

Top 10 Aircraft Wiring Mistakes

(and how to avoid them)

Over the last several years we've helped hundreds of builders plan, install and troubleshoot the electrical system on their aircraft. Through all of that we've found there are several common mistakes that people make – it's only natural as people venture into new areas.

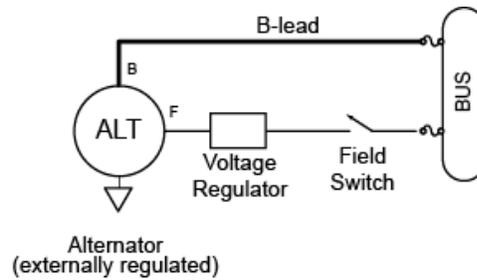
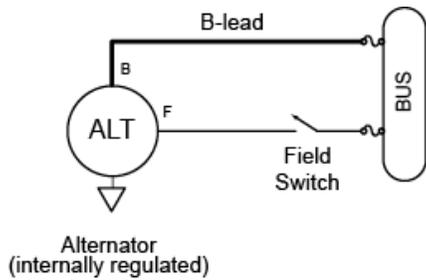
We've written this document to help you avoid those mistakes. These pointers apply equally to traditional wiring as well as aircraft wired using a Vertical Power system.

10. Not learning how the alternator works

There are several aspects of alternator operation that are often overlooked yet important to the proper wiring and operation of the aircraft. They are:

Alternator capacity. An alternator rated at 60 amps means that it should be able to put out 60 amps to support a 60 amp load from the avionics, lights, and other devices on the aircraft. That does not mean it always puts out 60 amps. It only puts out power equivalent to that being drawn by the devices on the aircraft. For example, the avionics might only draw 12 amps and the voltage regulator adjusts accordingly so that the alternator only puts out 12 amps. When you turn on a 6 amp landing light the voltage regulator adjusts and enables the alternator to put out 18 amps. It's also important to note that the alternator both recharges a low battery and keeps a full battery "topped off." For planning purposes, it's a good rule of thumb to derate the alternator capacity by 20% and assume that value is the maximum output. For example, 20% of 60 amps is 12 amps, so assume the alternator will handle 48 amps gracefully.

Field wire and voltage regulator. An alternator must have a voltage regulator to operate correctly. The voltage regulator continuously monitors the bus voltage and adjusts the output of the alternator. The regulator is powered from a bus through a wire called the field wire (hence the alternator field switch on your panel). It is called the field wire because it carries the power which generates an electrical field in the alternator causing power to be generated. This power goes out from the "B-lead" and to the main aircraft electrical bus. The current draw on the field wire increases as the electrical load of the aircraft increases, and is typically in the 2 to 4 amp range. Some alternators are internally regulated (the regulator is built in), and others have an external regulator (a separate box located outside the alternator).



B-lead. The B-lead is the big wire (typically a 6 or 8 gauge wire) that runs from the alternator to the bus. It carries the power generated by the alternator to the bus, which then distributes it to the individual devices and to the battery. An electrical bus (alternatively spelled "buss") is a common electrical connection between multiple electrical devices. It can be a solid piece of copper or wires connected together.

Operating voltage. Today's experimental aircraft are powered by either 14 volt or 28 volts systems. Often you may hear 12 volt or 24 volt systems. Why the difference? The reason is because the batteries are rated at either 12 or 24 volts. When the engine is running and the alternator is turned on, the alternator generates 14 volts or 28 volts, slightly higher than the battery voltage so it keeps the battery charged.

An overvoltage condition is caused by a failure of the voltage regulator which causes the alternator to generate voltage exceeding 16 volts (or 32 volts in a 28 volt system). An OV protection system typically shorts the field circuit to ground causing the breaker to pop and thereby collapsing the field in the alternator itself. This method is called a "crowbar" system. The breaker pops because of the short circuit, not because of the overvoltage itself (breakers pop based on current, not voltage).

