APLUXOR MARINE ELECTRICAL LIBRARY · PART II. WIRE, CONNECTIONS, PROTECTION — WHAT BURNS

Chapter 5. Wire and Connections: Why Things Get Hot and Why Voltage Drops

Which wire, how thick, and how to join it so that it stays cool and keeps its voltage

A wire too thin for its current or its length, or a joint that lets in water, turns voltage into heat in places nobody watches. This chapter shows you how to tell marine wire from automotive wire, size a wire by formula, and make a connection that survives salt and vibration.

AFTER THIS CHAPTER YOU CAN

- read the print on a wire and tell what the regulation and ABYC accept on a boat, automotive wire included;
- size the replacement for a wire marked in mm² on a European-built boat, never smaller;
- find a wire's ampacity where it runs: alone, in an engine space, or beside the other conductor of its cable;
- size a wire for its voltage drop with ABYC's formula over the round trip in feet, and take the larger of the two answers;
- read the DC colors on a boat as a hint, and trace a wire to prove what it is;
- replace a ring terminal or remake a splice with a ratcheting crimper and adhesive-lined heat shrink, and stack lugs on a stud in the right order;

- check a run for support, chafe and heat, and check a connection by its drop under load.

Read first: → 3.1, → 3.4, → 4.3

5.1 Marine wire: what it is
5.2 Reading the wire: gauge, circular mils and mm²
5.3 Ampacity and derating: engine space and bundles
5.4 Voltage drop: sizing a wire for 3 % or 10 %
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5.7 Routing and support
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5.9 Marine-grade or not? Automotive wire, store terminals, tape
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5.1. Marine wire: what it is

What makes a wire right for a boat, and may the automotive wire or the household cable you already have go aboard? Two documents answer it: the federal regulation for boat builders, 33 CFR 183, and the ABYC standard E-11. Both judge a wire by how it is built and by what is printed on it, not by the store that sold it.

The regulation asks that each conductor be insulated, stranded copper. It applies to a boat within its scope (→ 1.9), and it names eight exceptions: communications systems; electronic navigation equipment; electronic circuits with a current of less than one ampere; conductors totally inside an equipment housing; resistance conductors that control circuit amperage; high-voltage secondary conductors and terminations in ignition systems; pigtails with less than 7 in of exposed length; and cranking motor conductors. Each conductor installed on its own is at least 16 AWG; a conductor inside a multiconductor sheath may be 18 AWG and may leave the sheath for no more than 30 in. CFR

For a circuit of less than 50 V the regulation gives two ways to meet it. A conductor either meets the section for 50 V and more, or meets the insulation temperature rating requirements of SAE J378 together with

SAE J1127 or J1128, the SAE standards for battery cable and for low-tension primary cable. The section for 50 V and more accepts four kinds of conductor: one that meets UL 1426, the standard for boat cable; one whose insulation is listed as moisture resistant and flame retardant in Article 310 of the National Electrical Code; a flexible cord of type SO, STO, ST, SJO, SJT or SJTO listed in its Article 400; and one that meets IEEE Standard 45. So the regulation allows automotive wire made to J1127 or J1128, with J378's insulation rating, in a 12 V or 24 V circuit. Whether a given automotive wire suits a given place is decided by its print and its construction, and → 5.9 · p. 35 weighs it. CFR

ABYC's 2008 edition of E-11 accepts the same two constructions: UL 1426, or the temperature rating requirements of SAE J378 with SAE J1127 or J1128. It asks that these conductors be rated for at least 50 V. ABYC

UL 1426 covers electrical cables for pleasure boats. Its single conductors are stranded copper from 16 to 4/0 AWG, rated 600 V, with a dry temperature rating of up to 105 °C (221 °F) and a wet rating of up to 90 °C (194 °F); a cable marked for oil has insulation made for places where oil reaches it, at 60 °C (140 °F) and below. For its ampacity, UL 1426 points to the tables of the regulation.

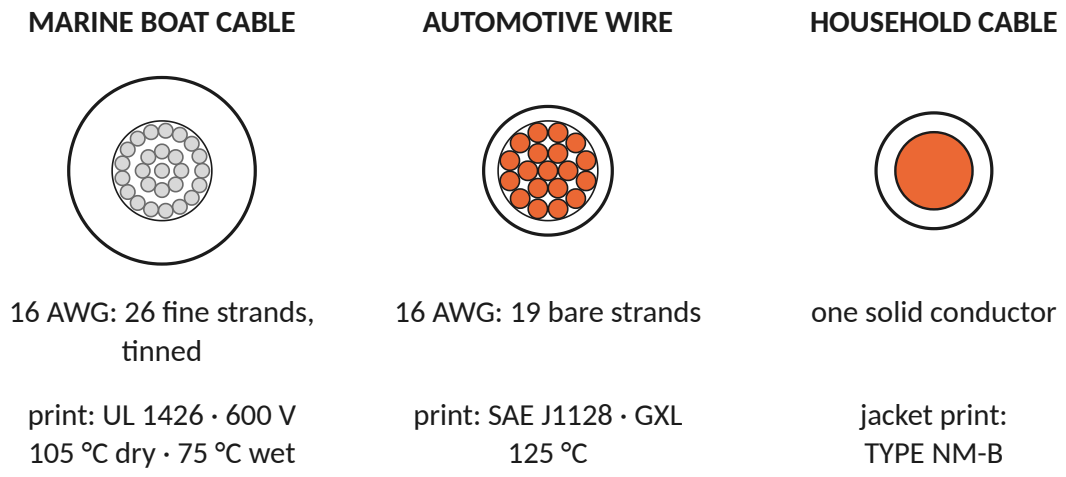


Fig. 5.1. Three wires of about the same size, cut across: marine boat cable, automotive primary wire and one conductor of household cable. The prints are examples; read the one on your own wire. On them, 105 °C is 221 °F, 75 °C is 167 °F and 125 °C is 257 °F.

ABYC also counts the strands. Solid wire, and any wire with fewer strands than its Type 2 count, is not to be used. Type 2 is the minimum for general boat wiring; Type 3, with more and finer strands, is for wiring that flexes often in normal use. For 16 AWG that means at least 19 strands for Type 2 and 26 for Type 3. A wire held still by its clamps needs only Type 2; a wire that bends each time a hatch opens, or that runs from an engine on flexible mounts to the hull, needs Type 3. ABYC

In an engine space ABYC asks for more: insulation that is oil resistant and rated at least 75 °C (167 °F) dry. The regulation's own table, for its part, has a factor for 60 °C wire in an engine space (→ 5.3 · p. 7). ABYC

ABYC writes that its temperature ratings assume wire routed above the bilge water, in places protected from dripping, weather, spray and oil. A boat cable has a wet rating as well as its dry one, and → 5.3 · p. 7 says where the wet rating counts. ABYC

Tinned copper is copper whose strands are coated with tin. The regulation's words are "insulated, stranded copper", and tin is not part of them. CFR

ABYC's 2008 text asks for stranded copper by its strand table, and does not name tin either. ABYC

Makers of marine wire add it. One maker's specification for its UL 1426 wire reads "tinned stranded copper", and a second maker sells its marine battery cable with tinned strands as well; one distributor's automotive GXL wire is bare copper, with tin as an option. MFR

One inverter maker's wiring guide asks for cables with tin-coated strands, which it calls "marine cables", in marine or moist places.

Household cable is built for a house. One maker's NM-B cable, the cable inside house walls, has a solid conductor in 14, 12 and 10 AWG, is made for "normally dry locations", and limits its ampacity to the 60 °C (140 °F) column. A solid conductor is what ABYC's stranding note rules out and what the regulation's "stranded" excludes. → 5.6 · p. 16 shows what ABYC's note on soldered joints says flexing does where solder has turned stranded wire solid. PRACTICE MFR

What decides, then, is the print. Read it on every wire you meet: a standard (UL 1426, SAE J1127 or J1128, or another that the regulation accepts), a gauge, a temperature rating, and a voltage. A wire whose print names none of the standards the regulation accepts gives you no evidence that it meets the regulation, whatever it was sold as.

5.2. Reading the wire: gauge, circular mils and mm²

What does the print on a wire tell you, and how do you choose its replacement from it? Read the print first. ABYC's 2008 text asks the maker to print on each conductor and its jacket at least its type or style, its voltage rating, its size and its dry temperature rating. ABYC

A wire's size in the US is its gauge in AWG, American Wire Gauge. A smaller number is a thicker wire: 10 AWG is thicker than 16 AWG. Thicker than 1 AWG, the sizes go on as 1/0, 2/0, 3/0 and 4/0, each thicker than the one before. Behind each gauge is an area of copper, measured in circular mils (CM): one circular mil is the area of a circle 0.001 in across. The area is what carries current and what the formulas of this chapter use (→ Table 5.1 · p. 5).

Table 5.1. Copper area of each AWG gauge, in circular mils, from the National Bureau of Standards copper wire tables

Gauge	Area	Gauge	Area
18 AWG	1,620 CM	4 AWG	41,740 CM
16 AWG	2,580 CM	2 AWG	66,360 CM
14 AWG	4,110 CM	1 AWG	83,690 CM
12 AWG	6,530 CM	1/0 AWG	105,600 CM
10 AWG	10,380 CM	2/0 AWG	133,100 CM
8 AWG	16,510 CM	3/0 AWG	167,800 CM
6 AWG	26,240 CM	4/0 AWG	211,600 CM

Automotive wire is sold by SAE gauge, and an SAE gauge holds less copper than the AWG gauge with the same number. ABYC's 2008 table lists both: 12 AWG is 6,530 circular mils, an SAE 12 gauge 5,833. ABYC

That is about 11 % less copper and about 12 % more resistance for the same length; from 16 to 2 gauge the SAE area is 6 % to 11 % smaller.

A wire whose print says SAE, or whose print you cannot read, is sized by its own copper area: the area its maker's sheet gives, or, without that, one size thicker than the AWG gauge that the formula of → 5.4 · p. 11 gives. One size thicker is enough at every gauge: ABYC's table gives each SAE size more copper than the AWG size one step thinner.

PRACTICE

On a European-built boat the print gives the area in square millimeters, mm², instead of a gauge (→ 2.5). One circular mil is 0.00050671 mm². Read the marking as printed, and replace the wire with the thinnest AWG gauge whose area is not smaller. A cable marked 6 mm² (between 10 AWG and 8 AWG) has 11,841 circular mils: 10 AWG, at 10,380, is smaller, so its replacement is 8 AWG. At large sizes the same mistake is made in the opposite direction, when a metric cable replaces an AWG one. 1/0 AWG is 105,600 circular mils, which is 53.5 mm²; a 50 mm² cable is 98,676 circular mils, smaller than 1/0. A 50 mm² cable is replaced by 1/0, and a 1/0 cable is never replaced by a 50 mm² one (→ Fig. 5.2 · p. 6). The printed metric sizes and their US replacements stand side by side in → App. B.

