The following document was brought to my attention on the AeroElectric list shortly after it was published on Blue Mountain's website. It's an extensive text that offers numerous recommendations and advice for individuals who are building their own airplanes. After reviewing the work in detail, I detected many statements that were in error. The mission for the AeroElectric Connection is to first be a gathering place for the best we know how to do and second offer a forum and filtering mechanism whereby bad information can be identified and rejected. The original document is duplicated without modification and then annotated with my own observations in a font and format that stands out clearly from the original text. All of the words in this font are those of the reviewer who welcomes alternative views if they can be substantiated with simple ideas in physics and matters of historical fact.

Robert L. Nuckolls, III
Revision -B- 25 Sept 2004

Aircraft Wiring for Smart People

~ A Bare-Knuckles How-To Guide ~

10 September 2004

Abstract

This is a step-by-step, *Foolproof 100% Gonna Work* guide to wiring your airplane simply, effectively and inexpensively that builds on one basic principle: people who build airplanes are smart folks who can do things. This booklet is about how to make our electrical systems simpler and easier to install.

Introduction

Flying around the country installing EFIS and Autopilot systems I've met a lot of builders. I've hung out in their shops, drank their beer and wired a lot of airplanes. I've also heard the same questions about how and when to use certain techniques, what to ground and what not to ground, how to size breakers and switches, whether to crimp or solder, and why some antennas pick up Radio Moscow but not the local AWOS.

 greg@bluemountainavionics.com

This booklet will show you how to wire your airplane so that it will work right the first time and teach you enough of the How's and Why's so that you know what you did and why you did it. This isn't about all the possible ways to accomplish the job – it's about one, *Foolproof 100% Gonna Work* way. The idea here is to find a method that'll work in all cases, and just cop out and use that method instead of trying to make everyone into an engineer. (There are only so many the world can stand!)

It's also time for a change. With few exceptions, homebuilts are wired like WW II fighters, and electronics have come a long way in 60 years. A two-year-old laptop may be old news, but up in the cockpit it's still 1939. Take a moment and think about a modern car compared to a modern light plane. A single keyswitch and automatic overload protection versus a stack of breakers and switches and a bundle of wiring to choke a horse. Does your car have an Avionics Master switch for its half dozen computers and on board FADEC?

Circuit protection can be made automatic; switches can serve as indicators, and less panel clutter means Easier to Use. We can do better!

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 greg@bluemountainavionics.com

WHERE TO GET PARTS, TOOLS, ETC. 55

How to Use This Booklet

According to my friend the Adult Education Expert, the way to get the most out of this booklet is to flip through it and look at the pictures, and see what looks interesting. Next, read the next section, entitled **Start Here,** and finally read through once to see what's what and get a feel for what we're going to talk about. Don't try to remember everything, just buzz through it like a story.

Once you've got a feel for the tools and the techniques at an overview level, work through the example in **Foolproof 100% Gonna Work Example** and cross-reference anything that doesn't make sense with the section that talks about it. Go ahead and make notes directly on the drawings – the PhD education types say that this is supposed to help a lot, and gives you and me an excuse to doodle in the margins.

Having read through, worked through the example, made your notes and re-read the stuff that didn't come in clearly the first time, you're ready to work out your own plan in the **Foolproof 100% Gonna Work Method**.

Pretty soon you'll be helping other guys with their projects, which is specifically what I have in mind. This is something that we, as a community, should be able to do well.

> ***Great idea. All of us should strive to be both good students and good teachers. Every day I can crawl into bed knowing something I didn't know that morning is a GOOD day. Every day I go to bed knowing that what I've learned was useful in solving a problem for someone else is a GREAT day. However, one thing that many PhD types overlook is a duty of every teacher to impart UNDERSTANDING. Too many individuals dispense great volumes of information . . . but fail to support it with underlying simple-ideas in physics and historical fact that foster understanding.***
>
> ***Students often successfully regurgitate the information in the appearance of having learned something while in fact; they have no understanding of the principals involved. This leads to mistakes of ignorance that are at least costly and sometimes dangerous. The saddest part is that many dispensers of information who would call themselves "teacher" have little or no understanding of the material they offer. It is the duty of other teachers and students alike to sift through the material to salvage those items of value and discard that which is in error or incorrect.***

Start Here

These next topics are the decisions builders agonize over (and debate without end) when wiring their planes, so we'll get 'em out of the way first so we can get down to business and do some real work. The question to be answered is: "If we weren't already doing it this way, how would we *want* do it?" This will give you a good idea of where we'll be headed in the rest of the booklet, so let's take a look.

12 or 24 Volts?

Cars are twelve (12) volts, airplanes are twenty-four (24). There you go, easy enough.

Here's my take:

As of mid-2004, just about anything you can buy in avionics will run on 10-32 volts DC and doesn't care either way. Single voltage items like landing lights and strobes can be all be had in 24 volt versions now, so that's a not an issue either. If you need a jump start, most FBOs are used to wheeling out the start cart for King Airs, Citations and such that are all – you guessed it – 24 volts.

Here's yet more detail for you:

1. Since a given load draws half the current at 24 volts that it does at 12, you can use smaller wire with the same results. You can use wire that's only ¼ the size, which is a pretty big deal when you 're running #18 and everyone else if running #14. Most small planes have nearly 50 pounds of wire in them. How'd you like to save 10 pounds of dead weight?

   I presume that "1/4 the size" means 4 American Wire Gage (AWG) steps smaller, not one-forth the cross section. One might think that a wire's ability to carry current is a function proportional to diameter (thus area) of the wire. Wire sized in American Wire Gage (AWG) world doubles or halves in cross-section every three steps in wire gage. So, if one assigns 5A as a current limit for 22AWG wire, then a 19AWG wire should be good for 10A, a 16AWG wire should be good for 20.

   Not quite. Two features in physics define current rating of a wire: (1) tolerable voltage drop and (2) temperature limits for the INSULATION. The ability of a wire to reject heat is a function of surface area. Surface area grows proportionally to diameter but cross section (area) grows in proportion to the square of diameter. So, while a 3AWG step to smaller gage offers twice the cross section, it offers only a 40% increase in surface area. 10AWG wire is 0.001 ohm per

foot. Let's run 30A through 1 foot of this wire and we get 30 millivolts of drop at 30A or 0.9 Watts/foot heat to reject. Now, let's assume a 13AWG wire at 0.002 ohms/foot and 15A of current. We get the same 30-millivolts/foot drop and 0.45-watts/foot heat to be rejecting. The 13AWG wire's power rejection is one-half that of the 10AWG wire but its surface area went down by only 30%. Therefore, the 13AWG wire will run COOLER than the 10AWG wire in spite of the fact that amperes/square-inch of current density and voltage drop per foot is the same for both wires.

If both wires are insulated with Tefzel and have the same temperature rise limits then doubling conductor diameter does not double current carrying ability of the wire. Since smaller wires carry current more effectively for the same temperature rise, and assuming that every 28 volt device draws one half the current of its 14 volt cousin, then being able to drop 4AWG gage steps is in the ball park but this wire size shift is about 2:1 not 4:1.

Let's consider another assertion concerning weight. Assume a Long-Ez with 30 feet of 2AWG at 4 oz per foot gives us 120 oz or 7.5 pounds of fat-wire. Let's assume 20' round trip for both wing tip landing/taxi lights –AND- pitot heater for a total of 60' at 0.035 lb/ft for 2.1 more pounds. Let's call out 40' of 20AWG for nav lights at .0053 lb/ft for 0.21 pounds. This comes to 9.8 pounds of wire for all the big-fuse items. Let's see . . . 50 minus 10 pounds leaves us 40# worth of 22AWG wire for the rest of the airplane which works out to about 10,800 feet of wire. Yup, that ought to be enough to wire up the rest of my "small airplane".

Now, let's assume that the 28-volt system lets us downsize the fat-wires by half their cross-section for about half the weight. So the fat-wire list drops from 10 pounds to 5 pounds. My 50 pound wire budget for a 14-volt "small airplane" drops to 45 pounds by going to 28 volts.

The 50 pound number is simply incorrect. The typical RV with firewall mounted battery is carrying closer to 2 pounds of 4AWG wire. The fat-wire budget is a lot smaller than for our hypothetical, all-plastic canard

pusher. Further, 10,800 feet of instrumentation and avionics wire seems a bit excessive for even the most gizmo-crazed builder. 200 feet of wire is closer to reality for a TOTAL wire-budget well under 10 pounds of which only 2 pounds MIGHT benefit from downsizing by going to 28 volts.

It's true that large airplanes can save significant wire weights with higher voltage systems. B-29 and B-17s could carry hundreds of pounds more fuel or armament by capitalizing on the reduction of fat-wire sizes at higher voltages. Most of the wire in small airplanes is signal or control wires fabricated from 22AWG as the smallest practical size for ease of installation and manipulation.

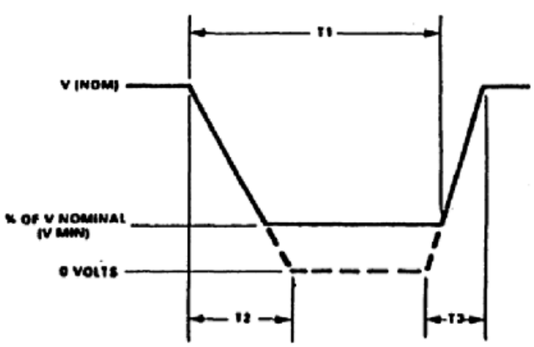
I've done this exercise dozens of times for the OBAM aircraft community over the last 15 years. I'm sorry, the results are always the same . . . weight savings for 28 volts is small assuming that all other accessories are a wash. Yes, one CAN get a lot more POWER from the same weight of alternator . . . but our need for power should be going DOWN not up. I'm working a program at RAC right now where an upgrade of systems and avionics promises to allow installation of SMALLER batteries and leave us much cooler running generators.

2. Engine start will drop a 12-volt system down to around 9 volts causing EFIS systems to reboot, radios to lose presets and fuel totalizers to restart. A 24-volt system will only drop to about 18 volts during engine start, which is well above the 10.5-volt minimum for modern avionics. No backup batteries, no switching, no relays, and no fiddly, complex systems to solve a non-problem.

   I don't know where the 10.5 volt minimum number comes from. Here's the operating voltage matrix right out of DO-160 . . .

Voltage	Categories		
	A and Z	Category B	
Maximum:	30.3 V	30.3 V	15.1 V
Nominal:	27.5 V	27.5 V	13.8 V
Minimum:	22.0 V	22.0 V	11.0 V
Emergency Operation:	18.0 V	18.0 V	9.0 V

Modern avionics should operate over the voltage ranges cited for each category of performance commensurate with the applicable system voltage. 28 volt equipment minimum operating voltage is 22.0 volts. So called "emergency" operations go down to 18.0 volts. Most protocols allow for much degraded and marginally useful performance at "emergency" supply levels. When a 24-volt battery has discharged to 22 volts, it retains less than 5% of rated capacity. I.e. the battery is for all practical purposes dead. "Modern avionics" with a 10-32 volt operating range will have but a few minutes more endurance in a 28V airplane than "antique avionics" because the battery delivers no useful quantity of energy over the range of 22 volts (less than 5% charged) down to 10 volts where the radio no longer functions. There is another aspect of DC input power considered by responsible suppliers of modern avionics. Again I quote DO-160:



Applicable Category	A, B, E, Z				A, E, Z			Z	A, B, E, Z			A, E, Z			Z
Test Condition No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
T1 (Milliseconds)	2	10	25	50	75	100	200	1000	10	25	50	75	100	200	1000
T2 (Milliseconds)	<1	20*	20	20	20	20	20	20	50*	50*	50	50	50	50	50
T3 (Milliseconds)	<1	5	5	5	5	5	5	5	20	20	20	20	20	20	20
% of V Nominal (V min)	0	50	15	10	5	0	0	0	80	50	0	15	5	0	0

* Voltage will not reach zero in this test condition.

This recommendation describes various power interruption scenarios that a supplier of avionics

should EXPECT in a modern aircraft. In addition to expected bus voltage drops to 6.0 (12.0) volts for as long as seven seconds, the graph and chart above describes various categories of complete power interruption down to ZERO volts.

The goals cited by these tests do not suggest that a piece of equipment function with any degree of utility during the described stress. The goal is to suffer this input power condition and GRACEFULLY RECOVER in a TIMELY FASION when power is restored.

3. A 24-volt system also has a LOT more reserve energy *available for use* than a 12-volt system. As in point #2, a failed alternator in a 12-volt system leaves you 2 volts from shutdown. It a 24-volt system you've got a lot more reserve before your avionics and FADEC drop offline.

   "Reserve" must be measured in some useful time-dependent energy units like watt-seconds. Battery manufacturers are fond of ampere-hours . . . which are proportional to energy but ignores the battery's voltage.

   I think he's really talking about "voltage headroom". A measure of how far voltage departs from normal operating levels down to "minimum" while operating in a battery only mode. The total excursion on a 24 volt battery might be 28.5 down to 22.0 volts while a 12 volt battery system would be 14.25 down to 11.0 volts. Yes, the headroom on the 28 volt system is 6.5 volts and only 3.25 volts on the 14 volt system. Is this the great advantage being proposed? A small advantage perhaps if the accessory under consideration has a modern, switchmode power supply that keeps the item functional down to 10.0 volts. That particular piece of equipment might stay lit up better during starter inrush brown-outs.

