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# Marine DC electrical systems



by Edward Kolbe  
Associate Professor of Agricultural Engineering  
Oregon State University Marine Science Center, Newport

Oregon State University  
Extension Marine Advisory Program  
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## MARINE DC ELECTRICAL SYSTEMS

These notes on Bonding and DC systems for boats summarize recommendations made at a series of Sea Grant workshops held between 1974 and 1978. The workshops were conducted by Don A. Cuning, instructor of marine electronics, Ketchikan Community College. The notes were prepared by Edward Kolbe of the OSU Sea Grant Marine Advisory Program. Technical reviewer was Mr. Rick Kiser, of Rick Kiser Marine Wiring, Newport, Oregon.

Ninety percent of marine electronics and underwater corrosion problems are related to bad wiring or other electrical problems. These notes recommend practices and materials important to construction of a sound boat electrical system. Part I describes "bonding"; Part II describes wiring of the DC system. Each section includes discussion of various components and sub-topics, listed alphabetically.

### I. BONDING

Bonding means tying all metal together electrically and connecting it to the ground system at a single point. This point should be on the cold part of the engine block, rather than the hot part where expansion/contraction can loosen the connection. In all cases, the bonding strap or wire is not to serve as a (current carrying) negative electrical wire.

The best bonding system will have a flat copper strip (minimum width of 1-1/8 inch) running the length of the vessel and attached to all metals. Keep the copper strip up out of the bilge water and protect it from corrosion by spraying with clear acrylic. To join sections of copper strip, bend as shown in Figure 1 and seal with solder paste. The flat strip is important for carrying off RF (radio frequency) energy; a copper tube is not good for this reason but can be used if it is slit open and flattened. If you must use wire instead of copper strip for the primary bonding system, it should be insulated, type TW, and of a size no smaller than #6; #4 is preferable. Note that some side bonding wires may have to be quite large also--on the order of #8 to #6.

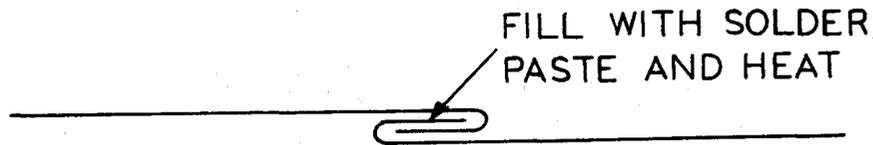


Figure 1. Joining copper bonding strip.

Bonding is very important for wood and fiberglass boats; it is also recommended for steel boats. The benefits of bonding are:

1. It removes the potential for stray current corrosion ("electrolysis") by preventing any voltage difference to build up between any two pieces of metal;
2. It stabilizes radio RF;
3. It suppresses noise;
4. It removes any resonant frequency lengths from the antenna system.

Each fixture or instrument must be bonded. The best way is to use shielded wires for the fixture--the shielding serves as the bonding wire. If this is not done, then run a third wire (a bonding wire) to each fixture.

Typical items that must be bonded include:

Machinery	Electrical panel
Rudder quadrant	Keel cooler
Stuffing box	Fuel tank
Shaft (with shaft brush)	Stays
Engine bed	Etc (any large piece of metal)
Ground plate	

Some important things to consider when bonding a boat:

#### Keel cooler

Make sure the keel cooler is bonded. Sometimes these are assumed to be tied into the system, but in fact are isolated because their only connection is a rubber hose.

#### Mast light

Along with running lights, mast lights are a notorious source of current leakage. Ground the housing with the armor (shielding) on the cable (shown schematically in Figure 2). It is impossible to keep this type of light completely sealed because of constant heating and cooling, so allow a small hole in the base to drain off moisture.

