be marked with the wire type or style, the voltage, the wire size, and the temperature rating dry. A separate ABYC table specifies detailed temperature ratings for flexible cords.

Wire and flexible cords must be stranded copper according. A table in E-8.11 shows minimum circular mil area and number of strands for each common gauge of wire.

Conductors and flexible cords must be sized according to the factors of engine space/non-engine space, the number of current carrying conductors in the wire bundle and the temperature rating of the wire insulation. These tables are reproduced by many companies supplying wire to the marine industry. Two interesting notes in E-8.14 concerning this issue are:

1. Where single conductors or multiconductor cables are bundled for a distance greater than 24 inches (610 mm), the allowable ampacity of each conductor must be reduced. Tables in E-8.14 show these reduced values for various bundle numbers.

2. When determining the allowable amperage of bundled conductors using the tables mentioned above, the AC grounding conductor and a neutral conductor that carries only the unbalanced current from other conductors are not considered to be current carrying conductors.

The AC grounding (green) conductor can be one size smaller than the current carrying conductors on circuits rated greater than 30 amperes.

All conductors in AC circuits must be at least 16 AWG unless they are conductors completely inside an equipment housing or pigtails less than 7 inches (178 mm) used as wiring on panelboards

18 AWG conductors may be used as internal wiring on panelboards and they can be used with other conductors in a sheath if they do not extend more than 30 inches (760 mm) outside the sheath.
.
The following are the colors required to be used to indicate circuit polarity in AC systems:

E-8.15 defines the details of AC wiring installation

All connections normally carrying current must be made in enclosures to protect against shock hazards. Nonmetallic outlet boxes, flush device boxes and covers used for this purpose must meet the requirements of UL 514C, Nonmetallic Outlet Boxes, Flush Device Boxes And Covers.

Junction boxes, cabinets, and other enclosures in which electrical connections are made must be weatherproof, or installed in a protected location, to minimize the entrance or accumulation of moisture or water within the boxes, cabinets, or enclosures. Weatherproof means constructed or protected so that exposure to the weather will not interfere with successful operation in rain, spray, and splash.

In wet locations, metallic boxes, cabinets, or enclosures shall be mounted to minimize the entrapment of moisture between the box, cabinet, or enclosure, and the adjacent structure. If air spacing is used to accomplish this, the minimum must be 1/4 inch (7.0 mm).

Unused openings in boxes, cabinets, and weatherproof enclosures must not be left open if unused and all conductors penetrating the enclosure must be strain relived.

AC conductors have to be kept separate from the DC conductors by sheathing.

Current carrying conductors must be as high as practicable above the bilge water level and other areas where water may accumulate. If conductors must be routed in the bilge or other areas where water may accumulate, the connections must be watertight.

Conductors must be routed as far away as practicable from exhaust pipes and other heat sources. Unless an equivalent thermal barrier is provided, a clearance of at least 2 inches (51 mm) between conductors and water-cooled exhaust components, and a clearance of at least 9 inches (230 mm) between conductors and dry exhaust components, must be maintained. Conductors may not be routed directly above a dry exhaust.

Conductors that may be exposed to physical damage must be protected by self draining; loom, conduit, tape, raceways, or other equivalent protection. Conductors passing through bulkheads or structural members must be protected to minimize insulation damage such as chafing. Conductors must be routed clear of sources of chafing.

Loom used to cover conductors must be self extinguishing, classified V-2 or better, in accordance with UL 94, Tests For Flammability Of Plastic Materials.

Conductors must be fully supported or they may be secured at least every 18 inches (460 mm) by:
1. Nonmetallic devices resistant to oil, gasoline, and water, and able to withstand a temperature range of -30°F (-34°C) to 250°F (121°C) without breaking. Nonmetallic straps or clamps must not be used over engine(s), moving shafts, other machinery, or passageways if failure would result in a hazardous condition.

2. Metal straps or clamps with smooth, rounded edges, to hold the conductors firmly in place without damage to the conductors or insulation. That section of the conductor or cable directly under the strap or clamp shall be protected by means of loom, tape, or other suitable wrapping to prevent injury to the conductor. Metal clamps lined with insulating material resistant to the effects of oil, gasoline, and water may also be used.

Electrical appliances and equipment designed for permanent installation must be securely mounted to the boat's structure.

Wiring connections shall be designed and installed to make mechanical and electrical joints without damage to the conductors.

Metals used for the terminal studs, nuts, and washers shall be corrosion resistant and galvanically compatible with the conductor and terminal lug. Aluminum and unplated steel shall not be used for studs, nuts, and washers.

Each conductor-splice joining conductor to conductor, conductor to connectors, and conductor to terminals must be able to withstand a tensile force specified in E-8.15 for the smallest conductor size used in the splice for a one minute duration, and not break.

Only ring or captive spade types terminals can be used. Friction connectors such as spade and bullet connectors may be used on components if:

1. The circuit is rated not more than 20 amperes or the manufacturer's rating for a terminal designed to meet the requirements of UL 310, Electrical Quick-Connect Terminals, or UL 1059, Terminal Blocks, and

2. The voltage drop from terminal to terminal does not exceed 50 millivolts for a 20 amp current flow, and

3. The connection does not separate if subjected for one minute to a six pound (27 Newton) tensile force along the axial direction of the connector, on the first withdrawal.

Set screw connections can be used if there is a pressure plate between the screw and the wire strands so that the wire strands will not be cut by the screw.

Twist on connectors, known as wire nuts cannot be used.

Solder cannot be the only mechanical connection in any circuit. Soldered connections must be located or supported to minimize flexing of the conductor where the solder changes the flexible conductor into a solid conductor.

Solderless crimp on connectors can only be applied with tools designed specifically for this application.

A maximum of four conductors can be on any one terminal stud, but multiple terminal studs can be connected together by jumpers or copper straps.

Ring and captive spade terminal connectors must be the same nominal size as the stud.

Conductors terminating at panelboards in junction boxes or fixtures must provide a length of conductor to relieve tension, to allow for repairs and to permit multiple conductors to be fanned at terminal studs.

Terminal shanks, except those used on ground systems, must be protected against accidental shorting with insulation barriers or sleeves.

E-8.16 is a very short paragraph on AC switches

Switches used in branch circuits must simultaneously open all ungrounded conductor(s) of that circuit. They must have voltage ratings not less than the system voltage, current ratings not less than the connected load, and must be rated for the type of load, i.e., inductive or resistive.

E-8.17 defines AC receptacle requirements

Receptacles must be installed in boxes that meet the requirements of UL 514A, Metallic Outlet Boxes, or 514C, Nonmetallic Outlet Boxes, Flush Device Boxes And Covers.

Receptacles must have a grounding receptacle for the safety (green) conductor.

AC Receptacles and matching plugs must not be interchangeable with receptacles and matching plugs used on DC systems.

Power wiring for receptacles must be connected so that the grounded (white) conductor attaches to the terminal identified by the word "white" or a light color (normally white or silver). The ungrounded conductor(s) shall be attached to the terminal(s) identified by a dark color (normally brass or copper) and, optionally, the letters X, Y, and Z or L1, L2, and L3.

A branch circuit supplying a combination of receptacle loads and permanently connected loads has a fixed load limit of 600 watts for a 15 ampere circuit and 1000 watts for a 20 ampere circuit.

It is encouraged that receptacles be installed in locations not subject to rain or spray. However, installation is permitted in these areas if the receptacle has a spring loaded, self closing cover that makes the unit "weatherproof" Receptacles installed in areas subject to flooding or momentary submersion must be "watertight" design. The standard suggests a threaded, gasketed cover to achieve this.