   Most airplanes are designed to carry so many watt-seconds of battery energy. An 14 volt airplane scheduled for a 28 volt "upgrade" might be fitted with a 24 ah, 12 volt battery. When the system voltage raises to 28v, the 24 volt battery is downsized to 12 ah . . .same total energy. What appears to be a comforting twice the headroom for voltage becomes little or no advantage because it's backed by a half

capacity battery containing the same energy as it's 12 volt predecessor.

The bottom line is the higher the supply voltage, the better off we're going to be up to a point where it starts to get dangerous. Quite a lot of telecom equipment runs on 48 volts DC, which is close to an optimal trade-off between voltage and safety.

If you've got to go 12 volts, that's fine, no biggie. We've just got to allow for a few extra things that 24 volts systems do as freebies.

Not supported in either physics or historical fact. There are no "freebies" in physics.

How Many Batteries?

If you go with 24 volts, that's an easy answer: One. There's a current fashion in backup batteries and essential bus designs, which I think is overkill. If you have a battery with enough grunt to start your engine, it'll run your avionics for longer than you can remain aloft.

Again, let's consider the energy-physics of batteries. It takes the same amount of energy to run a radio whether the radio is supplied from 14, 28 or 100 volts . . . watt-seconds is watt-seconds. Ignoring variability in efficiency, a 10-amp, 14-volt accessory is a 5-amp, 28-volt accessory or a 1.4 amp, 100-volt accessory. In all three cases we're talking about a 140 watt accessory.

Batteries deliver so many watt-seconds per pound of lead no matter how many cells you slice it into. So if you had a 25 pound battery in your 14 volt airplane, guess what? A 25 pound battery in a 28 volt airplane doesn't run the same accessories any longer.

The real issue is if there's a main bus fault or short, then everything drops and you're in trouble, right? Traditionally that's true, but there's a simple way around it:

Main bus faults are about as rare as wing bolts coming out or propellers flying away. It's not difficult to design them that way. The reasons for adding second batteries and/or multiple busses are driven by reliability issues but not the ones implied by worries for "hard bus faults."

<u>Provide multiple busses, not multiple power sources!</u>

Just like your house, car and computer, multiple busses and breakers solve the problem, not multiple power sources. How many people do you know who have more than one Power Company feeding their house?

If you have a 12-volt system, you'll need a small backup battery to give you some margin of reserve, but that's easily done, and doesn't weigh all that much.

> ***Under what conditions? Not every 14-volt airplane needs a second battery. This is a choice driven by performance of installed equipment –AND- how the owner intends to operate the airplane. The statement on weight is specious. Weight is a function of the task assigned to the second battery considered with duration of the task and probable condition of the battery due to aging. There's no one-line assertion that accurately addresses need for or selection of a second battery.***

One Alternator or Two?

One is plenty for almost all applications. If you have a good Alternator and regulator (I like the B&C stuff, it works well and the support is outstanding) the most likely reason for failure is bad wiring or overload. Either way, bringing another alternator on-line will probably just feed the fire.

> ***This ignores the range of missions and variety of design goals that a builder has for his airplane. Buy a C-172 and what-you-see-is-what-you-get. No choices irrespective of your personal desires as a consumer of the product. This statement also ignores a whole bucket full of variables that a builder may consider in optimizing the architecture of his/her project. E.g. yes, a BIG battery may provide all the standby power you need for boring holes in hundreds of miles of clouds . . . but would a small battery combined with a 3 pound #2 alternator offer a lighter and lower cost of ownership option?***
>
> ***The AeroElectric Connection features a variety of power distribution diagrams . . . NO SINGLE DIAGRAM IS OFFERED as the 100%, works-every-time option for everybody's airplane. Every architecture should be evaluated for suitability to the task. A day-vfr fun machine perhaps meets your goals without electrical system of any kind.***
>
> ***There are OBAM aircraft in existence today that have a battery, a starter, transponder and a nav-com radio.***

That's it. Stone simple, does what the owner needs to have done and he simply plugs the charger in while the airplane is stored.

If you have a big, 24 volt battery as discussed above, why bother with a backup alternator? The battery will carry your avionics and engine systems for hours.

What if the battery contactor fails or a wire controlling the contactor opens? If the alternator quits, is there not value in shedding all loads not needed for en route operations INCLUDING the battery contactor itself?

The only exception would be if you had high current draw, critical loads like de-ice boots or a hot prop to keep running. In which case, you really do need a second alternator. Might be a good idea to hang it on a second engine if you're planning on a lot of that kind of flying!

I'm unaware of any OBAM aircraft wherein the builder/owner/operator has crafted a system intended for flight into known icing. This means that all de-ice systems installed are temporary measures intended to forestall ice accretion until the pilot can extricate himself and aircraft from icing conditions.

Therefore, risks to airframe and crew are no greater for electrically dependent de-icing with a single alternator than they are for pump dependent de-icing using boots. I discourage OBAM aircraft builders from installing more than pitot tube de-ice equipment. Anything more tends to lull pilots into thinking that their airplane is "better than the average bear" when it comes to dealing with ice. In fact, ice and convective weather are the very best reasons for the immediate 180 and/or putting off a flight for better weather.

Secondary alternators are a neat idea, but with a single engine it doesn't really buy you that much more time aloft, and almost always buys you none at all.

. . . a specious argument without consideration for balancing mission, configuration, cost of fabrication and cost of ownership with the builder's intended use of the airplane.

Firewall Connectors

The time has come to go through a firewall, so how do we do it? By drilling a hole. There's a school of thought that favors swoopy, round, metal MIL-type connectors, and matching sub-harnesses but I've found that it takes a Swiss Watchmaker to put them on correctly, and then another day or two to find out which pin got wired wrong. You can usually tell by the burned smell but … OK, that's not funny. Sorry about that. By building the whole airplane harness on the bench and dropping it in the airplane, there's no need to ever remove the harness. And how often do you take off your firewall?

Anything that is serviceable and removable should have it's own Molex Connector located close to it. What good is a big connector on the firewall when you need to pull your alternator or igniter box?

Just run the harness through the firewall, use a nylon bushing to make sure nothing scratches or chafes and you're all set. If you do avionics wiring for a living, round MIL-type connectors on the firewall *are* very pretty. My contention is a homebuilder who will install three or four of them in his/her life will probably get two or three of them bugered up as part of the learning process. Not a good thing for reliability, but that's my opinion, right?

> ***Misses the point entirely. It's a given that there's no practical way to avoid putting holes in the FIREWALL for controls, wires and tubes. The primary goal mission of running controls, wires and tubes is not to compromise the integrity of the FIREWALL. One may argue the merits of one style of connector over another ad nauseam.***
>
> ***From the design perspective, #1 requirement is fire-resistant if not fire-proof penetrations. #2 is simplicity. A part that is NOT installed on your airplane is a part that is not going to fail due to poor installation technique, damage during maintenance or inadequate robustness of the product. Every other consideration runs a distant 3rd place or greater.***
>
> ***The nylon bushing technique suggested is NOT suitable for use on airplanes. See:***
>
> ***aeroelectric.com/articles/Firewall_Penetration/firewall.html***

Full Auto, No Manual

War Story Time: I've worked on a few homebuilts that are all but impossible to operate without recurrent training at Flight Safety every few months. On one very sexy homebuilt that rolled in to the shop you'd have to throw six (6) switches *and* press in four (4) breakers to get the EFIS to come up in normal operating mode. I never did understand the various emergency modes – they were beyond complex.

My thought is simple: No manual overrides, cross-feeds or other Apollo-13-wanna-be switches in the electrical system.

Here's why:

Most private pilots fly less than 100 hours a year, and almost never practice system failure drills. If in an emergency "that which is not practiced is not performed", there's real harm in putting complex manual features in an electrical system that can get you in more trouble than you had.

The first task in an emergency is to "Fly The Airplane", which is probably a better idea than trying to remember how to bring another alternator on-line and cross feed your essential bus from a backup system while not blowing your remaining breakers. This sort of thing can be made automatic by simply designing for it, so there's no need for the manual overrides. How do they do it on cruise missiles and satellites where there's no one to operate the electrical system? The same way we're gonna do it here!

Yes, simplicity of operation should be very high on the list of design goals. It should also be a design goal to prevent ordinary failures of components from becoming an emergency. All architectures offered in the 'Connection have been considered to minimize the numbers of switches to be operated and to ELIMINATE any potential for exacerbating the situation by misplacement of any switches.

Step By Step, Piece by Piece

There are six (6) fundamental kinds of things you're gonna have to deal with when wiring:

1. Power and Ground

2. Radios and Indicators
3. Audio and Entertainment
4. Antennas
5. EFIS, Autopilot and Other Digital Devices
6. Engine Monitor, FADEC and Sensor Wiring

Each of these is a little different, and use different tools and connectors, so we'll cover them one at a time. If you run into something new, like Satellite Weather for example, you're ready. It's got a computer like and EFIS and an antenna like a radio. After the next few pages, you'll know what to do!

Electrical Theory, Just a Quick Bit

Before we get into how to do the work, we need a little theoretical basis. Just a very little bit, so stay with me.

Voltage

Everyone talks about voltage, but what is it, exactly? It's the electrical equivalent of pressure – a 12 volt spark jumps less than 1/8 inch, but a 12,000 volt spark will jump an inch or more. Voltage is pressure. Guidelines:

- A regular D cell battery is about 1.5 volts
- A car battery is 12 volts
- An airplane battery is supposed to be 24 volts, but some are 12 like cars
- Most avionics will run on anything between 10 and 32 volts.

Current

Current is measured in Amperes, or Amps, and is the electrical equivalent of flow.

Guidelines:

- A 12 volt radio draws about 3 amps
- A 12 volt landing light draws about 10 Amps
- A starter can draw 150 Amps or more (800 for turbines!)

Power

Power is measured in Watts and is simply Volts * Amps. How much current times how much voltage is how much power. Guidelines:

- A 24 volt landing light drawing 5 Amps is using 5*24 = 120 Watts
- A 12 volt radio drawing 3 Amps is using 12*3 = 36 Watts
- 1 Watt dissipated in free air is warm to the touch
- 10 Watts in free air will burn your fingers

Resistance

If Voltage is like pressure and Current is like flow, Resistance is just that --l resistance to flow. Resistance is measured in Ohms and is equal to Volts / Amps. For a given voltage, the lower the resistance the more current will flow. Guidelines:

#18 wire has a resistance of 0.0064 Ohms per foot.
#22 wire has a resistance of 0.0161 Ohms per foot.
A good connection should read less than ½ an Ohm

> ***If one possesses an ohmmeter capable of detecting and displaying the resistance of a connection, a good connection will run in hundreds of micro-ohms up to perhaps a milli-ohm or two.***

Since the voltage measured across the wire is the Resistance of the wire times the Current flowing through it, you can see that you'll lose some voltage, *and* lose some precious power in your wiring. Take this example:

> ***"Precious" implies a condition that simply should not be a concern in the well considered system design. Economics is the study of limited resources for which there are multiple uses. In this case our limited resource is watt-seconds of energy available for operating accessories that make flight more convenient and enjoyable.***
>
> ***The number of watt-seconds available depends on whether or not engine driven power source(s) are operating –OR- how much energy is contained in battery(ies). If the main alternator is working, energy is essentially unlimited. If only a small standby alternator is running, quantity is limited but duration is unlimited. If no alternators are operating, batteries provide finite limits of storage where the designer must consider rate of usage such that minimum endurance requirements are met. The economics of energy generation, storage and utilization are what determines whether simple failures turn the flight harrowing, sweat-soaked experience or a ho-hum event. A design REQUIREMENT for system architecture and operation is to prevent watt-seconds from becoming "precious".***

A 10 foot chunk of #18 is carrying 5 Amps to run our transponder. Ten feet of #18 has a resistance of 0.064 Ohms, which means we'll drop 0.064 * 5 = 0.32 volts in *each* wire, both power and return. This means of the 12.5 volts you're sending to the transponder, the transponder only sees 11.86! Not a big deal, but when the battery gets low, it doesn't leave you a lot of margin. The voltage drop is only ¼ as much at 24 volts, and you have a lot further to go, but I believe I beat that horse enough for one day.

> ***First, I don't know of a transponder that needs 5A of operating current. Most are on the order of 2A or less. Obviously, we could wire with 22AWG and not have the wire get warm. Most manufacturer's call out 20AWG to reduce the source impedance of power from battery to transponder (some of them go doubled up 20AWG wires but let's thrash the numbers for a single strand). A transponder on the panel of an RV might need 5' of wire in each leg for a total of 10'. 20AWG is 10 milliohms per foot for a total of 100 milliohms. 2A load on 100 milliohms is 200 mV total.***
>
> ***Normal system operating voltage is never lower than 13.8 volts so that the transponder can reasonably expect to operate normally at a minimum of 13.6 volts . . . well inside the specified operating range for normal operation of a transponder.***
>
> ***Now, kill the alternator and the bus drops to 12.5 volts (12.3 on transponder) and goes down from there. We know things are running downhill from there. At what point does input voltage to the transponder become a matter of concern to you as a pilot? The DO-160 operating voltage matrix cited earlier suggests that any product supplied to the aircraft market should be operated at "normal low voltage 11.0 volts" and "emergency low voltage of 9.0 volts for 30 minutes" and then tested to show that it meets performance standards for normal and emergency voltage conditions. Okay, by the time a battery-only airplane's bus drops to 11 volts it contains less than 5% of its rated capacity. It's reasonable to suggest that in this case that 20AWG wire or even 22AWG wire is certainly adequate to the task without undue waste of "precious" watt-seconds. Any product delivered to DO-160 recommendations will NOT be the limiting factor for useful operation. The brick-wall limits will be battery capacity and the voltage at which a battery is essentially useless . . . which is HIGHER than the voltage where accessories quite working.***

To Review:

Power in Watts = Volts * Amps (Voltage across it times the current through it)

Volts = Ohms *Amps (Resistance of it times current through it)

Knowing this much, you can figure out just about anything in a DC circuit:

- What is the voltage drop in a 10 foot piece of #22 wire carrying 5 amps?