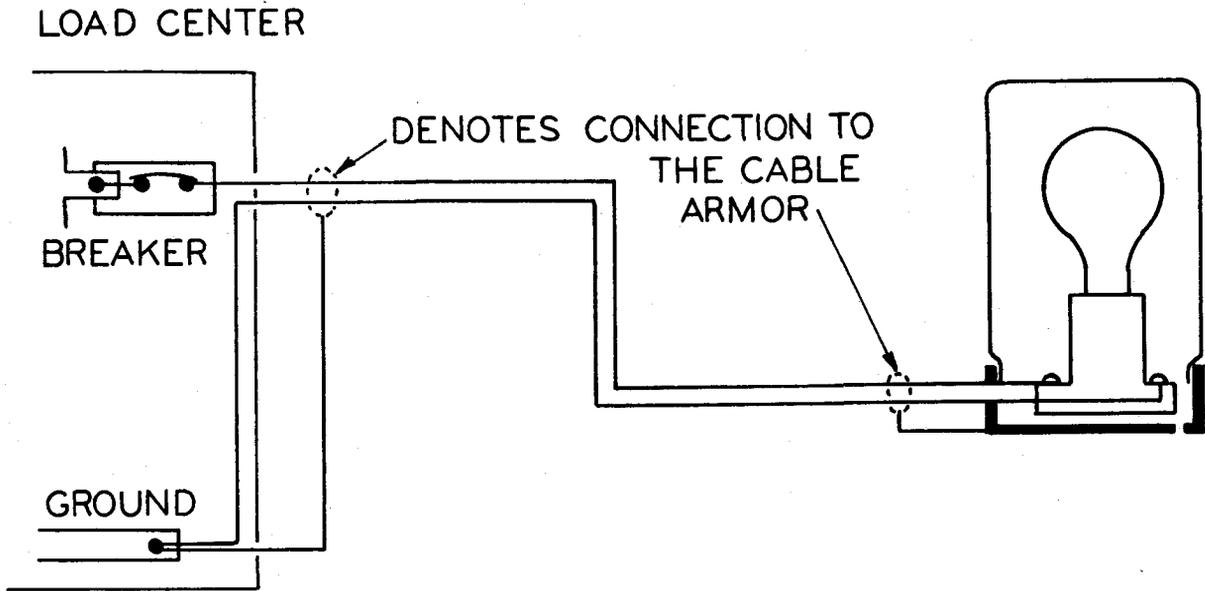


Figure 2. Wiring lights with shielded cable.

### Radio ground plate

A radio ground plate is needed to increase the capability of the HF (SSB) radio. It should be copper, measuring 16 square feet for any size boat and must be in contact with the water. A metal-hulled boat may not need one; but a steel or aluminum boat having high-quality epoxy paint will need an external ground plate. An alternative to a flat copper plate is a few 2-inch copper pipes, open at each end. Avoid the use of small-sized, porous metal plates sold as ground plates.

### Radios

Make sure radios are tied to the ground plate and electrical panel with a 1-1/8 inch-wide copper strip (not necessary with a steel wheelhouse). Note that this is an RF ground, and is separate from the bonding strip or wire. All boats should have an additional copper strip around the ceiling of the wheelhouse. This stabilizes the ground plane for the HF radio antenna system, and acts as a noise suppression shield.

### Shaft brush

You can make a shaft brush out of a Chore Girl (brass scouring pad) pressed against a brass shaft collar by a springy stainless bar. Put the shaft brush close to the engine to keep it out of the bilge slop.

Bonding the shaft is not always done--there may be cases of stainless shafts and prop (or other through-hull fittings) that may be better left unbonded. In this case, protect them with their own cathodic protection system, such as use of hub and shaft zincs.

## II. DC ELECTRICAL WIRING SYSTEMS

Figure 3 is a wiring diagram for a typical fishing vessel. Along with Figure 3, consider the following points:

### Alternator

Alternators are built more for automotive or industrial use--not marine use. On boats, they tend to overheat. Diodes are liable to give out if temperatures exceed 120°F. Make sure alternators will stay cool.