Receptacles in the galley must be located so appliance cords can be plugged in without crossing a traffic area, galley stove, or sink.

If installed in a head, galley, machinery space, or on a weather deck, the receptacle must be protected by a Type A (nominal 5 milliamperes) Ground Fault Circuit Interrupter (GFCI). Refer back to the discussion of ABYC E-8.12 for more GFCI information.

E-8.18 defines the methods for calculating the AC load requirements and their impact on distribution panels, gererators, shore power and inverters.

The total AC power required must be supplied in one of the following ways:

1. A single shore power cable, power inlet, wiring, and components with a minimum capacity to supply the calculated total load, complying with ABYC E-8.22.

2. Multiple shore power cables, power inlets, wiring, and components with a minimum total capacity to supply the total calculated load, complying with ABYC E-8.22. All sources need not be of equal capacity, but each power inlet must be clearly marked with voltage, ampacity, phase (if a three phase system is incorporated), and the load or selector switch that it serves.

3. An on board AC generator(s) or inverter(s) to supply the total load as calculated. Total minimum installed KVA for a single-phase system is: (Maximum Total Leg Amps. X System Voltage) / 1000.

4. A combination of Shore Power Cable(s), On-board Generator(s) and Inverter(s) - can be used simultaneously if the boat circuitry is arranged so that the load connected to each source is isolated from the other in accordance with ABYC E-8.5.5. Shore power cable(s) plus on-board generator(s) and inverter(s) capacity must be at least as large as the total calculated electrical load requirements. Generator(s) and inverters(s) installation and switching must meet ABYC E-8.20.

E-8.18.5 specifies how to determine the total AC load requirement

The following is the method for load calculation to determine the minimum size of panelboards and their main feeder conductors and the power sources supplying these devices.

Step 1: Determine Lighting Fixtures and Receptacles Wattage
Length times width of living space (excludes spaces exclusively for machinery and open deck areas) times 20 watts per square meter (2 watts per square foot).
Formula: Length (meters) x width (meters) x 20 = _____ lighting watts, or
Length (feet) x width (feet) x 2 = _____ lighting watts.

Step 2: Determine Small Appliance Wattage
Galley And Dinette Areas - Number of circuits times 1,500 watts for each 20-ampere appliance circuits.
Formula: Number of circuits x 1,500 = _____ small appliance watts.

Step 3: Add Lighting Watts to Small Appliance Watts
= _____ Total watts.

Step 4: Apply Load Factor
Formula: First 2,000 total watts at 100% = _____.
Remaining total watts x 35% = _____.
Total watts divided by system voltage = _____amperes.

Step 5: Divide totals into two legs if necessary
If a shore power system operates on 240 volts, split and balance loads into Leg A and Leg B. If a shore power system operates on 120 volts, use Leg A only.
Leg A /Leg B
_____/_____ Total Amperes

Step 6: Add nameplate amperes for motor and heater loads
Leg A /Leg B

_____/_____ exhaust and supply fans
_____/_____ air conditioners *,**
_____/_____ electric, gas, or oil heaters
_____/_____ 25% of largest motor in above items

_____/_____ Sub-Total

NOTES: *Omit smaller of these two, except include any motor common to both functions.
**If system consists of three or more independent units adjust the total by multiplying by 75% diversity factor.

Step 7: Add nameplate amperes at indicated use factor percentage for fixed loads:

Leg A /Leg B

_____/_____ Disposal - 10%
_____/_____ Water Heater - 100%
_____/_____ Wall Mounted Ovens - 75%
_____/_____ Cooking Units - 75%
_____/_____ Refrigerator - 100%
_____/_____ Freezer - 100%
_____/_____ Ice Maker - 50%
_____/_____ Dishwasher - 25%
_____/_____ Washing Machine - 25%
_____/_____ Dryer - 25%
_____/_____ Trash Compactor - 10%
_____/_____ Air Compressor - 10%

_____/_____ Battery Chargers - 100%
_____/_____ Vacuum System - 10%
_____/_____ Other Fixed Appliances

_____/_____ Sub-Total
_____/_____ **Adjusted Sub-Total

NOTE: **If four or more appliances are installed on a leg, adjust the sub-total of that leg by multiplying by 60% diversity factor.

Step 8: Determine Total Loads

Leg A Leg B

_____/_____ lighting, receptacles, and small appliances
_____/_____ motors and heater loads
_____/_____ fixed appliances
_____/_____ free standing range (See NOTE 1)

_____/_____ calculated total amperes (load)

NOTES: 1. Add amperes for free standing range as distinguished from separate oven and cooking units. Derive by dividing watts from Table VI by the supply voltage, e.g., 120 volts or 240 volts.
2. If the total for Legs A and B are unequal, use the larger value to determine the total power required.

E-8.19 Specifies the requirements for AC Distribution Panels.

ABYC calls Circuit Breaker Distribution Panels "Panelboards", however, this term is not commonly used in the marine industry.

Installation
E-***8.19. requires that distribution panels be installed***

1. In a readily accessible location

2. So that energized parts of electrical equipment are guarded against accidental contact by the use of enclosures or other protective means that are not used for non-electrical equipment. Access to energized parts of the electrical system must require hand tools.

3. All connections normally carrying current must be in enclosures to protect against shock hazards

4. Distribution panels be weatherproof or be protected from weather and splash.

Marking
The face of distribution panels must be permanently marked with the system voltage and either "VAC" or system frequency. If the frequency is not 60 hertz, the frequency must be shown.

For three phase systems the system voltage, phase, and number of conductors must be marked.

Meter Requirements
A system voltmeter must be installed on the main panelboard if the system is permanently connected to motor circuits, a generator, or an inverter. If the inverter does not have a true sinusoidal output, the voltmeter must be a true RMS type. See ABYC A-25, Inverters.
Inverter voltmeters need only be installed in proximity to the panelboard.

Separation of AC and DC distribution
Boats with both AC and DC electrical systems must have separate AC and DC distribution panels. If AC and DC are on the same distribution panel, during DC access there must be no access to energized AC parts without the use of tools.

E-8.20 specifies the characteristics of AC generators

AC generators must be connected to the electrical distribution system as required in ABYC E-8.5.5. See E-8.23.1, Diagram 2.

The power feeder conductor from the AC generator must be sized to at least accommodate the generator's maximum rated output and must be protected at the generator with overcurrent protection devices in accordance with ABYC E-8.11.1, E-8.11.2 and E-8.11.3. The rating of these overcurrent protection devices must not exceed 120 percent of the generator rated output.
EXCEPTION: Self limiting generators, whose maximum overload current does not exceed 120 percent of its rated current output, do not require additional external overcurrent protection.

E-8.20 specifies Galvanic Current Isolation via Isolation Transformers and Galvanic Isolators

Boats with aluminum or steel hulls or aluminum outdrives are subject to galvanic corrosion because the boat ground is electrically connected to the shore ground (via the grounding conductor). An isolation transformer system, or a galvanic isolator in the grounding conductor, may be used to reduce this problem. See E-8.23.

Only encapsulated type isolation transformers may be used and they must have:

1. A metallic shield between the primary and secondary winding and electrical insulation from all other portions of the transformer. The design must withstand, without leakage, a high potential test of 4000 volts AC, 60 Hz, for one minute, applied between the shield and all other components such as windings, core, and outside enclosure.
2. A separate insulated wire lead or terminal identified as the shield connection solidly connected only to the shield, and brought out only for external connection.
3. A shield and shield connection sufficient ampacity to provide a sustained fault current path for either the primary or secondary windings.
4. A metallic transformer case with a grounding terminal.