  Ohms = 10 feet * 0.0161 Ohms per foot = 0.161
  Vdrop = Ohms * Amps = 0.161 * 5 = 0.805 volts

- How much power is lost in that wire?

  Watts = Volts * Amps = 0.805 * 5 = 4 Watts (the wire would be warm touch!)

- A 24 volt radio draws 5 amps on transmit. What is the equivalent resistance of the radio?

  Ohms = Volts / Amps = 24 / 5 = 4.8 Ohms

  This means the radio acts just like any other 4.8 Ohm resistance.

This is good background, but since we're wiring power with #18 at 24 volts, and using 10 amp breakers on everything, you don't have to worry about it. It's handled, but now you know.

> ***Wouldn't argue for a minute about the value of knowing, planning and fabricating a system where wires, circuit protection, power generation and storage hardware are selected with a good working knowledge of simple ideas and design goals that drive the decisions. I will suggest that the discussions on wire sizing and system voltage selection offered here and elsewhere in this text argue with almost 100 years of DC power system design in all manner of vehicles including airplanes.***

RF and Noise

Everything we've talked about so far is DC (direct current) circuits, where a voltage drives a load of a known resistance. This covers 98% of aircraft wiring, and good thing too.

The other 2% are AC circuits, which you'll just hook up and otherwise not have to mess with. AC alternates between positive and negative and looks like a since wave on a 'scope. Radios and digital devices are full of high frequency AC, and Radio Frequency AC is called "RF" for short. Shielding is used to keep RF inside, in the case of coaxial cable, or outside in the case of shielded audio circuits. By following this booklet, RF and noise suppression is something you can say you heard about, but don't have to deal with.

> ***Not having to "deal" with something should not be taken as advice not to study and understand it. We go though life knowing how to install and operate a whole lot of things for which we have very little understanding. I'll suggest that most folks reading this document are doing so because they're tired of having no control over things they understand about airplanes and have elected to toss limited offerings of the spam cans in favor of the OBAM aircraft route.***
>
> ***I'll suggest further that the OBAM aircraft owner-operator has an obligation to himself and his passengers to UNDERSTAND as much as possible about all aspect of his aircraft and its accessories. To do anything less is toss the opportunities offered by our craft and community in which it's practiced.***

We'll cover it in detail when we get to Audio and Entertainment.

Power and Ground

First off, we've got to power the thing up, whatever it is, which brings me to Kirchoff's Law, which simply states that whatever electric current goes into something, has to come back out and return to the battery. Which means anything you power up needs two wires to make it go – one for Power and one for Return. This brings us to:

The Evil Ground

In a car or metal airplane some wise soul thought it would be a good idea to just use the chassis or fuselage as a common Return wire and save a few bucks. Great idea, if you want to spin motors and make lights blink in a Model T, but not so good for delicate electronics like EFIS, Radar, electronic engine monitors or FADEC. Both *Electronics International* and *blue mountain avionics* specify ungrounded EGT probes because most homebuilt airplanes have grounds all over the place and the stray currents that go with them can cause odd EGT readings.

"Bad Grounds" cause more problems than just about anything else.

So -- I offer the Zen solution of not making any grounds. <u>Ditch the whole, outdated, tragically useless concept</u>. If you stick to the two-wire rule, one for power and one for return, you'll never have a ground problem, and everything you connect will work the first time. This brings us to our second rule:

> **Rule #2:**
>
> **All circuits are wired with a power lead and a return lead of the same size. Power is color-coded yellow or red, return is color coded black.**

Color-coding is done in every branch of electronics except for light aircraft to make things easier. We're gonna start doing it too.

> ***Yes, there is value in the "single-point ground." This philosophy has been discussed in the 'Connection for over 10 years. The 'Connection and now B&C have offered kits of hardware to ease the task of crafting an effective single-point ground system for about that long. However, not everything needs to use the single-point ground. A teacher's duty is to explain how the single-point ground works and to discuss techniques for use that adds value to the system's performance.***

Sizing Wires and Breakers

We did a fair amount of figuring in the section above, which we can reduce it down to a simple rule:

Breakers are 10A for everything wired with #18, which is almost everything.

If you have a load that draws more than 8 Amps, you need to put it on a separate breaker. There are *very* few of these in practice, generally alternator output, landing lights in 12 volt systems and some gear pumps. Breakers should be loaded to less than 80% of their capacity, so the rule holds.

8 Amps * 24 Volts = 192 Watts, which is quite a lot of power.

A common practice in homebuilding is to size the breaker to match the size of the load. This sort of makes sense, but when you think about it, it really doesn't. The breaker is protecting the wiring, not the device being powered! If the wiring shorts out, we want the breaker to pop instead of melting the wire – right?

But, you say, the automotive industry use different sizes of fuses!

True enough. They use different sizes of wire too, because auto fuses are all one price while copper wire is priced per pound used. What makes good sense in high volume production isn't always the best method for one-off projects. For us homebuilders, simple and safe is what we're after.

> ***From a perspective of safety and convenience, I can deduce no big argument against this philosophy. I've had builders call and ask, "I got a heck of a deal on a whole raft of 10A breakers, can I use them for***

everything?" The correct answer is, "yes, if you wish." Is there value to the OBAM aircraft owner/operator for doing this? We'll explore this more later.

Radios and Indicators

This covers wiring everything from a basic Nav/Com to EFIS, Autopilots and Radar. The signals you'll be dealing with here are low level (less than a volt) and are susceptible to noise and interference. Wire all of these with #22 Teflon wire, and shield microphone, headphone and speaker leads. Shields are to be connected at the radio end **only**, and cut flush at the other end using your Flush Cutters. Power and Return are #18 in the usual colors.

Shields should be connected as shown in the manufacturer's installation instructions. Sometimes a shield is part of a signal path COMBINED with functionality as a shield and gets connected at both ends.

The manufacturer provides a standard drawing for the radio and indicator you bought, the only thing I can add is this:

Make sure you leave enough cable length to be able to take the indicator out of the panel and still connect and run it. These sloppy lengths of cable are called Service Loops and make the mechanic's life easier and your bill lower when it comes time to fix it. Anything you build, imagine having to take it apart and fix it later!

Antennas

Antennas are used to couple one circuit to another at a distance. Anyone who says otherwise is probably selling something. What we want in airplanes is to couple our transponder to a ground controlled radar station, to couple our Com radios to other Com radios and to get our Nav radio hooked up to the local VOR. Antennas come in a bewildering array of choices, so I'm gonna show you which ones work 100% of the time with no problem and save you the Learning Experience.

What antennas offered only work 80% of the time? I'm mystified as to the risks alluded to in this opening paragraph.

Kinds of Antennas

There are three frequency bands of interest for airplanes: VHF, Microwave and Long Wave.

- VHF is for Nav, Com, Localizer, Glideslope and Marker beacons. All the 1950's era about-120-MHz stuff you tune with an aircraft radio. These antennas are connected with RG-142 coaxial cable and BNC connectors.

For a metal airplane use a commercial whip antenna and make SURE that the bottom of the antenna is connected to the skin of the aircraft. No paint, oil, or any other yuck. This needs to be a solid electrical connection. Take the end of the coaxial cable that goes to your radio, and measure with an Ohmmeter from the shield to the skin of the your airplane.

Like the statement about resistance of connections cited earlier in this work, an ohmmeter test of antenna ground is meaningless. Meaningful measurement of airframe grounding cannot be accomplished with less than a low-resistance ohmmeter or bonding meter with display resolution in the micro-ohms.

It is true that the coax cable shield is connected to the antenna base by way of the coax connector on the antenna assembly. It is also true that the antenna performs best when the base is well bonded to the skin of the aircraft.

On the saddest antenna installations I've seen the builder cleaned the entire area of skin under the antenna of paint and did a similar job on the antenna base itself. We've discussed characteristics of a good electrical connection and used terms like "gas tight" to describe intimate metal-to-metal contact of two joined conductors. This same philosophy applies to getting an antenna base bonded to the aircraft skin.

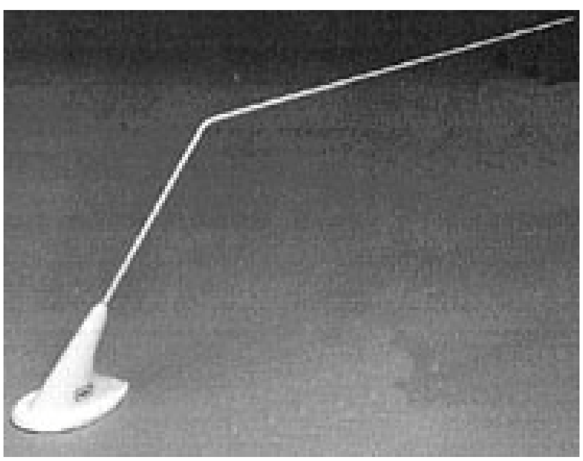
Suppose you've cleaned all the paint off of facing surfaces of the airplane and antenna. How much of that surface area might be expected to be gas-tight? "Very close to zero," is the correct answer. There is no value in messing up a couple of perfectly executed paint jobs to improve on grounding of an antenna.

Where is there any potential for gas-tight integrity of the installation? Exactly! Right at the mounting screws. What can we do to improve the odds? Clean the area under the screw heads on the antenna base. Clean the UNDERSIDE of the skin where the nuts and washers will contact the aircraft skin. Use hardware clean of corrosion. Use metallic locknuts to improve mechanical integrity of clamp-

up forces. Use internal tooth lockwashers for ELECTRICAL bonding of nut to skin. Throw away the cork or rubber gasket supplied with the antenna (it will crush or extrude with age and reduce clamp up forces). Get a non-hardening, sealant (windshield shops have this stuff) and run a bead of sealant around the periphery of the antenna base before installation. When the antenna mounting screws are fully tightened, you'll see sealant extruded from under the base which is easy to clean off. After installation, it may be useful to use some more sealant over screw-heads if they're counter-bored into the base.

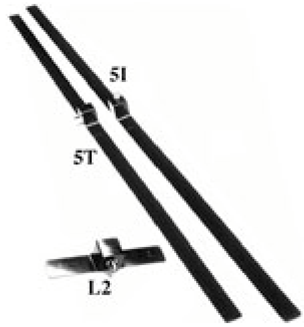
When this is finished, you will have crafted a joint between antenna base and skin that measures in hundreds of micro-ohms and will last the lifetime of the airplane. Best yet, those nicely painted surfaces are still painted.

It needs to be pretty close to a dead short, since the shield is bonded to the skin of the airplane at the antenna. Most antenna problems are caused by either connectors put on badly, or open shields. Check yours and make sure it's good.



The antenna shown above is the AV17 from Aircraft Spurce and is commonly seen on Van's designs.

For a composite airplane use a dipole. This is a vertical that has *another* vertical element to balance it since there's no metal aircraft skin to connect to it. These antennas always work, and almost never give problems.



The ones shown in the picture are from Advanced Aircraft Electronics, and work very well. Aircraft Spruce usually has them in stock. Just bond them in to the airplane, and forget about it. Jim Weir has plans for making a similar antenna with copper foil, although I'm partial to the AAE version.

> ***Antennas of the foil or metal strip variety are easy to fabricate. I'll agree that Fiberglas airplane builders can take advantage of radio frequency transparency of their airframe and mount antennas inside.***

Remember: COM is vertical, NAV is horizontal! Follow AAE's directions and you'll be in good shape.

- Microwave is for Transponder, Strike Finder, GPS, Satellite weather, Cellular phones and all the creations of the last few decades. These are typically connected with BNC connectors, but use RG-142 for lower loss at frequencies near 1000 MHz.

> ***. . . or RG-400***

Microwave antennas are best supplied by commercial sources since their active elements are so small making them is a real chore. Most microwave antennae require a ground plane like an aluminum airplane skin under them to work properly. If you are installing one of these in a composite airplane, either ask the manufacturer for an antenna that will work in a composite plane with no ground plane, or spray a ground plane using Super-Shield.

Super-Shield is basically metal foil in a spray can. Shoot three (3) coats of it on the outside of the plane, mount your external antenna and it's just like having a metal airplane without all the rivets. You can even paint over the stuff once the antenna is installed and no one will be the wiser but us.

http://www.mgchemicals.com/products/841.html

> ***Yes, all monopole antennas need a ground plane for***

optimum performance. Further, making an good electrical connection between coax feedline shield and the ground plane is a critical component of the performance equation. I'm mystified as to how one makes micro-ohm level connections to a coating painted on the inside surface of a fiberglas airplane. Ground planes are easy to construct from metals as described in the 'Connection. I have zero faith in the effectiveness of a spray on coating for a ground plane. I've used these coatings for interference attenuation . . . it's not intended for use as described here.

Safety Note About Transponder Antennas

A transponder puts out a couple hundred Watt microwave pulse in a frequency band that is none too healthy to be around.