Alternator grounding: don't depend on the alternator's mounting bracket for a ground. Run a heavy (#6 or #4) wire from the alternator case to the engine.

### Ammeters (see Figure 3)

#### Load current ammeter:

Get one that reads only one way, for example, 0-60 amps. The shunt shown in Figure 3 is for remote mounting of the ammeter and allows use of smaller wire. The beauty of the load center ammeter is that you see each individual circuit load (by switching off all others). When the load is newly installed and operating properly, write down the amount of current drawn. If it later begins to leak current, you will be able to identify the faulty circuit. For example, if a mast light is supposed to draw 0.5 amps, and you shut it off and note that the ammeter reading drops from, say, 12 amps to 10 amps, then you know there is a current leak in that circuit. Even a large capacity load ammeter of, say, 75 amps can measure a 1 to 2 amp change if it is a good one (costing on the order of \$75).

#### Generator current ammeter:

Shortly after starting, the current shown by this ammeter will exceed that shown by the load current ammeter. The excess is the amount going to recharge batteries. After a half-hour or so, batteries should have become recharged, and the two ammeter readings should be about the same. (They will always differ

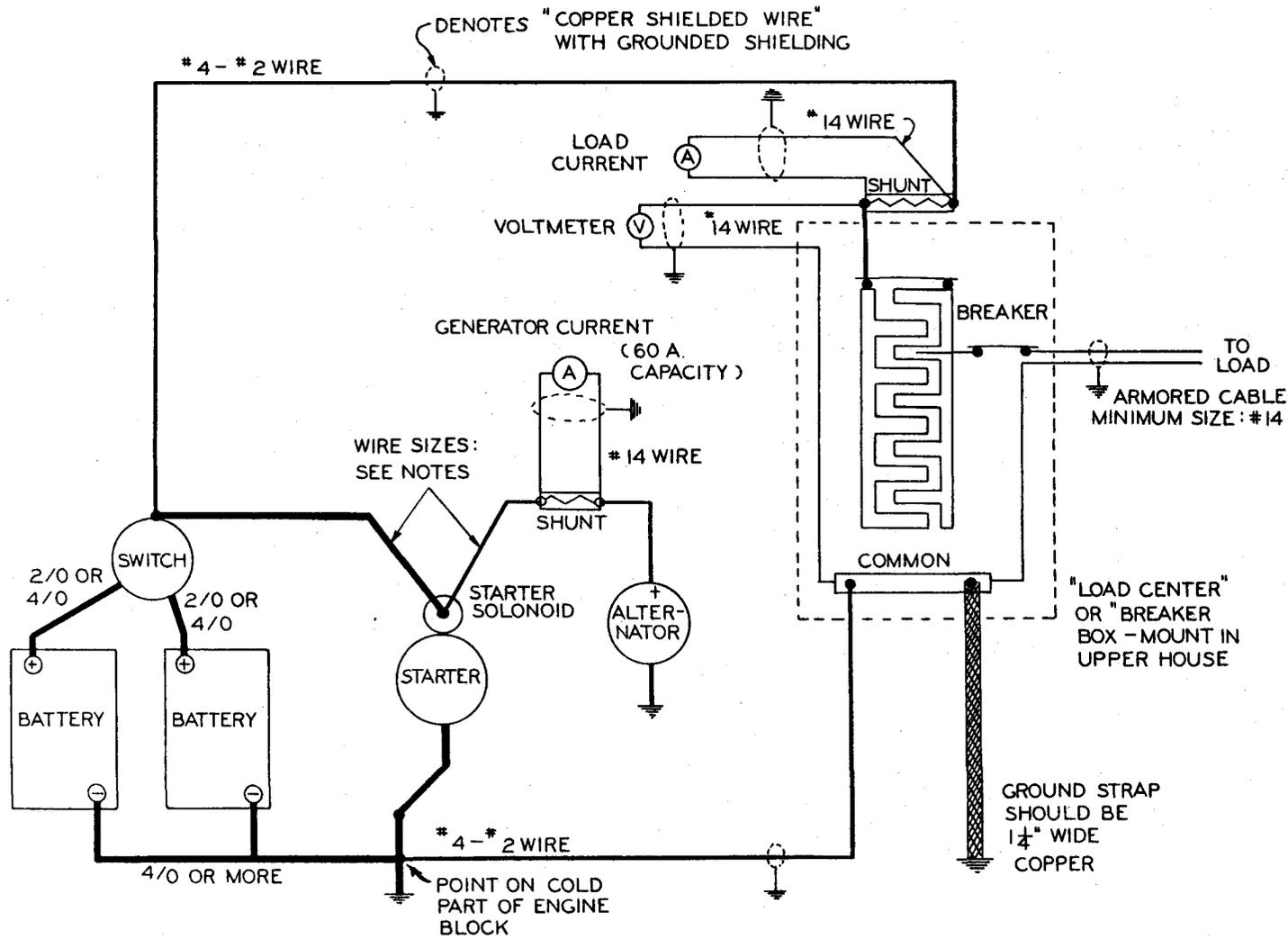


Figure 3. Boat wiring diagram (sizes for typical 12V system).

by a few amps; pulsed equipment like the autopilot will cause intermittent draw-down of the battery, leading to a continual small charge current.)

### Batteries

A great number of "electrolysis" problems result from battery leakage. Don't use wooden battery cradles that can become soaked with electrolyte; use plastic (fiberglass) battery boxes.

