Direct Current and Wiring Fundamentals

Every discipline has its own spoken and written language. Carpenters speak of "cripples, jacks and studs" while illustrating their tasks with familiar shapes that describe something as yet to be. Hydraulics designers use words like "pilot valve, cylinder, and bleeder" described on paper with yet another set of symbols. We promise not to try to make you an engineer but there are a few rudimentary analytic tools and language that will help you navigate this new terrain. If you already have a working knowledge of Ohm's Law, how to calculate power consumption and read schematics and wiring diagrams, then proceed directly to Chapter 2 If you do not possess these skills, spend some time with us in this chapter and we'll tell you about it:

The Story of Electron Behavior

A long time ago, in a galaxy not very far away there were four gentlemen named Volta, Ohm, Ampere and Watt. They aren't around any more but they left us with some tools that help us predict the behavior of some very tiny critters known as electrons. Nobody has ever seen one but we know where they are because they can be made to do some amazing and otherwise difficult tasks.

The Force Behind the Flow

The first behavior trait is described in terms proposed by Mr. Volta. The Volt is a unit of measure that represents the PRESSURE behind a source of electrons; its generic name is "electromotive force". The Volt has been given attributes much like pressure exerted on a liquid or a gas. For example, you can have an air bottle filled to 100 PSI of air. The PSI value represents a potential for doing work. The air could be used to run a rivet gun or drill motor. If the bottle's valve is closed, there is no movement of the air in spite of the pressure and no work is being done. In the electrical world, a 12-volt battery has twice the 'pressure' behind its stored electrons as a 6-volt battery. Until you connect wires to the battery and route the energy to some location to do work then the potential energy contained in the battery stays there waiting to be used.

Voltage is measured as a difference in electromotive force between two points. Voltmeters come with probes on two test leads and you touch the probes to two points simultaneously to measure the voltage between them.

The Flow

The next trait is measured in Amps, a unit that represents a RATE like jelly beans per day, miles per hour, and the like. An ammeter is a device that is hooked in series with a conductor supplying an electrical device with power. The term 'in series' means that you literally break the wire and insert the ammeter in the gap. In this way it can detect and display the number of electrons per second that pass through on their way to do work. If we made a comparison in the compressed air bottle analogy we would need to place a gauge in the air line to measure molecules per second of air flow.

A flow of electrons (amps) together with pressure (volts) will do work. They start engines, light lamps, spin gyro motors, run radios and do all manner of nifty tasks.

Tight Places Along the Way

Unfortunately, there is no way to move the electrons from their source (such as an alternator or a battery) to the location where they are to do work without losing some of their energy along the way. If you hooked one mile of air hose to the 100 PSI air bottle, you would be disappointed at

Ohm's Law in algebraic terms:

(1) VOLTS (FORCE) = AMPS (FLOW) X OHMS (RESISTANCE)