On a metal airplane this is no big deal, since the whole thing is one big, shielded can. On a composite bird, you can be sitting unpleasantly close to a powerful microwave transmitter, which is Not Good. Mount the antenna as far away as practical, or failing that, use SuperShield to shoot a ground plane between you and the antenna. One of my friend's airplanes actually has the antenna right under the pilot's seat!

This is hangar-legend with no foundation in physics or physiology. Somebody looked at a "200 Watt" rating on their transponder and tried to make a comparison with the "600 Watt" rating on their microwave and jumped to lots of conclusions founded on ignorance and exacerbated by hysteria.

I have taken on the task of researching the science behind my assertion and will be publishing a separate article on the matter on my website at

http://www.aeroelectric.com

Spotters Guide to GPS Antennas

GPS antennas come in two flavors, active and passive. Active antennas take a voltage (usually 5 volts DC) up the coax to power a small preamplifier in the antenna. Most Garmin GPS antennas are this variety, as are any of the small, plastic stick-on types. Active antennas are small enough to put inside the airplane on the glare shield or in the composite structure and are often hidden. Passive antennas are usually mounted on the skin of the airplane, and if the GPS receiver can has the gain to use them, can provide excellent performance.

If you're not sure which kind you have, or which kind to use, take your voltmeter and measure the voltage from the center conductor to the shell of the BNC connector on your GPS receiver. If you see about 5 volts, you're looking at an active antenna.

Most passive GPS antennas look like short circuits at DC and will short out a GPS receiver that is set to drive an active antenna. Best bet is to use the one the manufacturer sent with the radio.

GPS Antenna Mounting Tips

When mounting GPS antennas make SURE that there are no obstructions that block the sky. Imagine the bottom of the antenna sitting on a round plate ten (10) feet in diameter covered with a matching 10 foot dome. What's it gonna hit? If it's metal, that's a part of the sky you won't see. The vertical tail isn't wide enough to signify, but a chunk or glareshield or the top of the wing sure is!

Common troubles are putting them partially under a metal glareshield, beneath carbon fiber, or in the cockpit of a high wing design. GPS can 'see' through fiberglass, but not carbon, and certainly not aluminum. Got it next to another antenna? That's a chunk of sky you'll miss too!

You should be able to see 10-12 GPS satellites while flying, but 6-8 is much more common, I've found. Taking a little time to locate the antenna where it has an unobstructed view of the sky will gain you a world of performance.

> ***Generally true . . . but be willing to try less than ideal locations too backed up with the notion of moving to a better location if necessary. I've been flying hand-helds in the cockpit of high-wing, all-metal airplanes for almost ten years. I've achieved satisfactory performance by setting the handheld up on the glare shield and against the windshield with Velcro and windshield sealant (same stuff I talked about earlier for sealing antenna bases). From this much less than ideal location, the receivers perform quite well. If you can locate all your antennas in ideal locations, fine. But don't bust your buns to achieve ideal locations before first exploring the easy solutions.***

- Long Wave is for ADF. This is for tuning NDBs and AM broadcast stations and is the oldest of all the flying radios. Since the FAA is slowly killing off all the

NDBs, we won't cover it here in detail. If you have to hook up an ADF, treat it like VHF and you'll be more than fine.

> ***Not sure what this means. There are no functional or installation characteristics shared by VHF and ADF antennas.***

Audio and Entertainment

I rather enjoyed the look on my mechanic's face when she turned on the strobe pack and igniters and noticed that no difference in the Mozart playing in the headsets. "Jeez, that's quiet" she said. Same thing for radio transmissions "Sounds like FM" she says. There's no need for alternator whine, strobe noise or any other audio crackles and crunchies in an airplane any more than there is in a home theater system. Here's how you make it quiet:

Back to Grounding, Again

The guys at PS Engineering at just north of my shop in Tennessee are a sneaky bunch, I think. They put a solid ground bar on the back of their audio panels and ask you to solder all the "grounds" right there. There's a crew who isn't going to have any problems with ground loops! Your audio circuits should follow the same rule as all the others:

All circuits are wired with a power lead and a return lead of the same size.

This means that microphone, headphone, CD and everything else gets connected with two leads and that the Return leads are all connected to this audio "ground bar". Doesn't matter where or what it is, as long as they all go to one place. The PS Engineering crew has a lovely drawing in their installation guide that worth looking at for an example of how to do things well.

Since we're wiring our circuits in pairs, grounding is not a problem we have to solve anymore. There is no ground.

> ***Not true. There IS a ground. A carefully considered, artfully crafted ground that performs the electrical duties of a ground while AVOIDING problems associated with poor grounding practices. The next update to the 'Connection is going to discuss audio systems and expand on the grounding chapter to suggest an avionics and audio system GROUND that ultimately ties to the firewall ground. Ultimately, if one takes an ohmmeter reading between a microphone connector and the right wingtip of an RV, there WILL be some low resistance reading there. The important concept to be understood here is that grounding is not so much a task of making a connection between two components that expect to communicate with each other via "ground" . . . it's where and in what order the grounds are made so that***

undesired coupling between potential antagonist and victim systems does not occur.

Shielding

As mentioned in the section on RF and Noise, shielding is what we use to keep the wires from acting as antennas and either radiating or receiving unwanted RF. By using shielded wire for microphone, headphone, speaker and any other circuit carrying audio and connecting the shield to the ground buss described above you'll essentially have no problems ever.

Make sure you connect the shield at the ground buss end and cut it off flush at the other end.

If you don't the shielding won't work and you'll not be pleased. Which brings up a couple more rules of thumb:

If you want it quiet, give it it's own lead and shield it.

- Each headset
- Each microphone and PTT
- Each audio source (CD, cellphone, etc.)
- Speakers

Shields are connected at the source end, and cut off flush at the load end.

This approach has you running a few more cables, but gets you the perfect result every time. You can use the same kind of Teflon insulated, shielded six (6) conductor cable for each of these. As an added bonus you'll use the same kind of cable for your engine sensors, so you'll get good at working with it.

Nothing "wrong" with this approach but generally not necessary. Shielding has a limited, very specific noise mitigation characteristic. I can show you how to wire up headset and microphone circuits with shielded wire and have tons of noise. I can also demonstrate microphone and headset circuits that are NOT shielded and routed into wire bundles with lots of noise-bearing wires and have no noise. The style and depth of advice offered is short on explanation of physics and NOT a guarantee of success.

EFIS, Autopilot and Other Digital Devices

Engine Monitor, FADEC and Sensor Wiring

greg@bluemountainavionics.com

Tool Time!

Before we get into the How's and Why's, we need to get familiar with the tools we'll be using and the materials we'll be using them on. Read on – it's a lot simpler than you'd expect, and all of this stuff can be had from the sources at the back of this booklet.

Solder and Flux

Good solder comes as a spool of soft wire and is 63% Lead and 37% Tin called, not surprisingly, 63/37 solder. The flux that fills the hollow core of the solder cuts through the oxide layer on your wire and connector so that the solder will wet out and flow easily. Kester 44 is s good one, and comes in 18 Gauge for big stuff, and 23 gauge for fine work.

You'll sometimes here the term "rosin core solder" which generally means any solder that has a non-acid organic flux core. The stuff I prefer cleans up with water, and the smoke won't sting your eyes when you solder with it.

For soldering big lugs for your battery and alternator leads the flux core in the solder may not be enough. Kester makes a good liquid flux that rinses clean with water. We'll cover this in detail in the soldering section, but we *do* wash everything in water to remove excess flux and leave a clean, shiny joint. By the time you get through this booklet you're gonna be *good* at this!

> ***Solder and crimping are interchangeable technologies for joining wires and terminals. These paragraphs correctly cite the value of selecting the most effective materials and I'll add that some practice and understanding goes a long way toward insuring success.***

Heat Shrinkable Tubing

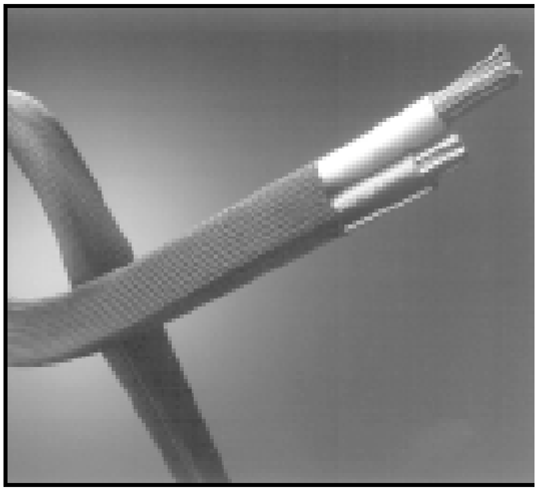
This stuff is great – solder a connection, sleeve it in heat shrink, and it's airtight and good as gold. We use heat shrink for covering splices and the ends of uninsulated connectors. The good stuff has glue inside that melts when you heat it up to form both a water and airtight seal, like 3M EPS-300. Digikey P/N EPS333-16K is one size of this tubing, which is available in many sizes.

> ***Dual wall heat-shrink is recommended with reservations. This stuff is extra thick and extra stiff as installed. Fine if you have the volume and need the support. Thinner, less bulky heat-shrink products do what needs to be done 90% of the time, goes on with less heating, and costs less.***

Snakeskin

This knitted cable covering make the difference between an OK and an exceptional looking installation. Put your spun leads inside this, and you're on your way to a truly gorgeous, and easily repaired, airplane.

Digikey P/N AG120NF12B-100-ND is made by Alpha Wire and looks like this:



> ***We use this stuff at RAC, mostly for test harnesses and only occasionally on an airframe bundle. Except for cases where I add this over-braid to mechanically protect a wire bundle, I find it a pain in the glutes.***
>
> ***Imagine cutting the toe out of a sock and running all the wires of a major wire bundle through it. You can't simply lay a new wire against other wires and tie it. They have to be threaded through this very limber tube with an inside wall that snags the end of wire. I've seen this stuff used on several show-quality airplanes and marveled at the builder's tenacity and energy. I wouldn't do it.***

Digital Volt Ohmmeter

You don't need anything super-duper here, but you do need something that can measure DC Volts, Ohms and has a continuity checker that beeps. Anything else is gravy for this kind of work. I'm very partial to Fluke, but then again I'm a geek and use my DVM like an A&P uses a wrench. Harbor Freight has what you need for less than $50. Make sure:

- The thing is digital
- That it autoranges – you should be able to read it without having to remember to multiply by 10 or 100 or whatever.

I'm mystified by this assertion. Both auto-range and manual range instruments will properly place the decimal point on the scale. There are no requirements to "remember to multiply" by anything with any digital instrument. You don't need to restrict your search to auto-ranging instruments to avoid confusion of readings.

- That it doesn't have a zero adjust for the Ohms ranges: good ones are automatic

  I've owned dozens of digital instruments and used many dozens more. All run-of-the-mill multimeters assume zero resistance test leads. When you short the tips together, you'll see a non-zero reading that must be subtracted from any reading you take on the circuit being explored. I have an old Fluke bench multimeter that features a special low resistance measurement feature with a zero-ohms adjuster. It functions only on the low resistance function and lets me null out lead-resistance for measurements with 0.1 ohm resolution. These are VERY rare.

- That is has a diode checker – they almost all do this now, and it's a nice feature

- It has a beeping continuity tester – you'll use this a lot

- $50 will get you a decent one, $150 will get you a great one, $300 will get you the one I use in the lab that has a laptop port and a book full of features.

  The last one I bought was from Sears. It was $19.95 and checked out to less than 1% variation for readings taken with my $high$ bench instruments. It's so very easy to achieve accuracy with digital technology that accuracy no longer drives prices. For the most part, extra dollars only buys you ruggedness or neat but seldom used features.

Automatic Wire Stripper

An automatic wire stripper saves time, money and frustration and is cheap, cheap. Nicked wires caused by bad manual stripping are about half of the broken connections I see, and this thing makes sure you get it right every time. There are various different types to fit every budget. The one pictured below is very nice, and can be had from Digikey or Allied.