### Circuit breakers

It is Cunning's opinion that these can be relatively inexpensive household AC breakers, and that they'll work well with any low DC voltage circuit (up to and including 32 volts). Higher voltages (such as 120 volts DC) will cause an arc which will burn out the contact. (Kiser's viewpoint is that all breakers used for DC systems must be "Rated for DC Voltages" to ensure proper arc suppression.) Under normal operation, the tungsten alloy contacts stay clean because of "wiping" action when they are closed. Note that circuit breakers work strictly on thermal effects.

Most load centers will have up to 24 circuits; one can "piggyback" breakers to get more circuits.

### Emergency battery

Put a separate battery high in the wheelhouse and wire it through a diode to the charger circuit. This diode will prevent the emergency battery from discharging. If the boat is sinking, the engine room flooded, and the main battery knocked out, you still have power left for radios.

### Fuses

Don't use cartridge fuses (Figure 4). One can often read voltage drops up to 3 volts due to corroded contacts. The resulting low voltage on motors will burn them up and cause many other problems as well.

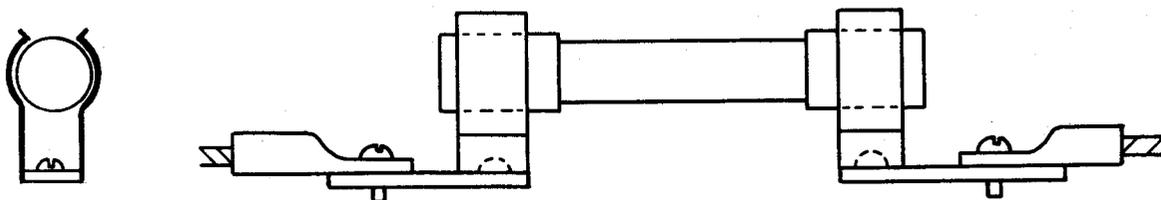


Figure 4. Cartridge fuse.

### Knife switches

Don't use them because of easily corroded contacts.

### Negative ground

The use of a negative ground rather than a positive or floating ground system is important for two reasons:

1. It minimizes damage due to "electrolysis" (stray current corrosion) in case of an electrical leak;
2. Most electronic equipment on the market is set up for negative ground; some units, which are grounded internally, make a floating ground system difficult to lay out. A positive ground system creates a further possibility of serious "cross-grounding" and damage due to stray current corrosion.