(2) $$\text{OHMS} = \frac{\text{VOLTS}}{\text{AMPS}}$$

(3) $$\text{AMPS} = \frac{\text{VOLTS}}{\text{OHMS}}$$

Figure 1-1 Ohm's Law - Three Variations on a Theme

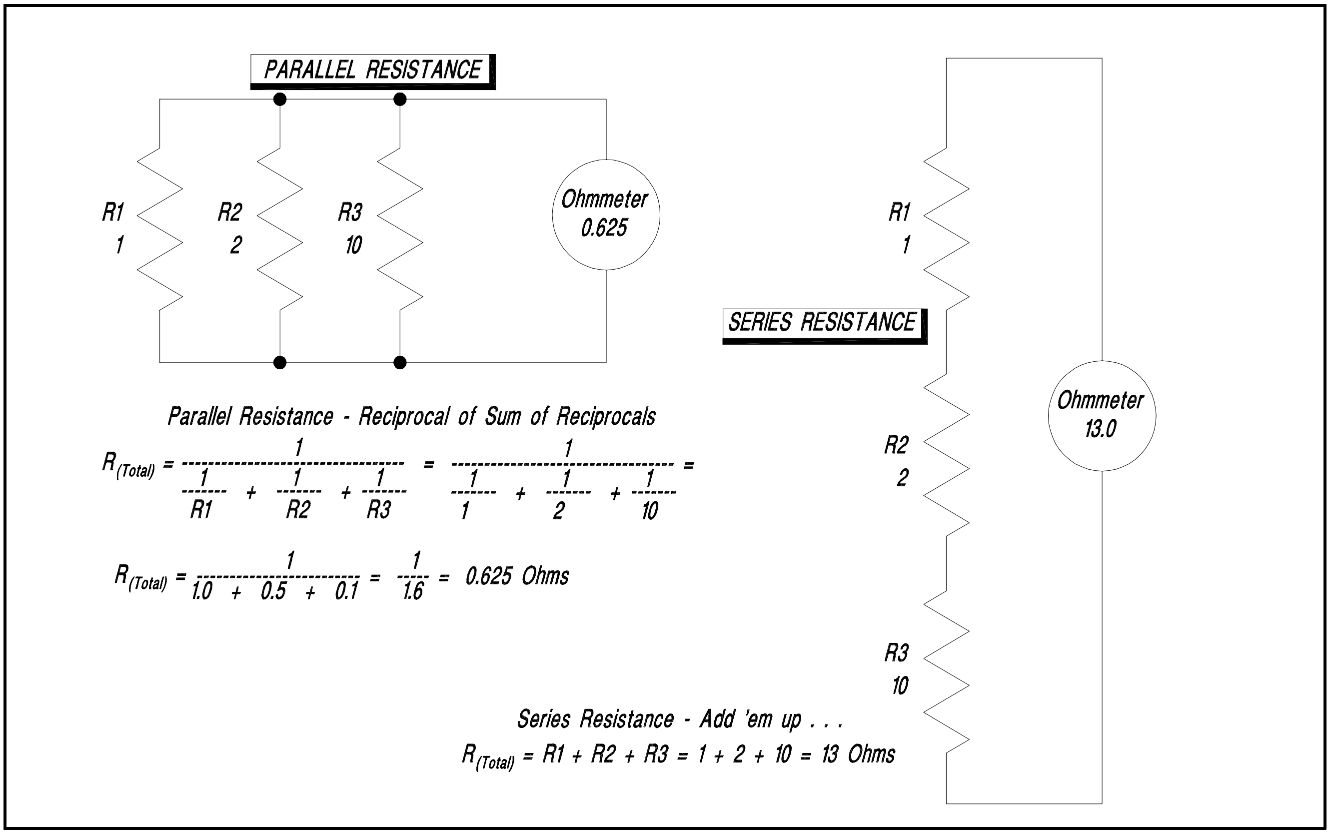


Figure 1-2. Series and Parallel Resistance Calculation

how little energy the air contained when it got to the other end. Something similar happens when electrons flow through a wire. The wire's ability to carry electrons is limited by its resistance, a sort of electrical friction.

The name for this characteristic is the Ohm. Ohms represent nothing but a potential for wasting energy. They are of little practical use in an airplane electrical system but they're always there. You can minimize them, make peace with and endure a certain number of them, but you cannot make them all go away. In order to talk about ohms and understand their effects, Mr. Ohm wrote a law. He said that if you pass one amp (electrons per second) of current through a conductor having a resistance of one ohm, you will experience a drop of one volt (pressure). If the flow is increased to two amps, then drop is two volts, etc. This gives rise to this mathematical model in Figure 1-1.

Resistance Combinations

When resistances to current flow are connected in series they are simply added to obtain of total resistance. Series means that they are connected end to end in a string. Parallel connection means that the resistors are connected up laying side by side like cordwood. Paralleling resistors is a little different. If all the resistors are equal, then the net total is equal to the value of one resistor divided by the number of resistors. For example, five 10-ohm resistors in parallel net a total of 2 ohms. If the resistors are not equal, then you need to get your calculator out and apply the following rule:

"The parallel value of any number of resistors is equal to the reciprocal of the sum of the reciprocals of each resistor." In Figure 1-2 I've illustrated a parallel combination of 1-ohm, 2-ohm and 10-ohm resistors that produces a resistance of 0.625 ohms for the combination.

When resistors are connected in series, the same current flows in each and the sum of the voltage drops across each resistor equals the total voltage applied to the string. When resistors are paralleled, the same voltage is impressed across each resistor. The sums of the current flowing in each resistor is equal to the total for the combination. These principles will be used throughout this publication to aid in selecting wire sizes, predicting performance of various equipment items and understanding the limitations of other items.

Energy Rate - The Watt

Now we can introduce the last gentleman of the quartet I mentioned before, Mr. Watt. He described a unit of energy rate (now named after him) as being proportional to the product of pressure and flow. The mathematical model for this and two corollaries are given in Figure 1-3..

Rules for calculating power:

$$(4)\quad WATTS = AMPS \times VOLTS$$

$$(5)\quad WATTS = \frac{VOLTS^2}{OHMS}$$

$$(6)\quad WATTS = AMPS^2 \times OHMS$$

Figure 1-3. Mathematical Identities for Calculating Watts.

Suppose you found a landing light bulb marked "150 Watts" on its face. It may or may not be marked for its rated operating voltage but in 14-volt systems (12-volt batteries) the design point for many large lamps is 13.0 volts. Later on in this publication there will be a section on wiring where you will find a wire table that says a 16 gauge wire has a resistance of .004 ohms per foot. Not much but significant. Let's suppose that your airplane is a composite structure and that the landing light is out on a wing tip. You need to run two lengths of wire, a source and a return line for the electron flow since there is no metal airframe to provide the second path. Suppose that the total run of wire in the schematic is 24 feet times .004 ohms/foot yields a total loop wiring resistance of .096 ohms.

To figure the voltage drop in the wiring, we must first deduce the amount of current required by the lamp. Applying formula (4) above we can say the following:

150 Watts = Amps x 13.0 Volts

Transposing we can say:

Amps = 150 Watts ÷ 13.0 Volts

and Amps = 11.54

If the total resistance of the wire is 0.088 ohms then we can apply formula (1) from Figure 1-1 as follows:

Volts = 11.54 Amps x .096 Ohms

and Volts = 1.1

This hypothetical is illustrated in Figure 1-4. The schematics don't show an alternator charging the battery but let's assume there is one so that the voltage at the battery terminals is 13.8 Volts. We have calculated a drop in the wires of 1.1 volts. Figure 1-4 shows 0.5 volts dropped along the ground path, and 0.6 volts dropped in the other (the switch adds a tad more resistance to the circuit). The lamp is being supplied with 13.8 - 1.1 = 12.7 volts. Not much below the rated 13.0 volts.

In working this example we have uncovered techniques used by manufacturers of electrical components to make your selection and application easier. Most heavy current devices are designed and rated for some voltage less than the nominal system voltage. In this case, a 13.0 volt rated lamp might be used in a 13.8 volt system and a 26 volt rated lamp would be used in a 27.6 volt system. The parts are