I won't spend a lot of time/words on strippers here. See:

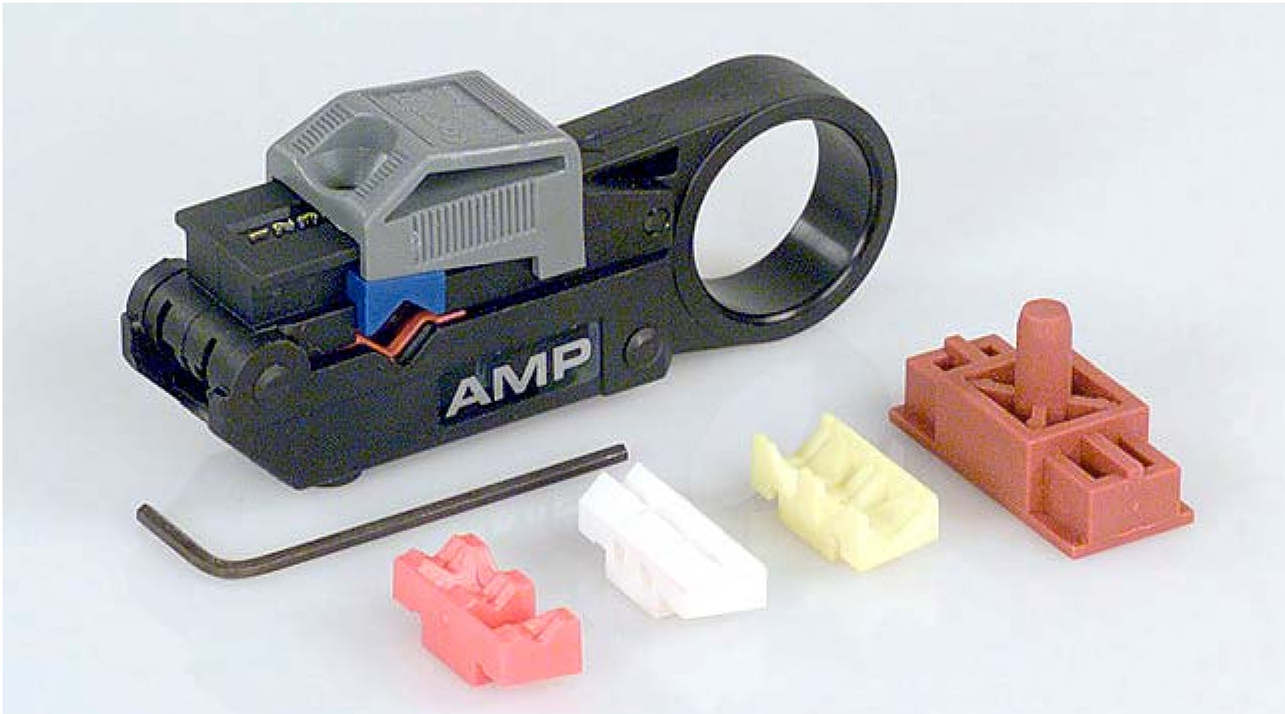
http://aeroelectric.com/articles/strippers/strippers.html

Flush Cutting Dykes

These are the normal 'wire cutters' that everyone uses with a twist – they make a flush cut with no burr. It's the avionics tech's secret weapon for a really nice job. Make sure you get a good set with cushioned handles and a spring that pops it open when you let go. Makes a real difference in fatigue at the end of the day. Don't let anyone cut safety-wire with these – the jaws are not hardened to cut steel wire, and it'll nick them badly and they won't cut clean anymore. My personal favorite is from Xcelite, and is a full flush cutter. Fry's or Digikey has 'em for about $6. The Cooper is shown below:

Coax Stripper For BNC Connectors

These nifty little gizmos strip the outer jacket, copper braid and inner insulation on coaxial cable in one go, and are available from several makers in varying price ranges. You won't be doing too many BNC connectors, but for what it costs it's cheap insurance that your connectors will all work right the first time. Failing that, borrow one from the avionics shop or cable TV guy.



Daniels Crimping Tool

This is the one to use for all the D sub connectors you see on avionics. If you are farming this out, you don't need it. These tools make a perfect crimp every time and are pretty expensive. It's worth borrowing one for as little as you'll use it, but use it you must, as there is no substitute.

> ***Daniels and others make some fine tools . . . most conform to industry and military specifications for the installation of machined pins for d-sub, AMP circular***

plastic, and other popular connectors. I own hundreds of dollars worth of crimp tools. For the OBAM aircraft builder, there are low-cost alternatives to the high dollar tools that produce entirely satisfactory results. See the range of offerings at

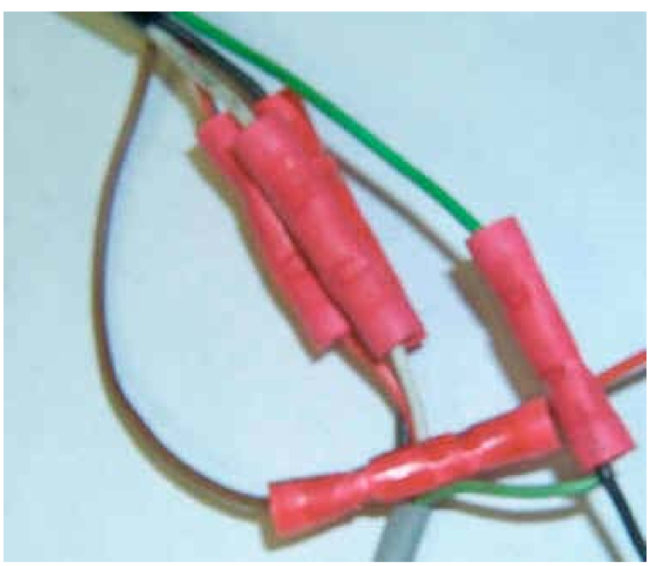
http://bandc.biz/cgi-bin/ez-catalog/cat_display.cgi?9X358218

Irrespective of where you find the bargains, be aware of the fact that low cost alternatives exist.

Soldering Iron

You'll need a good soldering iron in the 35 Watt range. As usual, Digikey, Allied or any of the other should have what you need. A common one looks like this:

Desoldering Pump



You'll need one of these for things you solder together and discover you didn't mean to.
Digikey P/N PAL1700-ND is a good one, about $20

Solderless Splices and Terminals

The automotive-style splices are HORRIBLE. Don't use them for anything except filling a dumpster. In the hands of a real pro they can be just fine, but none of the pros I know use them, oddly enough.

"Automotive" is a poor description of this part. AMP builds what they call a "Plasti-Grip" line of terminals that have no metal liners under the insulation grip. Hundreds of other manufacturers offer similar parts. Installed with the proper tool for use in benign environments, they'll perform as advertised. The splices in this view are obviously installed with the wrong tool. Terminals that do not feature metal lined wire grips are not recommended for aircraft. This topic has been addressed at length and in detail at:

http://aeroelectric.com/articles/rules/review.html
http://aeroelectric.com/articles/multiplewires/multiplewires.html
http://aeroelectric.com/articles/CrimpTools/crimptools.html
http://aeroelectric.com/articles/faston3.pdf
http://aeroelectric.com/articles/terminal.pdf

If you need to make a connection, solder it and cover it with shrink tube.

I've spent more hours chasing bad Butt Splices and under-crimped Ring Terminals than I'd care to count. Soldering takes a little more time, but once it's done, it's done well and completely and that's the last you'll ever mess with it.

These are very popular, but here's why I say pitch 'em in the dumpster:

1. A homebuilder won't use enough of them to get good at putting them on
2. You can't inspect them to see if the wire is cut, over-crimped or broken
3. These splices are, very often, used to cover-up a mistake that should be rewired anyway. Note the color code changes at the splice in the photo above. Makes for a long afternoon, somewhere.

A friend's Cozy had FOUR of these things in a two-foot power lead. Took us hours to find the intermittent problem caused by one of them, and another 30 minutes to cuss the shop that did it. Just say no!

May I suggest that this had more to do with using the wrong tool to install the crimped devices than it did with the style of device? The fact that one strand of wire had four splices is a tip-of-the-iceberg indicator of this builder's lack of understanding.

The above anecdote suggests that selection of the right style of terminal will hold the poltergeist of poor craftsmanship at bay . . . this is simply not so. I can demonstrate ways to hose up installation of some high quality terminals.

Hookup Wire

Everyone knows that Tefzel insulated wire is white, and you wire airplanes with it. As you might expect by now, I'm gonna disagree. Why make everything white? Can we possibly make the airplane any harder to work on?

> ***Tefzel is available in any coloration. I have a dozen colors of Tefzel wire on spools in my shop.***

And why Tefzel? Tefzel and Teflon are chemically similar, except that Teflon handles cold better, is impervious to almost everything, doesn't burn or outgas and is available in a zillion colors.

> ***All insulation will burn or outgas at some temperature. Tefzel, PVC Teflon, rubber, you name it. Get the any insulation hot enough and it will decompose into stuff even a Camel smoker would find unpleasant. That's what fuses and breakers are for, the dead short on any kind of wire will make your cockpit a most unpleasant habitat.***

Satellites are wired with Teflon. Military aircraft use Teflon.

> ***No airplanes that I'm aware of use Teflon airframe wiring. Teflon pre-dates Tefzel about 20 years. Limited amounts of Teflon were used for interior wiring of appliances and components beginning in the 70s, especially where temperature extremes are involved.***
>
> ***Electromech and Advanced Industries use real Teflon insulated wire for short pigtails that exit from high power motors that run HOT . . . Teflon was designed into these motors in the 70s when that was the best we had. Modern designs will use Tefzel unless there's a spec requirement for higher temperature materials.***
>
> ***Teflon was considered for airframe wiring but found to be too soft and too expensive. Teflon extrudes at such high temperatures that tin plated wire has to be replaced with silver plated stranding . . . raises the cost considerably and the insulation was just too fragile for airframe wiring.***

Kitplanes and General Aviation aircraft are still wired with Tefzel. You know why? Because old specs never die! Better stuff came along, but no one updated the spec.

> ***Spec? What spec? There is no spec for what wire one should consider for any particular task, only specs for lots of different wires to be considered for any task. I don't understand the statement "still wired" with Tefzel. He has the order exactly backwards. Teflon came first as an update to Mil-W-16878 type E and EE wire in the 60s . . .***

http://www.jaguarind.com/products/teflon/eteflon.html

http://www.jaguarind.com/products/teflon/eeteflon.html

> ***Cessnas and Pipers were being wired with Mil-W-16878 type BN (Nylon over PVC) at the time. See:***

http://www.interstatewire.com/SpecPage.asp?sCatalogPage=11b&ID=64

> ***About 20 years later, Mil-W-22759/16 Tefzel wire is developed and offered to the industry.***

See: www.interstatewire.com/SpecPage.asp?sCatalogPage=18c&ID=13

> ***Although early on, it was a export controlled material because of the advantages to military programs and we had to consider non-export controlled similar products like Raychem's Spec55 wire:***

www.raychem.com/resources/documents/datasheets/Wire_and_Cable/Spec55eng.pdf

> ***Spec 55 was equal to Teflon in many respects (200C operating temp) but more expensive than Tefzel . . . We almost went to Spec 55 and someone got our export license cleared and 22759/16 Tefzel wire was designed onto the Gates-Piaggio GP-180 in the early 80s. I'll have to ask out at RAC to see if anyone remembers when it went into Beech aircraft.***

According to my DAR, Teflon is an acceptable substitute for Tefzel in all applications since it is *better* in all respects.

> ***Again, not so. Check out this comparison of the two at:***

http://www.omega.com/techref/fluoro.html

At the bottom we find the following:

"Summary and Conclusion: . . . Tefzel fluoropolymer resin comes closer to Teflon than any other partially fluorinated resin, in chemical and electrical properties, **while providing enhanced mechanical ruggedness and economical processing."**

So we'll use the good stuff, and in color – Teflon wire can be had from any of the sources in the back of the book.

I will suggest that much of what's offered as fact and rational for the selection of Teflon over Tefzel is wrong. Tefzel has been the insulation of choice in aircraft for about 25 years. The only stories I've heard on military aircraft involve horror stories about Kapton insulation failing in the salt air aboard aircraft carriers and getting new harnesses crafted of Spec55 wire. I'm also told that Teflon was viewed with disfavor in the spacecraft industries . . . it cold flows under pressure. An overtight string-tie will squeeze insulation from between two wires and allow the conductors to short to each other.

Size Matters

With the exception of your starter and alternator cables, you only need two sizes of wire in your airplane: #18 and #22. #18 is good for 10 amps, and anything smaller than #22

Use #18 for Power and Return, #22 for everything else.

can be hard to work with unless you do it every day. The rule is:

Color Is Better Than Black and White

The following colors of Teflon wire to make things easy to trace and work on later.

Color	Meaning
Yellow	Power
Red	Power
Black	Return
Blue	Signal
Green	Signal
White	Signal

The rule is "the brighter the color, the higher the voltage" so Alternator output is Yellow while Alternator field is red. Both are power colors. Black is always return (ground if you must call it that!) and Blue, Green and White are used for signal leads as needed.

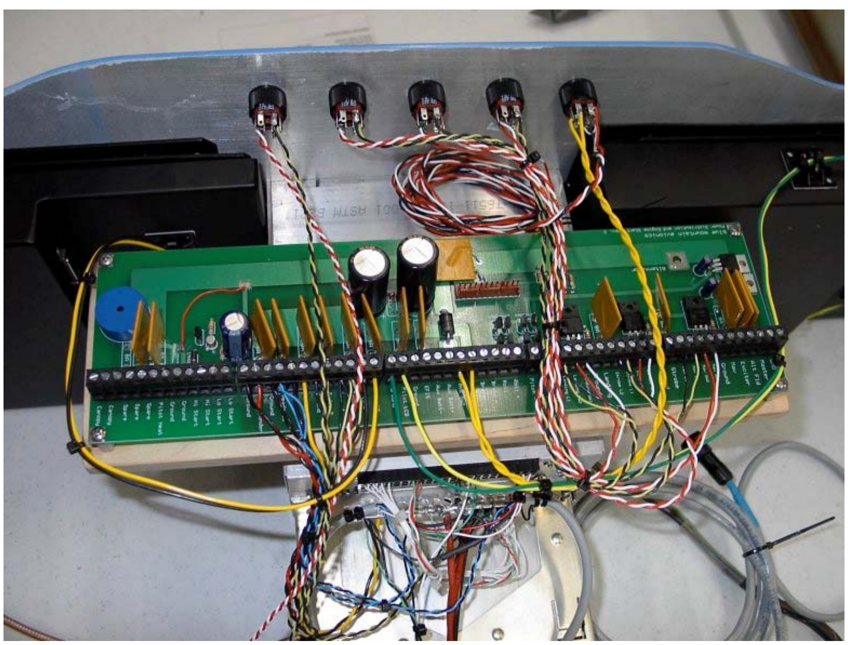
Example:

> A tachometer sensor needs power, return and a signal output lead. I chose Red, Black and White. Just looking at the sensor on the engine I can tell which lead is which, and I don't have to figure out how to keep wire labels from coming off under the cowl as time goes on and things get oily. Makes it easier!