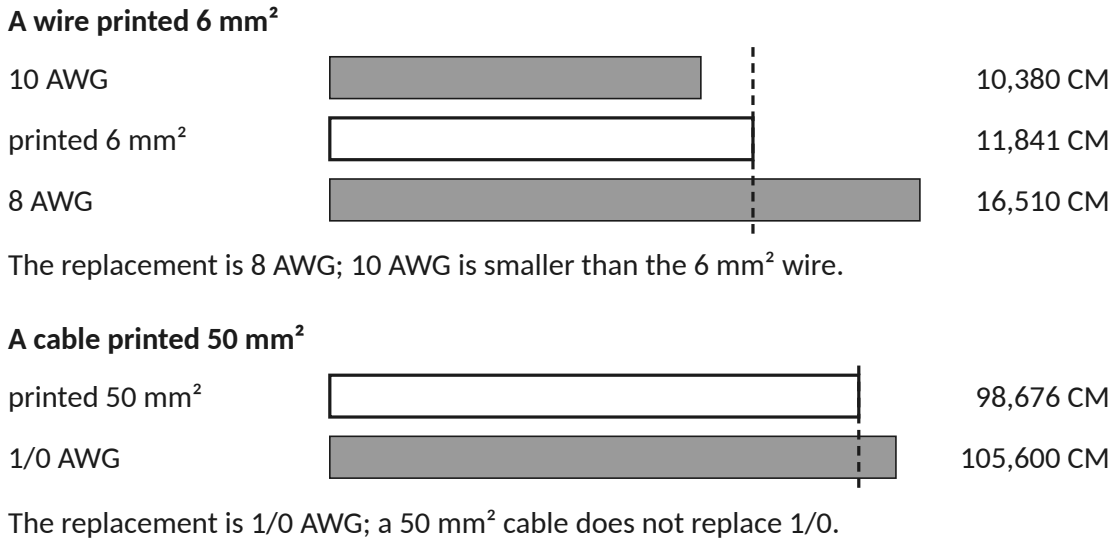


Fig. 5.2. The next-larger rule in copper area. Each group has its own scale; in both, the replacement is the AWG bar that reaches past the end of the metric bar.

Makers print pairs such as “16 AWG (1.5 mm²)” for the leads of one product. Such a pair names two sizes the maker accepts there, not two equal sizes: 1.5 mm² is 2,960 circular mils, more than the 2,580 of 16 AWG. A wire marked 1.5 mm² is replaced by 14 AWG. MFR

“Never smaller” settles one thing without a calculation: the new wire is not thinner than the old one. Its ampacity where it runs (→ 5.3 · p. 7) and its drop over its run (→ 5.4 · p. 11) are checked as for any wire.

> **WHY IT WORKS · WHERE THE NEXT-LARGER RULE IS STRICTER THAN THE STANDARD**
>
> ABYC’s own note lets a metric conductor be used if its circular-mil area is equivalent, and lets a smaller one be used with its ampacity corrected by the ratio of the two areas. That is a designer’s calculation, and it changes the voltage drop as well. A pro may size a metric wire that way and write the calculation into the Boat Passport; the next-larger rule needs no calculation and is never thinner than the wire it replaces. ABYC

Part numbers of US wire and lugs, and US replacements for the metric parts of a European-built boat, are the subject of → module “Components”.

5.3. Ampacity and derating: engine space and bundles

How much current may this wire carry where it runs? Its ampacity — the current a wire can carry continuously without its insulation getting hotter than its temperature rating — starts from its gauge and the temperature rating printed on its insulation, and it falls wherever the wire cannot shed its heat. This section gives it for a wire run alone and shows what lowers it.

A wire heats in proportion to the square of its current, as a joint does (→ 3.1), and it sheds that heat through its insulation into the air around it. Hot air around it, or warm neighbors in a bundle, slow the shedding, so the same current brings the copper and its insulation to a higher temperature. The temperature rating printed on the insulation is the

limit the ampacity tables are built around, so where the wire sheds heat less well it gets a smaller current.

On a boat within its scope (→ 1.9), the regulation sets that limit with its own table, not with a house-wiring table: each conductor carries no more than its Table 5 gives for its gauge and the temperature rating of its insulation, except for intermittent surges, such as the short inrush when a motor starts. → Table 5.2 · p. 8 prints it for one wire run alone outside an engine space. CFR

Table 5.2. Ampacity in amps of one conductor run alone outside an engine space, by the temperature rating of its insulation — 33 CFR 183.425, Table 5; 18 AWG only inside a multiconductor sheath (→ 5.1 · p. 2) CFR

Gauge	60 °C (140 °F)	75 °C (167 °F)	80 °C (176 °F)	90 °C (194 °F)	105 °C (221 °F)	125 °C (257 °F)	200 °C (392 °F)
18 AWG	10	10	15	20	20	25	25
16 AWG	15	15	20	25	25	30	35
14 AWG	20	20	25	30	35	40	45
12 AWG	25	25	35	40	45	50	55
10 AWG	40	40	50	55	60	70	70
8 AWG	55	65	70	70	80	90	100
6 AWG	80	95	100	100	120	125	135
4 AWG	105	125	130	135	160	170	180
3 AWG	120	145	150	155	180	195	210
2 AWG	140	170	175	180	210	225	240
1 AWG	165	195	210	210	245	265	280
1/0 AWG	195	230	245	245	285	305	325
2/0 AWG	225	265	285	285	330	355	370
3/0 AWG	260	310	330	330	385	410	430
4/0 AWG	300	360	385	385	445	475	510

In an engine space the regulation lowers the ampacity of Table 5.2 by a factor for each insulation rating: 0.85 for 105 °C (221 °F) insulation, 0.75

for 75 °C (167 °F) and 0.58 for 60 °C (140 °F); the Numbers below give them all. CFR

A wire bundled with other current-carrying wires carries less as well. The regulation corrects bundles only at 50 V and up; for 12 V and 24 V bundles the correction comes from ABYC. CFR

ABYC's 2008 edition of E-11 gives one factor for a DC circuit: where up to three current-carrying conductors are bundled, sheathed or in conduit, each carries 0.7 of its ampacity alone, outside an engine space and inside one. The positive and the negative of one circuit both carry its current. So the two conductors of a duplex cable — two insulated conductors under one jacket — are derated by the factor, and so is a positive tied in a bundle with its own negative. ABYC

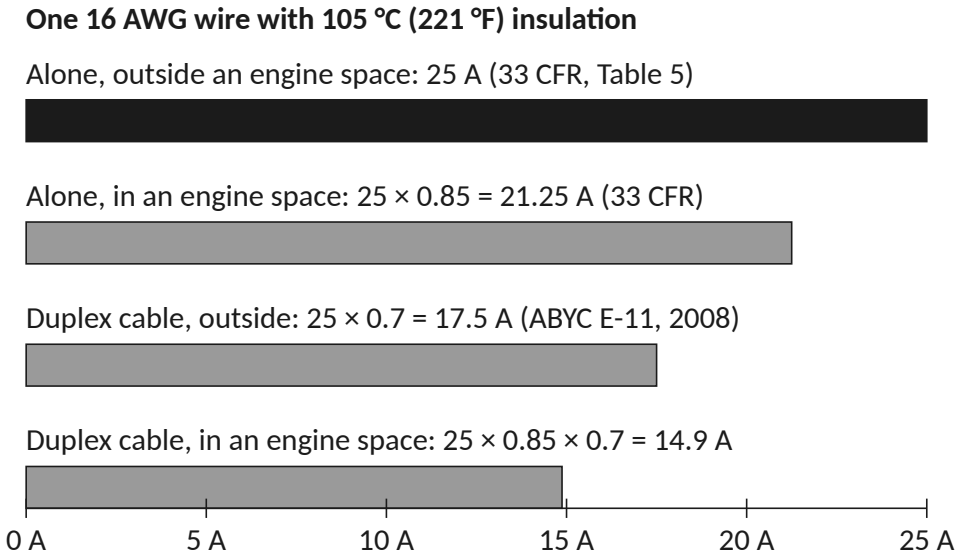


Fig. 5.3. One wire, four places. The same 16 AWG wire with 105 °C (221 °F) insulation carries 25 A alone outside an engine space and 14.9 A as one conductor of a duplex cable inside one.

A boat cable can show its two ratings as a code: one maker lists its boat cable as "UL Listed BC-5W2", rated 105 °C (221 °F) dry and 75 °C (167 °F) wet. MFR

Water and spray take away the dry rating. A wire that lies in bilge water or under spray is read in the column of its wet rating, from its print or, where the print gives only a code, from its maker's sheet. A wire whose wet rating you cannot find, or whose insulation shows no print, is read

in the 60 °C (140 °F) column until you know more, with this section's engine-space factor and bundle factor wherever it runs in an engine space or beside other current-carrying conductors. PRACTICE

NUMBERS · THE FACTORS AND THEIR DOCUMENTS

33 CFR 183.425, Note 1 to Table 5 — engine spaces: 0.58 for 60 °C (140 °F) insulation, 0.75 for 75 °C (167 °F), 0.78 for 80 °C (176 °F), 0.82 for 90 °C (194 °F), 0.85 for 105 °C (221 °F), 0.89 for 125 °C (257 °F), 1.00 for 200 °C (392 °F); each factor multiplies the value of Table 5.2 for that rating. CFR

33 CFR 183.435(b) — three or more conductors in one duct, bundle or cable, each at 50 V or more: 0.70 for three, 0.60 for four to six, 0.50 for 7 to 24, 0.40 for 25 and more. These factors do not apply to a 12 V or 24 V circuit. CFR

ABYC E-11, July 2008 edition — up to three current-carrying conductors bundled, sheathed or in conduit, AC or DC: 0.7 of the ampacity of one conductor alone, outside or inside an engine space. Its tables for four to six, 7 to 24, and 25 or more conductors are titled for AC circuits. ABYC

Four or more DC conductors in one bundle: 0.7 of the ampacity alone. VERIFY

WORKED EXAMPLE: A DUPLEX CABLE THROUGH THE ENGINE SPACE

Suppose a 10 AWG duplex cable with 105 °C (221 °F) insulation feeds a 30 A load through the engine space, behind a 40 A breaker. What decides is the ampacity where the cable runs. Alone outside an engine space 10 AWG carries 60 A (→ Table 5.2 · p. 8); in the engine space, 60 × 0.85 = 51 A; as one conductor of a duplex cable there, 51 × 0.7 = 35.7 A.

The triad of → 4.3 asks load current ≤ protection rating ≤ ampacity: 30 A ≤ 40 A holds, 40 A ≤ 35.7 A does not. The 40 A breaker would pass a 10 AWG wire run alone and fails this cable where it runs. A pro fits a rating that passes, or a heavier cable.

5.4. Voltage drop: sizing a wire for 3 % or 10 %

How thick must a wire be for the device at its end to get the voltage it needs? A wire that is safe for its current can still be too thin for its length. Every foot of copper has resistance, and the current loses voltage through it on the way out and on the way back (→ 3.1). A navigation light dims, a pump slows, electronics reset. ABYC limits that loss when the wire is chosen.

ABYC sizes conductors so that the voltage drop does not exceed 3 % for panelboard main feeders, bilge blowers, electronic equipment, navigation lights and other circuits where the drop must be kept to a minimum, and 10 % for lighting other than navigation lights and other circuits where the drop is not critical. ABYC

A load that neither list names — a windlass, a refrigerator, a bilge pump — is sized for the drop or the wire size its maker's manual gives; where the manual gives neither, sizing for 3 % gives a wire thick enough for either list. This book holds a bilge pump to 3 % (→ 3.5). PRACTICE

The wire is sized with ABYC's formula, the one basis this book uses for wire: CM = 10.75 × I × L ÷ E. CM is the copper area the wire needs, in circular mils; I is the load current in amps; L is the length of the circuit's wire from the positive power source connection to the device and back to the negative power source connection, in feet; and E is the drop allowed, in volts, taken at the system's nominal voltage: 0.36 V for 3 % and 1.2 V for 10 % at 12 V, 0.72 V and 2.4 V at 24 V. ABYC prints the formula for currents above the range of its own drop tables, which check the smaller circuits; this book uses the formula for every circuit. Take the gauge whose area in → Table 5.1 · p. 5 is not smaller than the CM the formula gives. ABYC

Where does the round trip start? ABYC lets the power source connection be the battery, or a panelboard or switchboard where the boat has one. On a boat with a panel, a branch circuit's L runs from the panel, through the branch breaker, to the device and back to the negative bus; the panel's feeder is a circuit of its own, sized for its own 3 % over its own round trip, from the battery through the battery ABYC

switch to the panel and back (→ Fig. 5.4 · p. 12). A drop you read from the battery's terminals to the device therefore covers the feeder and the branch together.