Galvanic isolators must meet the requirements of ABYC A-28, Galvanic Isolators.

E-8.22 SHORE POWER SUPPLY

All AC shore power inlets must be male connectors.
Inlets installed in locations subject to rain, spray, or splash shall be weatherproof whether or not in use.
Inlets installed in areas subject to flooding or momentary submersion shall be of a watertight design whether or not in use.

Metallic power inlets installed on metallic boats using an isolation transformer or a galvanic isolator shall be insulated from metallic structure and components. On nonmetallic boats using an isolation transformer or a galvanic isolator the power inlet must be insulated from metallic components connected to the boat's ground.

Any boat equipped with an AC shore power system must have a shore power cable that contains the conductors for the power circuit and a grounding (green) conductor.
Except where the shore power cable is permanently connected to the boat, the boat end of this cable must be terminated with a locking and grounding female type connector to match the boat power inlet.

The shore power cable must be flexible cord with the minimum properties of Type SO, ST, STO, SEO, or STOO, and suitable for outdoor use. The shore connection end of this cable must have a locking and grounding type plug with the required number of poles and must comply with Article 555 of the National Electrical Code.

A permanently mounted waterproof warning sign must be located at each shore power inlet location on the boat. It should state the AC shore power hazard and how to avoid them. An example of such a label is:

1 Turn off the boat's shore connection switch before connecting or disconnecting shore cable
2 Connect shore power cable at the boat first
3 If polarity warning indicator is activated, immediately disconnect cable
4 Disconnect shore power cable at shore outlet first
5 Close shore power inlet cover tightly

EXCEPTIONS:
1. Item 3 is not required if a polarity indicator is not installed. See ABYC E-8.10.

2. Items 2 and 4 are not required for permanently connected shore power cables.
TABLE I - CIRCUIT BREAKER INTERRUPTING CAPACITY (AMPERES)

E-8.22 also shows AC Circuit Breaker Interrupt Capacity requirements. These are reproduced in Blue Sea Systems' Technical Appendix. However, there are two important items that are contained in notes to the table:

1. The main circuit breaker must be considered to be the first circuit breaker connected to a source of AC power. All subsequent breakers, including sub-main breakers connected in series with a main circuit breaker, shall be considered to be branch circuit breakers.

2. A fuse in series with, and ahead of, a circuit breaker may be required by the circuit breaker manufacturer to achieve the interrupting capacity in Table I.

The following is a synopsis, interpretation and explanation of the most important information contained in the American Boat and Yacht Council Standards and Recommended Practices. It does not contain all the information contained in the standards and should not be relied on for definitive compliance with the Standards and Recommended Practices.

E-9 DC Electrical Systems

ABYC intends these standards and recommended practices contained in this version of E-9 to be followed after July 31, 1999.

E-9.1 PURPOSE

These standards and recommended practices are guides for the design, construction, and installation of direct current (DC) electrical systems on boats.

The United States Coast Guard has mandatory requirements for electrical systems in Title 33, CFR 183 Subpart I, Section 183.

E-9.2 SCOPE

These standards and recommended practices apply to direct current (DC) electrical systems on boats that operate at 50 volts or less.
They do not apply to any wire that is part of an outboard engine assembly and does not extend inside the boat.

E-9.3 REFERENCED ORGANIZATIONS

The following organizations are referred to in the standards:

ABYC - American Boat & Yacht Council, 3069 Solomons Island Road, Edgewater, MD 21037-1416 410-956-1050
CFR - Code of Federal Regulations and other government publications. Obtain from the Superintendent of Documents, United States Government Information, POB 371 954, Pittsburgh, PA 15250-7954. 202-512-1800 or FAX 202-512-2250. An excerpted edition of the CFR is also available from ABYC, Inc., 3069 Solomons Island Road, Edgewater, MD 21037-1416 410-956-1050
NEMA - National Electrical Manufacturers Association, 2101 L Street, NW, Washington, DC 20037 202-457-8400
NFPA - National Fire Protection Association, Batterymarch Park, Quincy, MA 02269 617-770-3000
SAE - Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096 412-776-4841
UL - Underwriters Laboratories Marine Department, POB 13995, 12 Laboratory Drive, Research Triangle Park, NC 27709 919-549-1400. Obtain standards from Global Engineering Documents, Inc., 15 Inverness Way East, Englewood, CO 80112 800-854-7179

E-9.4 DEFINITIONS

Defines the technical terms used in E-8. All of these terms can be found in Blue Sea Systems' Technical Glossary.

E-9.5 GENERAL REQUIREMENTS

1. All direct current electrical distribution systems must be two wire systems. This means that there is one positive conductor and one negative conductor between each DC load and its source of power. The only

exception to this is electrical devices mounted on the engine. In many cases these devices utilize the engine block itself as the negative return path.

2. This statement is an amplification of the preceding one. It specifically states that the hull on metallic boats and the bonding and DC Grounding systems may not be used as the return current path.

3. If a boat's DC system is grounded, it can only be on the negative side of the DC circuit with consistent polarity maintained throughout the boat.

4. If a boat has more than one engine with a grounded cranking motor including generator engine(s), the engines must be connected to each other by a conductor that can carry the cranking motor current of each of the grounded cranking motor circuits. Outboard engines must be connected at the battery negative terminals.

5. Boats meeting the multiple engine definition of 4, above, and having "cross-over (parallel) cranking motor systems", must have the engines connected together with a cable sized to carry the cranking motor current. This cable and its terminations must be "in addition to, and independent of" any other electrical connections to the engines including those required in 4, above. Boats with ungrounded DC systems and outboard engines are not required to comply with this

6. Paralleling switches must be sized to carry the largest cranking motor current and can be "either of the maintained or momentary contact type". Battery switches ratings are based on the UL Intermittent (5 minute) rating. See the Technical Glossary for definitions of the UL Battery Switch Ratings.

7. a) If the boat has an AC electrical system, the main AC grounding bus must be connected to the engine negative terminal or the DC main negative bus on grounded DC systems, or the boat's DC grounding (stray current) bus in installations using ungrounded DC electrical systems.

b) The negative terminal of the battery, and the negative side of the DC system, must be connected to the engine negative terminal or its bus. On boats with outboard motors, the load return lines must be connected to the battery negative terminal or its bus, unless the outboard motor manufacturer has supplied a means of connection to the engine negative terminal.

c) If an there is an accessory negative bus, it and its negative return must be at least equal to the ampacity of the feeder(s) to the panelboard(s) supplying the connected accessories.

d) If the negative side of the DC system is to be connected to ground, the connection must be only from the engine negative terminal, or its bus, to the DC grounding bus. This connection must be used only as a means of maintaining the negative side of the circuit at ground potential and is not to normally carry current.

e) Continuously energized parts, such as positive battery terminals and both ends of all wire connected to them, must have all energized surfaces insulated to prevent short circuits. Circuits that have CPD's at the power source as prescribed in E-9.12 are exempt from this. It is interesting to note the ambiguity in this passage. Nowhere in the Standards is the term "continuously" defined. If the term is strictly defined, then all those circuits turned off when the boat's main battery switch is off would be exempt from this section. This is not, however, the common interpretation of the section.

E-9.6 MARKING

1. Each switch and electrical control must have its usage marked unless its purpose is obvious and its mistaken operation will not cause a hazardous condition.