### Safety switches

You should have a safety switch for each two batteries in parallel. This allows the starter to be disconnected if a solenoid should stick, and it allows checking for stray current corrosion (Figure 5). Most safety switches are good enough for a starter circuit--for example, 175 amps continuous, 300 amps intermittent. Figure 6 shows the internal operation of safety switches. One commonly used is Cole-Hersee, of Boston, Massachusetts. Their small size model is rated at 175 amps continuous, 325 amps intermittent (e.g. for starter); their large size is rated at 600 amps intermittent.

### Soldering

Cunning's opinion is that you should solder all terminals. The primary reason is to seal the joints so they won't corrode. Soldering also helps add physical strength. Solder

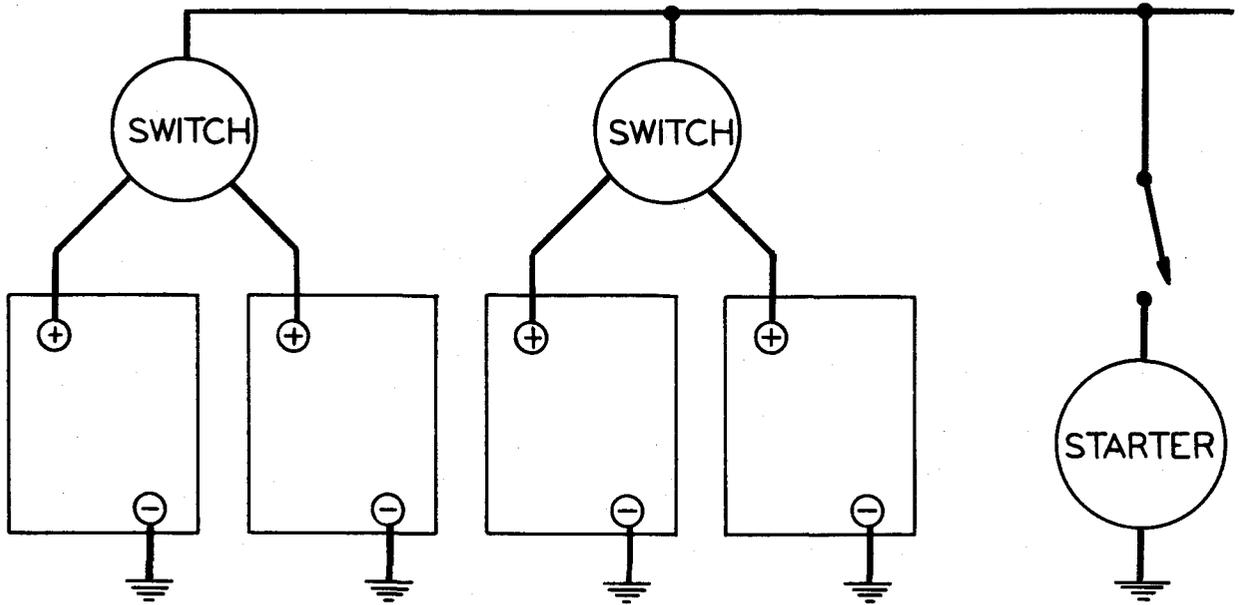


Figure 5. Safety switch for each two batteries.

