This is Part Two of a four part article covering marine wire and electrical systems for small boats. The first part covered the wire itself, this part is going to show you how to determine the proper size wire (gauge) to operate your electrical equipment on your boat so that the wiring is safe and delivers the proper amount of voltage to each electrical device on your boat. This is by far the most important part of this article series. Determining the proper wire size in addition to proper fusing is what keeps your wiring system from starting a fire on your boat. There is minimal mathematics required to make this determination as long as your boat is less than 30 feet in length. This article will make use of tables that will keep you from having to overwork your calculator.

Sizing Marine Wire – One Size Does Not Fit All

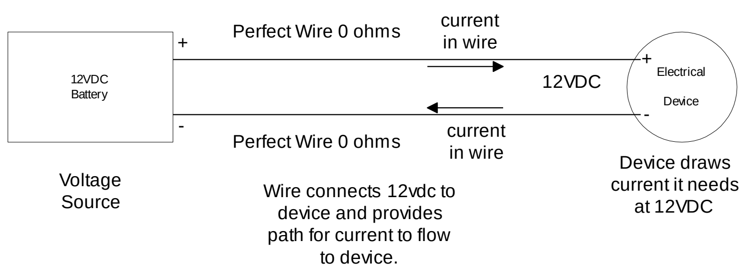
It has been already said in Part One of this series and in the introduction paragraph of this article as to the reasons for properly sizing the wire in your boats electrical system. But to review, the most important reason is FIRE. This cannot be overemphasized enough. Wire that is carrying more current than it can handle WILL OVERHEAT, melt wire insulation and start a FIRE. A fire in a boat is a deadly occurrence, particularly in a gas powered boat. The second reason is voltage loss. It is not as dramatic as fire but important none the less. Most small boats use 12 volt DC power for starting engines and running all of the electrical and electronic equipment on the boat. In order for this equipment to operate to specification the voltage being supplied by the wire to the device must be 12 volts DC or within some small percentage of 12 volts. If the voltage delivered to the device(s) is too much less than 12 VDC, your navigation lights may not operate properly or may not operate at all. Navigation lights need to be a certain brightness, if the voltage is too low feeding the navigation lights, then they will not be bright enough, which may make your boat less visible in the dark or fog and also makes your navigation lights illegal. Another example is your marine radio. Your marine radio may not put out enough transmitter power with low voltage which could keep you from getting necessary help in times of an emergency. So voltage level is very important and the wrong wiring wire size could reduce the operating voltage of a device. What about too much voltage? Wire size never causes too much voltage. The only way for too much voltage in an electrical system is where the engine alternator is charging batteries meaning the engine alternator voltage level is applied to your electrical system. This is controlled by a device called a voltage regulator. The regulator can fail in such a way that the voltage on your 12 VDC system can approach upwards to 50 VDC.

Some Easy Math

Remember from Part One, the relationship of wire length and wire diameter and the current level flowing in the wire? The longer the wire the more resistance it has which will lower the voltage fed to the device connected to that wire. In addition to length, another wire property that reduces voltage is the wire diameter. The smaller the diameter of the wire, the higher the resistance, which lowers the voltage to a device. How do we figure this out? Current flow through a wire obeys an electrical rule known as Ohm's Law. We will not require you to use this formula in everyday practice. It is shown here in hopes it will help you understand the relationship between all of the electrical factors involved in sizing marine wire. Ohm's Law is stated mathematically as follows:

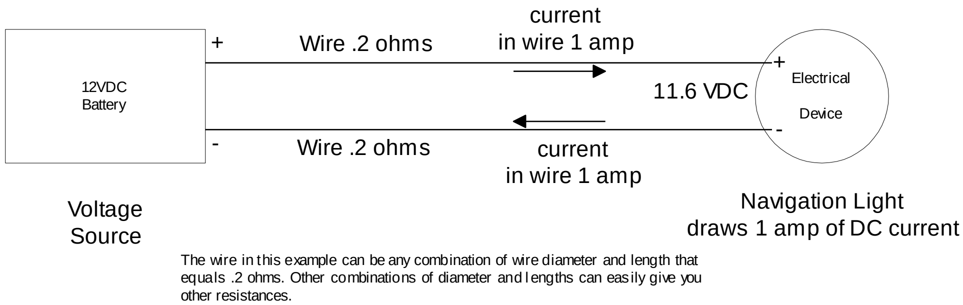
$$I=E/R \quad R=E/I \quad E=IR \quad \text{where } E=\text{voltage} \ \ I=\text{current and } R=\text{resistance}$$