Indicator of alternator failure. If the voltage is around 14 volts then the alternator is working normally. If the bus voltage falls to about 12 volts then the alternator is failing to operate correctly. It really is that simple. The failure could be due to:

- Loose alternator belt or mount
- Loose wire (the connector on the field wire at the alternator is a common culprit)
- Failed voltage regulator
- More current draw on the alternator than it can provide, which means the electrical system has been poorly designed or you're trying to charge a dead battery
- Failed field breaker or B-lead fuse
- Overvoltage condition caused the field breaker to pop (on systems with OV protection).
- A bad battery could be pulling the bus voltage down
- Alternator field switch is off

Two alternator operation. If you have a primary alternator and a secondary (backup) alternator, only one alternator should be powered on (in other words, only one field wire is powered) at a time. If both are on simultaneously, they do not equally “contribute” to powering the loads. The one whose voltage regulator is set to the highest voltage provides all the current (sometimes called current hogging), possibly overloading the alternator. If you do have two alternators installed, be sure to use a switch that only allows one to be on at a time. The exception is a dual-independent bus architecture where each alternator is on its own bus and both alternators run simultaneously.

Alternator output can vary with RPM, notably the SD-8 or -20 backup alternators mounted on the vacuum pad. You may not get full voltage at idle RPM.

9. Not using proper techniques

Today’s aircraft depend heavily on the electrical system, so correct wiring techniques are important for safety and on-going reliability. If you’re not sure how to crimp a wire, get some terminals and wire and practice. They’re relatively inexpensive. Carefully read the instructions that come with the crimp tool. It’s easy to be lulled into thinking that a crimper is pretty simple to use – and it is once you know the right technique. Vertical Power offers a free crimp tool instruction guide on its web site (under Documents). If you’re not comfortable soldering, find a friend who can help you practice. Learn how to work with shielded wire and coax wire. Coax can be tricky and cause problems down the road if not done correctly. Experimental aviation is about learning – use this opportunity to do so. Here are some good reference documents:

- FAA Advisory Circular AC 43.13, *Acceptable Methods, Techniques, and Practices - Aircraft Inspection and Repair* available from www.faa.gov
- Connector manual http://verticalpower.com/docs/Connector_Service_Manual.pdf
- Aeroelectric Connection book, available from www.aeroelectric.com
- EAA “Hints for Homebuilders” videos on the EAA web site <http://www.eaa.org/video/homebuilders.html>

8. Poor crimp connections

Each crimp connection is a possible failure point. Follow the basics and you should be OK:

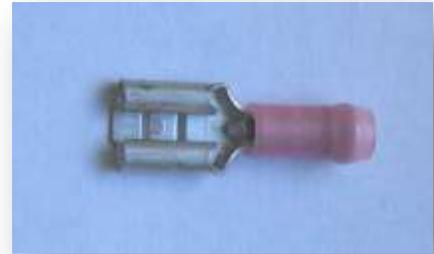
Size the crimp terminal for the wire size. Better quality terminals have a stamp that shows the recommended wire size. Insulated terminals are also color coded based on wire size (Yellow=10/12 AWG, Blue=14/16, Red=18/20/22).

Use the correct crimp tool. Many of the better crimp tools require the terminal to be installed one way only. Crimping in the wrong direction may look ok, but the integrity of the crimp is compromised. Further, use the right crimp tool for that specific terminal.

Use a good quality terminal. For insulated terminals, use the nylon (semi-transparent) insulation and not the vinyl (opaque) insulation.

Give each crimp a good tug. Verify it is properly crimped and visually inspect the crimp.

Surprisingly, even terminals that pass an informal pull test can fail in the future, so go back and tug on the connections if a certain circuit is problematic in the future.



Use the right terminal. Crimp terminals are designed to be used with a specific connector housing. For example, there are standard and high density d-sub pins. The high density pins will fit in the standard connector housing, but not quite exactly right. They also require different crimp tools.

7. Falling into the “single point of failure” trap

For some reason, there appears to be lots of lore about making sure you don't have any single points of failure in your wiring system or even the whole aircraft. This statement is simply too broad and imprecise to act as a guideline for planning your aircraft systems.

There are many single points of failure in aircraft today because it is impractical or unnecessary to add backups. Conversely, backups should be used where absolutely necessary. There is always a tradeoff which usually adds complexity, weight, or reduces overall system reliability. Redundancy should be chosen carefully.