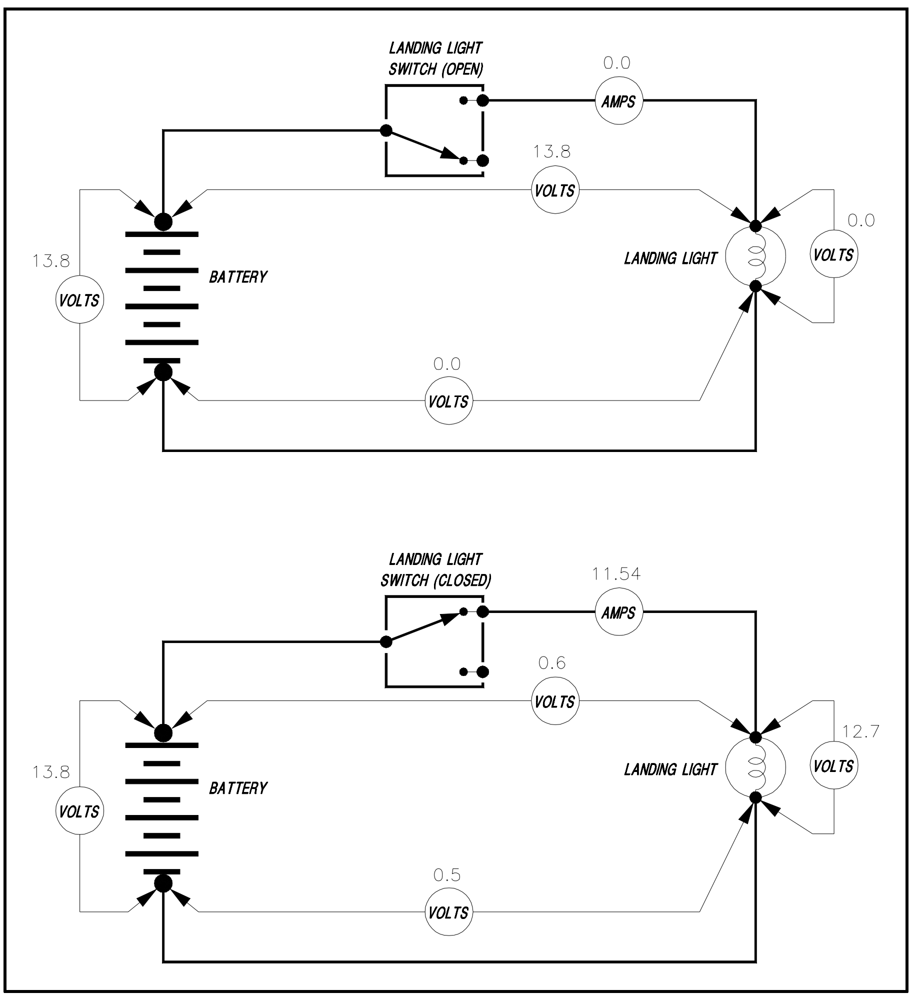


Figure 1-4 Current and Voltage in a Simple Landing Light Circuit

designed with the knowledge that it is not practical to supply power to the product with wire so large as to have insignificant resistance. We must compromise and selected wire that is reasonable in size and wastes a tolerable amount of power. How much power? Applying formula (4):

Watts = 11.54 Amps x 1.1 Volts

and Watts = 11.78

Not too bad considering; 150 watts of energy DOES get to the lamp's filament! But you can see there is a compromise that says an 8% or so loss of power IS acceptable.

Open the switch and the path is broken. No flow (amps) can occur. The voltage is still there as a potential for keeping the lamp's filament hot but you cannot stuff electrons into one end of a device without having some place for them to go out the other end. Figure 1-5 shows what the voltage readings would be when the lamp is off.

Wirebook and Schematic Symbols

WIRES: We've already used some symbols to described an electrical circuit for purposes of explaining how the units of electrical measurement are related to each other. Let's start with those devices and work up.

The most rudimentary component for herding electrons is a wire or other conductor used to covey electrons from one place to another. This symbol is a line. Like road maps for cars, conductor maps for electrons may embellish the line with variations in width, style or color. There are no hard conventions or rules for variations on a theme of diagraming a wire or any other component. If you compare the wiring diagram for a European automobile with a similar diagram for an American or Japanese product, you'll see some striking differences in presentation philosophy and some minor variations in how the same kinds of components are portrayed. By-and-large, these variations are simple variations of "linguistics" akin to the use of "pancake, flapjack or griddlecake" being used to describe the same item of food.

The style I've developed for the AeroElectric Connection is a blend of my experiences in electronics and aircraft power distribution. In 40 years I've worked with many styles of schematic and wiring diagrams. Some features (in my not so humble opinion) detracted from ready understanding of meaning. Other features were not esthetically pleasing. However, like mathematics, wiring diagrams and schematics have a degree of commonality that crosses all barriers of spoken language.

Because the 'Connection is not yet printed in color, variations in our schematic representations for wire will be limited to weight of the line combined with some label that will convey additional information about the wire's size, color and position in the system. For example, if you see a wire label like this:

-----20AWG- -----

You may deduce that this conductor is a size 20 American Wire Gage conductor. You can assign no additional meaning to this label. In many cases, this is all that's needed. Suppose you see this:

------- RED22 ------

Here we'll suggest that the wire is 22 gage in size and red in color. This is about as far as we need to go for labeling wires in our relatively rudimentary drawings.