The drop is one of two checks. ABYC sizes a wire for its ampacity and then checks it against the drop; where the two give different gauges, the larger wire is used. ABYC

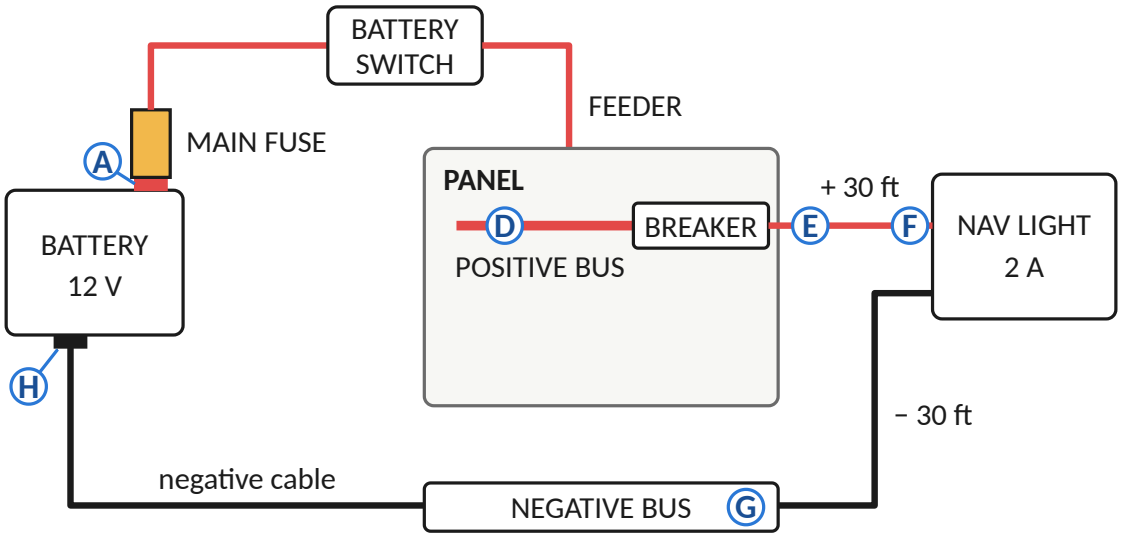


Fig. 5.4. The circuit of the worked example. Points: A, the battery's positive terminal; D, the positive bus; E, the branch breaker's output; F, the light's positive terminal; G, the negative bus; H, the battery's negative terminal. The letters name the same points as in the anatomy figure of → 4.1; this circuit needs no B or C, and its panel is drawn without a main panel breaker. The branch counts its round trip from the panel; the run from the battery to the panel and back is sized on its own.

WORKED EXAMPLE: A NAVIGATION LIGHT 30 FT FROM THE PANEL

Suppose a navigation light draws 2 A on a 12 V boat, and its wires run 30 ft from the panel to the light. The basis: ABYC's formula with 10.75, and the round trip from the panel, L = 30 ft + 30 ft = 60 ft — from E to F and back to G on → Fig. 5.4 · p. 12. Navigation lights are held to 3 %: E = 0.03 × 12 = 0.36 V.

CM = 10.75 × 2 × 60 ÷ 0.36 = 3,583. 16 AWG has 2,580 circular mils, too few; 14 AWG has 4,110, enough. With 14 AWG the 60 ft have R = 10.75 × 60 ÷ 4,110 = 0.157 Ω and drop 0.157 × 2 = 0.31 V, which is 2.6 %. With 16 AWG they would drop 0.50 V, 4.2 %.

The ampacity check is easy here: 14 AWG with 105 °C (221 °F) insulation carries 35 A alone outside an engine space (→ Table 5.2 · p. 8), far above 2 A. The drop decides this wire.

WORKED EXAMPLE: WHEN THE AMPACITY DECIDES

Suppose a 12 V load draws 50 A, 5 ft from its power source, on a circuit where the drop is not critical. The basis: ABYC's formula with 10.75, L = 10 ft round trip, E = 1.2 V for 10 %. CM = 10.75 × 50 × 10 ÷ 1.2 = 4,479: by the drop, 12 AWG, with 6,530, is enough.

By ampacity it is not. 12 AWG with 105 °C (221 °F) insulation carries 45 A alone outside an engine space, and 10 AWG carries 60 A (→ Table 5.2 · p. 8). The larger wire is used: 10 AWG. Suppose the positive and the negative run together in one duplex cable: 10 AWG then carries 60 × 0.7 = 42 A, still less than 50 A, and the wire is 8 AWG, with 80 × 0.7 = 56 A (→ 5.3 · p. 7).

The two tables below do the arithmetic for 12 V; they are this book's own results of the formula, worked with the areas of Table 5.1. Each cell is the thinnest gauge that keeps the drop within its limit for that current over that round trip. A result thinner than 16 AWG is printed as 16 AWG, the thinnest wire installed on its own (→ 5.1 · p. 2). A current or a round trip between two printed values is read in the next larger current and the next longer round trip: that cell never gives a thinner wire than the formula. For a 24 V circuit, read the column for half its round-trip

length, and between two columns the longer one: at twice the voltage the same percentage allows twice the volts.

Table 5.3. Smallest wire for a 3 % drop at 12 V (0.36 V), by load current and round-trip length — this book's results of ABYC's formula

Current	10 ft	20 ft	30 ft	40 ft	50 ft	60 ft	80 ft	100 ft
5 A	16	14	12	12*	10	10	8	8*
10 A	14	12*	10	8	8*	6	6	4
15 A	12	10	8	6	6	4	4	2
20 A	12*	8	6	6	4	4	2	2
30 A	10	6	4	4	2	2	1	1/0
40 A	8	6	4	2	2	1	1/0	2/0
50 A	8*	4	2	2	1	1/0	2/0	3/0
100 A	4	2	1/0	2/0	3/0	4/0	over 4/0	over 4/0

Table 5.4. Smallest wire for a 10 % drop at 12 V (1.2 V), by load current and round-trip length — this book's results of ABYC's formula

Current	10 ft	20 ft	30 ft	40 ft	50 ft	60 ft	80 ft	100 ft
5 A	16	16	16	16	16	14	14	12
10 A	16	16	14	14	12	12	10	10
15 A	16	14	14*	12	10	10	8	8
20 A	16	14	12	10	10	8	8	6
30 A	14	12	10	8	8	8*	6	4
40 A	14†	10	8	8	6	6	4	4
50 A	12†	10	8	6	6	4	4	2
100 A	10†	6	4	4	2	2	1	1/0

Two marks in the tables. * — for a wire sold by SAE gauge, or a wire whose print you cannot read, take one size thicker: its smaller SAE area falls short of the formula's CM. In a cell without that mark, the SAE area of the printed gauge is enough as well. † — the drop allows a wire that carries less than the load even with 105 °C (221 °F) insulation, run alone

outside an engine space; its ampacity decides a thicker wire (→ 5.3 · p. 7). Every other cell still gets the ampacity check of → Table 5.2 · p. 8 and 5.3 for its insulation and its place.

> **WHY IT WORKS · WHAT 10.75 ASSUMES, AND WHAT A WARM WIRE DOES**
>
> The constant 10.75 stands for the resistance of copper. The National Bureau of Standards gives annealed copper 10.371 ohm-circular mils per foot at 68 °F, and its resistance rises about 0.22 % for each degree Fahrenheit. By that table, 10.75 is copper at about 85 °F. A wire running at its 105 °C (221 °F) rating has about 29 % more resistance than the formula assumes, and one at 75 °C (167 °F) about 17 % more. So a wire sized right at its limit drops more than its limit while it runs hot, by those same percentages; the formula is the yardstick for choosing a wire, and a wire with room above its limit keeps its voltage when it runs warm.
>
> The same formula gives the resistance of a length of wire: R = 10.75 × L ÷ CM. Every worked example in this book that needs a wire's resistance uses it, with the round trip in feet.

Long runs — to a masthead, a bow thruster, a transom — and the combinations of drop, warm wire, engine space and bundle are worked in → module "Calculators".

5.5. The DC color code

What do the colors of the wires on your boat tell you, and what do you do when they do not follow the code? ABYC gives each function of a DC wire a color. The three that matter most are red for a DC positive, black or yellow for a DC negative, and green or green with a yellow stripe for the bonding system; the full list, with the engine and accessory colors, is Table 2.3 (→ 2.4). ABYC

The color is a hint; the proof is tracing the wire to both ends. On a boat whose DC negatives are black, a yellow wire can be the bilge blower positive. On a boat wired to the ABYC code, a green wire with a stripe of any color except yellow is trim or tilt power, not bonding. A black

wire can be the hot conductor of 120 V AC wiring. On a 120/240 V boat a red wire can be the second hot. PRACTICE

Your boat can follow another scheme. ABYC's DC standard E-9, in the edition recommended for boats built after July 31, 1999, asks that each conductor have a means to identify its function; it calls the colors for engine accessory wiring "one selection", and allows another scheme for them when the boat comes with a wiring diagram that shows it. Green, or green with a yellow stripe, stays the color of the bonding conductors. Wires added after the boat was built follow whatever the person who added them chose. So a color tells you where to look, never what a wire is. ABYC

Trace each wire you work on from end to end, by eye and by hand, without pulling on it, wherever you reach it dry and outside a panel with AC breakers on it; where it runs into the bilge water or behind such a panel, the procedure for your work says how it is traced there, with its signs (→ 5.6 · p. 16, → 5.8 · p. 28). Mark both ends with what it feeds (→ 5.7 · p. 25) and write it into the Boat Passport (→ 2.3). A wire that is added or replaced gets the code's color for its function, so the next person who opens the panel reads it right.

A European-built boat follows European colors for the DC negative and for AC wiring. You only need to recognize them, and → 2.5 shows them.

5.6. Terminals and crimping

How do you join a wire so that the joint keeps its low resistance through salt, water and vibration? A joint fails in two ways: it works loose, or it corrodes. Either way its resistance rises, and under current it heats (→ 3.1). Three things keep it sound: a terminal that cannot slip off its stud, a crimp made with the tool built for that terminal, and a seal that keeps water and salt away from the strands. That is why connections on board are crimped, sealed with adhesive-lined heat shrink and covered: an insulating sleeve over the shank of each terminal, and a cover over a positive stud that is live all the time with no fuse between it and the battery.

