BASIC MARINE DC WIRING

is a white paper by Russ Lawrence W7SFR
Even though His intended audience is boat owners , he explains in detail very good practices to follow when doing low voltage wiring . Do it once and do it to last and there will be fewer *surprises when a surprise could be done without*

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BASIC MARINE DC WIRING 101

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Prologue:

This document is created to assist our fellow Arima Boat Enthusiasts in electrical projects and maintenance. It is a practical guidance to answer basic questions. It is not intended to design circuitry or provide direction for any particular installation.

Safety is always a paramount concern when dealing with electrical circuitry. You are strongly urged to follow any and all safety recommendations. That being said, this manual is not intended to be a comprehensive document for circuit development or safe working techniques. The reader must take the information contained herein simply as a reflection of our experience. The authors specifically accept no liability for any results that may come from applying the information contained herein. The reader is strongly urged to seek professional assistance for any activities they are not comfortable performing on their own.

Codes:

Specific wiring codes applicable to marine wiring may be found in publications available from American Boat and Yacht Council. Here is a link to their color code recommendations. http://www.marinewireandcable.com/p/marine-wire-color-codes.html

The Marine Electrical Environment:

The Marine electrical environment has a number of unique characteristics that must be allowed for to ensure long life of your circuitry. In general, those characteristics center around water and chemistry. We found it interesting to learn that pure water is a really poor electrical conductor. However, when you start adding impurities, such as salt, chlorine, dissolved dirt, etc., it more readily conducts electricity. Pure (distilled) water simply does not naturally occur. The closest water comes to that condition is rain drops, and even then each drop contains a small element of dirt or other contaminant.

Obviously our boats are operated in some 'moist' environment. When near saltwater, that moisture contains more chemical elements than moisture found near a high mountain lake. But the moisture, with its chemical elements, is still there.

When the moisture and its chemical elements come in contact with electrical circuitry, a chemical reaction, called electrolysis, occurs. This involves, among other things, oxidation and other changes in the chemical composition of the wiring carrying the electrical current.

Your job, as a boat owner working on your craft, is to keep the moist atmosphere away from the electrical conductors to the extent practicable. We will touch on how to maximize this in later sections. It involves choosing the right materials and using good construction techniques.

DC Electrical Principles

Before digging into how to do and what to use, we must have a good understanding of how electrical circuitry works.

There are two kinds of electrical current, Alternating Current (AC) and Direct Current (DC). With AC current that we normally associate with, the electrons providing the power travel at close to the speed of light, changing direction 60 times a second. As one would expect, the electrons that are moving, don't go very far in that time. This characteristic allows the use of solid core wire in its circuitry without developing significant heat. This also allows significant voltages and amperages to be transferred across long distance. There are many volumes of information about the characteristics of AC power. However, since our boats, unless connected to shore-power, have no AC circuitry, we will go no further in that discussion.

Our boat circuitry is DC powered. As you might surmise, the electrons in DC circuitry only travel in one direction. There are conflicting theories, offered by folks with lots of letters following their names, regarding which direction those electrons move, positive to negative or negative to positive. For the purposes of our discussion we will assume the electrons are moving from a positive source to a negative source, much like water through a hose or pipe.

Because the electrons do not change direction, they must travel a considerable distance from the positive source to the negative source. As they do so, they encounter resistance. Passing through this resistance creates energy loss in the form of heat.

Let us provide a very brief discussion about the relationship between voltage, amperage and resistance. Perhaps, you could think of DC current as being similar to water passing through a hose. The voltage is the pressure, amperage is the amount of water going through the hose and resistance is the elements slowing the flow of the water.

Voltage: Voltage can be thought of as the pressure that causes electrons to flow through a circuit. We deal with just 12 volts. Since we cannot increase the voltage (pressure) to overcome the resistance (caused by wire size) to electrons flowing through the circuit, we must adjust the wire size to reduce the resistance. In our hose example, a larger hose moves more water than a smaller hose from the same faucet (pressure)

Amperage: Amperage can be thought of as the amount of electrical energy successfully passing through the circuitry without being lost as heat. Amperage is what does the work in our electrical equipment.

Resistance: As we all know, we can move more water more efficiently (less pressure loss) through a larger diameter hose or pipe than one with a smaller diameter. It's the same with amperage in DC current. In order to minimize losses, the whole system must be the same size, or larger. If you start out with a 2" hose, and splice in a piece of 1" hose somewhere in the system, you effectively have limited the amount of water that can be passed to what will run through the 1" section of hose. That can be referred to as changing the resistance in the system. When you change the gauge (size) of wire in a circuit, you are doing the same thing with electrical energy (amperage) flow.