Wiring diagrams

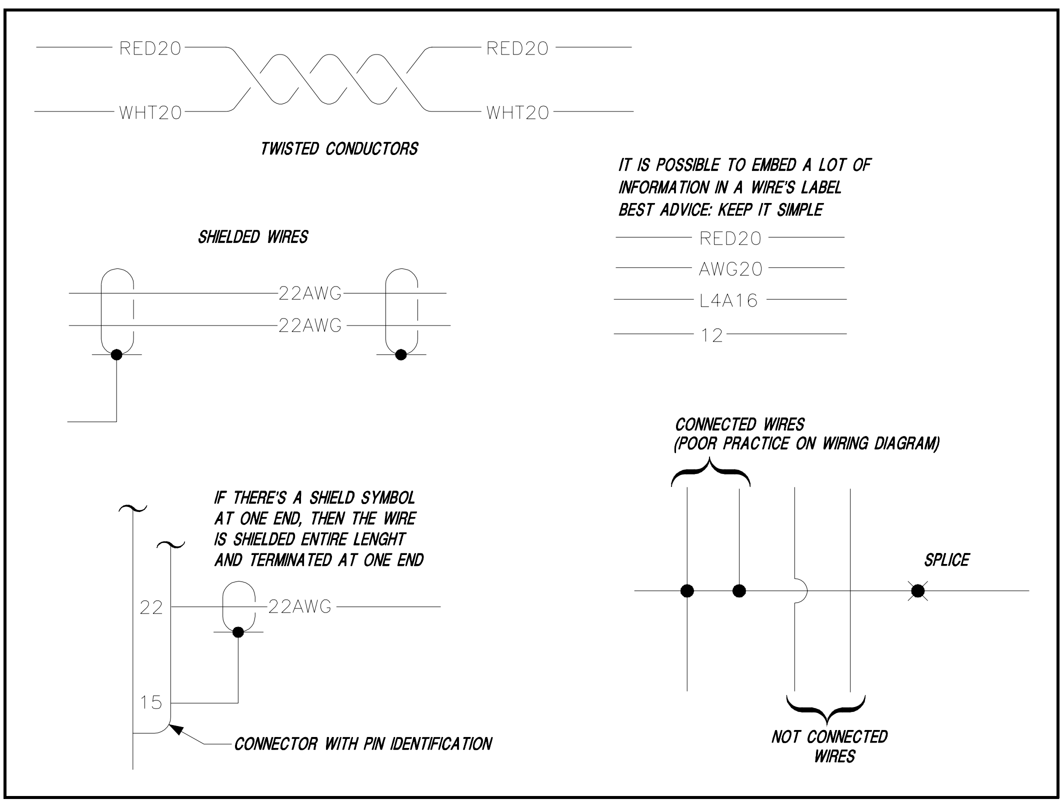


Figure 1-5. Wire and Wiring Symbols

provided for other people's products may use more elaborate system for wire labeling. For example. Suppose you see a label wire label in a wirebook that looks like this:

----- L4A16------

In many airplanes this label is also repeated on the wire itself by means of hot-stamping or other means; usually about every 6" along the entire length of the wire. The wire marking operation is accomplished on special machines that measure, mark and coil every conductor in the airplane as if it were a separate part number.

With verbose wire marking systems, the wirebook should include a key for decoding the system's labeling conventions. For example, if I found this label on a wire an a B-52, my first pass at decoding it would suggest that "L" means some kind of lighting circuit. The "4" would mean it's the 4th lighting circuit of perhaps several more. The "A" means it's the first segment in that circuit. Segment A might run from circuit breaker to switch. Segment B would go from switch to perhaps some connector at the wing root. Segment C would continue on out to a light fixture. The digits "16" would suggest this circuit is wired with 16AWG material.

Obviously, this kind of wire coding scheme can be used to convey a lot of meaning about the wire and its function - valuable information when dealing with complex systems on complex airplanes with fat wire bundles.

I don't recommend that the owner-built-and-maintained (OBAM) airplane project be extended to include such effort. First, the relative simplicity of our airplanes will not benefit much from being able to tell which wire in a bundle of dozen or so wires is used to power a landing light vis-a-vis the nav lights. Second, it takes TIME to design, document and fabricate this kind of detail in your project's drawings. Unless you plan to build the ultimate show aircraft where one may gain points for crafting and implementing an articulate wirebook, this kind of detail is a waste of time.

However, if you're designing a new Sky Thrasher 2000 with a goal of manufacturing kits and pre-fabricated wire bundles, then your project's documentation will have to be more comprehensive with a bill of materials that includes the actual length of each wire segment. This is the only case where I could justify spending much effort on a complex wire labeling system.

If you want to label your wires for easing future maintenance efforts, a simple numbering of a wire segment will suffice. The 4AWG wire from battery contactor to starter contactor might have the number "1" depicted at each end of the segment. Similarly, the next segment from starter contactor to starter might be "2" . . . or any OTHER number unique to that segment. The same number would be used to label that segment on your wiring diagram where you might call them "1-4" and "2-4" meaning segments 1 and 2 fabricated from 4AWG wire. I wouldn't bother to put the wire gage callout on the wire itself as most wire suited for aircraft is already labeled as to its size.

It's not even necessary or useful to use EVERY number in sequence. For example: my first drawing might be the landing light circuit wherein perhaps 4 wire segments are used to hook up the system. I might used the numbers 10-14 to label these wires. For the next system, I might use 20-26. This leaves some open spaces between system so that if you change anything later and need to add a segment, there are open numbers next to the original numbers that can be used to identify the new wires.

This gives rise to the possibility of assigning groups of wires to various systems. For example, labels 1-19 might be reserved for DC power generation and distribution. 20-29 for the starter system. 30-39 for landing light, 40-49 for nav lights, etc. This way, you can know which system a particular wire belongs to by observing the group in which its label resides. This scheme generally leaves handy gaps in the numbering so that any later additions to the system have unused numbers reserved within that grouping.

In some of wiring diagrams, I may use "fat" lines on drawing to depict the major power distribution pathways which are generally 2 to 8AWG conductors. I won't go beyond this simple convention for explaining how a system is fabricated.

When I hook wires up on paper, I try to convey as much meaning as possible and avoid ambiguous symbology. For example, wires that cross each other in a diagram may have a "hump" in one wire to show that they do not connect. It's okay to leave the hump off and assume that they do not connect unless there is a "dot" at the intersection. I never use a mid strand intersection without being very specific as to how the wires are joined. I use a specific symbol for a splice that tells you that it's my intent that the wires be simply joined in mid span between major components. Unless a mid-span splice is intended and planned, wires on our diagrams will always come together at a location conducive to implementing the connection. I.e, the stud of a contactor or the wire grip of a terminal. The act of tying two wires together mid-span with a simple dot is used on a schematic . . . a kind drawing intended to convey functionality without specifics as to the mechanics of implementing fabrication.