ABYC's DC standard E-9, in the edition recommended for boats built after July 31, 1999, says what a sound connection is (→ Table 5.5 · p. 17); the date names the edition, and the table is a yardstick for the joints of a boat of any year. Its rules on wire nuts, on ring and captive spade terminals, on solder, on crimping tools and on terminal shanks stand in E-11 as well, as one maker of marine wire quotes it. Each row also tells you what you see on a boat where the rule was not followed. ABYC

Table 5.5. What ABYC E-9 asks of a connection, and what you see where it was not done ABYC

What the standard asks	What you see where it was not done
Terminals of the ring or captive spade type; a push-on connector only under the standard's conditions (→ 3.5)	An open fork spade, or a bare wire under a screw: either slides out when the screw loosens, where a ring stays on its stud as long as the nut holds it
A ring or captive spade the same nominal size as its stud	A ring terminal whose hole is wider than its stud
No more than four conductors on one terminal stud; more are joined by a jumper or a copper strap to another stud	Five or more lugs on one stud
No twist-on connectors (wire nuts)	A wire nut, or wires twisted together and taped: vibration loosens them, and a loose joint heats
Crimp-on connectors put on with a crimping tool designed for the connector used	A barrel flattened by pliers, or crushed off center
Solder never the only mechanical connection; a soldered joint held so that the wire does not flex where the solder ends; a battery lug may be soldered along at least 1.5 times the conductor's diameter	Wires joined only by solder, with nothing crimped or clamped
Connections protected from the weather, in a weatherproof enclosure, or watertight; watertight wherever they can be under water	A joint in the bilge or under spray with no seal; a green or white crust
Studs, nuts and washers corrosion resistant and galvanically compatible with the wire and the lug; no aluminum and no unplated steel	Rust on a nut or a washer

What the standard asks	What you see where it was not done
The shank of each terminal covered by an insulating barrier or sleeve, except on the conductors of the bonding system	A bare metal barrel beside another stud or a metal panel

Solder is not the answer to a joint that must withstand vibration. Where solder soaks into a stranded wire, it turns that part of the wire into solid copper, and a note in E-9 warns that flexing can then break the wire at the end of the solder unless the joint is well supported. A ABYC crimp leaves the strands flexible right up to the barrel. That is why solder on a boat comes on top of a crimp, not in place of it; E-9 makes one exception, a battery lug soldered along at least 1.5 times the conductor's diameter.

A ratcheting crimper makes the crimp a barrel was designed for. Its handles do not open until the crimp cycle is complete, so a half-squeezed barrel cannot come out of it; two tool makers describe their ratchets this way. One maker's crimper for heat-shrink terminals has three cavities, for 22–16 AWG (red), 16–14 AWG (blue) and 12–10 AWG (yellow) terminals: the terminal's color and the wire range printed on its package name the cavity. The same maker sells other ratcheting crimpers for insulated and for non-insulated terminals: the kind of terminal chooses the crimper, and its color chooses the cavity. MFR That crimper stops at 10 AWG; a lug for a battery cable takes a crimper made for its size.

Heat shrink comes in two kinds. Adhesive-lined heat shrink has a layer inside that melts as the tubing shrinks and fills the space around the wire. One maker writes that its adhesive forms "a permanent, non-drying, flexible and water resistant barrier" once it cools; a second maker's tubing "environmentally seals and protects", and the same maker's heat-shrink terminal carries the adhesive inside its own sleeve and gives a "splash proof and strain relief connection". Plain heat shrink, without the lining, is insulation: its maker describes it as a shrink-fit insulation over splices and terminations and makes no claim of a seal. Neither maker calls its lined tubing waterproof or rates it for a joint under water, and one pump maker asks for every wire connection

above the highest water level: the joints of this section's procedure are made where the bilge water does not reach them (→ 5.7 · p. 25). MFR

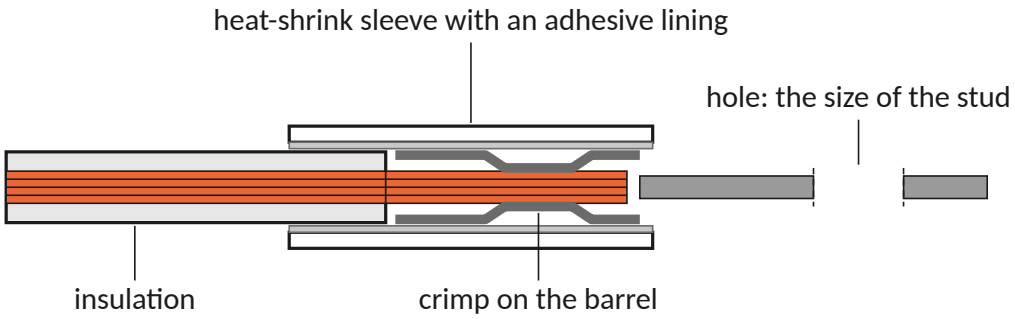


Fig. 5.5. A good crimp, cut lengthwise: strands all the way in, insulation stopping at the barrel, the crimp on the barrel, the sleeve sealed over the insulation and the barrel, the ring the size of the stud.

A heat gun shrinks the tubing. One maker's adhesive-lined tubing shrinks from 250 °F and its plain tubing from 212 °F, while one heat-gun maker writes that its guns blow air hotter than 875 °F. Air that hot can set fire to the material behind a joint if the gun pauses in one spot, both heat-gun manuals warn, and the nozzle stays hot after the gun is off: one manual gives it 20 minutes to cool, the other 30. Both keep the gun away from wet conditions. Step 8 of the procedure in this section uses the gun the way these manuals ask. MFR

On a stud the lug lies flat on the contact face — the bus bar, the base of a terminal, the device's terminal — with nothing between them, and the flat washer, the lock washer and the nut, or a serrated flange nut in place of the washers, sit on top of it (→ Fig. 5.6 · p. 20). A battery maker writes that a washer between the battery terminal and the lug creates high resistance and heats the connection and terminal; an inverter maker's wiring guide asks that nothing — no washer and no fuse — sit between the lug and the surface. A terminal fuse made to sit on a battery post under the lug is its maker's design, not a washer (→ 4.4); whose work a lug on a battery terminal is, → 1.8 says. PRACTICE

One maker of panels and bus bars marks as wrong a lug placed on its non-conductive washer: the lug belongs on the conducting face, under the washer and the nut. Where several lugs share one stud, each lies flat on the one below it and lined up with it, and the count stays within the standard's four. Each stud has its maker's torque: one battery maker gives 9–11 ft-lb for its terminals, one bus bar maker 140 in-lb for its studs. These numbers belong to those products; yours are in your own part's manual, and step 9 of the procedure in this section says what is done where it gives none. MFR

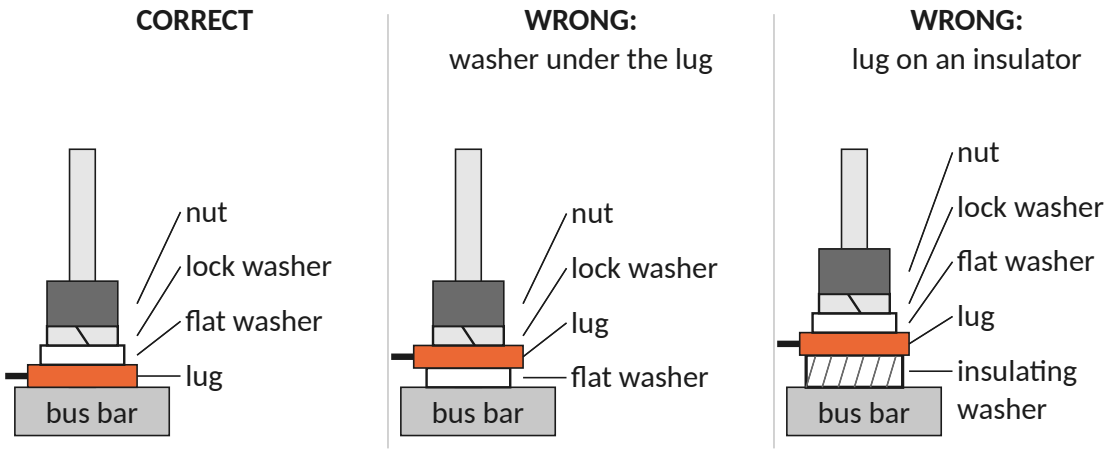


Fig. 5.6. The stack on a stud. The lug lies on the conducting face; washers and nut go on top of it.

"Covered" has one more meaning. The regulation asks that each ungrounded terminal or stud — one on the positive side — that is continuously energized either meet its overcurrent rules or have a boot, nipple, cap, cover or shield that prevents accidental short-circuiting. A positive stud that is live all the time, with no fuse between it and the battery and no cover over it, goes into the Boat Passport; a cover that fits only with a lug taken off is a pro's job (→ 5.10 · p. 37). CFR

Procedure: Replacing a terminal on a wire after the battery switch

For a ring or captive spade terminal on a stud, or a crimped butt connector that joins two wires of one gauge, on a wire of 10 AWG or smaller: at a device, a breaker, a fuse block or a bus, outside a panel or

behind a DC-only panel, on a wire after the battery switch, or on a circuit wired around it once its own fuse at the battery is out (step 2). The same steps remake a wire nut or a joint held only by solder that joins two wires, and replace a stretch of wire rubbed through to the copper. A joint of three or more wires is remade on a terminal strip or a bus bar: a ring terminal on each wire, no more than four on one stud, and studs joined by a jumper or a copper strap where more wires meet (→ Table 5.5 · p. 17). On a boat with no battery switch, the entry of the PROVE IT DEAD sign says what takes its place.

Where the joint is decides whether this procedure applies. A lug on a battery terminal, or on a stud that stays live with every battery switch OFF: the entry of the SHORT CIRCUIT sign says whose work that is. A connection behind a panel with AC breakers on it (→ 4.5), a push-on terminal and a wire you cannot trace to both ends are a pro's (→ 5.10 · p. 37). The negative lug on the engine block has its own procedure (→ 3.8), and the joints of the starter circuit and of the charging circuit carry their full current only while the engine cranks or runs: → 3.4 and → 3.8 say who reads and repairs them. A wire of the bilge pump's circuit is made dead by the procedure "Making the pump's circuit dead before work" (→ 12.2) in place of steps 1 and 2 below, and that procedure's restore takes the place of step 10 and of the restore below, except its first item. In a compartment with a gasoline engine or tank, the entry of the GASOLINE VAPOR sign says where the joint is made.

You need a ratcheting crimper made for heat-shrink terminals, with a cavity for the terminal's size; heat-shrink ring terminals of the stud's size, or heat-shrink butt connectors, whose printed wire range covers the gauge; a length of the same wire, for a wire that turns out too short; for a joint of three or more wires, a terminal strip or a bus bar; a wire cutter and stripper; a heat gun; your meter; a wrench that fits the nut, and a torque wrench where the stud's maker gives a torque.


PROVE IT DEAD

SHORT CIRCUIT

METER LEADS

GASOLINE VAPOR

AC — PRO

BLOWN FUSE

BILGE PUMP

CARBON MONOXIDE

SHOCK IN WATER

1. Find the ring terminal, the spade or the splice you will replace, and trace its wire to its other end (→ 5.5 · p. 15): what it feeds, and whether it is a positive or a negative. A positive with its own fuse at the battery is wired around the switch, whether or not a breaker after the switch feeds it as well, and so is any other positive that no breaker or fuse after the switch feeds: its own fuse at the battery comes out in step 2. On a negative wire, the circuit is that of its device: the device's positive is made dead the same way. A wire you cannot trace to both ends: a pro traces it, and the joint waits as it is, written into the Boat Passport; the procedure "The drop across one connection" (→ 5.8 · p. 28) says meanwhile whether it heats.
2. If the boat needs its navigation or anchor lights, or its electronics, while the battery switch is OFF — at anchor after dark, or under way — stop here until it does not. Otherwise, with the engine stopped, prove that the wire is dead, as the entry of the PROVE IT DEAD sign says: its first reading with the battery switch and the load's own switch still ON and, on a circuit wired around the switch, its own fuse at the battery still in; then the load off at its own switch, the battery switch OFF and that fuse out, as step 3 of the procedure in → 4.6 takes it out. On a negative wire, read its device's positive as well.
3. On any negative connection — a ring or a spade on a negative bus or a negative terminal, or a splice in a negative wire: with the meter's black lead on that negative, read from it to each stud or terminal within reach of the tool that carries a positive. Where the positive terminal of a charger, an inverter or a DC-DC charger is within reach, first turn OFF the DC breaker or isolation switch that feeds it, or take out its own fuse at the battery where that fuse sits in a holder that opens by hand, in the state the entry of the SHORT CIRCUIT sign gives for that fuse. Each reads 0 V. Any voltage there, or a stud or terminal you cannot identify: stop here — the work is a pro's. Then read battery voltage from that negative to the battery

side of the battery switch — on a boat with none, to the line side of what takes its place — to prove the meter again after those 0 V readings. If it does not read battery voltage, the 0 V readings proved nothing: find why the meter failed (→ 3.7) and take this step again.