Example: If you are connecting a piece of electrical equipment to the positive terminal with 14 ga wire and then running from that equipment to the negative terminal with 18 ga wire, you are effectively wiring the entire system with 18 ga wire. Further, if the equipment needs the amperage supplied by 14 ga wire, the 18 ga wire will soon heat up, perhaps to the point of melting the insulation and, perhaps catching fire.

Because of this, you must include the length of the wire from the positive terminal to the equipment AND the length of the wire from the equipment to the negative terminal when designing your circuitry. We will lightly touch on circuitry design later in this document.

This also helps us to understand why we need to have much a larger positive and negative wire feeding a distribution panel than the wiring going from the panel to the individual pieces of equipment. The wiring supplying the panel must pass all of the amperage needed to operate the many pieces of equipment.

Example: Say you are running a fish finder/GPS unit requiring 5 amps; radio, requiring 6 amps; Navigation lights, 4 amps; wipers, 5 amps each side; a bilge pump 5 amps; hydraulic trim tabs, 3 amps; and a troll master, 3 amps, from a fuse panel. Your potential amperage draw will be 36 amps. While none of these units will likely need more than 14 ga. wire for their circuitry, you will need to size the wire to the fuse panel to handle more than 36 amps. ***Safety Issue:*** Some might say the likelihood of running all of these circuits is small so you would be able to use a smaller draw in sizing wire or fuses. This could be true, but if you are in a situation where all these need to be running and a wire fails or fuse blows, what then???

Fuses: When you try to pass too much DC current through too small a diameter wire, the current encounters a lot of resistance. As the current meets this resistance, it generates heat. If the wiring is too small, the heats quickly builds (remember the electrons in the current are still moving at close to the speed of light) to a point that something in the system must fail (melt) thus breaking the circuit from the positive source to the negative receptacle.

The current really does not care if what fails is a cheap piece of metal (a fuse) or a vital part of an expensive piece of electrical equipment (motor circuitry, fish finder, radio, whatever). That is why fuses are installed in a circuit, between the positive connection and the equipment it is protecting. The fuse will heat and fail more quickly than the elements of the equipment, thus protecting it from current overload

Tools:

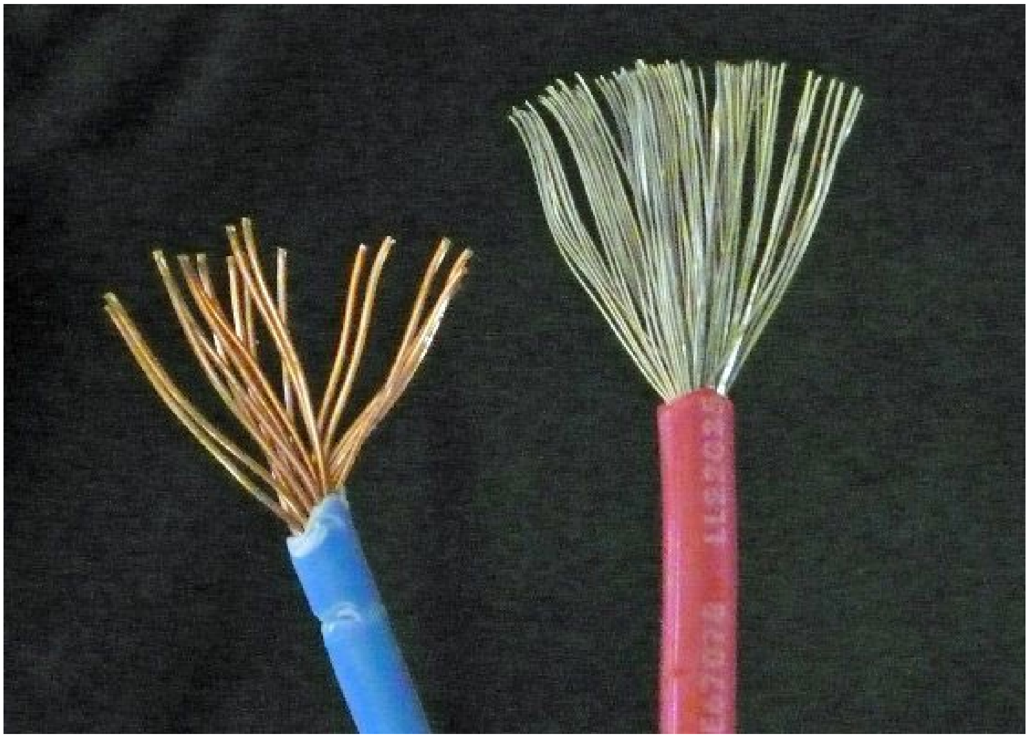
There is an old saying that a poor craftsman blames his tools. This can apply to electrical work as well. A good craftsman will get the job done, even with poor tools. However, it will likely take longer and a lot more effort that having the right tools.