2. Each separate piece of electrical equipment, when not embodied as part of a larger assembly, such as an engine, must be marked by the manufacturer with:
a) manufacturer name
b) product identification;
c) DC electrical rating in volts; and rated amperage or wattage of electrical equipment may be marked on the device.
d) the terminal polarity or identification, if necessary to operation;
e) "ignition protected," if applicable. This must be identified by a marking such as "SAE J1171-Marine," "UL Marine Ignition Protected," or "Ignition Protected."

3. This section of E-9.6 also says that "Rated amperage or wattage of electrical equipment shall be available" and indicates that it may be marked on the device. How it is to be made "available" is not specified, presumably it could be included in the product packaging or instructions.

E-9.7 AMBIENT TEMPERATURE

The ambient temperature of machinery spaces is considered to be 50°C (122°F), and of all other spaces is considered to be 30°C (86°F). It should be noted that these temperatures do not match some values used as ambient temperatures in some of the standards published by ABYC referenced bodies, such as SAE. For instance, SAE 1625, a common standard for circuit breakers stipulates a 25°C low ambient and an 82°C high ambient. There are many ambient temperatures used in the various standards.

E-9.8 CASES REQUIRING IGNITION PROTECTION

On gasoline boats

Electrical sources of ignition located in spaces containing gasoline powered machinery, or gasoline fuel tank(s), or joint fitting(s), or other connection(s) between components of a gasoline system must be ignition protected, unless the component is isolated from a gasoline fuel source as described in below. Boats using diesel fuel as the only fuel source and outboard engines mounted externally or in compartments open to the atmosphere in accordance with the requirements of ABYC H-2, Ventilation of Boats Using Gasoline are exempt from this.

On boats with LPG and CNG

If LPG or CNG is on the boat, all electrical sources of ignition in a compartment containing LPG or CNG appliances, cylinders, fittings, valves, or regulators must be ignition protected.

Boats with LPG or CNG systems installed in accordance with the requirements of ABYC A-1, Marine Liquefied Petroleum Gas (LPG) Systems, or ABYC A-22, Marine Compressed Natural Gas (CNG) Systems, and stoves complying with ABYC A-3, Galley Stoves, and electrical devices in the following compartments are except from this rule:

1. Accommodation spaces.

2. Open compartments having at least 15 square inches (970cm2) of open area per cubic foot (0.28cm3) of net compartment volume exposed to the atmosphere outside of the craft.

An electrical component is isolated from a gasoline fuel if:
1. A bulkhead that meets the requirements an Isolating Bulkhead is between the electrical component and the gasoline fuel source, or

2. The electrical component is lower than the gasoline fuel source, and a means is provided to prevent gasoline fuel and gasoline fuel vapors that may leak from the gasoline fuel sources from becoming exposed to the electrical component; or

3. higher than the gasoline fuel source, and a deck or other enclosure is between it and the gasoline fuel source; or

4. the distance between the electrical component and the fuel source is at least two feet (610mm), and the space is open to the atmosphere. "Open to the atmosphere" is defined as having 15 square inches of ventilation opening per cubic foot of compartment space.

This is a very significant passage in the Standards that provides a way to install non-ignition protected devices in gasoline engine spaces when necessary.

Definition of Isolating Bulkhead

Separates the electrical component from the fuel source, and extend, both vertically and horizontally, the distance of the open space between the gasoline fuel source and the ignition source, and

Resists a water level that is 12 inches (305mm) high, or one-third of the maximum height of the bulkhead, whichever is less, without seepage of more than one-quarter fluid ounce (7.4cc) of fresh water per hour, and

Has no opening higher than 12 inches (305mm), or one-third the maximum height of the bulkhead, whichever is less, unless the opening is used for the passage of conductors, piping, ventilation ducts, mechanical equipment, and similar items, or doors, hatches, and access panels; and the maximum annular space around each item or door, hatch or access panel shall not be more than one-quarter inch (6mm).

migration of carbon monoxide

To minimize the potential for migration of carbon monoxide from machinery compartments containing gasoline

engines to adjacent accommodation compartments, bulkhead and deck penetrations shall be in accordance with the requirements of ABYC H-2, Ventilation of Boats Using Gasoline.

E-9.9 LOAD CALCULATIONS

ABYC offers a method that must be used for calculating the total electrical load requirements for determining the minimum size of each distribution panel and its main conductors. The information may also be used to size the alternator, or other charging means, and the battery.

The process involves dividing the boat's DC electrical loads into two categories. "A" category items are loads that must be available for continuous usage, while category "B" items are those that are intermittent.

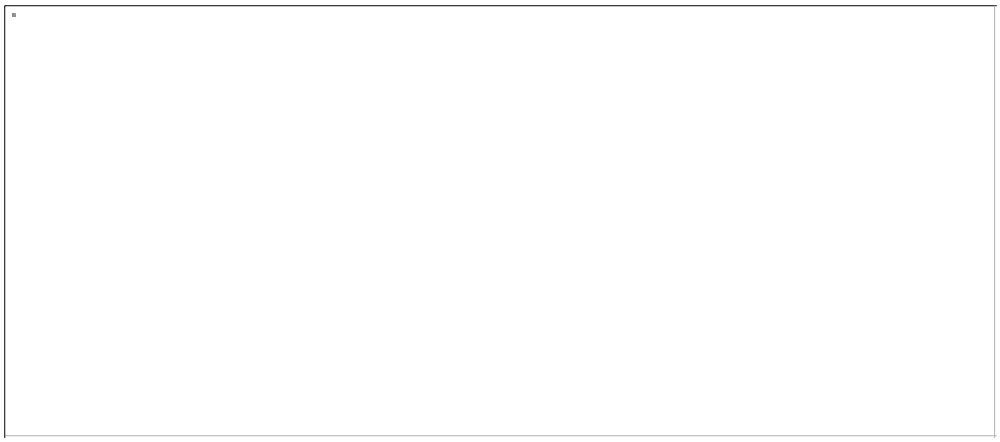
The steps are these:

1. Determine the current rating in amps of the Category "A" loads that must be available for use on a continuous duty basis for normal operations.

2. Determine the current rating in amps of the remaining loads that are intermittent, and total these loads.

3. Take 10% of the total load in column B, or the current draw of the largest item, whichever is greater, and add this value to the total from column A to establish the total electrical load.

Calculations are based on the actual operating amperage for each load, and not on the rating of the circuit breaker or fuse protecting that branch circuit.



There are two main areas of ambiguity in this section. The wording of E-9.9 suggests that the listed Category A and B loads are the only loads that are to be taken into account when making load calculations. Clearly this cannot be the case. If the boat has other continuous loads that are routed through the distribution panel, then clearly these loads must be taken into account. Conversely, it may be that some Category A listed in E-9.9 loads are not routed through the panel and should not be included in the calculation.

The second area of ambiguity concerns the modest equipment inventory covered in the two categories. Most modern boats above 35 feet will have far more electrical loads that will have to be considered in making load calculations.

Our interpretation of E-9.9 is that it is meant to give an example of how to approach the issue of load calculation rather than being a comprehensive step-by-step procedure.