In a small boat E will always (not always but usually) be 12 Volts DC (direct current as from a battery). I will be the current (DC current measured in amps) that the electrical or electronic device will need to operate at 12 VDC. The device draws what it needs from the battery; every device has its own current requirement. R is resistance (measured in 'ohms') of the wire and the wire only. Resistance is an electrical property of the wire that 'resists' the flow of current in a circuit. So what does all of this mean? The battery supplies voltage (12VDC), the device requires 12 VDC and draws a certain current from the battery. The wire connects the battery to the device and in a perfect world the wire would not have resistance, HOWEVER wire has resistance, there is no way around it. Three factors affect the resistance of wire, its material, its diameter and its length. For marine purposes our material will always be copper and all of our calculations and tables will assume copper as the wire material. The second factor is its diameter which is the wire gauge (diameter). The larger the diameter the less resistance per foot the wire has. As the diameter is reduced the resistance gets larger. For example, a 10 gauge wire has a larger diameter than a 16 gauge wire, giving the 16 gauge wire a higher resistance per foot than the 10 gauge wire. The third factor is the wire length. This is simply means 'the longer the wire the more resistance it will have'. The only way to overcome the resistance due to length is increase the wire diameter (gauge). So our goal is to size the wire so its resistance is as close to zero as possible by balancing the diameter of the wire with its length with regards to the particular circuit the wire is used in. This means that for different devices and the different lengths of the wire to those different devices, your wire size (gauge) may be different for each device. How do we determine this? By applying Ohms Law. Out of the three formulas mentioned above the one that will be of the most interest to us here will be: E=IR. You have to think of the wire as a component just as the battery and your electrical device are components. Your battery supplies 12 VDC, your device needs a 12 volt level at its terminals, which means the wire can have no voltage across it from one end to the other (voltage drop). This perfect wire would have zero resistance. See the basic circuit below:



Basic Circuit

With perfect wire there is no resistance therefore no voltage is lost across the wire meaning all battery voltage goes to the devices. BUT, wire is not perfect. It has resistance. Copper is one of the lowest resistance materials that is REASONABLY priced. Gold is the best with silver coming in second place as far as resistance is concerned. But even those expensive metals have resistance. For our work, we must work around the resistance of copper wire. The formula (E=IR) states that the voltage across the wire is determined by multiplying the current drawn by the device by the resistance of the length of wire involved. Whatever the voltage is from this calculation, it is subtracted from the battery voltage and the remainder is what is available to the device. This means that if the diameter of the wire is too small for the required length of the wire needed between the battery and device, then too much voltage is lost across the wire, reducing the voltage available to the device therefore not allowing the device to function properly. Study the following example to see how wire resistance lowers voltage to electrical devices.



In the circuit shown here, the battery is 12 VDC. The device requires 12 VDC to operate correctly. The device shown here also draws 1 amp from the battery during normal operation. The wire shown is a length and diameter that has a resistance of .2 ohms. Since the positive wire and the negative wire are both the same length as they should be in a proper set-up, each wire contributes .2 ohms to the wire resistance giving a total wire resistance of .4 ohms. Now applying the formula: E=IR we have E= 1amp x .4 ohms which equals .4 VDC across the wires (.2 volts across each wire). Subtract .4 VDC from 12 VDC and you get 11.6 VDC at the terminals of the device. This is approximately 3.2% lower than 12 VDC. (round to 3%, this is okay)

Most quality marine electrical equipment will operate properly with a 3% tolerance, above or below 12 VDC. Many devices will work fine with a 10% tolerance. The American Yacht and Boat Council (ABYC), who have written the electrical standards for the marine world, have specified 3% and 10% as the tolerance standards by which to design your wiring system.

Which Tolerance Level Should I use?

The choice of tolerance level has to do with a couple of factors. First and foremost, the voltage specification of the electrical device you are powering. This is determined by looking at the devices data sheet. Most equipment will list a voltage specification. However marine lighting may not list a specification. It is up to you to know that applying 15 or more volts to their lights will probably burn them out pretty quickly. We will learn how to figure out current for lights in Part Four of this article series. Low voltage will not burn out a light but it may not be bright enough to give you the illumination you want. This is extremely important with navigation lights. They need to be as close to 12 volts as possible as the illumination is directly related to the applied voltage. All navigation lights must be wired with a 3% or better voltage tolerance. All pumps and motor devices should be wired to 3%. Horns can be 10% as can most convenience lighting. Marine electronics should be 3% but a check of the data sheet will tell you what the manufacturer wants. This is important for marine radios and radar sets. If in doubt wire everything to 3%. Now be aware that wiring everything to 3% can cost you more money, because wiring to 3% means you may have to use larger gauge wire for 3% to ALL devices when you could use smaller and therefore cheaper wire for devices that only need 10%. But unless you are building multiple boats in a production environment the extra cost of keeping everything at 3% is not that much for one boat but at least you know that your voltage tolerances are right on for everything in your boat.