There are a few special cases for wiring symbology. Sometimes, the designer would like for you to twist the wires together. The most common reason to twist wires is to minimize their susceptibility to magnetically coupled noise (more on this in the chapter on noise). Sometimes it's done simply to custom fabricate a pair of wires that work together in some system. Whatever the case, my favorite way to depict a twisted pair is shown in the adjacent figure. Another special case is shielding. When you see the little "race track" surrounding one or more wires, this tells you that they are shielded. The most common shielding techniques use either an overbraid of fine bare wires or an overwrap of thin aluminum foil. The overbraid is made from tinned copper wire. It's easy to make an electrical connection with overbraid shields.

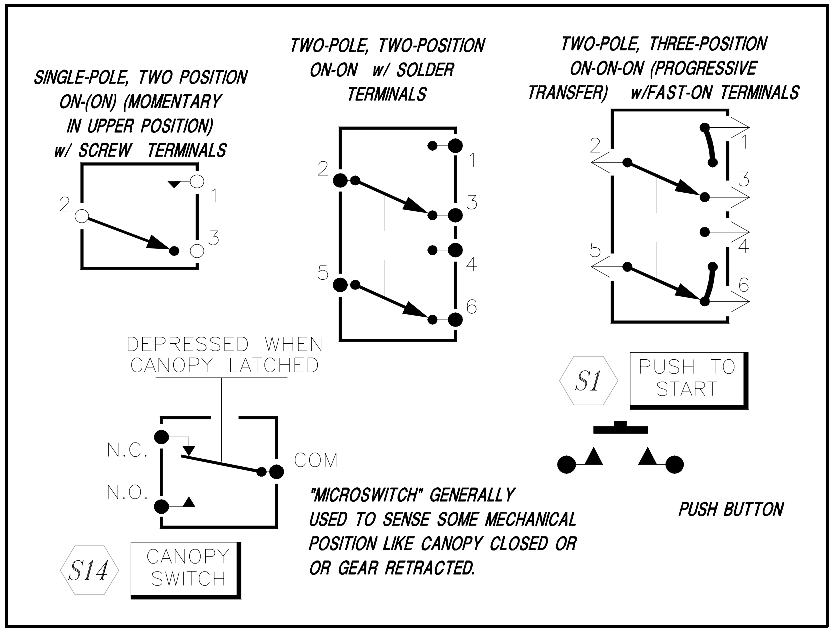


Figure 1-7. Switches and Pushbuttons

Foil shields cannot be soldered to. Manufacturers who produce this wire will include a bare "drain wire" in the compliment of insulated wires to be shielded. The drain wire makes connection with the inside surface of the aluminum foil shield over its entire length. Being made up tinned copper conductors, the drain wire offers a means for efficient electrical connection to the shield.

The symbol for shielding is the same irrespective of the material from which it is made. The designer should show you exactly how the shield is to be treated at BOTH ends. In some cases, both ends are connected but not always. If you see a shielded wire symbol on one end of a wire segment, it means the entire length of that segment is shielded whether or not the other end has a shield symbol. Obviously, if the designer intends that both ends of the shield are connected to something, the symbol will appear at both ends along with a depiction of where the shield is terminated at each end.

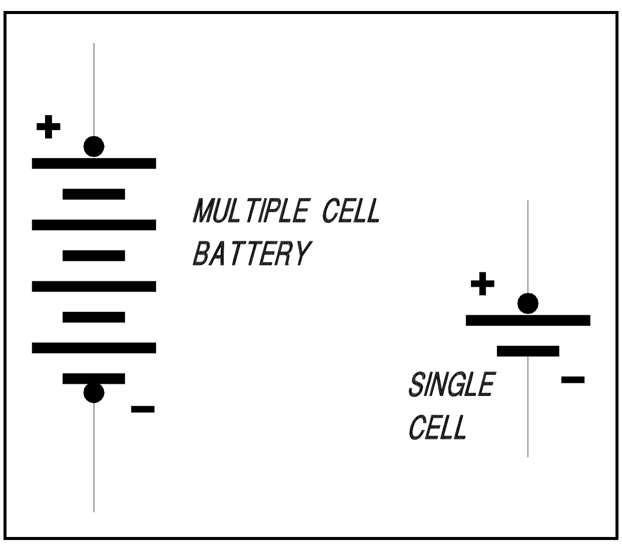


Figure 1-6. Cells and Batteries

BATTERIES: The symbol for a "cell" is depicted as a long and short line where the most common convention is to assign (+) terminal of a cell to the longer of the two lines. A "battery" is a collection of two or more cells. Some folks try to be accurate in their depiction of battery symbols by including the same number of cells in the symbol as for the battery called out in the drawing. I don't bother with that so the battery symbol you see here will be used consistently irrespective of the number of cells and the operating voltage of the battery.

SWITCHES: The symbols for switches are pretty good physical representations of switch operation. There are detailed examples of the various switches that appear in our drawings in the chapter on switches later on in this volume. A convention used by many designers and used throughout this book uses a triangular contact to denote a momentary contact while a circular contact is a sustained switch position.

Some designers will include additional information about the mode of attaching wires to their switches . . . an open circle denotes screw terminal and a solid dot is a solder joint. The –>>– symbol on the wire denotes some form of pin and socket connection. I'm really sold on the reliability and convenience of the push-on spade or "Fast-On" tabs and terminals. The same symbol is show on one of the switch depictions where Fast-Ons are featured. Detailed depictions of solder, screw, or pin-socket connections may not be consistently called out on our drawings for various products.