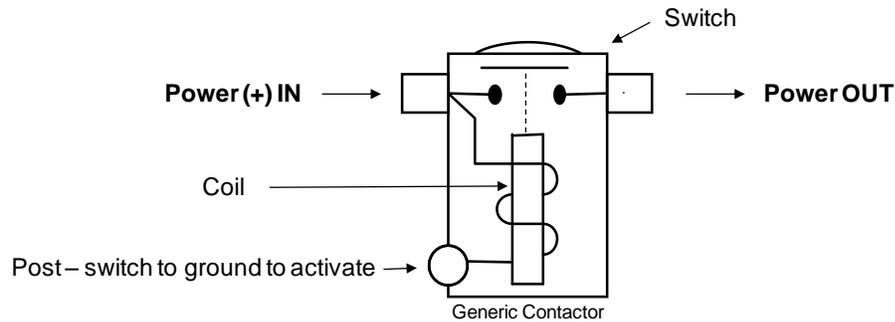
As part of your electrical system planning (and other systems too) you should consider what happens if any single component fails. Does it cause a catastrophic failure or is it simply an inconvenience? What is the likelihood of failure? A lot of decisions depend on the intended mission of your aircraft. A failure of the EFIS, for example, has very different consequences for an IFR aircraft versus a pancake run airplane. Build the plane that's right for you.

"Simplify and Add Lightness." - Ed Heinemann

6. Not learning how contactors work and differences between them

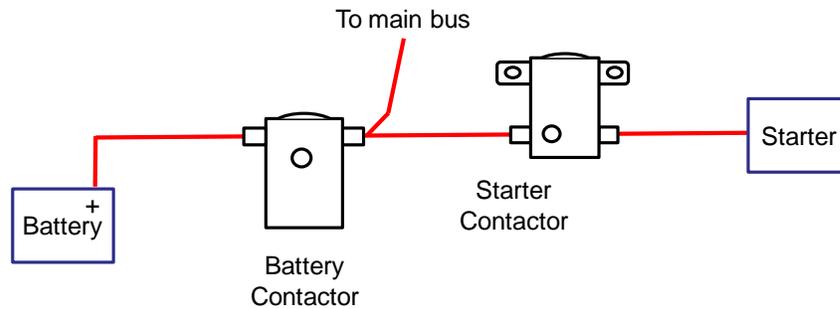
Contactors are used to switch high-current loads on the aircraft. Think of them as a big relay. A coil, when energized, creates a magnetic field and pulls the mechanical switch

closed. The coil only draws a little bit of current but allows you to switch very high-current loads like the starter. Below is a diagram showing a generic contactor:



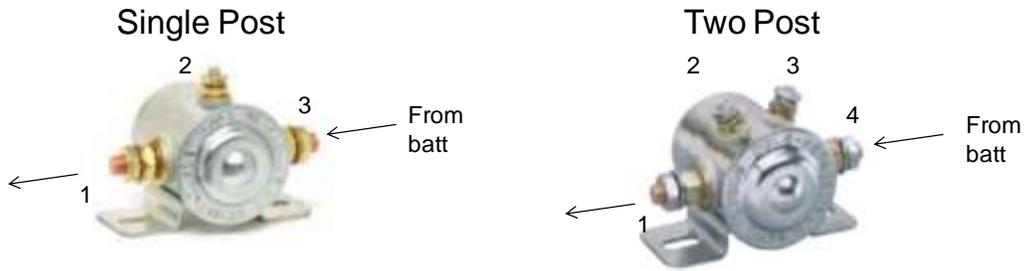
The master contactor is used to isolate the battery from the rest of the aircraft. Shutting it off (via the master switch) generally removes power from the aircraft and cockpit in case of an emergency.

The diagram below shows how the contactors are wired in a typical electrical system.



