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Wire Size Selection

Trade Offs Between Keeping it Cool and Getting Power to the End of the Wire . . . .

If the material from which wires are made had zero resistance, then any size wire could carry any amount of current! Consider the formula for power where watts = volts x amps. This relationship works whether the watts are used to do something useful (light up a bulb) or worthless (warm up a wire). First a little background:

As a useful rule of thumb, remember that 10AWG wire has a resistance of about 1 milliohm per foot. Every time you step three AWG sizes, you double/half the wire's cross section. So, it follows that 13AWG wire is 2 milliohms/foot, 16AWG is 4 milliohms/foot, 19AWG is 8 milliohms/foot and 22AWG is 16 milliohms/foot.

In the other direction, 7AWG is a half milliohm; 4AWG is a quarter milliohm and 1AWG is one-eighth milliohms/ foot. An excellent estimate on intermediate sizes is calculable; just do linear interpolation. For example, 20AWG is about 1/3rd of the way between 8 and 16 milliohms/foot. So, take 1/3 of the difference (8 / 3 = 2.6) or 2.6 milliohms per wire step. Take the 19AWG value of 8 milliohms; add 2.6 milliohms to yield approx 10.6 milliohms/foot. A check of a REAL wire table sez 20AWG is is 10.2 milliohms per foot . . . Not bad for a quick approximation. By memorizing the 1 milliohm/foot value for 10AWG along with the 3AWG steps for doubling/halving resistance allows you to do fast, estimates on wire resistance.

Now, knowing the resistance, you can calculate the LOSSES in any particular wire. Suppose we draw a 7-amp load through a piece of 20AWG in a composite airplane and round trip from bus bar to load and back to ground is 15 feet. 15 feet times .0102 ohms is .153 ohms. Ohms law sez Volts = Amps x Ohms so the voltage drop in this hunk of wire is 7 x .159 or about 1.113 volts. Hmmmm 1.114 volts/14.0 volts shows that 8% of the energy intended for the device at the other end of the wire isn't getting there.

In the table below, you can look up the resistance of various AWG sizes of copper wire, the current ratings for the wire assuming 35EC and 10EC rise, and feet of wire run for 5% loss at the each temperature-limited current rating.

Wire Data Table					
AWG	Milli-Ohms/ Foot	35EC Rise		10EC Rise	
		Amps	Max Feet	Amps	Max Feet
2	0.156	100	44	54	83
4	.249	72	39	40	70
6	.395	54	33	30	59
8	.628	40	28	20	55
10	1.00	30	23	15	47
12	1.59	20	22	12.5	35
14	2.53	15	18	10	28
16	4.01	12.5	14	7	25
18	6.39	10	11	5	22
20	10.2	7	10	4	17
22	16.1	5	7	3	15

We know further that watts = volts times amps. So a 1.113 volts drop in the wire at a 7 amp load is 7.8 watts. This power is lost to the air and surrounding mass as HEAT.

Referring to the wire table note that 20AWG wire will suffer a 35 degree C temperature rise when loaded with 7 amps. This is a free-air figure. Suppose the wire is buried in a wire bundle? Closed up where air cannot circulate freely around the wire, 7 amps will cause it to get much hotter. Okay, let's take the free air rise and say we're going to run this wire through the tailcone where we expect to see a hot-day soak up to 65EC. With a 35 degree rise, the wire surface can be expected to top at 100 degrees C . . . pretty toasty. 100EC is right at the limit for even the best PVC insulated wires.

The copper wire isn't in any trouble at 100EC but the insulation might be. From the study thus far we can readily see that wire sizing considerations are-two fold:

(1) Temperature rise for any given conductor should be tailored to the wire's INSULATION. Mil-W-22759/16 wire is good for 150EC.

-and-

(2) the voltage drop to the powered device needs to be evaluated for acceptable performance. I like the rule of thumb that limits system wiring losses to 5% or less for any single device.

In the 20AWG, 7-amp, 15-foot scenario I illustrated above, voltage drop is the condition I'd like to correct. Upsizing to 18AWG wire would reduce both voltage drop -and- temperature rise. For those interested in the math note that from Ohms law, Ohms = volts/amps. In the example below, the volts and amps cancel ohms leaving feet:

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  1000 mOhm/Ohm C 0.7 Volts
----------------------------- = 15.6 Feet
  6.39 mOhm/Ft C 7.0 Amps
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So, 18AWG would do fine in our 7 amp, 15 foot loop. Simplifying the formula above reduces to this:

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                  700
Max Path Feed = --------
                  R C A
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To compute the max allowable path length for your own situation, substitute milliohms per foot for the wire gage you're considering for R and the expected current draw by the powered device for A and crank out the answer (For 28 volt systems, change the constant 700 to 1400).

There are no hard rules for de-rating a wire If you suspect that voltage drop might be an issue, do your own analysis like that above . . . I like to keep wire losses less than 5% (0.7 volts drop in 14V system) but that's MY rule of thumb.

In some cases, a gross overload of a wire is an acceptable design parameter. For example: 250 amps to crank an engine is routinely handled with 2AWG wire . . a TEMPORARY 250% overload. Here, voltage drops are very important. I've had a lot of canard-pusher builders wrestle with starter performance when their ships were wired with 4AWG and the battery was in the nose. This is about a 24-foot round trip. Play with the numbers a bit yourself and see how much of a 12-volt battery (with it's own internal resistance of say .004 ohms) is going to get to a starter on the far end of 4AWG wires in a Long-Ez.

On the other hand, an RV with the battery right behind the Firewall can tolerate 4AWG cranking circuits because the round trip is only 4 or 5 feet long. For regulators that use the field supply line to also sense bus voltage, I'll routinely use 20AWG wire in a 3 amp circuit! This is a voltage drop consideration. Some regulators become unstable with mere millivolts of uncertainty about bus voltage. A 22AWG field supply, 5 feet long inserts 240 millivolts of "rubber band" in the regulator's sense circuit with a 3 amp load. Dropping to 20AWG drops the uncertainty to 150 millivolts.

This little mini-seminar on wire is to illustrate the potential pitfalls of grabbing any wire chart and hooking things up accordingly. This is where networking with other builders and individuals willing to share a career's worth of experience is very much worth your time and trouble. I hope this effort dispels another myth surrounding wire selection. We have very few concerns for "burning up" a copper wire. The major considerations are insulation ratings -and- making sure the things you hook up have enough juice to run properly.

When in doubt as to temperature rise (wire passes though a hot section of the airplane or is buried in a bundle of wires) pick the next larger AWG number for the circuit. When in doubt as to voltage drop, calculate it out. For a continuous running load to lose more than 5% of it's voltage enroute is another good cause to put in bigger wire. Finally, if you expect to exceed 150EC (rise plus ambient) on a wire run, consider re-routing the wire, shielding it from heat sources or put in fatter wire. This study helps us understand some of the physics of getting electrons from one place to another via wires. Note that as a wire doubles in cross section (resistance is half) it's ability to carry current does NOT double. This is because a wire's ability to shed heat is a function of outside surface area which grows only directly with an increase in diameter while it's apparent ability to carry current (cross sectional area) goes up as the square of diameter. This is why the fatter wires have a better ability to carry their rated current for longer distances . . . they've been de-rated to control temperature rise.