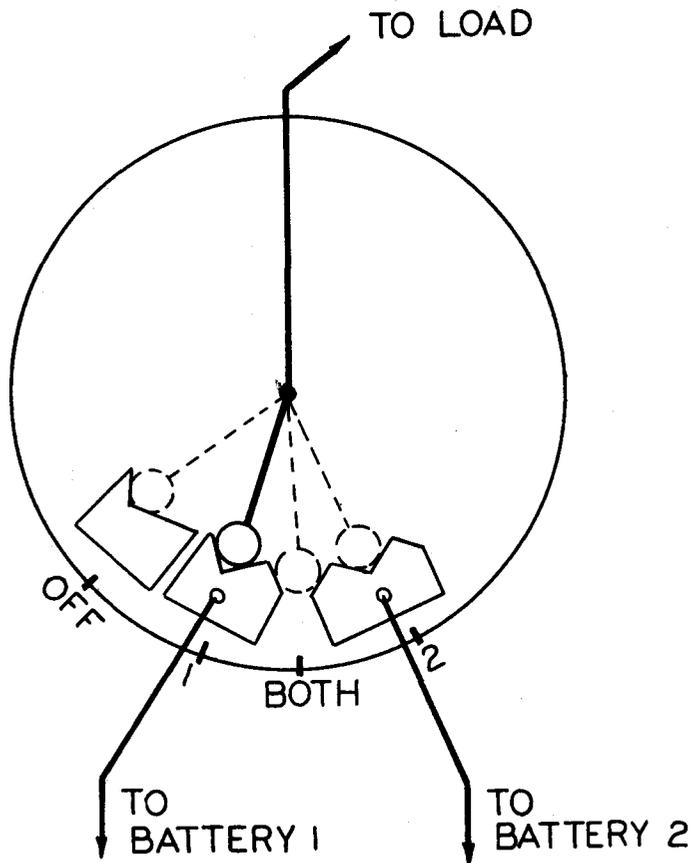


Figure 6. Safety switch.

is not a particularly good conductor of electricity, however, so don't rely on it for that.

Use 50/50 or 60/40 (tin/lead) solder in most cases. Use a big soldering iron rather than an open flame. On big connections, you might wish to use silver solder for better conduction. After making the solder connection, seal it up with Scotch-Kote or clear acrylic.

(Kiser feels that properly crimped wire ends can be as good or better than soldered connections. However it is important that the terminal and wire sizes be correct, and that adequate pressure is applied to a proper crimping tool.)

### Terminals

Satisfactory connections can be made with either a soldered wire loop or a crimped "lug" end as shown in Figure 7. You can make satisfactory lugs from copper tubing; don't buy terminals with plastic coatings.



SOLDERED WIRE  
LOOP MAKES  
TERMINAL



CRIMPED COPPER  
TERMINAL, SEALED  
WITH SOLDER

Figure 7. Two types of terminals.

When wiring junction boxes, always use terminal strips. When a wire is opened to join to a strip or other fixture, always seal the end back up with something like 3M Scotch-Kote.

### Voltage regulator

If the voltage regulator gets too hot, it will shut down the field current. Mount it in a cool spot--it's best to have a vent to supply cool, salt-free air to both regulator and alternator.

### Voltmeter

The voltmeter is very important because it will indicate the performance of the alternator.

Wire sizes

Wire sizes must be large enough to pass the needed current without excessive voltage drop. The maximum voltage drop that can be tolerated on a boat is 1%--that is, for example, 0.126 volts on a 12-volt system. Note that some wire tables don't specify allowable voltage drop. Instead they give maximum current flow that can be tolerated before overheating occurs.

Some example wire sizes for different 12-volt circuits are as follows:

## A. Starter circuit:

- For 200-amp starter: use 2/0-3/0 wire
- For 300-amp starter: use 4/0 wire
- For 400-amp starter: use 350 circular mil wire

## Notes:

1. There shouldn't be more than 0.5 volts drop during a start.
2. One 3/0 wire equals two 2/0 wires; note that 2/0 wire is a size often used for welders.
3. A rule of thumb is that the starter current will be about 1 amp per cubic inch of engine displacement.