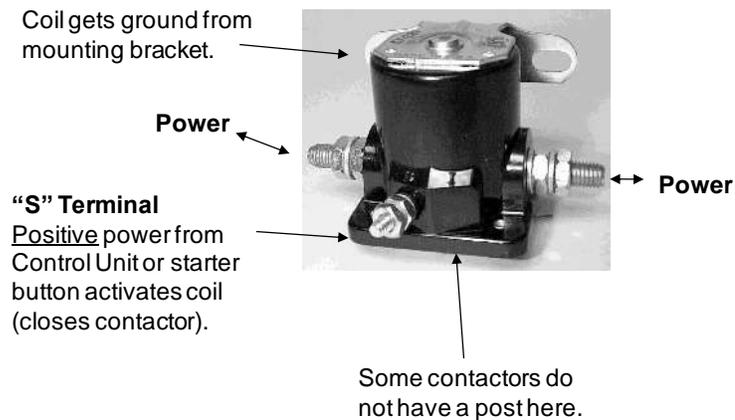
There are two types of contactors generally used in experimental aircraft. One is a continuous duty contactor (usually on) and the other is an intermittent duty contactor (only on for a few seconds at a time). Vertical Power provides an in-depth look at contactors here http://verticalpower.com/docs/Contactor_Wiring.pdf

The battery contactor (aka master relay, master contactor, master solenoid) is a continuous duty contactor and it does become quite warm during normal operations. It comes with either one or two posts for the coil. It typically draws about 0.7 amps at 14 volts. This contactor is switched with a wire that comes from the master switch in the cockpit. The master switch is wired to GROUND. When you turn on the master switch, the wire to the battery contactor becomes grounded and then the contactor closes which then provides power to the bus and starter contactor. This is different than the starter contactor which is engaged with a +12v (or +24v) wire.



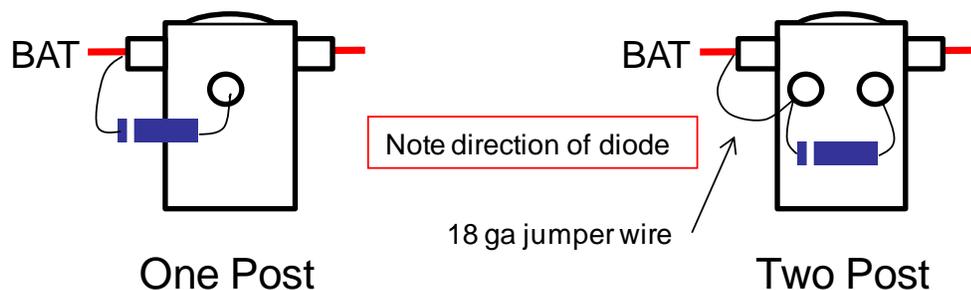
The starter contactor (aka starter relay) is an intermittent duty relay meaning it is designed to be turned on only for short periods of time. This contactor draws about 4A at 14v. You'll notice from the diagram below that the contactor coil is grounded via the bracket on the back of the contactor. Therefore, the starter coil is energized when +12v is applied to the small post (coil).

Below is a diagram showing a typical starter contactor:



The starter contactor and master contactor are designed to be activated in different ways for safety reasons.

Based on experiences we've seen in the field, we recommend installing a diode across the coil on each contactor used in the aircraft (master, starter, landing gear, air conditioning, etc.). You can use a common 1N5400 diode available from any electronics supply house.



Battery Contactor Diode Installation

5. Using the wrong tools

It's common to think a Molex crimp tool, for example, can crimp the pins for any Molex connector (or even an AMP or other connector). Molex, AMP, and others make hundreds of different types of connectors, and each connector has a specific crimp tool. Be sure you know which crimp tool goes with each type of connector.

We recommend using a double-crimp die for insulated crimp terminals. One crimp crimps the electrical connection and the other crimps the insulation. Each crimp is slightly different, and the terminal must be inserted only one way.

Here is an example of a double-crimp die and crimp tool:



Get the right tools for stripping and assembling coax connections. Here are some good sources for coax instructions:

- <http://www.terminaltown.com/Pages/Page2.html>
- <http://www.extron.com/download/files/userman/cabtermkit-man.pdf>
- <http://www.aeroelectric.com/articles/bnccrimp.pdf>

D-sub pins, which are very common on aircraft, come in several varieties. Note the difference - each has a unique crimp tool. We recommend the machined-barrel pin.



Machined-Barrel Pin



Crimp Pin

Finally, the big cables (0 through 8 gauge) typically use non-insulated ring terminals. You can insulate the big terminals with heat shrink tubing after crimping. Do not crimp these with pliers or Vice-Grips. There are special tools available to properly crimp these cables. The crimper indent on the terminal is formed on the side opposite the brazed seam.