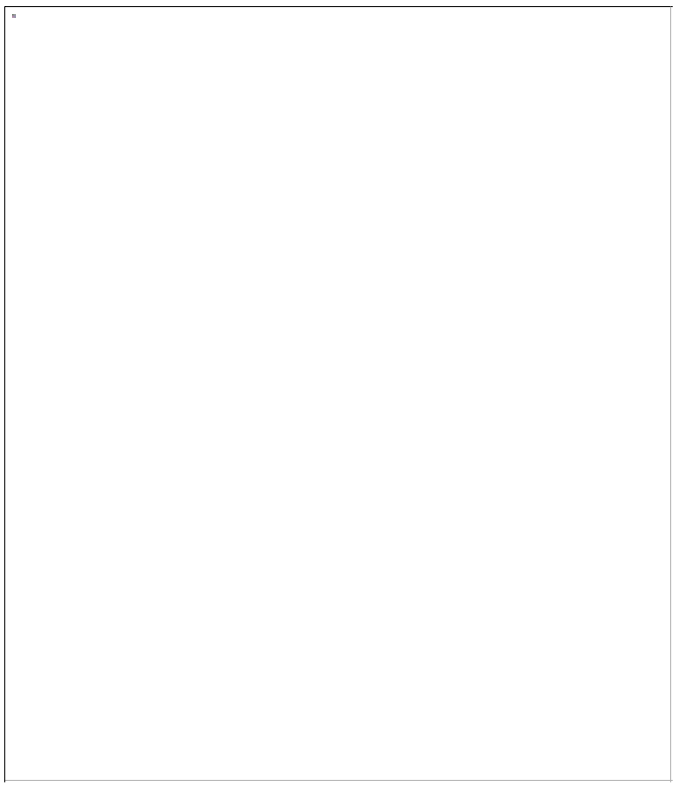
E-9.10 BATTERY CAPACITY

This section states the requirements for a boat's battery banks, stating that the battery bank must meet the following criteria:

1. A boat's battery bank must have at least the cold cranking amperage required by the engine manufacturer.

2. For boats with one charging source the battery must be capable of supplying the total load of Category A discussed in section E-9.9 for a minimum of 1 1/2 hours. For boats with multiple simultaneous charging sources, the capacity of all charging sources, except the largest charging source must be subtracted from the total load of Category A. The battery must be capable of supplying the resulting differences for a minimum of 1 1/2 hours.

This section offers a table to be used to calculate the reserve capacity values. It should be noted that in this section ABYC is not using the term "reserve capacity" as it is normally used in reference to battery capacities. See Blue Sea Systems' technical Appendix.



This section also gives Peukert's equation for calculating the required reserve capacity:
T = 0.0292 x I 1.225 x 60
T = battery reserve capacity in minutes
I = total current of Category A loads from E-9.9.1

E-9.11 DC POWER SOURCES

Where Overcurrent Protection is Required

Ungrounded conductors must have overcurrent protection within 7 inches (175mm) of the conductor connection to the source of power measured along the conductor. There are two exceptions to this rule:

1 If the conductor is connected directly to the battery terminal and is contained entirely in a sheath or enclosure such as a conduit, junction box, control box or enclosed panel, the overcurrent protection must be as close as possible to the battery, but not more than 72 inches (1.83m).

2 If the conductor is connected to a source of power other than a battery terminal and is contained throughout its entire distance in a sheath or enclosure such as a conduit, junction box, control box or enclosed panel, the overcurrent protection must be as close as practicable to the point of connection to the source of power, but not more than 40 inches (1.02m).

Ungrounded conductors connected to a battery charger, alternator, or other charging source, must have overcurrent protection within 7 inches (175mm) of the point of connection to the DC electrical system or to the battery. There are two exceptions to this rule:

1. If the conductor is connected directly to the battery terminal and is contained throughout its entire distance in a sheath or enclosure such as a conduit, junction box, control box or enclosed panel, the overcurrent protection must be placed as close as practicable to the battery, but not more than 72 inches (1.83m).

2. If the conductor is connected to a source of power other than a battery terminal and is contained throughout its entire distance in a sheath or enclosure such as a conduit, junction box, control box or enclosed panel, the overcurrent protection must be placed as close as practicable to the point of connection to the source of power, but not to exceed 40 inches (1.02m). Overcurrent protection is not required in conductors from self-limiting alternators with integral regulators if the conductor is less than 40 inches (1.02m), is connected to a source of power other than the battery, and is contained throughout its entire distance in a sheath or

enclosure.

Additionally, the ungrounded conductor must have overcurrent protection within the charging source, or within 7 inches (175mm) of the charging source, based on the maximum output of the device, unless the device is self-limiting. See the Blue Sea Systems' Technical Glossary for a definition of Self-Limiting.

Battery Switches
A battery switch must be installed in the positive conductor(s) from each battery or battery bank with a CCA rating greater than 800 amperes. This is about the CCA of one large Group 24 Starting Battery. There are two exceptions to this rule:

1. Trolling motor conductors connected to dedicated trolling motor batteries provided with overcurrent protection at the battery and a manual means of electrical disconnect separate from the trolling motor controls.

2. Conductors supplying the following may be connected to the battery side of the switch (see Figure 12):
a. Electronic equipment with continuously powered memory;
b. Safety equipment such as bilge pumps, alarms, CO detectors and bilge blowers;
c. Battery charging equipment.

The battery switch must be in a readily accessible location as close as possible to the battery.

The intermittent rating of a battery switch must not be less than the maximum cranking current of the largest engine cranking motor that it serves. The minimum continuous rating of a battery switch must be the total of the ampacities of the main overcurrent protection devices connected to the battery switch, or the ampacity of the feeder cable to the switch, whichever is less. The ratings referred to here are the UL standards for Battery Switches. See the Blue Sea Systems' Technical Glossary for a description of these standards. An ambiguity in this part of the standard is the requirement for a battery switch to have an "intermittent rating … not be less than the maximum cranking current of the largest engine cranking motor". If this is interpreted literally, it would be almost impossible to locate such a switch for any but the smallest engines. Even relatively small diesels of 200 HP have maximum amperage draws of nearly 1000 amperes. In practical application the standard is referring not to the maximum current, but to the plateau that proceeds the maximum current.

E-9.12 OVERCURRENT PROTECTION

M**otors or Motor Operated Equipment**
Motors and motor operated equipment, except for engine cranking motors, must be protected internally at the equipment, or by branch circuit overcurrent protection devices suitable for motor current. The protection provided must prevent a fire hazard if the circuit, as installed, is energized for seven hours under any conditions of overload, including locked rotor.

To achieve this it may be necessary to:
1. Use thermally responsive protection devices on the equipment or system if the motor is not capable of operating continuously at maximum possible loading.

2. Test as installed in order to assure compliance with the locked rotor requirement. Voltage drop, due to wire size, and delay characteristics of the overcurrent protection device may have to be adjusted to protect the motor.

Non-motor Loads

The rating of overcurrent protection devices used to protect a load other than a DC motor must not exceed 150 percent of the ampacity of its supply wire.

Branch Circuits
Each ungrounded conductor of a branch circuit must have overcurrent protection at the connection to the main switchboard unless the main circuit breaker or fuse provides this protection.
Each fuse or trip-free circuit breaker must be rated in accordance with Motors or Motor Operated Equipment and Non-Motor Loads, above, and must not exceed 150 percent of the rated wire ampacity.

Panelboards and Switchboards
A trip-free circuit breaker or a fuse must be at the source of power for panelboards and switchboards, and must not exceed 100 percent of the load capacity of that panel, or 100 percent of the current carrying capacity

of the feed wires. The exception to this is that the trip free circuit breaker or fuse at the source of power may be rated at up to 150 percent of the conductor ampacity if there is a sub-main circuit breaker or fuse in the panelboard or switchboard that is rated at no more than 100 percent of the load capacity, or the feeder ampacity, whichever is less.