4. Take the old joint apart. A ring terminal or a spade on a stud: loosen the nut and lift it from the stud. A splice — a wire nut, a joint held only by solder, an old butt connector — or a stretch rubbed through: cut the wire on each side of it. Look at each wire's end: green or black strands, and strands stiff with solder, are cut away in the next step.
5. Cut each end back to bright, flexible copper, and strip it to the length the maker of the terminal or the splice gives, without nicking or cutting a strand. Where a wire no longer reaches its stud without pulling, or two ends no longer meet, join in a length of the same wire, no thinner. Each joint goes where a clamp can hold it and the bilge water does not reach it (→ 5.7 · p. 25); a joint that cannot go there is a pro's.
6. Take a ring or a captive spade of the stud's size, or a butt connector, whose printed wire range covers the gauge. Push the stripped end into its barrel until the insulation meets the barrel's mouth; into a butt connector, one wire from each side.
7. Put the barrel in the cavity of the terminal's color, on the crimper made for heat-shrink terminals, centered in the jaws, and squeeze until the ratchet releases; each half of a butt connector is crimped the same way. Then look: each barrel is pressed in its middle, every strand is inside it, and the insulation stops at its mouth (→ Fig. 5.5 · p. 19). A small tug does not move the wire. Anything else: cut the crimped part off and start again at step 5.
8. Shrink the sleeve with the heat gun the way its manual asks, in a dry place: look first at what lies behind and around the joint — other wiring, hoses, foam, wood — then move the gun from side to side until the sleeve has shrunk tight all round from end to end, and take the heat away at once. Lay the hot gun down only where

nothing can burn, and do not leave it unattended while it runs or cools.

9. A ring or a spade: put it on its stud, flat on the contact face with nothing under it, then the flat washer, the lock washer and the nut — new ones of a metal Table 5.5 allows, where the old ones are rusted — or a serrated flange nut (→ Fig. 5.6 · p. 20). Tighten the nut with the torque wrench to the torque the stud's maker gives; where the maker gives none, until the ring no longer turns on the stud when you push it by hand, and the reading of step 11 judges the contact.
10. Turn the battery switch back to its working position, the engine still stopped, and put back the fuse step 2 took out, if it took one out.
11. Read the new work by the procedure "The drop across one connection" (→ 5.8 · p. 28), with the load at its full work: a ring terminal on its stud reads under 5 mV from P to Q, and a wire with a new splice reads no more from R to P than the circuit's other wire of the same gauge and length — where the two wires differ in gauge or length, the sum of their two R–P readings stays within the 3 % or 10 % of → 5.4 · p. 11, as step 3 of that procedure reads it. If its breaker trips or its fuse blows as the load comes on: switch the load off, take the work apart again from step 2, and look for a strand or a shank that touches metal; the entry of the BLOWN FUSE sign says when the breaker is reset or the fuse replaced.

PUT THE BOAT BACK IN SERVICE

- A wire you could not finish stays off, before the battery switch goes back to its working position: its breaker OFF or its fuse out — on a circuit wired around the battery switch, the fuse step 2 took out stays out — with a label on it, and each bare end taped so that it touches no metal. If that wire feeds the CO alarm, the high-water alarm or a bilge pump, write down that it has no power: the entries of the CARBON MONOXIDE and BILGE PUMP signs say what you do meanwhile.
- If you stopped before step 10 with the wire finished or not yet taken apart: the battery switch back at its working position, the engine still stopped, and the fuse step 2 took out back in its holder.

- A charger, solar panels or any other source you turned off for the readings of step 2, and a DC breaker, an isolation switch or a fuse that step 3 turned off or took out: back as you found them, a fuse in the way it came out and in the state the entry of the SHORT CIRCUIT sign gives for that fuse, except a feed that reaches a wire the first item keeps off. The AC sources you turned off: the inverter and the generator back as you found them, and shore power back last, in the order of → 17.2.
- The load back as you found it, and the panel cover back in place if you opened it.
- The meter's dial at OFF.
- A CO alarm wired after the battery switch lost its power while the switch was OFF, and one on a circuit wired around it while the fuse step 2 took out was out; the entry of the CARBON MONOXIDE sign says how you see that it is working again.
- If you turned the battery switch: check that the bilge pump's automatic switch has power (→ 12.2).

5.7. Routing and support

Where and how does a wire run so that nothing wears through it, heats it or pulls on its ends? A run of wire fails where something works on it: an edge that rubs through the insulation as the boat moves, an exhaust that heats it, bilge water that soaks its joints, a sag that pulls on its terminals. ABYC answers each of these in its DC standard E-9, in the edition recommended for boats built after July 31, 1999, and the regulation answers chafe; you can check every one of them by eye (→ Fig. 5.7 · p. 26).

Support: ABYC asks that conductors be supported along their whole length or secured at least every 18 in, with clamps sized to hold them firmly; battery cables within 36 in of a battery terminal and cables attached to an outboard motor are the exceptions. Plastic straps or clamps are not used over an engine, a moving shaft, other machinery or a passageway where their failure would leave a hazard; there, metal

straps with smooth, rounded edges over a protective wrap, or metal clamps lined with insulation, hold the wire. ABYC

Chafe: the regulation asks that each conductor or group of conductors that passes through a bulkhead, a structural member, a junction box or another rigid surface be protected from abrasion. CFR

ABYC adds self-draining loom, conduit, tape or raceways wherever a wire can be damaged, and asks that wires be routed clear of steering cables and linkages, engine shafts and throttle connections. ABYC

Water and heat: ABYC asks that current-carrying conductors run "as high as practicable" above the bilge water and other places where water collects; where a wire must run there, the wiring and its connections are watertight. Wires run as far from exhaust and other heat as the boat allows, with at least 2 in from a water-cooled exhaust and 9 in from a dry exhaust, and no wire directly above a dry exhaust, unless an equivalent thermal barrier is fitted; wiring on the engine itself and an exhaust temperature sensor's wiring are the exceptions. ABYC

One pump maker asks for every wire connection above the highest water level, and the joints of the procedure in → 5.6 · p. 16 are made there. MFR

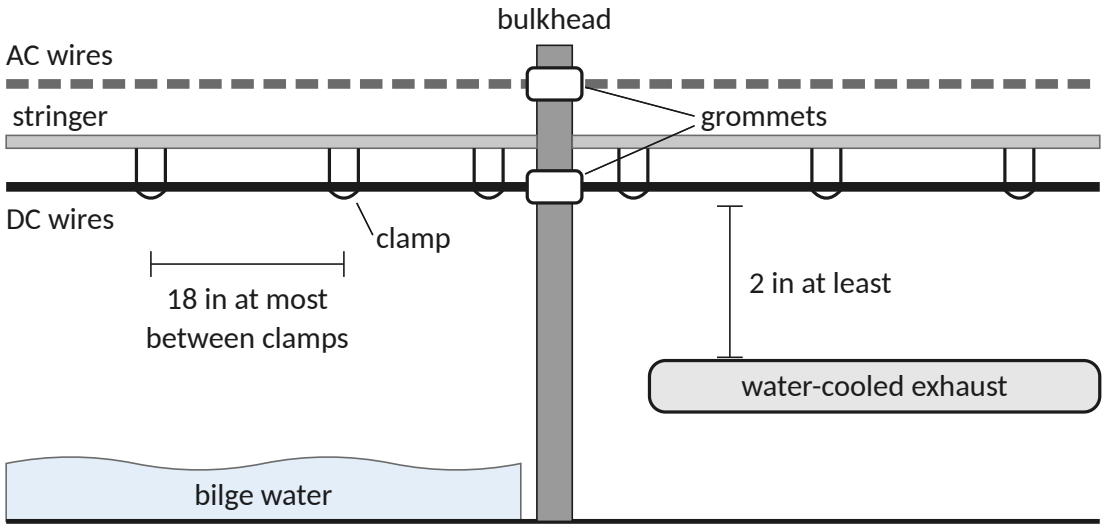


Fig. 5.7. A run done right: the DC wires supported by clamps, both bundles through grommets at the bulkhead, clear of the exhaust and above the bilge water, with the AC and DC wires apart. The distances are those of ABYC E-9.

Battery cables without overcurrent protection — a negative battery cable without a fuse, and the starter cable on the positive side (→ 4.2) — have rules of their own: they run above normal bilge water along their whole length and clear of metal fuel system parts, and the positive one stays clear of any part of the engine or the drive train. ABYC

Neighbors: DC wires are sheathed, bundled or otherwise kept apart from AC wires. Near the compass the wiring makes no magnetic loops, and DC wires that can make a field there run as twisted pairs. At a panel, a junction box or a fixture, each wire ends with enough slack to take the pull off its terminal, to allow a repair, and to fan several wires out at a stud; and each conductor has a means to identify its function — its color, a number or a label at its ends. ABYC

An electrical part installed or replaced where gasoline vapor can reach it is ignition protected (→ 4.6).



GASOLINE VAPOR

With the run in place and no terminal taken off, you can add a clamp where it sags, screwed in by hand or with a cordless driver; a split grommet, loom or a sleeve where it rubs; and a label at each end — wherever you reach the run dry and outside a panel with AC breakers on it. A wire rubbed through to the copper is repaired by the procedure in → 5.6 · p. 16, which cuts out the damaged stretch and joins in a length of the same wire. A run moved to a new route, and a new branch circuit, are in “Do it yourself or hire a pro” (→ 5.10 · p. 37).

WALK-AROUND CHECK: ONE WIRE RUN

Follow one run from the panel to its device by eye, opening only hatches and covers that lift off by hand — not the cover of a panel with AC breakers on it — with your hands on nothing but dry insulation and out of the bilge water. Look for a run neither supported along its length nor clamped at least every 18 in, or a wire that sags between its clamps; plastic ties over the engine, a shaft or a walkway; a hole in a bulkhead with no grommet or sleeve, and insulation rubbed shiny or flat where it passes; a wire in the bilge water; a wire closer than 2 in to a water-cooled exhaust or

> 9 in to a dry exhaust, or right above a dry exhaust, with no thermal barrier between them; a wire pulled tight at its terminal; AC and DC wires tied together; a wire with no label at either end. The exceptions of this section — battery cables near the battery, cables on an outboard, the wiring on the engine and an exhaust temperature sensor's wire — are no finding. Write each finding into the Boat Passport with where it is, and close the hatches you opened. Copper showing through the insulation: → 5.10 · p. 37 says who repairs it and which circuits stay off until then. On the stretch between a battery and the first switch, fuse or breaker on its wire, nothing on the boat switches it off (→ 4.2), and that repair is a pro's.

5.8. Checking it yourself

How do you tell, on your own boat, whether a wire or a connection is sound? Three checks do it, each for its own question. Your eyes, nose and hand, with the circuit at work, find where heat is. The voltage drop across one connection under its working current says whether that connection heats (→ 3.4). And a continuity reading on a dead wire says only whether the wire is whole or broken.