Twisted Pairs Are Easy to Trace

If you are going to have two or more wires going to a single device, I say spin 'em. Use an electric drill to twist them into a cable that'll stay together and you'll be amazed how much neater your bundles look, and how much easier it is to tie all this stuff down.

Just take your bundle, clamp one end in a vise, stretch them all parallel and fold your end over and twist. Put that twist in your electric drill and spin 'em up. After they look like you want, give a gentle tug to stress relieve the bundle, and it won't snap back when you let go.



Spun cable sets and power board in N722

> ***These paragraphs cover a lot of ground that goes to issues of system architecture, cost of fabrication, cost of ownership and builder craftsmanship. It's a little tough to decide where to begin. It's worth mentioning that "simplification" of a complex subject***

into a hand-full of pages offering "rules of thumb" fall far short of what we should be seeking in the crafting of an OBAM airplane. This is why the AeroElectric Connection is 270 pages long and still growing.

I don't want this effort to appear as a sales tool for the 'Connection so I'll spend some effort to make this critique stand alone. Let's begin with the photo above. I have to ask, is this a picture from an airplane in which folks regularly fly? I observe what appears to be soldered connections on the back of indicators or switches that have no vibration support – no heat shrink over the finished joints. Wires that carry power to aircraft accessories come off strands clamped under threaded fasteners (not gas tight) and run into a rat's nest of random bundles . . . no routing of wires and treatment for vibration resistance. Every one of the wires you see in the picture above is at risk for vibration induced breakage.

The text implies that there is great value in color coding wires . . . ostensibly for assistance in troubleshooting. It's quite true that the Big Guys will number their wires. When you have a bundle of wires as big as your wrist that fans out to a half dozen connectors on a bulkhead, there is not only value but a necessity for individually identifying each wire. Further, hot stamping numbers is the ONLY way to go. Color codes in this situation (base colors with two strips) would be a nightmare and increase probability of error rather than reduce it. But how do colors help for putting the airplane together?

When I build a complex wire bundle, I almost never use colored or hot stamped wire. Masking tape tags on the far end of a strand lets me show where the wire goes and makes it easy to hook up the far end later. Once the wire bundle is built, how do colors or numbers help? Not at all. Electrons run from one end of the wire to the other without regard to color or numbers on the wire. How about troubleshooting? Hmmm . . . you've got an airplane with 100 hours on it and something quits working. Your wirebook will point out exactly which group of wires need investigation. I'll suggest that every wire is just as identifiable by

WHERE and WHAT it connects to as it is for what color it is or what numbers mark it.

Further, broken wires are way down on the list of probable difficulties. Even when you're looking for a broken wire, you're going to locate it by direct observation and tactile exploration and probing with test equipment. Colors and numbers add very little utility to this effort.

Let's explore the $time$ it takes to either color or number wires. First you have to order and stock the various colors. Folks like to come to my shop to build things because I have 1000' spools of several colors in stock. How many spools of wire do you want to inventory in your shop? Each color of wire will have to be ordered, inventoried and supported on some kind of rack convenient for usage. You will find that getting colored wire at the best prices involves purchase of full spools (usually 1000'). When you run out of one color and you're three strands of wire from having a task finished, how much value is there in delaying the project for a few days while another spool of the right color wire comes in?

Yeah, I've got a few spools of colored Tefzel wire . . . right above three spools of white wire. The white wire comes in on 10,000 to 15,000 foot spools for really cheap and at great convenience for building bundles of any number of wires. If somebody orders a project that specifies colored or numbered wires, I'm more than willing to comply . . . but it's going to $cost$. Further, the additional investment adds no value for future performance or cost of ownership for the bundle. Approach this decision with care and consideration. I'll suggest that the value to be realized is a fraction of the effort and expense of using colors and/or otherwise marking the few wires it takes to get your airplane functioning.

Coaxial Cable

Coax comes in several flavors, but to make matters simple and keep your tool investment to a workable minimum we'll just pick one: RG-142. This is the copper-colored coax that avionics shops usually refer to as "The Good Stuff" and use on transponders and radar antennas. It's the same as RG-58 in every way except it's better: higher temperature, lower loss, everybody wins. You can use it on anything from GPS to ADF and it'll work just fine.

RG-142 is a bit more money than RG-58, but you'll usually come off cheaper wiring one airplane with all RG-142. Check this out: If you're buying a minimum length roll of 250 feet of cable, you've got more than you need anyway. If it's cheaper to buy just one roll of the good stuff!

RG142 is equivalent to RG-400, so either number gets you the same stuff.

> ***RG-400 has the same performance characteristics as RG-142 but RG-400 has a stranded center conductor. There are a number of suppliers (including B&C) that offer cut lengths at reasonable prices. Unless you have a ton of antennas, you're unlikely to find the economics of buying lots of coax cable very attractive.***

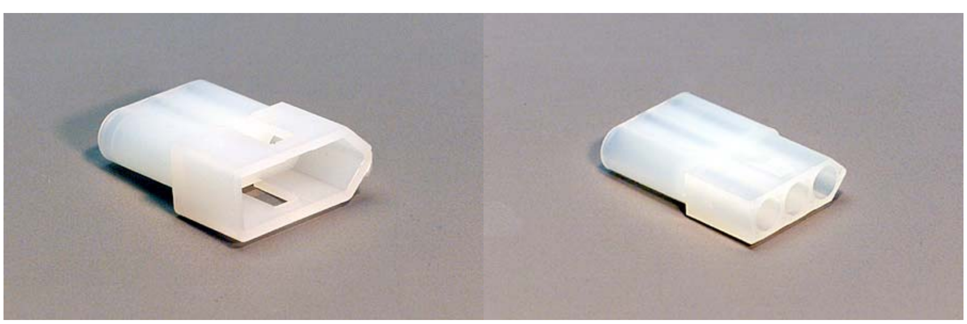
Connectors

Power Connectors

The ubiquitous "Molex Connector" shows up all over the place. Your Whelen strobe packs have 'em, and every A&P in America has a box full somewhere. Molex makes a world of connectors (it's almost like saying "Ford Engine"), but the ones aircraft people call "Molex Connectors" have three wires in them and go by these numbers:

Male Plug	03-09-2032	Pin: 02-09-2103
Female Receptacle	03-09-1032	Pin: 02-09-1104

These take the little pins specified above. The pins can be crimped on, and the ones above are good for wire sizes 14 – 20, which means our #18 fits perfectly. Use these to hook up strobe packs, trim motors, anything you may have to take out and fix, fiddle with or replace. These are used on certified aircraft, and are pretty easy to work with.



> ***Cessna began to incorporate this style of connector into production wire bundles in the mid 60s. The first new kid on the block was AMPs Mate-n-Lok series connectors. I tried to get you some good links to AMPs***

website for this product . . . but given that they have about the sorriest excuse for a website on the Web, it's not practical to give you some good links in this document. Molex came along a few years later with SIMILAR but (not inter-mateable wth AMP) connectors to compete with AMP. These connectors use sheet metal, open barrel pins that need specific tools like the one described at:

www.aeroelectric.com/articles/matenlok/matenlok.html

Radio Shack stocks a small variety of this style connector. See Interlocking Connectors at:

www.radioshack.com

Battery and Alternator Connections

Big power leads like battery cables should have big lugs sweated on with a torch. Yup, with a torch. Dunk the lead in flux, heat it up and tin the exposed copper. Put some flux in the lug, get it hot and stick the tinned lead in. Add solder until the lug is full. The connection will be low resistance, won't corrode and will look good. Wash the whole thing in water to remove any residual flux and put shrink tube over the whole shooting match to relieve the stress point where the solder made the wire solid.

First, take your solder and run off about 20 feet of it. Loop it around your hand and elbow like a rope and make 10 loops. Twist until you've got a thick bundle of solder. You can also buy bigger stuff, but why spend the money just to do two connectors?

As noted earlier, these are the only leads that won't be #18 or #22. The Alternator lead will be #10 (up to 100 amps) and the battery leads are #2/0. That's size 00, and I suggest using welding cable from your local welding supply house. Yes, it's heavy, so make sure to keep these short. The amount of power wasted heating up start cables can be significant with today's smaller batteries. It's really worth using the big cables, and putting the battery close to the engine.

#10 wire is marginally big enough for a 35A alternator much less a 100A machine and battery leads of #00 wire are ridiculously too large. The piece correctly identifies soldering as an alternative to crimping for installation of terminals on fat wires but misses some important points of technique. See:

http://www.aeroelectric.com/articles/big_term.pdf

Coax Connectors

BNC connectors are about all you'll see in light airplanes. Anything else, follow the instructions or get a pro to help you. There's nothing magic about SMC, TNC or the rest, just no sense in beating yourself up to put on ONE oddball connector ONE time. You'll do a few BNCs, though, and here's what they look like:

The BNC – Digikey A24410-ND

A step, by step professional guide to attaching these can be found on the 'Net at:

http://www.extron.com/download/files/userman/cabtermkit-man.pdf

Learning To Solder

This is a better guide than I could write:

http://www.circuittechctr.com/guides/7-1-1.shtml

The only thing I'll add is that solder and shrink tube come as a pair. If you solder a lead, it's best to put shrink tube over the connection to keep it from oxidizing, and most importantly to strain relieve it. Solder makes stranded wire solid, and solid wires crack and break under vibration. Apply shrink tube from the solder joint out to where the wire is flexible (usually about an inch) and you'll have a connection that'll outlast the airframe.

> ***Generally true. Solder is an excellent alternative to crimped joints. When fabricated with understanding and proper materials, the soldered joint is no better nor worse than the crimped joint. Both technologies have unique requirements for performance and pitfalls for failure. There are tons of articles on the 'net that speak to soldering techniques but most focus finely on electronic assembly of parts on etched circuit boards. Few OBAM aircraft builders are going to need this***

skill . . . most opportunities for use of solder in aircraft fabrication deal with bringing wires to terminals and connectors. I'll try to expand on the fat-terminal article cited above to cover all the common cases for solder in airframe wiring.

Foolproof 100% Gonna Work Technique

The Standard Drawing

The Drawing for Your Project

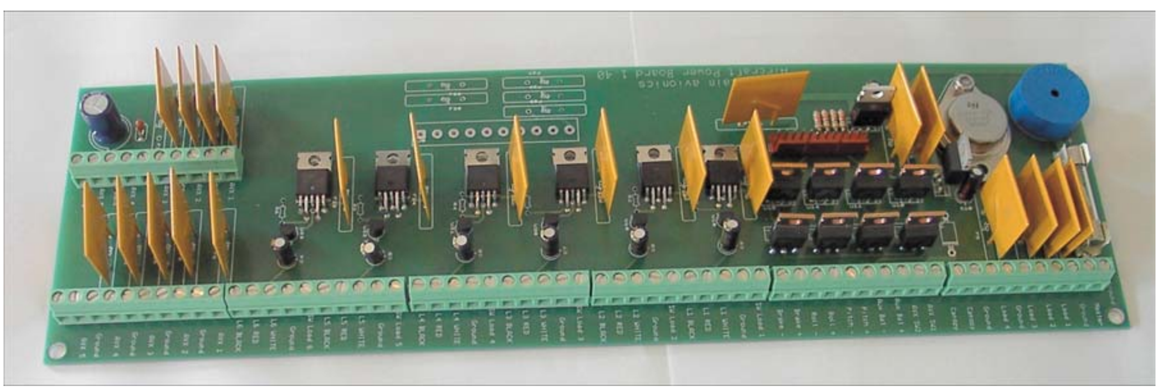
Finding Problems and Correcting Mistakes

Foolproof 100% Gonna Work Power System

Power Board Design and Artwork

About 75% of the wiring in an airplane is the same whether you're flying an RV, Cozy or a 7E7. You've got to have a way to turn things on and off, a place to connect up all your avionics and a few places to hook up things that come up with the Master switch like the Alternator field and panel lights.

I figured the obvious thing to do was build a circuit board: one place to connect it all.



Here's what we've got:

- Nine (9) circuits that come on with the Master switch
- Six (6) switched circuits with provision for driving backlit switch/ indicators
- Ten (10) filtered circuits that come on with the Avionics switch
- Provision for external Flap / Speed Brake switch

 greg@bluemountainavionics.com

- 12 volt, 10 amp regulated power supply for Pitch and Roll trim motors and five (5) circuits 12 volt loads. Really nice to have in a 24 volt ship.

- Provision for connecting coolie hat to operate Pitch and Roll trim

- Runs on 10-32 volts DC
- Main power bus is fused at 35 Amperes
- All other circuits are individually protected by resettable PTC solid-state fuses

The power board is very simple – everything connects to it except your Master switch and Alternator output, which should be wired separately to the battery.

Here's how to wire it (and the airplane) step by step:

Mounting the board

Mount the circuit board on standoffs board using 6-32 machine screws and LocTite. I used a piece of plywood, but fiberglass is fine. Metal is asking for trouble here!

Master Switch

Connect the your Master Switch to an external Master Relay with the output of that relay feeding the first lug on the powerboard. It's marked MASTER. The reason for a separate switch and relay is in the event of a dropped screwdriver, you want a separate means of disconnecting the power board. Master Relays should be rated for continuous duty, and can be had from any number of aircraft suppliers. The reason I still recommend a mechanical master is that you can hear it *thunk* when you switch the master on or off, and your DAR may not approve a solid-state equivalent just yet.