Here a link to a good document on crimping Mate-n-Lok connectors:

<http://www.matronics.com/aeroelectric/articles/matenlok/matenlok.html>

Good wire strippers are important too. Bad ones can compromise the wire itself with nicking or cutting. We recommend the Stripmaster or similar (available in various sizes for different gauges of wire – you’ll probably need two) as shown below:



4. Using the wrong gauge wire or incorrect circuit breaker

Circuit breakers (and fuses) protect the wiring, not the device. If the breaker is too large, the wire or insulation may overheat and fail. If too small, the breaker may trip inadvertently.

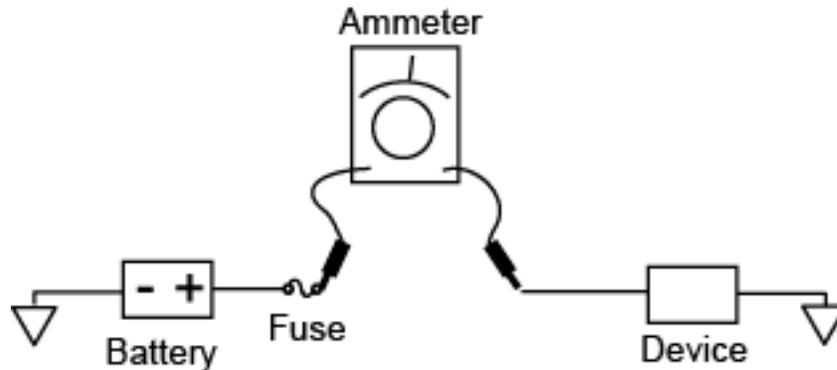
It can't hurt to use wire that is too big, but it can be bad to use wire that is too small. Wire that is too small:

- gets hot and may lead to insulation failure, and
- causes excessive voltage to drop along the length of the wire.

In larger aircraft you may need to calculate voltage drop along the length of the wire to determine the correct wire size. However, our aircraft are small enough that the following table provides an easy reference:

Up to (amps)	Use wire size (AWG)
5A	20
10A	18
18A	14
Data signal	22

If you're not sure, err on the side of using a larger wire. The weight impact is negligible (18 gauge tefzel wire weighs 0.00789 lbs per foot, for example). Most kit aircraft companies and avionics companies provide recommendations for sizing wires and breakers. If not, you can use an ammeter (typically under \$50 at Radio Shack, etc.) to measure the current draw of each electrical device and then determine the size yourself. Wire an ammeter in series to measure current, as shown in the diagram below:



Connect the ammeter in series between the battery and the load.

3. Not paying attention to power vs. ground leads

Connecting wires to the battery backwards can cause avionics and other equipment to fail (accompanied by popping sounds and smoke). This can be easy to do if you install the battery backwards or don't label the wires. To minimize this risk in the future, use color coded heat shrink (black for negative and red for positive) on the wire terminals. If possible, shorten the wires so that they cannot be connected if the battery is installed backwards.

Important: Disconnect the battery ground cable first, then the positive cable. When re-connecting, connect the positive cable first then the ground cable. Doing so ensures you won't spark the positive connection to the airframe (and burn a hole in the firewall).

The battery(ies) in the aircraft should not be connected until the wiring is installed and each circuit is individually tested. Do not run wires while the battery is connected. Of course this is not a hard and fast rule, but simply a way to help avoid those dumb unintentional mistakes that we all make.

2. Trivializing grounds

It's not uncommon to think that the power, or positive, wire is the most important wire to provide electricity. The electrical ground is just as important, as electricity must flow the entire path from the power source to the device and back to the source. The ground wire

must be the same wire gauge or a larger diameter (smaller gauge number) as the wire that provides power to the device.

A ground loop occurs when electricity takes two different paths, and each path has a different resistance. Ground loops are most noticeable in aircraft audio equipment and can produce a variety of problems, most notably unwanted noise.

Grounding is as much of an art as it is a science. With that in mind, several options for grounding your system are provided below. Choose the one that best fits your needs. Keep in mind that more wiring means more weight (although likely negligible). Also, note that in all the examples below the avionics grounds are kept together.

Option 1: Run a ground wire from each and every electrical device back to a common grounding point, typically a ground bus (or terminal farm) on the firewall.