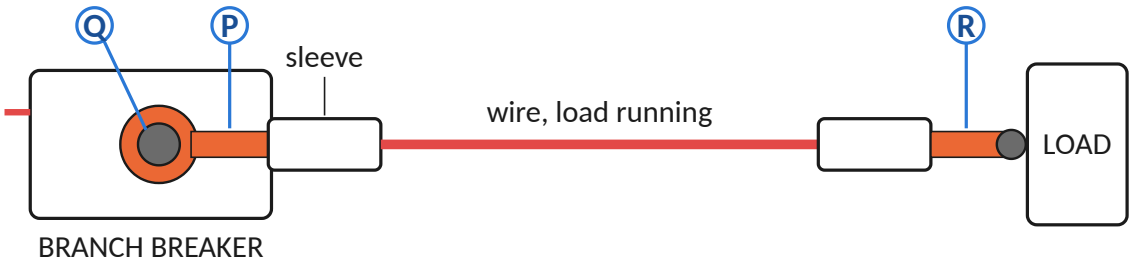
A bad joint makes heat only while current flows through it (→ 3.1). So the first two checks are made with the load at its full work: every load on that circuit on, each doing the most it does in normal use. A joint that at other times carries a larger current, such as a lug on a feeder that an inverter or a windlass shares, is judged at that larger current.

A home-wiring booklet of the Consumer Product Safety Commission draws a line a hand can feel for switch plates, outlet covers, cords and plugs in a house: they may be warm, but "should never be hot-painful to touch or discolored from heat". This book uses the same line as a first check for a boat's DC joints, and the meter then gives the number. Each of these clues has more than one cause, and → Table 5.6 · p. 29 names what else looks the same. PRACTICE

Table 5.6. What heat looks like at a wire or a connection, and what else looks the same

What you notice	What can cause it	What decides
Smoke, a burning smell, or a smell of hot insulation; insulation going soft or darker at a warm joint while the load runs	A wire or a joint overheating now; a slipping belt, a hot motor or an exhaust leak can smell alike	The card “Smoke, a burning smell, or an overheated wire” (→ emergency card)
One spot warmer than the wire on both sides of it	A joint that heats; or a joint beside something hot, such as an engine or an exhaust	The drop across that joint under load
A wire warm along its whole length	A wire too thin for its current; a load above its rating; heat from the engine space or the sun	Its current, read with a DC clamp meter (→ 3.3), against its ampacity where it runs (→ 5.3 · p. 7)
Insulation browned or melted at a terminal, or a melted connector, found with the circuit off and cold	A joint that has heated before	The terminal replaced by where it sits (→ 5.6 · p. 16), and its drop read after the repair
Darkened or discolored metal on a terminal	Heat, or corrosion	The drop under load
A green or white crust at a terminal	Corrosion from water and salt; by itself it says nothing yet about heat	The drop under load; the terminal replaced (→ 5.6 · p. 16) and the water’s way in found

On a heat-shrink terminal the wire’s metal is under the sleeve, so the probes go on the metal you can reach (→ Fig. 5.8 · p. 30). P is the ring terminal’s bare tongue beside its ring; Q is the stud or the bus bar it sits on; R is the bare tongue of the ring terminal at the wire’s other end. A reading from P to Q measures the contact between the ring terminal and what it sits on. A reading from R to P measures the wire with the crimp inside each sleeve. A probe pushed through a sleeve would read the crimp directly and leave a hole where water gets in.



P–Q: the ring terminal on its stud
R–P: the wire, with the crimp inside each sleeve

Fig. 5.8. Where the probes go on a heat-shrink terminal, here on a branch breaker's output stud. P: the ring terminal's bare tongue; Q: the stud under it; R: the bare tongue of the ring terminal at the wire's other end.

Procedure: The drop across one connection

This is the one-section reading of → 3.4, applied to one crimped terminal and its wire, with points P, Q and R of → Fig. 5.8 · p. 30. Some loads are read another way. On a windlass or thruster circuit the machine runs only for each reading: take the readings by the procedure "A windlass or a thruster as the load" (→ 3.4). A joint of the starter circuit carries its current only during a crank: the procedure "The starter circuit's drop map" (→ 3.4) reads it. A joint of the charging circuit carries its full current only with the engine running, a reading → 3.4 leaves to a pro. A connection behind a panel with AC breakers on it is read by the route "A connection, a holder or a wire runs hot" (→ 4.8), with its signs.

GASOLINE VAPOR · SHORT CIRCUIT · METER LEADS · AC — PRO
BILGE PUMP · SHOCK IN WATER

1. Switch the load on at its full work; a bilge pump runs in MAN only while there is water for it to move (→ 12.1). With it running, touch the insulation beside each joint of its run with the back of a finger; the warm spot is where you read first. Smoke or a burning smell: go to the card "Smoke, a burning smell, or an overheated wire" (→ emergency card).

2. With the load still running, put the probes on P and Q and read the voltage. A minus sign on the display only means the leads are the other way round: compare the number without it. Under 5 mV — 0.00 V on the volts range — at the largest current the joint carries is a sound contact; 5 mV or more means that the contact loses volts and heats (Table 3.2, → 3.5).
3. Where your leads reach both ends of the wire, put the probes on R and P and read again: the wire with the crimp inside each sleeve. Read the circuit's other wire the same way, from its ring terminal at the load to the one on the bus it lands on. The two readings added together are the drop of the circuit's wires: compare the sum with the 3 % or 10 % of → 5.4 · p. 11 for its kind of circuit. Of two wires of one gauge and one length, the one that reads more holds the extra loss. Where your leads do not reach both ends, the procedure "The drop of a running circuit" (→ 3.4) reads the run section by section.
4. Write each reading, with the load that was running, into the Boat Passport (→ 2.3). A P–Q reading of 5 mV or more, or a connection above its yardstick or a holder standing out on the drop map of → 3.4: where the joint sits decides who repairs it, as step 4 of the route "A connection, a holder or a wire runs hot" says (→ 4.8); a terminal or a splice after the battery switch is remade by the procedure in → 5.6 · p. 16. A switch above its yardstick on that map, with the connections on its terminals under theirs, is replaced, not remade: where it sits decides who replaces it (→ 1.8), and a battery switch is a pro's. A sum of the two R–P readings above its 3 % or 10 %, or a whole run above it on the drop map with no connection or switch above its yardstick and no holder standing out: read each connection of the run from P to Q, as in step 2 — each end of a fuse in a clip or terminal the probes can reach among them — and each switch across its terminals; repair each one above its yardstick as above, and read the run again. A holder whose contacts sit inside its body, such as an in-line holder with its fuse closed in, gives no reading of its own contacts, and no number judges it: with nothing else above its yardstick and the run still above its 3 % or 10 %, that holder is replaced first, where it sits deciding who replaces it as above, and the run read again. On a boat with a panel, the feeder

and the branch are each held to their own 3 % or 10 % (→ 5.4 · p. 11): a whole run from the battery is parted into the two by reading the branch's two wires as in step 3, with a clip lead on one probe where your leads do not reach, and the feeder's part passes only when read with every load on the panel at full work (→ 3.4). With nothing above its yardstick, every holder of that kind in the run replaced, and the run still above its 3 % or 10 %, the loss is in the copper — the wire and the crimps inside its sleeves: the run is replaced as "Do it yourself or hire a pro" says (→ 5.10 · p. 37), sized by → 5.4 · p. 11 for the current the load draws, read with a DC clamp meter (→ 3.3), and never thinner than the old wire (→ 5.2 · p. 5) — the next larger gauge where 5.4's answer is the gauge the run already has.

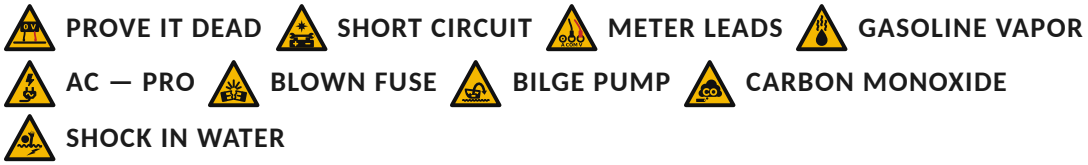
PUT THE BOAT BACK IN SERVICE

- The load back as you found it, and any cover you lifted back in place; a pump switch you held or set in MAN back where the pump's automatic switch has power and nothing runs the pump by hand, as → 12.2 checks.
- The AC sources you turned off: the inverter and the generator back as you found them, and shore power back last, in the order of → 17.2.
- The meter's dial at OFF.

Procedure: Is this wire whole?

Continuity answers one question: is there a path from one end of a wire to the other? A meter beeps below its own threshold — one meter below 50 Ω — so a wire held by one strand beeps like a good one (→ 3.4). Use the beep to find a break, never to pass a connection. The MFR wire is after the battery switch, or on a circuit wired around it once its own fuse at the battery is out (step 2), with neither of its ends behind a panel with AC breakers on it; on a boat with no battery switch, the entry of the PROVE IT DEAD sign says what takes its place. Ends farther apart than your leads reach: a clip lead — a wire with a clip at each end — on one probe extends it. A wire of the bilge pump's circuit is made dead by the procedure "Making the pump's circuit dead before work" (→ 12.2) in place of steps 1 and 2 below, and that procedure's restore

closes the work in place of step 6 and of the restore below, except its first item.



1. Find both ends of the wire and what each connects to (→ 5.5 · p. 15). A positive with its own fuse at the battery is wired around the switch, whether or not a breaker after the switch feeds it as well, and so is any other positive that no breaker or fuse after the switch feeds: its own fuse at the battery comes out in step 2. On a negative wire, the circuit is that of its device: the device's positive is made dead the same way.
2. If the boat needs its navigation or anchor lights, or its electronics, while the battery switch is OFF — at anchor after dark, or under way — stop here until it does not. Otherwise, with the engine stopped, prove that the wire is dead, as the entry of the PROVE IT DEAD sign says: its first reading with the battery switch and the load's own switch still ON and, on a circuit wired around the switch, its own fuse at the battery still in; then the load off at its own switch, the battery switch OFF and that fuse out, as step 3 of the procedure in → 4.6 takes it out. On a negative wire, read its device's positive as well.
3. Loosen the nut at one end and lift that ring terminal from its stud — at the device's end where you can reach it; on a negative wire, only after the readings of step 3 of the procedure in → 5.6 · p. 16. With one end free the meter reads only this wire; with both ends on, it would also read through the device and through any other path between them.
4. Set the dial to continuity, or to the lowest ohms range, and touch the probes together: the meter beeps or reads near 0 Ω. Then put one probe on the bare metal at each end of the wire. A beep means there is a path from one end to the other; it says nothing about the hundredths of an ohm that make a joint heat. No beep: first move each probe to clean metal — paint or crust under a probe gives no

beep either — and read again. Still no beep: the break lies between the probes — in the wire, in the crimp inside a sleeve, or in a splice or an in-line fuse holder on the way. Move one probe to each such point you can reach, and read section by section: the section with no beep holds the break. A crimp, a splice or a stretch of the wire is remade by the procedure in → 5.6 · p. 16; for a fuse that is open, the entry of the BLOWN FUSE sign says when a new one goes in. Until then the wire stays off at its breaker or its fuse, labeled.

5. Put the ring terminal back on its stud, flat on the contact face with nothing under it, under its washers and nut, and tighten the nut as step 9 of the procedure in → 5.6 · p. 16 says.
6. Turn the battery switch back to its working position, the engine still stopped, and put back the fuse step 2 took out, if it took one out and step 4 did not leave the wire off at that fuse.