Your DAR has no approval or disapproval authority over your choice of components. If you discover a solid state contactor that meets system requirements for controlling battery outflow currents of up to 300A and recharge currents equal to the rating of your alternator, and it floats-yer-boat, then by all means use it.

Alternator output

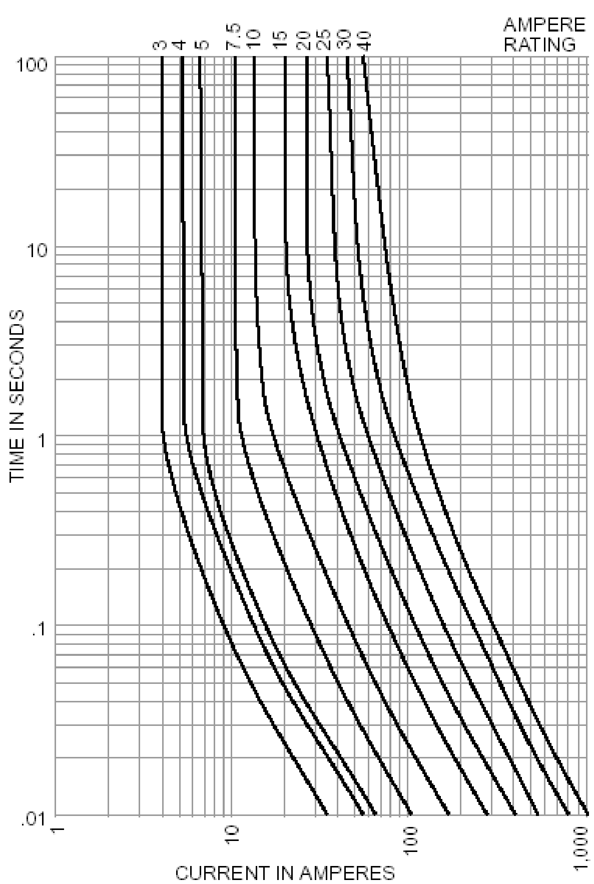
The Alternator output should be connected directly to your battery through an appropriately sized circuit breaker.

Not directly to battery but on the downstream side of the battery contactor. Quite often, the hot side of a starter contactor is located conveniently to the alternator b-lead and makes a good place for tying alternator output into the system.

A fuse is also a reasonable choice here since the only reason this would blow is if the Alternator was running away and going over voltage, or if there was a fault large enough to damage the alternator. Either way, it's not something you'd be likely to want to reset in flight.

<u>Size this breaker or fuse for 1.25 times the rated Alternator output in Amperes.</u>

Example: A 35 Amp alternator would get a 1.25 * 35 = 43.75 amp fuse. 50 is the next closest size in circuit breakers, or a 45 Amp fuse would do it. Remember, a fuse or breaker won't hold above 80% of what it says on the nameplate; so a 50 Amp breaker will pop at 40 amps after 20 or 30 minutes. Just long enough into the flight to be a bother!



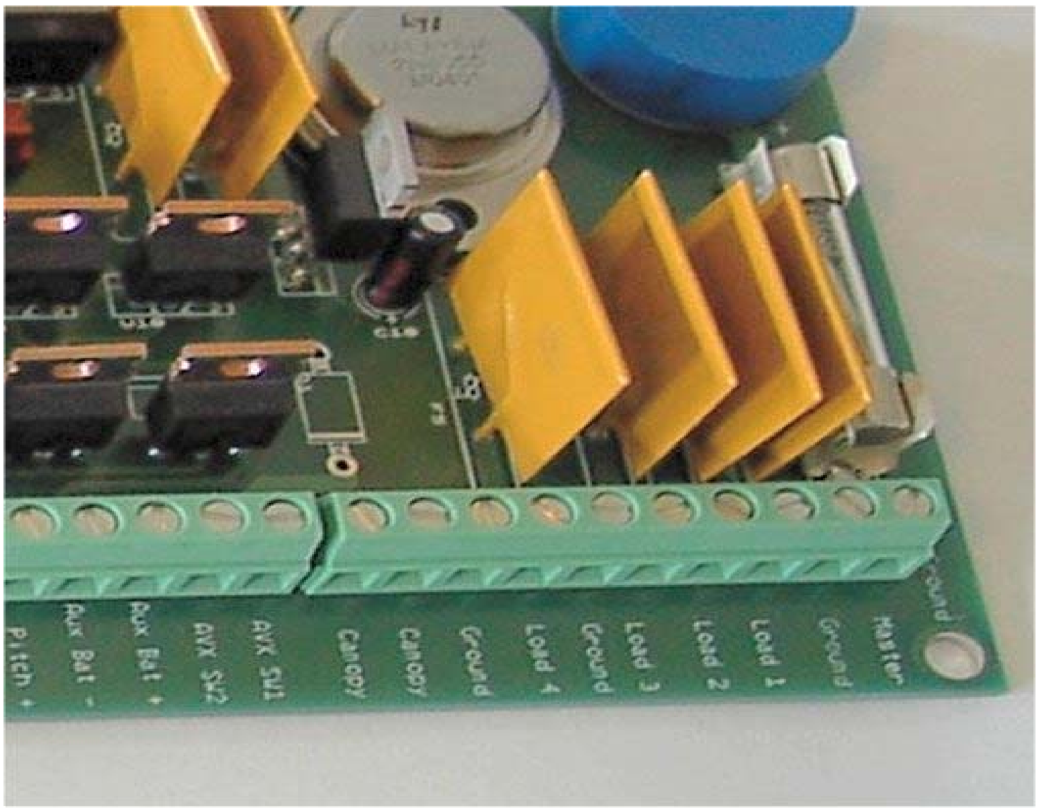
I'm mystified by this assertion. Every circuit protective device I've ever specified into a design has infinite hold time at rated current. Consider the graph on the left

Note that the blowing time for a 3-amp ATC fuse goes asymptotic (parallel) to infinite blowing time at 4-amps. This tells me that the manufacturer of the device is guaranteeing me that his 3-amp fuse will be just fine running at 100% of it's rated value and that he has ALREADY de-rated it about 25% to insure predictable performance.

Over-sizing the alternator fuse as described is a good idea, not because you need to de-rate a fuse but because alternators are rated for worst case conditions – HOT!.

A cold alternator will put out 10-20% more than nameplate rating. EVERY airplane I know of with a 60A alternator installed also incorporates a 60A b-lead breaker. This breaker routinely nuisance trips on certified aircraft. OBAM aircraft don't need to suffer this silliness . . . the OBAM aircraft builder will understand enough about the electrical system operation to consider this phenomenon and accommodate it with what appears to be an "oversized" fuse.

Here's what the input section of the board looks like up close:



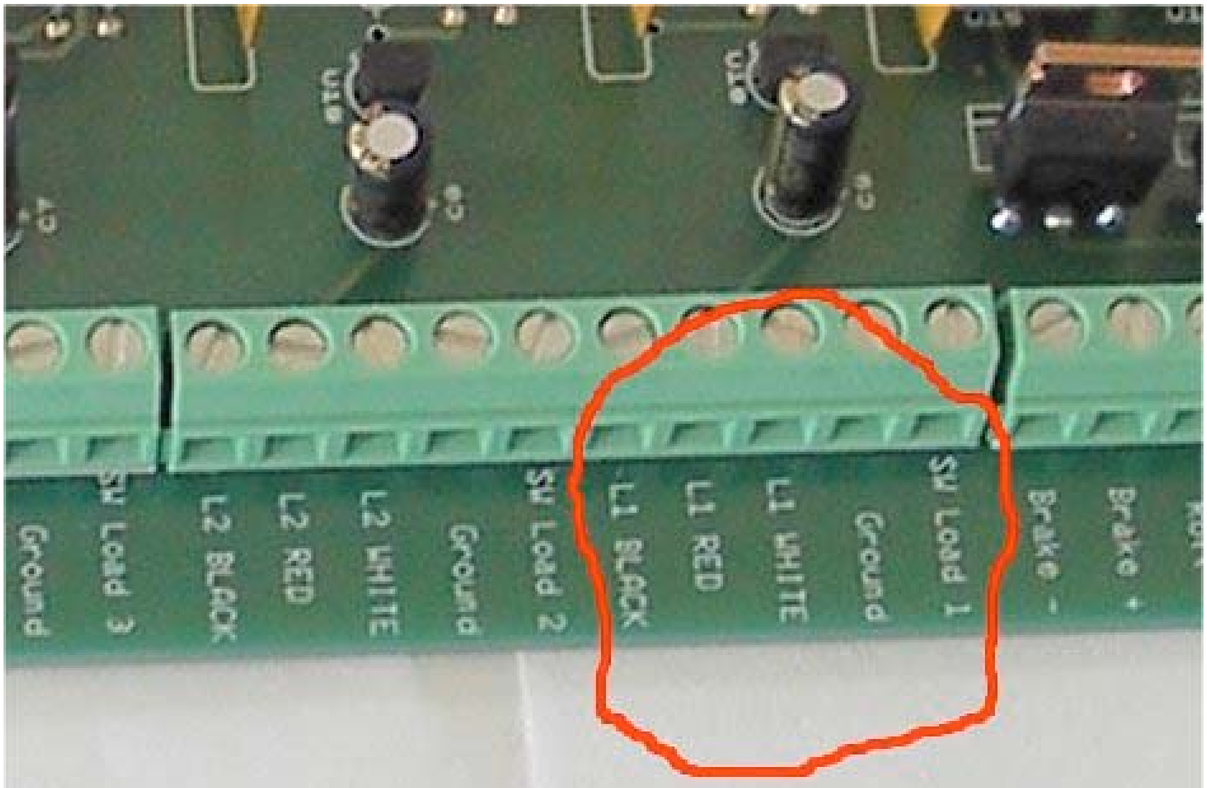
1. Alternator Field and Master Circuits

The powerboard has Nine (9) circuits that come up with the Master switch. The first of these is usually the Alternator Field or Voltage Regulator. Connect this to one of the terminals on the first block with the Master, marked Load 1 through Load 4.

Switched loads

There are Six (6) switched loads that you can use for just about anything – lights, strobes, Pitot heat, de-ice, whatever you need. Simply connect the device to be powered to the Load and Ground terminals and the Switch to the color-coded switch terminals to turn it on and off. The PTC fuses will hold up to 9 Amperes on these loads, and will trip if anything shorts out.

The circled area shows the Load, Ground and switch terminals for the first of six switched loads:



The circled are shows Switched Load 1, which is labeled SW Load 1 and Ground.

Color coding for the switch itself is also easy:

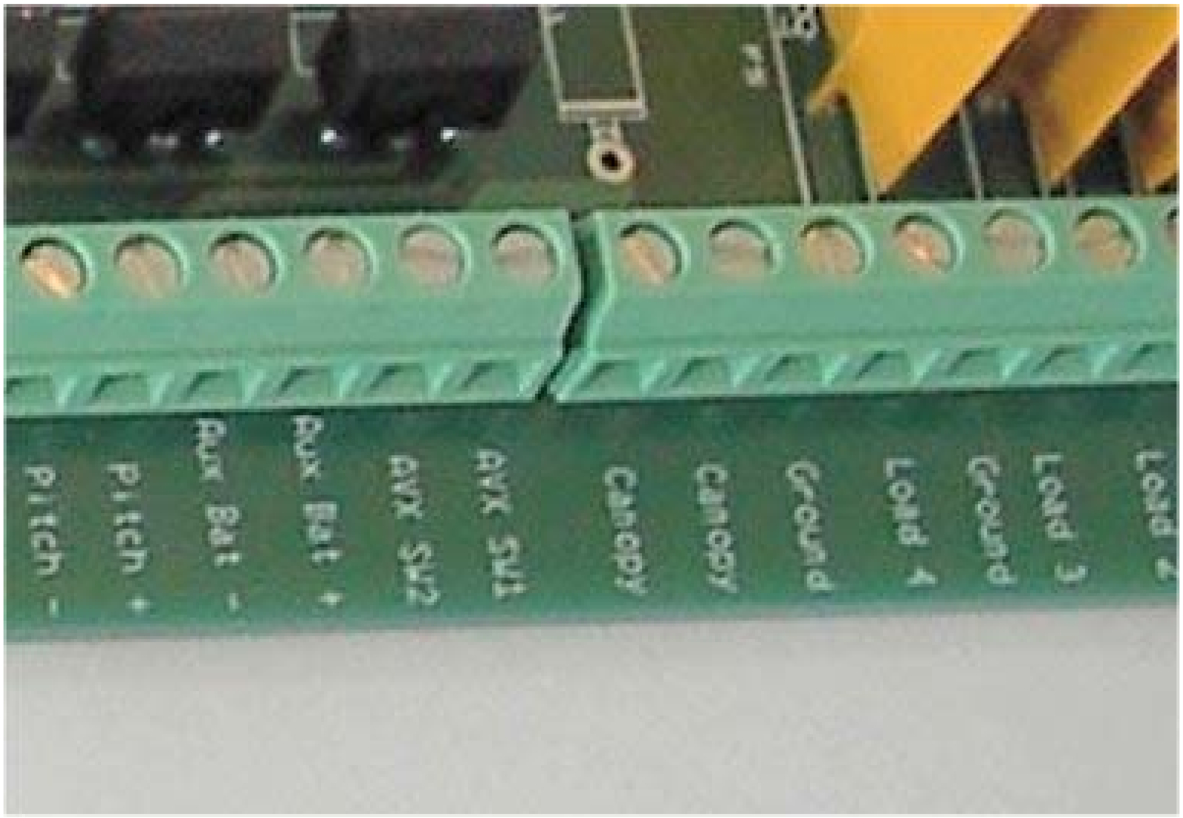
- L1 RED is +5
- L1 BLACK is ground
- L1 WHITE is turns the circuit on or off.