Circuit Breakers
Circuit breakers installed in spaces requiring ignition protection must comply with SAE J1171, External Ignition Protection of Marine Devices, or UL 1500, Ignition Protection Test for Marine Products. If internal explosion tests are required, the ignition of the test gas must be created at 4 times the current rating of the device being tested.

Circuit breakers must:
1. have a DC voltage rating of not less than the nominal system voltage, and
2. be of the trip-free type (See the Blue Sea Systems' Technical Glossary for a definition of Trip-Free), and
3. be capable of an interrupting capacity according to Table III, and remain operable after the fault. A fuse in series with, and ahead of the circuit breaker, may be used to achieve the required Interrupt Rating

Integral overcurrent protection in electrical devices are exempt from this requirement.

Fuses
1. Fuses must have a voltage rating of not less than the nominal system voltage.

2. Fuses installed in spaces requiring ignition protection must comply with SAE J1171, External Ignition Protection for Marine Devices, or UL 1500, Ignition Protection Test for Marine Products. If internal explosion tests are required, the ignition of the test gas must be created at four times the rating of the fuse.

Integral Overcurrent Protection Devices
Integral overcurrent protection devices without a manual reset may be used as an integral part of an electrical device if the rest of the circuit is protected by a trip-free circuit protection device(s) or a fuse(s).

Pigtails
Pigtails less than 7 inches (175mm) in length are exempt from overcurrent protection requirements.

Switches
If single pole switches are used in branch circuits they must be installed in the positive conductor of the circuit. The are two exceptions to this:

1. Engine mounted pressure, vacuum, and temperature operated switches.
2. Switches such as those used for control of alarm systems.

Switches must have voltage ratings not less than the system voltage, current ratings not less than the connected load, and must be rated for the type of load, i.e., inductive or resistive. Battery switches are exempt from this. The intermittent rating of a battery switch must not be less than the maximum cranking current of the largest engine cranking motor that it serves. The minimum continuous rating of a battery switch must be the total of the ampacities of the main overcurrent protection devices connected to the battery switch, or the ampacity of the feeder cable to the switch, whichever is less.

E-9.14 APPLIANCES AND EQUIPMENT

DC Appliance Design
Appliances and fixed DC electrical equipment must be designed so the current carrying parts of the device are insulated from all exposed electrically conductive parts. There are eight exceptions to this:

1. 12-volt equipment not located in machinery spaces, not in contact with bilge, and not in contact with a fuel line.
2. Communications and audio equipment
3. Electric navigation equipment
4. Instruments and instrument clusters
5. Liquid level gauge transmitters. For installation of fuel tank transmitters on conductive surfaces. See Grounded Liquid Level Gauge Senders.
6. Navigation lights operating at nominal 12 volts. See ABYC A-16, Electric Navigation Lights.
7. Auxiliary generator sets
8. Engine mounted equipment. See E-9.5.1.

All these devices, 1 through 8 above, must be installed with the case negative, and the positive connection

identified.

Appliances requiring DC Grounding Connection
All exposed electrically conductive non-current carrying parts of fixed DC electrical equipment, and appliances that may normally be in contact with bilge water or seawater, must be connected to the DC grounding system. There are four exceptions to this:

1. Boats not equipped with a DC grounding system.
2. Equipment with an effective double insulation system.
3. Metal parts isolated in non-conductive material
4. Electric trolling motors

Grounded Liquid Level Gauge Senders
Grounded liquid level gauge transmitters mounted on fuel tanks or tank plates must have the transmitter negative return conductor connected directly to the DC main negative bus, the engine negative terminal, or for outboard boats, the battery negative terminal or its bus. No other device can be connected to this conductor. This conductor must also serve as the static ground and/or the bonding conductor for the tank and fill. If a fuel tank is included in the lightning protection system the conductor between the fuel tank and the DC main negative bus must meet the requirements of ABYC E-4, Lightning Protection.

E-9.15 SYSTEM WIRING

Standards for Wire
Conductors and flexible cords must be rated at least 50 volts.

Insulated cables and conductors must meet the requirements of:
1. UL 1426, Cables for Boats, or

2. the insulating material temperature rating requirements of SAE J378, Marine Engine Wiring, and SAE J1127, Battery Cable, or SAE J1128, Low-Tension Primary Cable.

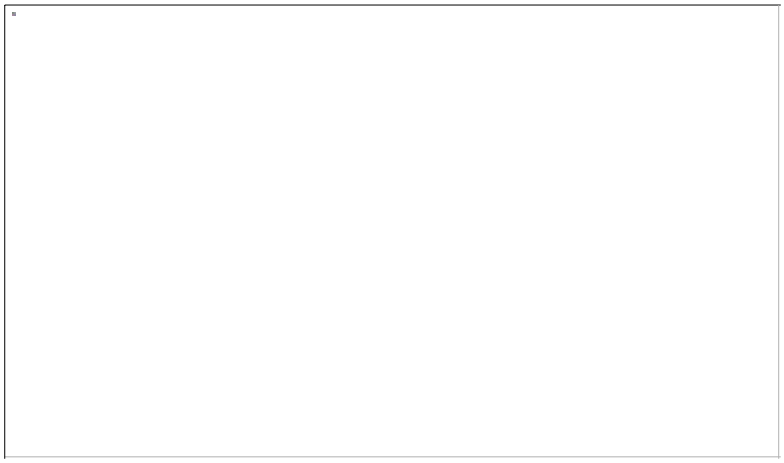
Allowable Wire Types
Conductors may be selected from the types listed in 3 ABYC tables:
1. SAE CONDUCTORS
2. FLEXIBLE CORDS
3. CONDUCTORS

The standards state: "The temperature ratings shown contemplate the routing of wires above bilge water in locations protected from dripping, exposures to weather, spray, and oil."

Wire Marking
Marking of the individual conductors and their jackets must include:
1. type/style,
2. voltage,
3. wire size, and
4. temperature rating, dry.
Flexible cords in Table VI are exempt from this

Flexible Cords
Flexible cords must conform to the National Electrical Code, and be one of following types:
SO Hard service cord, oil resistant compound
ST Hard service cord, thermoplastic
STO,SEO Hard service cord, oil resistant thermoplastic
SJO Junior hard service cord, oil resistant compound
SJT Junior hard service cord, thermoplastic
SJTO Junior hard service cord, oil resistant thermoplastic

Stranding
Conductors and flexible cords must be stranded copper according to this table:



Amperage Capacity Required of Wires
Conductors used for panelboard or switchboard main feeders must have ampacities as determined in E-9.9, above. Conductors used for branch circuits or in electrical systems that do not use a panelboard or switchboard must have their ampacities determined by their loads (see Table I).

Voltage Drop Sizing of Wires
Conductors used for panelboard or switchboard main feeders, bilge blowers, electronic equipment, navigation lights, and other circuits where voltage drop must be kept to a minimum, must be sized for a voltage not more than 3 percent. Conductors used for lighting, other than navigation lights, and other circuits where voltage drop is not critical, must be sized for a voltage drop not more than 10 percent.

Determination of Wire Size by Tables
To determine conductor size and insulation temperature rating, use the ampacity as specified in E-9.15.7 in conjunction with the table "Temperature Rating of Conductor Insulation". This table is reproduced in the Bue Sea Systems" Catalog and the web site. Then use either the table "CONDUCTOR SIZES FOR 3 PERCENT DROP IN VOLTAGE" of "CONDUCTOR SIZES FOR 10 PERCENT DROP IN VOLTAGET" to check the conductor size for compliance with the maximum allowable voltage drop. In the event of a conflict between the ampacity table and the voltage drop tables, the larger conductor size must be used. Remember, the lengths specified in the tables are for the positive and negative legs.