Determining the Required Wire Size for the Tolerance You Need

To determine the wire size you need for your device or devices you first need to determine what tolerances you need for your equipment. Once your tolerance level is determined you can do one of two things. You could calculate the wire sizes from wire resistivity tables and applying the Ohm's Law formulas with wire diameter tables showing gauge versus diameter, and calculate the wire size. While this is the most accurate it is also very time consuming and prone to human error. But we do not need to do that here! We will use tables (Tables 1 and 2) for 3% and 10% tolerance levels that show the length of wire and current draw of your circuit (device). To use the Tables, all you do is look up your length (round to next highest length if your exact length is not shown) choose your current level (again go to the next highest current if your current is not shown) then read your wire size where length and current intersect and there you have it, the required wire size. No mathematics, no physics tables. It is that simple.

Is Voltage Tolerance All I Need To Worry About?

Now that you have an understanding of wire size versus voltage tolerance there is another important factor to consider. That factor is the CURRENT CARRYING CAPABILITY of the wire. Once you have determined the wire length to your device and the required wire gauge to give your device power wire the voltage tolerance it needs, you need to determine if that wire size will safely carry the current the device will draw from the battery. This is done by consulting a special table that lists wire sizes and their safe current carrying capability (Table 3). With this table you simply look up the wire size you have determined you need and go down to the current carrying capability. If it is higher than your device or total circuit requirement then your wire size is good. You are ready to wire. Take notice on Table 3 there are two areas current is specified, 'Outside Engine Spaces' and 'Inside Engine Spaces'. Use the current levels in the table depending on where the wire will run. If it goes through the hot area to other parts of boat use the 'Inside Engine Space' current even though the wire may be mostly out of the engine space. You should see that the current levels in the 'Inside Engine Space' are lower than the 'Outside Engine Space' This is because there is already heat in the engine space and it will take less current to heat the wire to melt the insulation. All wire used in an engine compartment should have an insulation rating equal to or better than engine space temperature. Avoid running wire through the engine compartment that have no use in the engine compartment. A good overall rating for wire insulation is 105°C. This rating for the average boat under 30 feet will work with all wiring needs without having to worry about Inside or Outside engine spaces. But you still have to watch current levels in engine spaces.

Putting It All Together

Now we are going to put some of this knowledge together. The following is an outline of what you should do to determine wire sizes for equipment on your boat.

1. Determine where you are going to install your equipment (batteries, devices, etc.)
2. Determine the lengths of the wire from your battery or fuse/circuit breaker panel. (more will be covered on this in Part 4 of this article). It is important here to remember to MEASURE THE LENGTH OF THE ACTUAL PATH THE WIRE WILL BE RUN, NOT A STRAIGHTLINE path. Then double that number, because your device power wires will ALWAYS consist of TWO wires, a positive wire and a negative wire, and they will normally be run side-by-side to the device. Example: run = 14 feet, total wire length will be 28 feet. That is the number for the voltage tolerance tables.
3. Determine the required voltage tolerance needed for the wire run based on device requirements.

4. Determine actual current requirements of the device by looking at specification sheet
5. Go to tolerance Tables, plug in required current and wire length and determine the wire gauge.
6. Now go to your current carrying table and check to see that the wire can handle the current. If it can you are done. It is rare that it doesn't. If for some reason it doesn't, increase the wire size until it does. Remember, the larger the wire in diameter (gauge) the lower the resistance so it is okay to use wire sizes (gauge) larger than the tolerance tables tell you. Also the length has nothing to do with current carrying capability, it is strictly the diameter.