Good tools for DC electrical work will include, wire strippers, wire cutters, connection crimpers, heat gun, and a reliable multi-meter. You should be able to get a pretty good set of these tools for less than $100. What you want to avoid is multi-use tools. Strippers and crimpers often come with wire cutters. Some tools combine stripper/crimper/wirecutter. It is our opinion that combination tools do a lot of things, *poorly*. Get the right tools and they will last you a lifetime and you will enjoy using them.

If you only plan to use them a couple of times, get the combination tools at Harbor Freight. However, you must keep in mind if you have one electrical 'fix' to be done on your boat, there are probably a bunch more you are not yet aware of… Most boat manufacturers and dealers save a few bucks by using automotive grade (ASE) wire and connectors. Not a bad choice if the boat is likely to hit the junk pile in 10 years. Not so good with an Arima.

Materials:

There are two general types of DC wire available…. Automotive and Marine. Both are stranded. ***Safety Issue:*** Don't use solid core wire with DC circuitry. For our purposes, we strongly recommend the marine option.


Automotive (ASE) wire on left, marine on the right

Telling the difference is easy. The automotive wire (SAE) is bare stranded copper under the insulation. The marine wire has bright silvery stranded wire. ***Safety Issue:*** If the wire is dull silver, it is likely aluminum and should not be used in automotive or marine environments.

The marine wire has been ‘tinned’. Tinning wire is a process where a protective coating of inert metal (usually some kind of solder) has been applied to each strand before the core of the wire is assembled and insulation applied.

Connecting wire to equipment or in splices can be done in a number of ways. We only recommend one. The ‘wrong’ ways include twisting cores of wire together, twisting together and using electrical tape, soldering with a wrapping of electrical tape, and using crimped automotive connectors regular or with heat shrink without adhesive.

We only recommend using crimped connectors that have heatshrink with heat activated adhesive. These connectors form a watertight connection with the insulation of the wire, thus keeping that pesky moisture away from the exposed wire core. Ancor is a good source for these connectors. You may wish to purchase in the bulk packs (25 or more) as they are less expensive in bulk and don’t deteriorate. You will likely use them much sooner than you anticipate and most stores don’t carry them. That being said, hardware stores that carry underground sprinkler system components may be a good source for these type connectors…

When purchasing and using these connectors, be sure to use the right size connector with the gauge of wire being connected. The connectors come in yellow, blue and pink/red.

The yellow connectors can accommodate 12 & 10 Gauge wire, blue – 16 & 14 gauge and red/pink 22 & 18 gauge. There are special connectors and crimper tools for smaller than 22 gauge wire. You may wish to have a professional with the right parts and tools make those connections.

When making a connection, strip sufficient wire to completely fill the crimped portion of the connector, but not so much the stripped wire extends beyond the plastic (heat shrink) of the connector. As heat is applied, you will see the adhesive 'connect' to the wire insulation, it will become much brighter and appear to be wet where the connector adhesive and insulation meet.

Regular heat shrink comes in a variety of colors and sizes. When ordering heat shrink, be sure it has heat activated adhesive and is less than 3 times the diameter of the material it is being applied to. Example, if you are dealing with 1/8 inch diameter wire insulation, you do not want to use heat shrink larger than 3/8 inch. It simply will not shrink enough for a tight connection. If you do not have a tight connection, why use heat shrink at all?? Moisture is sure to get in…

Stripping Wire:

Before going further, we need to note that wire gauging is counter intuitive, that is, the bigger the gauge number the smaller the diameter of the wire core. There is a story behind how that came to be, however, we are not going to take the time to get into it here.

You will need to remove insulation from the core of the wire to make good connections. As previously noted, DC wire core is stranded. Be sure you avoid dealing with bare copper wire when you can. Some equipment does not give you a choice, it comes with bare copper wire going into the equipment. When this occurs, be sure you make a good water tight connection with an adhesive heat shrink connector and use marine grade wire from there on.