The power source connection may be the battery, or a panelboard or switchboard, if used.

Determination of Wire Size by Formulas
If the ampacity as specified in E-9.15.7 exceeds the ampacities in the tables, the conductor size necessary to keep voltage drop below the maximum permitted level may be calculated by the following formula:

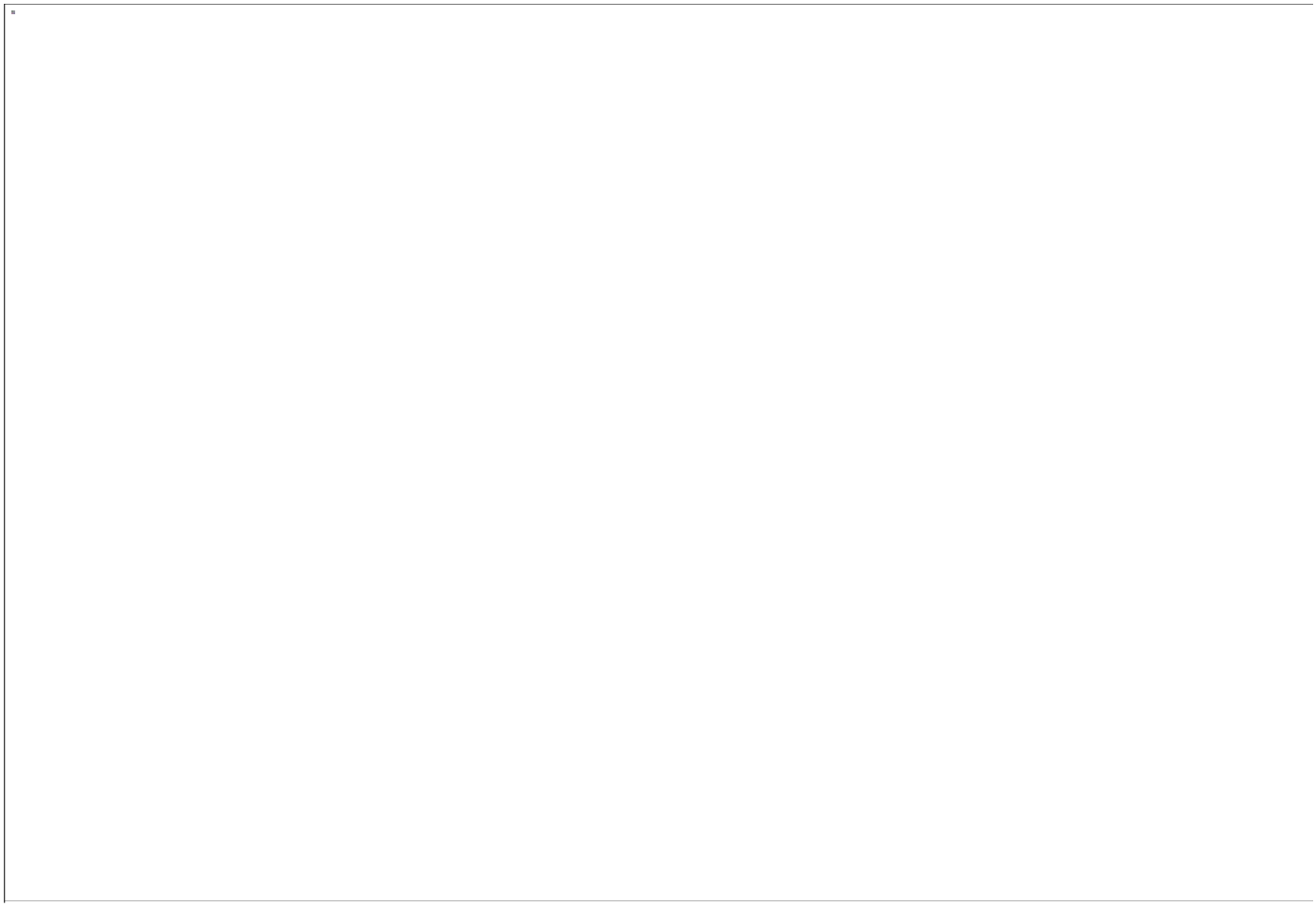
Use Table VII to convert circular mils to conductor gauge. If the CM area falls between two gauge sizes, the larger conductor must be used. See the Technical Glossary for an explanation of Circular Mils.

E-9.16 WIRING IDENTIFICATION
Each electrical conductor that is part of the boat's electrical system, except pigtails less than 7", must have an identification of its function in the system.

Insulated grounding conductors must be identified by the green or green with yellow stripe(s).

The following colors are to be used for DC general wiring purposes on boats:

Also contained in this section is a table identifying a selection of colors that may be used for coding engine accessory wiring. This scheme is not mandatory and other schemes may be used if the key to the coding is provided with the boat.



The color-coding does not need to be on the entire wire length. It may be sleeving or color application at the wire terminals. If tape is used to mark a wire, the tape must be at least 3/16 inch (5mm) wide and must make at least two complete turns around the wire. The tape must be visible near each terminal.

E-9.17 INSTALLATION

Wiring must be installed to avoid magnetic loops near compasses and magnetically sensitive devices. Direct current wires that may create magnetic fields in these areas must be run in twisted pairs.

Junction boxes, cabinets, and other enclosures in which electrical connections are made, must be weatherproof or installed in a protected location.

In wet locations, metallic junction boxes, cabinets, or enclosures must be mounted to minimize the entrapment of moisture between the box, cabinet, or enclosure and the adjacent structure. If air spacing is used to do this, the minimum spacing must be 1/4 inch (7mm).

Current carrying conductors must be as high as possible above the bilge water level and other areas where water may accumulate. If conductors must be routed in the bilge, or other areas where water may accumulate, the wiring and connections must be watertight.

Conductors must be routed as far as possible from exhaust pipes and other heat sources. Unless an equivalent thermal barrier is provided, a clearance of at least 2 inches (51mm) between conductors and water-cooled exhaust components, and a clearance of at least 9 inches (230mm) between conductors and dry exhaust components, must be maintained. Conductors other than engine and exhaust temperature sensor wiring must not be directly above a dry exhaust.

Battery cables without overcurrent protection must:
1. Be routed above normal bilge water levels throughout their length;
2. Be routed to avoid contact with metallic fuel system components;
3. Be routed to avoid contact with any part of the engine or drive train if an ungrounded cable.

Conductors that may be exposed to physical damage must be protected by self-draining loom, conduit, tape, raceways, or other equivalent protection. Conductors passing through bulkheads or structural members must be protected to minimize insulation damage such as chafing. Conductors must be routed clear of sources of

chafing such as steering cable and linkages, engine shafts, and throttle connections.

DC conductors must be sheathed, bundled, or otherwise separated from AC conductors.

Conductors must be at least 16 AWG. 18 AWG conductors may be used if included with other conductors in a sheath, and do not extend more than 30 inches (760mm) outside the sheath or have a current flow of less than one amp in communication systems, electronic navigation equipment and electronic circuits or are completely inside an equipment housing.