Table 1

Wire Sizes For 3% Voltage Drop for 12 VDC electrical systems

	Length of wire from power source or fuse/breaker panel to device multiplied by 2 in feet										
	10	15	20	25	30	40	50	60	70	80	90
Circuit current in amps	Wire Size (gauge)										
5	18	16	14	12	12	10	10	10	8	8	8
10	14	12	10	10	10	8	6	6	6	6	4
15	12	10	10	8	8	6	6	6	4	4	2
20	10	10	8	6	6	6	4	4	2	2	2
25	10	8	6	6	6	4	4	2	2	2	1
30	10	8	6	6	4	4	2	2	1	1	0
40	8	6	6	4	4	2	2	1	0	0	00
50	6	6	4	4	2	2	1	0	00	00	000
60	6	4	4	2	2	1	0	00	000	000	0000
70	6	4	2	2	1	0	00	000	000	0000	0000
80	6	4	2	2	1	0	000	000	0000	0000	
90	4	2	2	1	0	00	000	0000			

Example: 6 amp current draw device that is 15 feet from power source will require a #10 wire. You use the 10 amp line for current and 30 feet length for your length (2 x 15) and read #10 where 5 amps and 20 feet intersect.

Table2

Wire Size For 10% Voltage Drop for 12 VDC electrical systems

	Length of wire from power source or fuse/breaker panel to device multiplied by 2 in feet										
	10	15	20	25	30	40	50	60	70	80	90
Circuit current in amps	Wire Size (gauge)										
5	18	18	18	18	18	16	16	14	14	14	12
10	18	18	16	16	14	14	12	12	10	10	10
15	18	16	14	14	12	12	10	10	8	8	8
20	16	14	14	12	12	10	10	8	8	8	6
25	16	14	12	12	10	10	8	8	6	6	6
30	14	12	12	10	10	8	8	6	6	6	6
40	14	12	10	10	8	8	6	6	6	4	4
50	12	10	10	8	8	6	6	4	4	4	2
60	12	10	8	8	6	6	4	4	2	2	2
70	10	8	8	6	6	6	4	2	2	2	2
80	10	8	8	6	6	4	4	2	2	2	1
90	10	8	6	6	6	4	2	2	2	1	1

Example: 2amp current draw device that is 10 feet from power source will require a #18 wire. You use the 5amp line for current and 20 feet length for your length (2 x 10) and read #18 where 5 amps and 20 feet intersect.

Table 3

Current Carrying Capability of Single Conductor Wire for 12 VDC Systems

Temperature Rating of Wire Insulation												
	60°C (140°F)		75°C (167°F)		80°C (176°F)		90°C (194°F)		105°C (221°F)		125°C (257°F)	
Wire Size	Outside Engine Spaces	Inside Engine Spaces	Outside Engine Spaces	Inside Engine Spaces	Outside Engine Spaces	Inside Engine Spaces	Outside Engine Spaces	Inside Engine Spaces	Outside Engine Spaces	Inside Engine Spaces	Outside Engine Spaces	Inside Engine Spaces
18	10	Not Allowed	10	7.5	15	11.7	20	16.4	20	17	25	22.3
16	15		15	11.3	20	15.6	25	20.5	25	21.3	30	26.7
14	20		20	15	25	19.5	30	24.6	35	29.8	40	35.6
12	25		25	18.8	35	27.3	40	32.8	45	38.3	50	44.5
10	40		40	30	50	39	55	45.1	60	51	70	62.3
8	55		65	48.8	70	54.6	70	57.4	80	68	90	80.1
6	80		95	71.3	100	78	100	82	120	102	125	111.3
4	105		125	93.8	130	101.4	135	110.7	160	136	170	151.3
2	140		170	127.5	175	136.5	180	147.6	210	178.5	225	200.3
1	165		195	146.3	210	163.8	210	172.2	245	208.3	265	235.9
0	195		230	172.5	245	191.1	245	200.9	285	242.3	305	271.5
00	225		265	198.8	285	222.3	285	233.7	330	280.5	355	316
000	260		310	232.5	330	257.4	330	270.6	385	327.3	410	364.9
0000	300		360	270	385	300.3	385	315.7	445	378.3	475	422.8

Example: #12 wire with 105°C (221°F) temperature rating can carry 45 amps outside engine spaces and 38.3 amps in engine spaces.

These Tables are condensed for use in boats under 30 feet. For a complete set of wiring tables consult ABYC Standard E-11 .

In Summary

Part Two of this article contains the information that you must master in order to set-up a proper wiring system in terms of wire sizes. This will minimize the chance of fire as well as make sure your electrical devices have the voltage they require. The tables shown here will help you accomplish this without using the electrical formulas.

Part 3 of this article will cover circuit protection, a vital component of fire safety in a boats electrical installation. Part 4 will put all of the first three parts together and show you how to develop a safe and reliable wiring system for your boat project. Remember this article is for boats under 30 feet with simple electrical systems.

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ABYC – American Yacht and Boat Council www.abycinc.org Standard E-11 can be purchased separately from other standards from ABYC.