PUT THE BOAT BACK IN SERVICE

- A wire with a break you have not repaired stays off at its breaker or its fuse — on a circuit wired around the battery switch, the fuse step 2 took out stays out — labeled until it is repaired. If that wire feeds the CO alarm, the high-water alarm or a bilge pump, write down that it has no power: the entries of the CARBON MONOXIDE and BILGE PUMP signs say what you do meanwhile.
- If you stopped before step 6: the ring terminal back on its stud as step 5 puts it, then the battery switch back at its working position, the engine still stopped, and the fuse step 2 took out back in its holder, unless the first item keeps it out.
- A charger, solar panels or any other source you turned off for the readings of step 2, and a DC breaker, an isolation switch or a fuse that the readings of step 3 turned off or took out: back as you found them, a fuse in the way it came out and in the state the entry of the SHORT CIRCUIT sign gives for that fuse, except a feed that reaches a wire the first item keeps off. The AC sources you turned off: the inverter and the generator back as you found them, and shore power back last, in the order of → 17.2.
- The load back as you found it, and the panel cover back in place if you opened it.
- The meter's dial at OFF.

- A CO alarm wired after the battery switch lost its power while the switch was OFF, and one on a circuit wired around it while the fuse step 2 took out was out; the entry of the CARBON MONOXIDE sign says how you see that it is working again.
- If you turned the battery switch: check that the bilge pump's automatic switch has power (→ 12.2).

5.9. Marine-grade or not? Automotive wire, store terminals, tape

Wire, terminals and tape from an auto parts store or a hardware store cost less and are easier to find. Which of them belong on your boat? As with fuses and breakers (→ 4.7), the answer is in what is printed on the part and what it is built for, not in the name of the store.

MARINE-GRADE OR NOT? · AUTOMOTIVE PRIMARY WIRE

Automotive primary wire, SAE J1128, type GXL. The regulation allows it in a circuit under 50 V when its insulation meets SAE J378's temperature rating, and ABYC's 2008 text accepts the same construction (→ 5.1 · p. 2). One maker's sheet and one distributor's sheet for GXL describe bare copper, 19 strands in 16 to 10 AWG, and insulation rated to 125 °C (257 °F); the distributor's sheet adds 60 V. Nineteen strands meet ABYC's Type 2 count for general wiring at those gauges, not its Type 3 count for wire that flexes in use. Its SAE gauge holds about a tenth less copper than the AWG gauge of the same number, so it is sized by its own area (→ 5.2 · p. 5): one size thicker where Table 5.3 or 5.4 marks the cell, and one size thicker than the formula's AWG answer when you work the formula (→ 5.4 · p. 11). MFR

Verdict: Allowed, sized by area

MARINE-GRADE OR NOT? · HOUSEHOLD CABLE

Household cable, NM-B. One maker's NM-B cable has a solid conductor in 14, 12 and 10 AWG and is made for "normally dry locations". A solid conductor is what ABYC rules out and what the regulation's "stranded copper" excludes (→ 5.1 · p. 2). ABYC's note on soldered joints says what flexing does where a wire has turned solid (→ 5.6 · p. 16). MFR

Verdict: Not on board

MARINE-GRADE OR NOT? · WELDING CABLE

Welding cable for battery cables. It is flexible and sold in heavy sizes. One maker sells its welding cable as "Non-UL": its specification sheet gives bare copper strands and insulation rated 105 °C (221 °F) and 600 V, and says nothing about oil, fuel or boats. With none of the standards the regulation accepts on its print, nothing on it shows that it meets the regulation (→ 5.1 · p. 2). A welding cable whose print does show one of those standards is another cable, and its print is what you read. A battery cable is also work at a battery terminal (→ 1.8). MFR

Verdict: Read its print first

MARINE-GRADE OR NOT? · TERMINALS FROM A GENERAL STORE

Crimp terminals from a general store. What decides is each feature, and each one is on the terminal or its package: a ring or captive spade, never an open fork spade; a ring the size of the stud; a printed wire range that covers your gauge; a terminal of the kind your crimper is made for, with a barrel that fits its cavity; and a sleeve lined with adhesive. One maker's heat-shrink terminal has a tin-plated copper barrel and an adhesive-coated sleeve. An open fork spade slides out from under its screw when the screw loosens (→ Table 5.5 · p. 17), and a sleeve without an adhesive lining is not sealed to the wire. MFR

Verdict: Judge the features

MARINE-GRADE OR NOT? · ELECTRICAL TAPE

Vinyl electrical tape. One maker rates its tape as primary insulation for splices up to 600 V and 105 °C (221 °F) and for harnessing, resistant to moisture, abrasion and weather, and writes that it gives “moisturetight electrical and mechanical protection”; it is wound in half-lapped layers with no tension on the last wrap so that its end does not lift. The same maker’s sheet says nothing about oil. MFR

The regulation counts electrical tape as a sheath (→ 4.2). The joints of this chapter’s procedure carry their own adhesive-lined sleeve (→ 5.6 · p. 16); tape is used within its maker’s ratings. CFR

Verdict: Within its maker’s ratings

Makers and part numbers of wire, terminals, crimpers and heat shrink on the US market are the subject of → module “Components”.

5.10. On board

Your boat shows you its wiring in a few places — behind the panel, at the battery, along the engine, at each device — and each of them tells you how it was built. This section turns what you see into a first check, says which jobs are yours, gives you the words for a pro, and lists what an older boat’s wiring shows first.

ON BOARD: GOLDEN RULE

Size a wire by two numbers — its ampacity where it runs and its voltage drop over the round trip — and use the larger wire. Judge a connection by its drop under the working current, not by its look: a joint that is crimped, sealed and held keeps its low resistance, and one that is loose or wet turns current into heat.

What it means

Each first check below names the procedure that takes it; the signs at the start of that procedure go with it.

Table 5.7. What it means

What you notice	What is happening	First check	Yourself or a pro
A wire or a terminal is warm, and nothing trips	Heat at a joint at its normal current, or a wire too thin for its current	Smoke or a burning smell: the card "Smoke, a burning smell, or an overheated wire" (→ emergency card). Otherwise the procedure "The drop across one connection" (→ 5.8 · p. 28); a wire warm along its length: the route "A connection, a holder or a wire runs hot" (→ 4.8)	**Do it yourself, if… you can take that procedure, with its signs; where the joint sits decides who repairs it (→ 4.8)**
Lights dim or a pump slows when another load comes on	A wire or a connection that both loads share loses volts under their added current, or the battery's own voltage sags under it	The procedure "The drop of a running circuit" (→ 3.4), with both loads running, for a wire or a connection the loads share; the battery itself by its resting voltage and its load test (→ 3.5, → 3.6)	**Do it yourself, if… you can take that procedure, with its signs**
A green or white crust at a terminal	Corrosion from water and salt; the joint can heat already, or not yet	The procedure "The drop across one connection" (→ 5.8 · p. 28)	**After the battery switch: Do it yourself, if… you can take the procedure in → 5.6 · p. 16, with its signs; elsewhere, by where it sits (→ 4.8)**
The wire colors on your boat do not match the code	Another scheme of identification, or wires added later	Trace each wire to both ends (→ 5.5 · p. 15)	**Do it yourself**
The print on a wire is in mm²	A European size	The smallest AWG gauge not smaller (→ 5.2 · p. 5), then its ampacity and its drop	**Do it yourself: the reading. A new run: as "Do it yourself or hire a pro" says (→ 5.10 · p. 37)**

What you notice	What is happening	First check	Yourself or a pro
A wire nut, a joint held only by solder, a bare wire under a screw, or an open fork spade	A joint that vibration loosens until it heats	Write it into the Boat Passport (→ Table 5.5 · p. 17)	**After the battery switch, a joint of two wires, a joint of three or more wires remade on a terminal strip or a bus, or a terminal on a stud: Do it yourself, if… you can take the procedure in → 5.6 · p. 16, with its signs. Anything behind a panel with AC breakers on it: Hire a pro**
Automotive wire on your boat	Allowed under 50 V when its print shows SAE J1127 or J1128 and an insulation rating that meets SAE J378; then its gauge, its temperature rating and where it runs decide	Its print (→ 5.1 · p. 2, → 5.9 · p. 35)	**Do it yourself: the reading**
The continuity check beeps, and the device still works weakly or not at all	A beep passes a wire held by one strand; or the fault is elsewhere in the circuit	The procedure “The drop of a running circuit” (→ 3.4), section by section	**Do it yourself, if… you can take that procedure, with its signs**
A wire rubs, sags, lies in the bilge water or touches an exhaust	Insulation wearing through or heating; joints soaking	The walk-around check (→ 5.7 · p. 25)	**Do it yourself: a clamp, a grommet or loom on the run in place. Copper showing, or a joint in the bilge water: Do it yourself, if… you can take the procedure in → 5.6 · p. 16, with its signs; on the stretch between**

What you notice	What is happening	First check	Yourself or a pro
			a battery and the first switch, fuse or breaker on its wire: Hire a pro (→ 4.2). A new route: as "Do it yourself or hire a pro" says (→ 5.10 · p. 37)

IF YOUR BOAT IS 20 TO 40 YEARS OLD

1. **Check first:** the joints behind a DC-only panel and at each device, by eye: wire nuts, bare wires under screws, open fork spades, more than four lugs on one stud, rings larger than their studs, and joints held only by solder (→ Table 5.5 · p. 17). Then the wire itself: insulation with no print, solid household wire, and wire in the engine space whose print gives less than 75 °C (167 °F). ABYC Wire with no print is read as → 5.3 · p. 7 says until you know more; solid household wire and engine-space wire rated below 75 °C are replaced with new runs (→ 5.10 · p. 37, "Do it yourself or hire a pro").
2. **Replace first if you find it:** a joint that lies in bilge water or under spray with no seal; a wire rubbed through at a bulkhead hole; a wire touching an exhaust; rusted nuts and washers on a stud. After the battery switch, or on a circuit wired around it, the joint, the nuts and washers or the damaged stretch by the procedure in → 5.6 · p. 16, and the run moved clear and protected as → 5.7 · p. 25 says; at the terminal of a 12 V lead-acid battery, on its own or in a bank joined in parallel, by the planned job on a battery (→ 6.5); at any other battery terminal, on a stud that stays live with every battery switch OFF, or behind a panel with AC breakers on it, by a pro.
3. **What may be missing, and how you can tell:** support, where a wire sags between clamps more than 18 in apart and nothing else holds it; a cover over a positive stud that is live all the time with no fuse between it and the battery, where you see bare metal and no boot or cap; a fuse at the start of each positive that leaves a bank, or the battery side of a battery switch. The short cables that join the batteries of one bank are part of the bank, not positives that leave it (→ 4.2); whether your bank needs protection between its batteries is

a question for its battery maker and a pro, and the answer goes into the Boat Passport. **BLOWN FUSE** Any other positive with no fuse at its start is an unprotected positive (→ 4.2); the starter cable, known by tracing it to the starter, is the one exception, and a wire taken off the starter's battery terminal to feed anything else is not part of it.

Do it yourself or hire a pro

DO IT YOURSELF OR HIRE A PRO · WIRE AND CONNECTIONS

STOP · Smoke, a burning smell, or insulation melting at a joint while you check it: a wire or a joint is overheating now.
What to do this minute: Go to the card "Smoke, a burning smell, or an overheated wire" (→ emergency card).