Conductors other than battery cables less than 36" long and cables attached to outboard motors must be supported throughout their length or shall be secured at least every 18 inches (455mm) by one of the following methods:

1. By non-metallic clamps sized to hold the conductors firmly in place. Non-metallic straps or clamps shall not be used over engine(s), moving shafts, other machinery or passageways, if failure would result in a hazardous condition. The material shall be resistant to oil, gasoline, and water and shall not break or crack within a temperature range of -34°C (-30°F) to 121°C (250°F);

2. By metal straps or clamps with smooth, rounded edges to hold the conductors firmly in place without damage to the conductors or insulation. That section of the conductor or cable directly under the strap or clamp shall be protected by means of loom, tape or other suitable wrapping to prevent injury to the conductor;

3. By metal clamps lined with an insulating material resistant to the effects of oil, gasoline, and water.

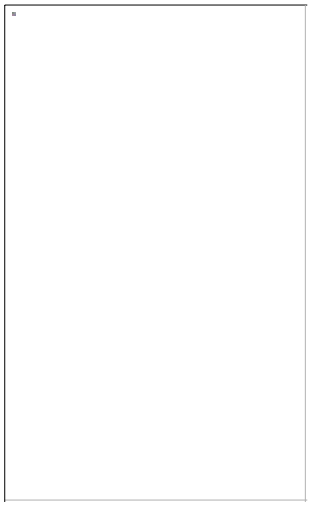
Electrical appliances and equipment designed for permanent installation must be securely mounted to the boat's structure.

Wiring Connections
All connections must be in locations protected from the weather, or in weatherproof enclosures, or watertight. If connections are exposed to immersion they must be watertight.

Wiring connections must be designed and installed to make mechanical and electrical joints without damage to the conductors.

Metals used for terminal studs, nuts, and washers must be corrosion resistant and galvanically compatible with the conductor and terminal lug. Aluminum and unplated steel may not be used for studs, nuts, and washers.

Each conductor splice joining conductor to conductor, conductor to connectors, and conductor to terminals must be attached with crimping tools designed for the connector used, and to produce a connection able to withstand a tensile force equal to at least the value shown below for the smallest conductor size used in the splice for a one minute duration and not break:



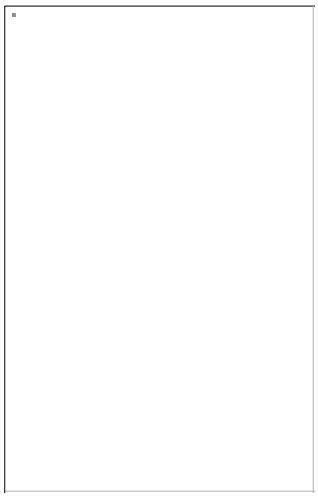
Terminal connectors must be ring or captive spade. Friction type connectors may be used if the voltage drop from terminal to terminal does not exceed 50 millivolts at 20 amps and the connection does not separate under a six pound (2.75kg) tensile force along the axial direction of the connector for one minute.

Connections may use a setscrew system if there is a means to prevent the screw from bearing directly on the wire strands.

Twist-on connectors, i.e., wire nuts, may not be used.

Solder must not be the only mechanical connection in any circuit. If soldered, the connection must be located or supported to minimize flexing of the conductor where the solder changes the flexible conductor into a solid conductor. Battery lugs with a solder contact length of not less than 1.5 times the diameter of the conductor are exempt from this.

Crimp-on connectors must be attached with crimping tools designed for the connector used, and to produce a connection able to withstand a tensile force equal to at least the value shown below for the smallest conductor size used in the splice for a one minute duration and not break:



No more than four conductors may be on any terminal stud. If additional connections are necessary, two or more terminal studs may be connected together with jumpers or copper straps.

Ring and captive spade type terminal connectors must be the same nominal size as the stud.

Conductors terminating at switchboards, in junction boxes, or fixtures shall be arranged to provide a length of conductor to relieve tension, to allow for repairs, and to permit multiple conductors to be fanned at terminal studs.

Except for terminal shanks in grounding systems, terminal shanks of must be protected against accidental shorting with insulation barriers or sleeves

E-9.18 RECEPTACLES

Receptacles in locations subject to rain, spray, or splash must be weatherproof when not in use. This can be by means such as spring-loaded, self-closing, or snap-type receptacle covers.

Receptacles installed in areas subject to flooding or momentary submersion must be of watertight design, whether in use or not.

Receptacles and matching plugs used on DC systems must not be interchangeable with receptacles and matching plugs used on the boat for AC systems.

E-9.19 PLUG CONNECTIONS

Multi-wire plugs and receptacles used in with harness type wiring systems must:

1. Incorporate means, such as cable clamps, molded connectors, insulation grips, extended terminal barrels, etc., for supporting all wires to limit flexing at the connection, and

2. Must be weatherproof, or if subject to immersion, watertight.

Each terminal in a multi-wire plug and receptacle must be protected from accidental short-circuiting to adjacent terminals.
Plug connectors must have a minimum disengagement force of 6 pounds (2.75kg) along the axial direction of the connector for one minute.

The plug connector's capacity must meet or exceed the ampacity and temperature rating of the connecting conductors in addition to its wire size capability.

E-9.20 MAIN DISTRIBUTION PANEL

A main distribution panel must be in an accessible location, and must be weatherproof or protected from the weather and splash.

Distribution panels used on boats with more than one system voltage must have a permanent marking showing the system voltage and type (AC or DC).

Distribution panels must have no exposed energized AC parts accessible to the operator when the DC panel is open.

E-9.21 DC GROUNDING AND BONDING

What is Connected
If a DC grounding system is installed, the DC grounding conductor must connect metallic non-current carrying parts of the following DC devices to the engine negative terminal or its bus to minimize stray current corrosion:

All exposed electrically conductive non-current carrying parts of fixed DC electrical equipment, and appliances that may normally be in contact with bilge water or seawater. Except equipment with an effective double insulation system, metal parts isolated in non-conductive material, or electric trolling motors.

Conductor Sizing
A DC grounding conductor must not be smaller than one size under that required for current carrying conductors supplying the device and not less than 16 AWG.

Conductor Routing
The DC grounding conductor must be routed from the device to the engine negative terminal or the DC main negative bus together with the current carrying conductors as a third wire or as a separate conductor.

Bus Required
The DC grounding conductor must be connected to a DC grounding bus as described below in DC Grounding Bus Requirements

Connections
DC grounding conductor connections must be according to the E-9.17 section titled Wiring Connections.

DC Grounding Bus Requirements
The DC grounding bus must be connected directly to the engine negative terminal or the DC main negative bus.

The DC grounding bus serving more than one electrical device must comply with Conductor Sizing, Conductor ***Routing, and Connections,*** above, for the largest device, and must:

1. be at least 1/32 inch (0.8mm) thick and 1/2 inch (13mm) wide if made of copper or bronze strip; and

2. be drilled and tapped if this provides no less than three full threads of engagement for the terminal screws; or

3. be through-drilled, and the connections made with machine screws and locknuts.

Copper pipe may be used if its wall thickness is sufficient for the pipe to be drilled and tapped as required above. Copper braid may not be used.

Combined DC Grounding and Bonding Systems
The DC grounding conductors may be combined with the following systems if all the requirements with respect to conductor size are met for each system:
1. Lightning Protection - See ABYC E-4, Lightning Protection.
2. Cathodic Bonding - See ABYC E-2, Cathodic Protection.
3. Static Electricity Grounding - See E-9.14.4, ABYC H-24, Gasoline Fuel Systems, and ABYC H-33, Diesel Fuel Systems.

Radio Ground Plate
If the radio ground plate is connected to the engine negative terminal, the connecting conductor must meet the requirements of ABYC E-4, Lightning Protection, since a radio ground plate may also function as a lightning ground plate.

Coaxial Cables and Conduit
The metallic braid of coaxial cables and metal conduit used for radio interference, or any form of radio shielding or armoring, must be