So, connect a 5 volt lighted switch between RED and WHITE, and the light between WHITE and BLACK. That way, the switch lights up when it's on, goes dark when the PTC blows, and can be reset to light up again when it resets.

Avionics Master and Backup Battery

I prefer my avionics to come up with the Master switch, so I installed a #18 jumper wire in the Avionics Switch terminals. If you want an Avionics Switch, this is where it goes – between **AVX SW1** and **AVX SW2**.

If you are running a 12-volt system, you'll want a backup battery to keep your electronics up and active during engine start. Connect it to the **Aux Bat +** and **Aux Bat –** terminals as shown below. It's diode isolated and comes on and off with the avionics switch (or Master is you jumpered the avionics switch), so all you have to do is hook it up!



Avionics Loads

Each device hanging off the avionics buss will come on with the Avionics Master (or Master Switch if you jumpered it). You can connect up to ten (10) loads, which is usually sufficient for radios, EFIS, intercom, etc. Try and keep noisy things like motors and fans off this buss as it is filtered to keep the radios quiet.

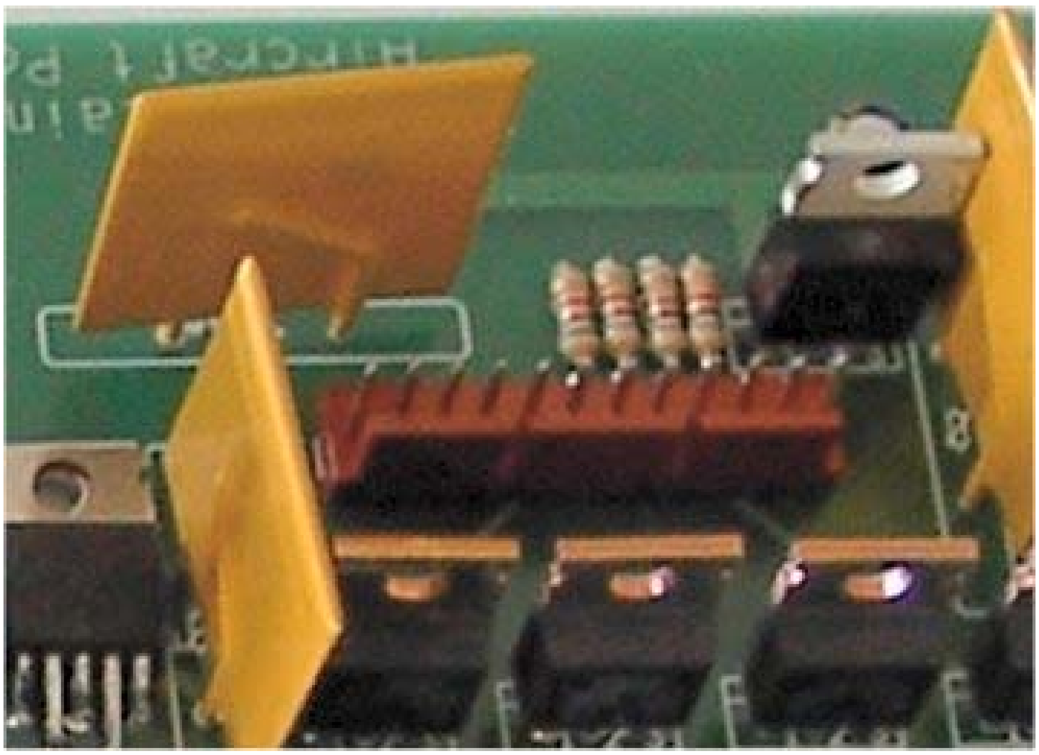
Flaps, Pitch and Roll Trim

There is a KK Connector provided to hookup a coolie hat switch and a DPDT flap switch to drive a DC motor forward and backward for flaps or a dive brake or belly board. Connect the flap/brake motor to the terminals marked **Brake+** and **Brake-**.

Flap and Trim Motor Voltages

I assume that you got the right voltage motor for your flaps, so whatever the battery voltage is, that's what you're going to get to the flap motor.

Now, 24 volt trim motors are a little hard to come by, and most people use trim servos like the Ray Allen (used to be MAC) which are 12 volt. That's why trim circuits come from ther 12 volt regulated supply, regardless of input voltage. That's right, you can use 12 volt trim motors even on a 23 volt airplane.



Pin 1 on the connector is nearest the right in the picture. Pinout is:

1. Ground

2. +5 volt power to coolie hat trim switch
3. Pitch UP from coolie hat
4. Pitch DOWN from coolie hat
5. Roll LEFT from coolie hat
6. Roll RIGHT from coolie hat

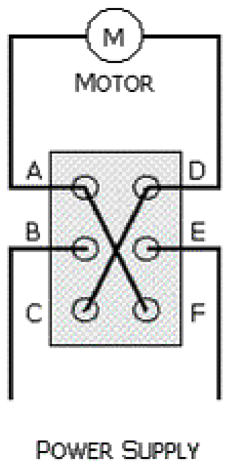
7. +Aircraft power
8. Ground

9. +Flap Power to DPDT reversing switch (B in drawing below)
10. –Flap Ground to DPDT reversing switch (E in drawing below)

11. Flap Power UP from DPDT reversing switch (A in drawing below)
12. Flap Ground UP from DPDT reversing switch (D in drawing below)

Wiring a Motor Reversing Switch

A reversing switch is made by simply connecting the DPDT switch so that the center poles take the input power and one pair of contacts take the output, with the other pair wired in reverse like this:



Pitch, Roll and Flap motors can be connected directly to the powerboard at the terminals provided. Pitch and Roll trim are 12 volts regulated at up to 10 Amps and is suitable for using 12 volt MAC servos (or similar) in 12 or 24 volts systems. The Flap circuit uses ship's power and assumes the flap motor is the same voltage as the airplane's battery.

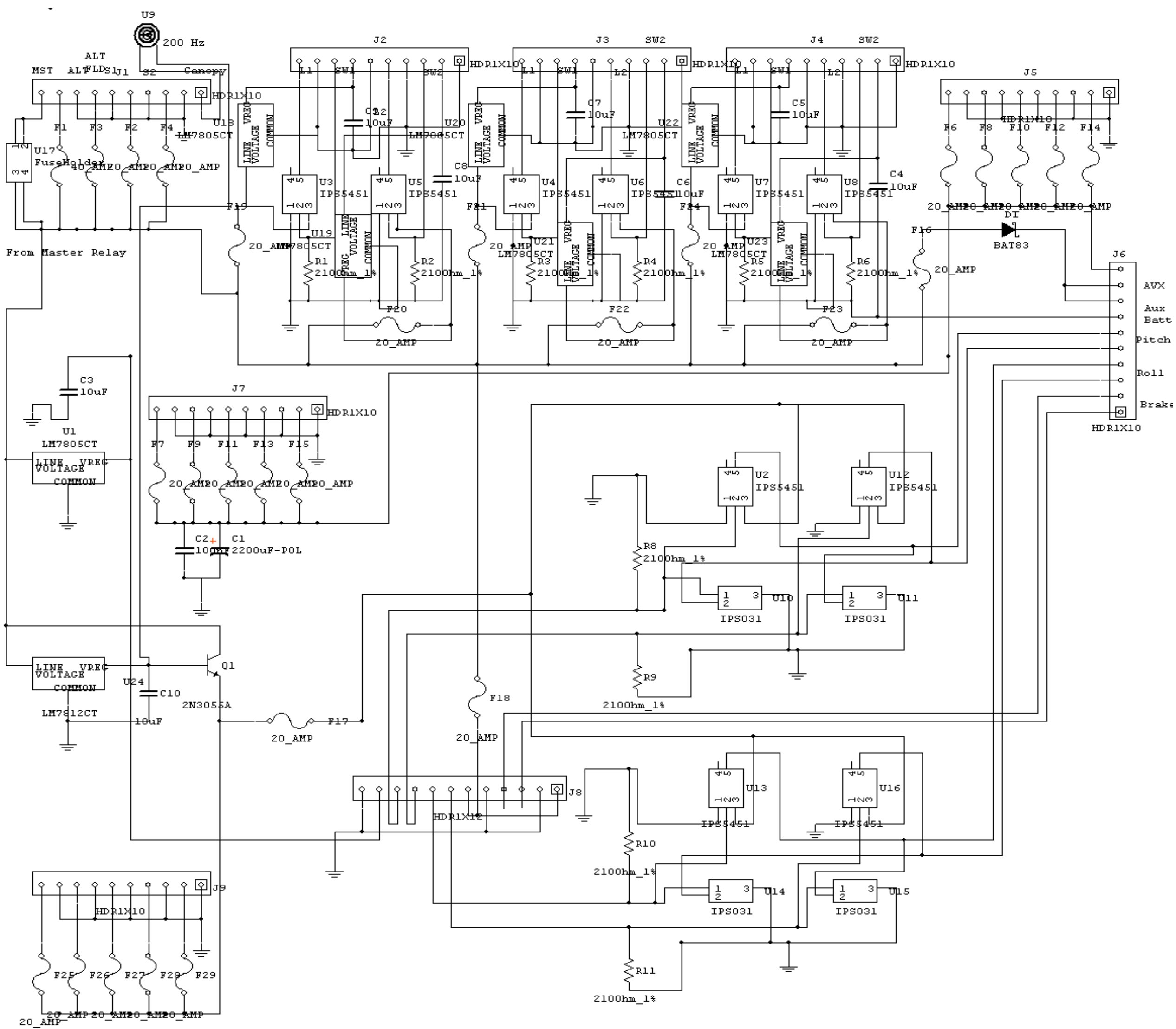
Warning System

A pair of terminals is available on the first block for the Sonalert buzzer. You can run these to a switch, and when closed the Sonalert will beep intermittently until the switch is opened. This is great for canopy warning, gear warning, or whatever you need most.

That's all there is to it. Connect up the Master switch, place a breaker for your Alternator and everything else goes to the board. Saves a *lot* of time, and ground loops just don't happen. If you want to use the board, just drop me an email and I can either send you the board artwork to make your own, or a completed circuit board if that's a better deal.

Power Board Schematic

For reference, here's the schematic. Engineers will note the extensive use of PTCs and internally protected devices. I have assumed that eventually, almost anything will be crossed up with everything, and have tried to make the board as smoke-proof as practical.



Okay, deep breath . . .

The etched circuit board power distribution products have bubbled up from time to time over the last 15 years. Several flavors are still around. I discussed the EXP-bus in several postings on my website. See:

http://www.aeroelectric.com/articles/expbusad.html

http://www.aeroelectric.com/articles/expbusthd.html

EXP-bus discussions were my first attempt to introduce concepts of system design where (a) architecture, (b) parts count, (c) costs to acquire, (d) install, and (d) maintain the system are traded off with perceived convenience for installing any particular collection of parts into a finished system.

In the case of products like EXP-bus and the board described in this document, there are also issues of parts selection and fabrication techniques. For example, in photos of the power distribution board I see electronic components standing off the board supported by their own solid copper leads. I would never attempt to sell this fabrication technique to a customer. Those parts are at-risk for breaking off the board. This technique will not pass DO-160 recommendations for resistance to vibration. The terminal strip selected for off-board wiring does not provide gas-tight connections. Further, I try to avoid threaded fasteners where ever practical.

The etched circuit board featured in this article is offered to make the system "simpler". An inspection of the schematic suggests otherwise. If one studies the component count and number of connections for circuits serviced by the board assembly and compare it with a Bussman fuseblock, a row of switches, and a single point ground block, I'll suggest that the later installation wins the race hands-down. Further, there are no components in danger of shaking off boards, no labor to assemble said board, and no risk for extra ordinary time or skills to trouble shoot, procure replacement components and time to replace them.

Finally, the architecture using this technique is fixed. This "standard" suggests that there is no value in considering the array of options described in Appendix Z of the 'Connection and making the system do what you want to do. Instead, it's suggested that accept this cookie-cutter approach to configuration of an airplane in which you've invested thousands in time and dollars.

Where To Get Parts, Tools, Etc.

Digikey, at http://digikey.com has got everything you need in one place. Allied Electronics is also good at http://alliedelec.com , as is Mouser. Digikey has a great search feature on the Website that will really help you find things like "soldering iron" and show you a list and pictures without having to know the part numbers.

In summation: I cannot recommend this document as a guide for the neophyte builder. Much of the advise is specious . . . it has the appearance of solidarity with attractive industry practices but fails critical review. Proposed design philosophies offer no options for supporting a builder's unique requirements.

Your humble scribe and others have considered PTC circuit protectors at both RAC and Learjet for certified ships at least twice over the last 20 years. There were simply too many downsides that could not be offset by what is purported to be a "convenience".

It's not my intention to hold Mr. Richter to standards I'm not willing to embrace myself. If anyone discovers errors of perception or fact in what I've offered here please let me know.

Robert L. Nuckolls, III
bob.nuckolls@cox.net