Option 2: Run ground wires from all the avionics to an intermediate grounding point, then run a larger wire from the local ground bus to the firewall ground. Run wires from all the other devices to the firewall ground.

Option 3: Run the ground wires from the avionics to the firewall ground, and run the other ground wires to a local ground (a metal part of the airframe located near the device). Typically lights and pitot heat can be grounded locally.

Audio grounds are also important to plan carefully. The ground on audio lines (typically called audio LO) is different than the chassis ground (note: we're talking about the lines between the audio panel and the headset jack, not the ground wire for the audio panel itself). Most systems isolate this ground to minimize external noise. If you tie the audio ground to the chassis ground you are likely introducing noise into the headset. Be sure to use fiber washers or other means to isolate the headset jacks from the chassis.

The engine grounding strap plays an important role in today's electric, glass-panel aircraft. If this comes loose, the starter, alternator, and some of the engine sensors cannot operate. Consider installing two independent engine ground straps.

Magneto grounding. The magneto should be grounded back to itself via the shielding. This is the best way to ensure a reliable ground.

Shielding. Follow the manufacturer's instructions for shielding. Avoid grounding the shield at both ends when the shield goes between the engine and the airframe.

1. Not planning ahead

It's fun to jump right in and do some wiring, but the time you spend up front planning will more than pay for itself later. Once you have the drawings completed, here's what you'll use them for:

- Making cutouts in the bulkheads, ribs, etc.
- Create a shopping list for wires, terminals, etc.
- Installing wires and components
- Labeling wires
- Configuring avionics (where did that signal com from again?)
- Ongoing maintenance and troubleshooting
- Future modifications and upgrades to the aircraft (yes, you will add the latest new gizmo that comes out three years from now).

Here are some things you can do to plan ahead:

1. Determine the mission and intended use of your aircraft. It's very tempting to overbuild your aircraft just because you can. But you may end up with something that doesn't match your needs once you start using it. Having a clear idea of the aircraft's mission drives many decisions that affect weight and complexity (and cost!) of the aircraft.
2. Make an inventory of all the electrical equipment on the aircraft. Even if you're not sure exactly which EFIS or which nav light you want, this forces you to look at each product in detail and determine if it's right for you. Determine the circuit breaker value and wire gauge to be used. Determine the switch or bus to which it is wired.
3. Determine the current draw of each electrical device. Calculate the total current draw of all the electrical devices, which you can then use to size the main bus wires and alternator. You can ignore flaps and trim from the total as they only run briefly and don't draw much current. Use 3 amps as a proxy for the alternator field. If the manufacturer does not list current draw (which is common), call them or measure it on the bench with an ammeter. We digress a bit, but we recommend calling the manufacturer if you have any questions. Information on web forums can be spotty.
4. Draw a diagram showing the location of everything in the aircraft. Using multiple diagrams makes it easier. You can have a diagram for lights, another for avionics, and another for antennas, for example. It doesn't need to be fancy - draw it by hand or use PowerPoint.
5. Draw a diagram showing the major wire and cable runs throughout the fuselage, firewall, and wings. You'd be surprised how many holes you're going to have to drill,

and it's much easier to drill and de-bur those holes when the fuselage and wings are open.

6. Lay out the switches on your panel, then go through a complete flight and the emergency procedures until you're comfortable with the layout. Make sure the switches are rated for the load they are planned to carry (it's a good idea to de-rate the switches by a healthy amount, perhaps 30%-50%). Including the stick switches.
7. Draw a wiring diagram showing each wire and where each end of the wire is connected. This includes diagrams for connectors on the avionics and also your own connectors like wing-fuselage connectors, for example. It's not a bad idea to provision a few extra circuits for future changes. To keep it manageable, you can put different systems on separate sheets of paper. Include labels on each wire as well. A simple way to make wire labels is to print them in small type on a printer, cut them out, then wrap around the wire and cover with clear heat shrink.

Once your drawings are done, wire the aircraft and update the drawings as you go along and inevitably make changes. Even if your wiring is perfect, make as-built drawings so you can modify and maintain the aircraft later!!! When you wire the plane or need to change something in the future, or troubleshoot a problem years from now these documents will be invaluable.