HIRE A PRO · Work at a battery terminal, or at a stud that stays live with every battery switch OFF, on a lug or a cable there, and a cover there that fits only with a lug taken off: the entry of the SHORT CIRCUIT sign says which of that work is yours (→ 1.8). Any connection made, loosened or remade behind a panel with AC breakers on it (→ 4.5). A new run fed from a battery, from the battery side of a battery switch or from the panel's feeder, and protection for a wire that has none (→ 4.3). A lug on a wire thicker than 10 AWG, where this chapter's procedure stops. A push-on terminal, whose replacement has to meet the standard's conditions (→ 3.5). A joint that can go only where the bilge water reaches it. A connection on the negative side where a positive within reach of the tool still reads voltage at step 3 of the procedure in → 5.6 · p. 16. A wire you cannot trace to both ends. Order the work in the words of "What to tell the pro" below, and accept it by the checks there.
If no pro is available: **SHORT CIRCUIT** **CARBON MONOXIDE** **BLOWN FUSE** **BILGE PUMP** Until the pro comes, a circuit you suspect of heating, or whose copper shows through its insulation, stays off and labeled at its breaker or its fuse — except a circuit that feeds an alarm, and one that feeds the lights or the steering under way or at anchor after dark, as the sentences below say; a fuse at the battery comes out as step 3 of the procedure in → 4.6 takes it out. A bilge pump on it is off with it, and the boat is watched as the entry of the BILGE PUMP sign says. A circuit that feeds a CO alarm or a high-water alarm

stays on instead, with every other load on it — a bilge pump included — off at its own switch and labeled, so that the circuit carries only the alarm's own current. Where the alarm cannot stay on without another load, that circuit goes off too, and the entries of the CARBON MONOXIDE and BILGE PUMP signs say what you do while the alarm has no power. A circuit whose copper shows through its insulation stays off even where it feeds an alarm, and the same entries say what you do while the alarm has no power. Under way, or at anchor after dark, a circuit you suspect of heating, or whose copper shows through its insulation, that feeds the navigation or anchor lights or what steers the boat stays on, as the entry of the BLOWN FUSE sign says. Write what you found into the Boat Passport.

When a pro may do it differently: A pro may size a metric wire smaller than the next AWG size by ABYC's area note, with its ampacity corrected and its drop worked out again (→ 5.2 · p. 5), and may fit a push-on connector that meets the standard's conditions (→ 3.5). You see it in the calculation or the clause the pro names and writes into the Boat Passport.

DO IT YOURSELF, IF…

The procedures of this chapter, each with the signs at its start: "Replacing a terminal on a wire after the battery switch" (→ 5.6 · p. 16), which also joins two wires with a butt connector, remakes a joint of three or more wires on a terminal strip or a bus and replaces a damaged stretch; "The drop across one connection" and "Is this wire whole?" (→ 5.8 · p. 28). With them: a clamp, a grommet, loom or a label added to a run without taking a terminal off (→ 5.7 · p. 25); a new branch circuit, or a branch run moved to a new route, after the battery switch, from a spare breaker on a DC-only panel; and a branch run replaced along its route, after the battery switch, on its own breaker on a DC-only panel. For each new or replaced run: the breaker's rating and the wire chosen by the triad of → 4.3 and the two numbers of → 5.3 · p. 7 and → 5.4 · p. 11, a breaker you keep checked again by that triad; each terminal and splice made by the procedure in → 5.6 · p. 16, the run supported and protected as → 5.7 · p. 25 says along a route you reach dry, and the work accepted by the readings of → 5.8 · p. 28 under full load.

DO IT YOURSELF · Read the print on a wire; size a wire on paper with the formula and Tables 5.1 to 5.4; trace a wire by its color and its route, and

write it into the Boat Passport; take the walk-around check of → 5.7 · p. 25.

On someone else's boat there are three levels, not four: switches and buttons — yes; tools — no; the gray zone — only with the permission of the charter base or the owner, by phone (→ 2.6). A crimper and a meter are tools: there you look and smell for heat with the loads running, and tell the base or the owner what you found and where.

What to tell the pro

WHAT TO TELL THE PRO

Ask for this: "Size each new or replaced conductor for its ampacity where it runs, engine space and bundling included, under 33 CFR 183.425 and ABYC E-11, and for a voltage drop of 3 % or 10 % under ABYC E-11, with the round trip measured from the power source connection. Use conductor printed UL 1426, or SAE J1127 or J1128 with an SAE J378 temperature rating, with Type 3 stranding where it flexes. Use ring or captive spade terminals crimped with a crimping tool designed for the terminal used and sealed with adhesive-lined heat shrink, with every connection above the highest bilge water. Support every run, protect it from chafe, and label it at both ends." Accept the work by three checks. The print on each new wire shows its type, gauge and temperature rating; its gauge is not thinner than the larger of the two answers of → 5.3 · p. 7 and → 5.4 · p. 11 for where it runs, and its fuse or breaker passes the triad of → 4.3. Each new connection reads under 5 mV across it under the full load of its circuit, and the pro shows you the readings. The Boat Passport holds each changed circuit the same day: what it feeds, its gauge, its protection rating and its round-trip length.

REMEMBER

- A wire is right for a boat by its print: stranded copper, a standard — UL 1426, or SAE J1127 or J1128 with a J378 rating — a gauge and a temperature rating. The regulation allows automotive wire made to SAE J1127 or J1128, with SAE J378's insulation rating, under 50 V.

- A metric wire is replaced by the thinnest AWG gauge whose area is not smaller: a 50 mm² cable is smaller than 1/0.
- Ampacity falls in an engine space and in a bundle; each conductor of a duplex cable is derated by 0.7, by the 2008 edition of ABYC E-11.
- CM = 10.75 × I × L ÷ E, with L the round trip in feet. Size for ampacity and for drop, and use the larger wire.
- A color is a hint; tracing the wire to both ends is the proof.
- A good connection is a ring or captive spade of the stud's size, crimped with a tool made for it, sealed with adhesive-lined heat shrink, and laid flat on the contact face under its washers and nut.
- A joint is judged by its drop under working current; a continuity beep says only that the wire is not broken.

Self-check

1. **On paper.** Suppose a 12 V bilge blower draws 4 A, and its wires run 10 ft from the panel to the blower. What is the smallest wire for its 3 %, with AWG wire and with SAE wire?
   Answer: L = 20 ft and E = 0.36 V, so CM = 10.75 × 4 × 20 ÷ 0.36 = 2,389. With AWG wire, 16 AWG (2,580); with SAE wire, one size thicker, 14, because an SAE gauge holds less copper than the AWG gauge of the same number (→ 5.2 · p. 5, → 5.4 · p. 11).
2. **Two places.** Suppose a 10 AWG wire with 105 °C (221 °F) insulation runs alone through the engine space, and then the same wire runs there as one conductor of a duplex cable. What is the ampacity of each?
   Answer: 60 × 0.85 = 51 A alone; 51 × 0.7 = 35.7 A in the duplex cable (→ 5.3 · p. 7).
3. **A metric print.** Suppose a cable on a European-built boat is printed 35 mm². Which AWG gauge replaces it?
   Answer: 35 mm² is 69,073 circular mils. 2 AWG, with 66,360, is smaller; 1 AWG, with 83,690, replaces it, and then its ampacity and its drop are checked (→ 5.2 · p. 5).

4. **Before you measure.** Suppose P–Q across a lug reads 1 mV while 3 A flows through it, and the same lug carries 30 A when its whole circuit runs. What will it read then, and did the 1 mV pass it?
   Answer: its resistance is 0.001 ÷ 3 = 0.00033 Ω; at 30 A it reads 0.00033 × 30 = 0.01 V, which is 10 mV: not under the 5 mV of a sound contact. The 1 mV passed nothing: read it again at full current (→ 5.8 · p. 28).
5. **Where is the heat?** A sleeve feels warm, and P–Q at that terminal reads under 1 mV at full load. Where is the heat, and which reading shows it?
   Answer: not in the contact between the ring terminal and its stud, which P–Q shows sound. A warm sleeve has two places to look: the crimp inside it, or something hot beside it (→ Table 5.6 · p. 29). R–P across that wire, against the same reading on the circuit's other wire, tells them apart: a higher reading on this wire puts the loss in its crimps or the wire itself (→ 5.8 · p. 28).
6. **On your boat.** Read the print on three wires — one at a fuse block or a DC-only panel, one in the engine space, one at a pump or a light — and write down for each its standard, its gauge and its temperature rating.
   Answer: a wire whose print you cannot read is taken at the 60 °C (140 °F) column, with the engine-space factor of → 5.3 · p. 7 for the one in the engine space and its bundle factor for any that runs beside other current-carrying conductors, and at the SAE area, until you know more (→ 5.4 · p. 11).
7. **On your boat.** Without loosening anything, look at one stud with lugs on it: count the lugs, compare each ring with the stud, and see what lies under the lowest lug.
   Answer: four lugs at most, rings the stud's size, and the lowest lug flat on the contact face with nothing under it (→ 5.6 · p. 16); anything else goes into the Boat Passport.
8. **On your boat.** Take the walk-around check of → 5.7 · p. 25 along one run, and write down each finding with where it is.
   Answer: a sound run is supported along its length or clamped at least every 18 in, has a grommet or sleeve wherever it passes through, a gap from the exhaust, nothing in the bilge water, and a label at each end; the exceptions of → 5.7 · p. 25 are no finding.

Terms

marine-grade wire
Wire made to UL 1426, the standard for boat cable: stranded copper, rated 600 V, with a dry and a wet temperature rating.

tinned copper
Copper strands coated with a thin layer of tin.

stranded wire (Type 3)
A conductor made of many strands; ABYC's Type 3 has more and finer strands than its Type 2, for wiring that flexes often in normal use.

solid wire
A wire whose conductor is one piece of copper.

AWG
American Wire Gauge, the US system of wire sizes: a smaller number is a thicker wire, and thicker than 1 AWG the sizes go on as 1/0, 2/0, 3/0 and 4/0.

circular mil (CM)
The unit of a wire's copper area: the area of a circle 0.001 in across.

wire gauge
The size of a wire's conductor, printed on its insulation.

ampacity
The current a wire can carry continuously without its insulation getting hotter than its temperature rating, set by the gauge, the insulation rating and where the wire runs.

derating (hot engine room, bundle)
Lowering a wire's ampacity for the heat around it, as in an engine space, or for other current-carrying conductors beside it in a bundle, a cable or a conduit.

duplex / triplex cable
Two or three insulated conductors under one outer jacket.

round trip (L)
The length of a circuit's wire from the power source connection to the device and back, in feet: the L of the voltage-drop formula.

voltage drop
The voltage a cable, connection or switch loses while current flows through it, measured across that part under its working current.

color code
The colors ABYC gives DC wires by their function: a hint to what a wire is, proven only by tracing it.

ring terminal
A crimped terminal whose end is a closed ring that goes over a stud.

captive spade
A spade terminal shaped to stay under its screw when the screw loosens.

lug (battery lug)
The crimped part on the end of a heavy cable, bolted to a battery terminal or a stud.

crimp
A joint made by pressing a terminal's barrel onto a wire's strands with a tool made for that terminal.

adhesive-lined heat shrink
Heat-shrink tubing with a layer of adhesive inside that melts as the tubing shrinks and fills the space around the wire (→ 5.6 · p. 16).

wire nut
A twist-on connector screwed over twisted wire ends, made for house wiring.

chafe protection
A grommet, sleeve, loom or conduit that keeps a wire's insulation from wearing through where it rubs or passes through a hole.

support (wire support)
A clamp or strap that holds a wire in place along its run.

stud stack order
The order of the parts on a stud from the contact face up: the lug, then the flat washer, the lock washer and the nut.

continuity
A path for current from one end of a wire to the other, as a meter's beep shows it.

starter cable (cranking motor conductor)
The cable from the battery to the starter, directly or through the battery switch: the one wire that leaves a bank and may run without protection, identified by tracing it to the starter.

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