The intent of this discussion is to make you aware of the variety of connection technologies and how they may be depicted on a wiring diagram. You should take advantage

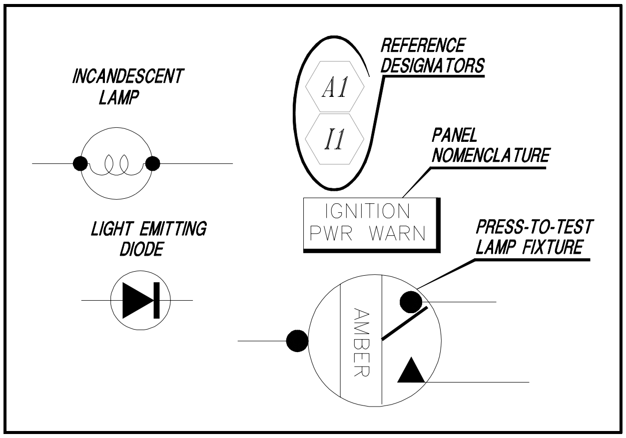


Figure 1-8. Various Lamp Symbols - plus examples of supporting data included in many of our drawings.

of this symbology to put as much meaning into the drawings you produce for your project.
Switches come in a variety of styles and functional capabilities. These devices are discussed in more detail later in this book. It's relatively easy to depict functionality in the device's wiring symbol and it's no sin to craft or revise a symbol in a way that clarifies meaning. For example, I first encountered progressive transfer, two-pole, on-on-on switches at Cessna about 1965. I was editing a service manual for an ARC autopilot. The engineering drawings provided to me drew a two-pole, progressive transfer switch looked just like an ordinary two-pole, three position, on-off-on switch.

There was a written note on the drawing that tried to explain the special functionality of this switch. I decided it would be helpful to craft a modified symbol exactly like that shown in figure 1-7. My boss about had a cow . . . NOT because he disagreed with value of added understanding offered by the "new" symbol . . . but because I had the temerity to ADD a word to a language described in great detail in "approved"military specification design language dictionaries.

LAMPS: The symbol for an incandescent lamp is another one of those graphics that nicely depicts the physical reality of an incandescent lamp. The symbol shows an envelope (glass) surrounding a curlicue (filament) inside. The other common light source depicted in our drawings is the light emitting diode (LED) that is shown as a diode inside a circle. If the lamp is to have a specific color, then it's often shown adjacent to or inside the symbol. Another symbol you may encounter in our drawings is for the classic, press-to-test fixture that doesn't even show the lamp but does show how to hook up the three leads from the fixture in order to make the press-to-test feature work.

Additionally, I've illustrated data items commonly found on wiring diagrams. When you choose a particular part or piece of equipment for your project's electrical system, you should build a list of such parts and assign a reference designator to the part. Your list, or bill-of-materials, can be quite verbose in describing the part, its part number, manufacturer, ratings, etc. You don't want to put all that data on the face of a drawing . . . this is where the reference designator comes in. In my drawings, I enclose the designator in a hex box . . . this is not a standard convention, other folk use variations on the theme but they'll be easily recognized for what they are; a label that speaks nothing about the part's ratings or number . . . it's simply a pointer to a more verbose part description in another document.

In this case you see A1 and I1 as reference designators next to the symbol for a press-to-test lamp fixture. If you went to a bill of materials to look for A1, you might find that it's an MS-XXXX fixture. The symbol I1 might take you to a callout for a #330 lamp.

Another feature of my drawings is to add a panel label for the device. Switches and lights may have a shadow-box adjacent to the symbol to display suggested words that might be placarded on the panel to describe the device's function.

The odd-ball among lamps is the light emitting diode or LED. These solid state light emitters are rapidly replacing incandescent lamps in many aircraft illumination applications. The symbol for an LED is the diode with a circle around it.

Finally, if the light emitter is to be assigned a specific color, it's easy to add this to your diagram too. Note the press-to-test fixture is an amber colored device. I might include a small "R" , "G", "A" etc inside the circle of a lamp symbol to call out red, green, amber, etc. colors for that particular device.

RESISTORS: We've already had some discussion about resistance as an impediment to the free flow of electrons which always warms things up and turns otherwise useful electrical energy into wasted heat.

From time to time, there are instances when we WANT to do a little considered "wasting" and there are thousands of varieties of resistors available to do just that. Check the blister-pak racks of any Radio Shack store and you'll find a selection of wired devices ranging from 250 milliwatts of dissipation rating to 10 watts or more. The power rating of the resistor is determined by its ability to reject the heat dissipated in operation without getting so hot that the part self-destructs. As you might well expect, a 10 watt resistor is much larger than a 25 milliwatt device.

Resistors come in a huge range of sizes. The surface mount devices in your cell phone may be only 0.030" by 0.060" and rated for 100 milliwatts of dissipation. The dynamic braking resistors in a diesel-electric locomotive wouldn't fit

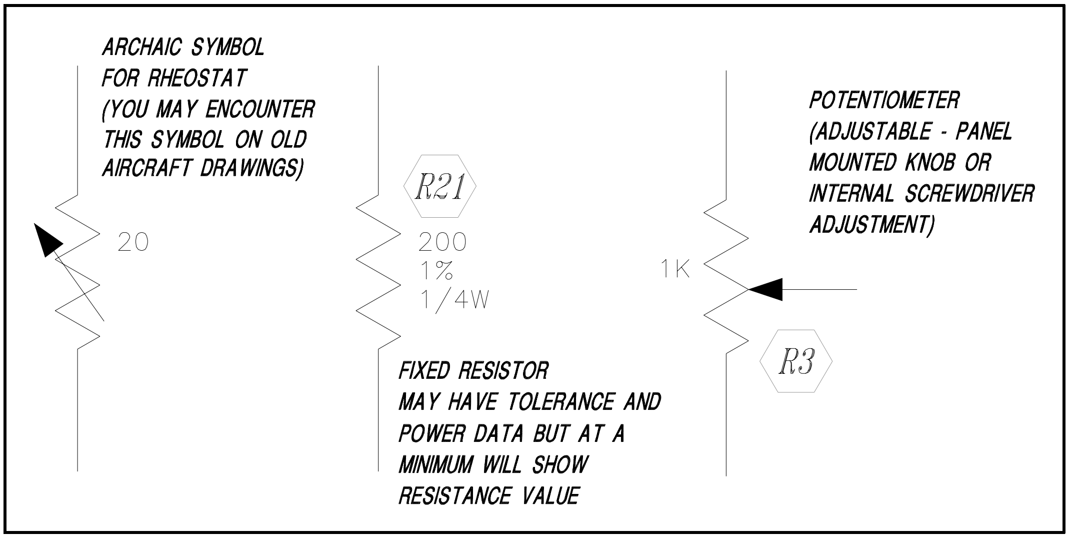


Figure 1-9. Resistor Symbols

into a 35 gallon drum and are designed to turn tens of thousands of watts of electrical energy into heat.