Most strippers have a selection of gauges noted on the stripper tool. Some differentiate between solid and stranded -- same gauge, different size cutter. Make sure you use the right gauge for the wire you are working with. The wire might have the gauge printed on the insulation, spool and for sure on the package it came in. Do not use a smaller gauge stripper than needed for the wire. Doing that will end up cutting strands and reducing the carrying capacity of the wire (effectively making it a smaller wire).

If you are not sure of the gauge size, start with a larger gauge and work down until the insulation is cut and removable.

Making Good Wire Connections:

Strip about 3/8" (10 cm) of insulation from the wire. Be sure to use the correct gauge on the stripper. If you have strands left in the insulation, you used too small a stripper slot. Be sure you have marine grade wire--- **bare copper or solid wire are no-no's.** Use your fingers in a rolling motion as the insulation is removed, and after, to twist the strands together. Be sure there are no stray strands. Insert the twisted wire into the end of the connector. Be sure the insulation is well into the connector's heat shrink. Use the proper crimping portion of the crimper to squeeze the metal portion of the connector tightly around the wire. Use the same technique to connect the other side of the circuit. Apply heat (heat gun recommend – ***Safety Issue:*** don't use HER hairdryer) until you see the heat shrink connect with the insulation. Don't shrink the connector with only one side of the wiring inserted. You will not likely be able to insert the other side if you do… Once you have shrunk the connector, give the connection a gentle tug to ensure the mechanical connection is good. Then use your ohm-meter to check to be sure your electrical connection is made. This may not be possible when connecting to equipment. That can only be checked when the equipment is turned on.

Circuit design:

There are several critical elements to circuit design. Perhaps the more important of those, for our purposes, is load, distance and if the equipment is critical or not. The load is the total amperage draw anticipated through the wire and distance is how far you are **from** the source (battery or fuse panel) supplying the current and **back** to the electrical source…

At some point you may need to decide what equipment is critical or just convenient. We suggest at a minimum your radio, GPS unit, bilge pump and navigation lights are critical for safety purposes. The stereo system, perhaps not so much… However, given the difference in wiring costs, you may wish to size all your wiring as if all your electronics were 'critical'.

Distance example: You are powering a 5 amp bilge pump (aft of the fish box) from a switch next to the helm. The initial power source is the fuse panel in the cuddy. The fuse panel is fed from a battery in the rear of the boat (properly sized wire for anticipated total load). There is a grounding block in the rear of the boat connected to the battery negative with a properly sized wire. In this case we would consider the circuit as running from the fuse panel to switch, then to the pump and finally to the grounding block.

Distance from the fuse panel to the switch, 3 feet (1 m); from the switch to the bilge pump18 feet (6 m); from the bilge pump to the ground block in the aft of the boat 7 feet (2 m). The question is, what is the proper gauge wire for this circuit. Load is 5 amps :::: is the distance 3 feet (1 m), 7 feet (2 m), 18 feet (6 m), 21 feet (7 m) or 28 feet (9 m)? The correct answer is 28 feet (9 m). Go to a DC wiring chart (we recommend http://assets.bluesea.com/files/resources/newsletter/images/DC_wire_selection_chartlg.jpg), look up 5 amps for 28 feet. The chart lists 25 and 30 feet (always go for the longer distance) and you will find 12 or 16 ga is recommended, depending if you consider the bilge pump to be a critical piece of equipment. A quick check of the internet shows the 12 gauge costs about twice what 16 ga costs. When this was written that difference was about $2.50 (US). How much is peace of mind worth?

When selecting the gauge wire for the fuse block, we recommend you consider it to be critical and that all equipment powered from it will also be grounded through it, i.e., the positive and negative wire be the same size. Smaller gauge wiring, such as in the above distance example, should not be considered when sizing wire for the fuse block. Remember our initial discussion. The ability of the circuit to carry the amperage load is limited by the smallest gauge wire in the circuit… If you have critical equipment running from the fuse block, then the wiring to that fuse block needs to be sized as 'critical'.

Closing

The above is intended to be introductory in nature to help folks better understand DC circuitry needs. It is not intended to be a step by step instruction manual for DC wiring. It is merely a compilation of knowledge and experience gained over the years. Those wishing to do DC wiring are advised to do so at their own risk. The foregoing is simply some basic information and guidelines to help you get started.