## B. Alternator circuit:

- 35-amp alternator: #4 wire
- 60-amp alternator: #2 wire
- 80-amp alternator: #0 wire

## C. Typical load circuits:

- |                       |                               |
|-----------------------|-------------------------------|
| Masthead and          | Echosounder/recorder: #12-#10 |
| running lights: #14   | VHF radio: #10                |
| Vent blower: #12      | HF, SSB radio: #10-#4         |
| Fresh water pump: #12 | Spotlight: #8-#6              |
| RDF: #12              | Bilge pump: #8-#6             |
| Flasher sounder: #12  | Autopilot: #6                 |
| CB radio: #12-#10     | Radar: #4                     |
| Loran: #12-#10        |                               |

## Notes:

1. The minimum wire size that should be used on a boat is #14.
2. A #6 wire corresponds to about 7 strands of #14; #4 wire corresponds to about 7 strands of #12.

3. Some of these loads have "pulsed power" characteristics. As an example, radar, CB, autopilot, and depth recorder all have a high power over short term intervals. The wire must be adequately sized to handle the short term surge. An autopilot might be sluggish due to undersized wire; it won't handle the surge on motor start-up.

### Wire type

Use shielded, stranded copper wire. Do not use solid copper or aluminum wire. Aluminum will corrode easily in salt air, doesn't hook to copper very well, can't be soldered satisfactorily, and has no spring-back (and as a result, termination will loosen).

Shielding is important because it makes bonding easier; but more significantly, it prevents interference. Any wire carrying a current also carries a magnetic field around it, as wire #1 has in Figure 8. If the current and thus the magnetic field of wire #1 is nonsteady, the expanding/collapsing magnetic field will induce a current to flow in wire #2, and this leads to such things as radio noise. Shielded cable provides for a metal shield around wire carrying a nonsteady current (such as AC). It is important for VHF and CB radio operation, and very important on voltage regulator wire. The shield will concentrate and contain the magnetic lines, preventing any interference in adjacent wires. The shield should be grounded; a typical shielded wire application appears in Figure 9.

Besides alternator wire, a notorious source of noise is windshield wipers--you might have to use armored cable (shielded wire) as well as a filter. The best type of shielded wire is "copper sheet-wrapped wiring."

Note that the DC marine wiring color code differs from AC household wiring practice. In DC marine wiring, positive is any colored wire; negative should be black. Alternating current convention (household and marine) is that the hot wire is black, "neutral" is white, "ground" is green.

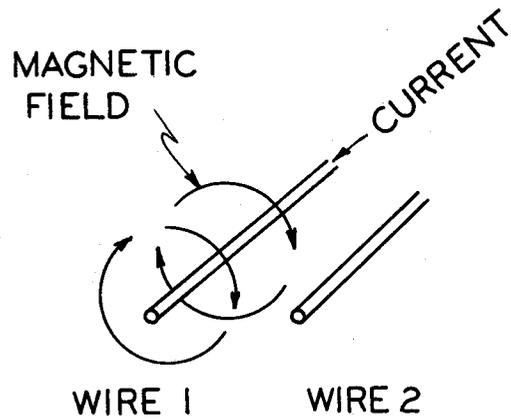


Figure 8. Interference in wire #2 due to expanding/collapsing magnetic field of wire #1.

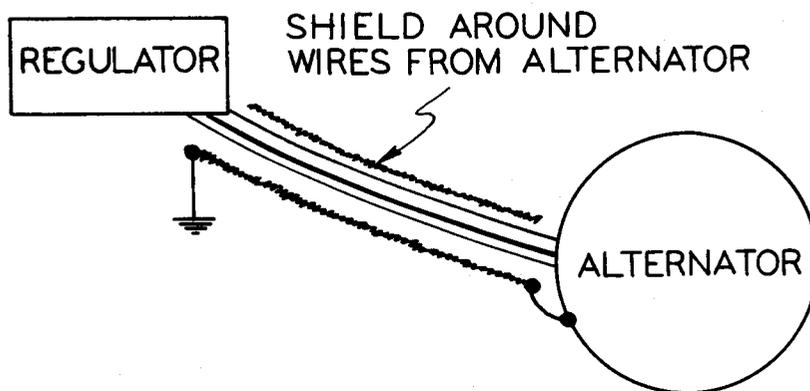


Figure 9. Typical shielded wire application.

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