The electrical symbol for all of these devices is the same. You will find this symbol used very seldom on our power distribution diagrams . . . potentiometers are used to dim panel lights and the occasional resistor may show up as a current limiting device to be used in lieu of a fuse in some applications. By-in-large, resistors will show up only as components internal to some appliance like an audio distribution amplifier or other “black box”.

DIODES: Diodes will appear in most of our drawings for two purposes. (1) Spike catcher diodes are connected across the coil terminals of some relays and contactors and (2) Power control or steering diodes are used between the main bus and essential bus of our drawings to make up the normal power feed path for the essential bus.

A diode is an electrical check valve. Current will flow through one direction of the diode and not if it’s reversed. Alternators use diodes inside to rectify the AC voltage of the power output windings into DC voltage. A variation of the diode symbol is also used with light emitting diodes as described earlier.

The silicon junction diode is the most mature semiconductor device in your electrical system. Power versions of the device were incorporated into automotive alternators back in the 60's. Compared to their vacuum tube and selenium rectifier ancestors, they ARE a lightyear ahead in terms of efficiency and compactness.

Diodes come in lots of sizes and packages. Surface mounted devices for electronics can be as small as 0.030" in diameter and 0.080" long. These diminutive devices may be rated at a few hundred milliamperes forward conduction current and 50 to 100 reverse volts. Diodes used locomotives can be the size of a gallon bucket, rated for thousands of amperes and have reverse voltage ratings in the killovolts range.

A diode is not a perfect check valve . . . when current flows through the device in the forward (conductive) direction, there is a relatively fixed voltage drop on the order of 0.6 to 0.8 volts. Generally speaking, this has little if any practical effect on system performance but it does mean that the critter gets warm.

For example: a steering diode between the main bus and essential bus insures that the e-bus is powered any time the main bus is up. Assume an e-bus continuous load of 6 amps.

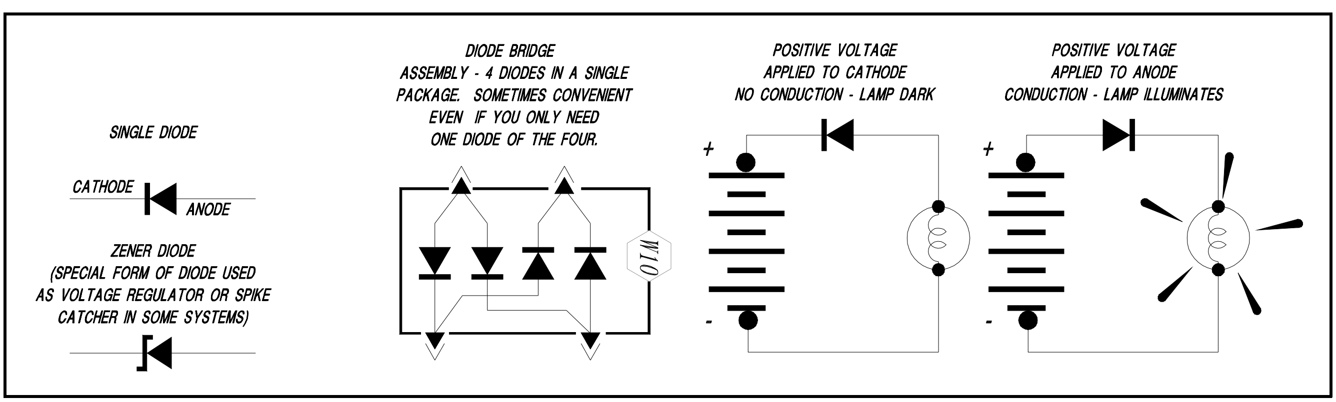


Figure 1-10. Diode Symbols

6 amps times 0.6 volts = 3.6 watts. Not a great deal of power but significant in terms of what a small, lead mounted device can handle without external heat sinking. You can purchase leaded devices good for this kind of current but they're difficult to deal with. Small plastic cylinders with wires coming out each end are intended to be soldered into an etched circuit board.

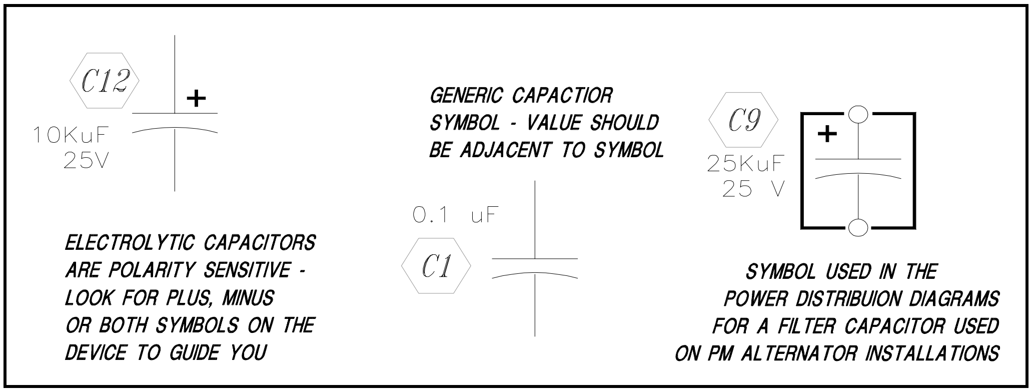
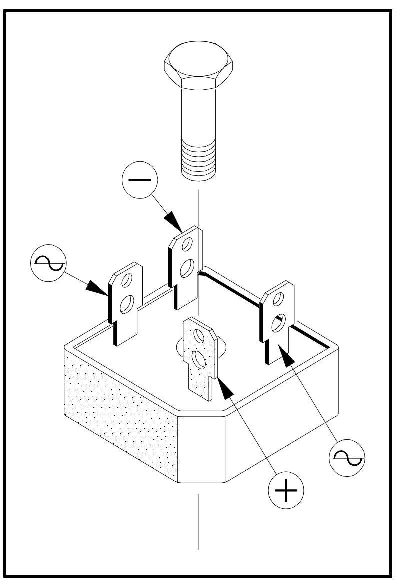


Figure 1-11. Capacitor Symbols

Here's a handy product for dealing with applications requiring a diode to carry more than a few amps. There's a genre of diode assemblies called "bridge rectifiers". A full bridge is assembled from a ring of 4 diodes with terminals brought out for connection into a full-wave rectifier for a DC power supply.

A version of particular interest to us looks like the adjacent view.



It's approximately 1.2" square, 0.4" thick and is fitted with four Fast-On tab terminals. The device mounts to structure with screw through a convenient center hole.

The act of attaching this device to a metal surface provides heat sinking. I recommend this gizmo as a means for installing the aforementioned main-bus to e-bus steering diode. Only one of the four diodes is used (two unused connection tabs can be snipped off). The mounting and interconnection features of this device make it very useful in our airplanes.

If you're looking for this device, most electronics supply stores can provide you a device that LOOKs exactly like this one. This package houses assemblies rated at 25 amps or more and nobody builds a diode with less than a 50 volt rating. So, irrespective of it's part number, any device packaged as shown above is suited as a main-bus to e-bus steering diode or any other task in your airplane that needs a continuous current capability of more than a couple of amps.

Note this package has a chamfered corner. Note further that the terminal adjacent to the chamfered corner is turned 90° to the other three. The "odd" terminal is always the (+) connection to the diode bridge assembly (two cathodes tied together).

CAPACITOR: The capacitor is a device constructed not unlike its symbol suggests. Two conductors or plates separated by an intervening insulator or dielectric material. A couple of pieces of aluminum with a sheet of glass sandwiched between them is an excellent example of a capacitor. This device can store a charge, it can also couple varying or AC voltage variations across the insulator.

Capacitors come rated in Farads (a really big capacitor) or in smaller, more convenient sizes called microfarads (1 millionth of a Farad), nanofarads (1 billionth) and picofarads (1 trillionth). They'll also have a voltage rating that describes the largest voltage to which the capacitor can be charged without arcing over or damaging the insulator between the conductive plates. Physically, they can range in size from the tiny surface mount devices up to bathtub sized devices. Capacitors are also offered in a huge combination of construction methods to best suit the task. The capacitor you will find most often in our drawings is an aluminum electrolytic. It's a plastic covered cylinder 1.3 to 2.5 inches in diameter and 3 to 6 inches long. It will be fitted with two 10-32 threaded connections on one end. The schematic symbol I use for this device is illustrated in figure 1-x and depicts the threaded fastener connections as represented by the open circles in the drawing.

INDUCTOR: The inductor's symbol is intended to convey the notion of many turns of wire - usually wrapped around some core of magnetic material. There are some minor variations on the theme for inductors but they'll be recognized for their similarity to the devices depicted here.

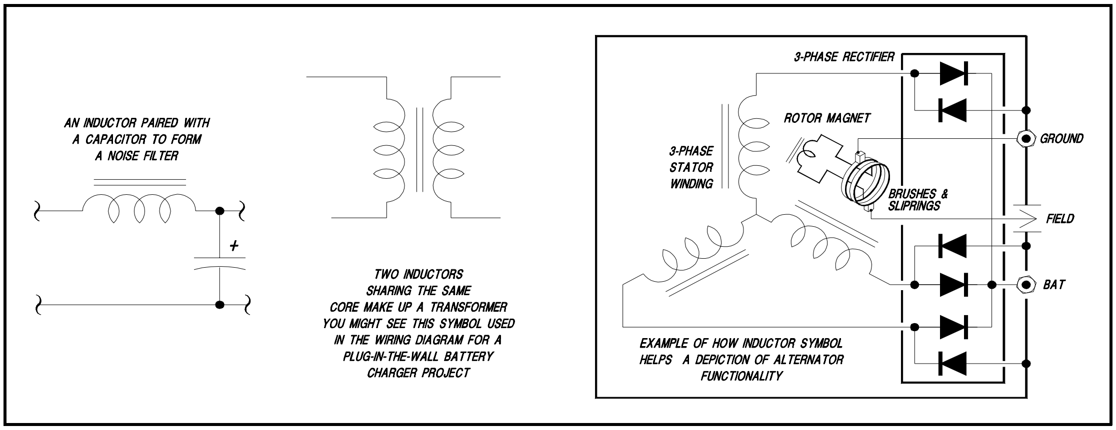


Figure 1-12. Inductor Symbols

You won't find the symbol used very much in this book. Inductors as unique components that you install to accomplish some task are rarely used or needed at the airplane system assembly level.

In the chapter on noise we'll speak to the use of inductors to fabricate noise filters that can reduce or prevent noise from propagating into or out of some part of your electrical system. The places I'll most often use the symbol is in the depiction of internal workings of devices that utilize inductors such as motors and alternators.

FUSES, CIRCUIT BREAKERS AND BUS BARS: I get a lot of questions about "bus bars" and "busses" . the word is used a lot in aviation vernacular but I'm not sure its well understood. The general term "bus" refers to a common connection or distribution mechanism for a variety of power and/or signal connections. For example, our airplanes have data busses . . . a means by which multiple components talk to each other on a common connecting structure. That structure could be a wire, a coax cable, a twisted pair of wires, even a fiber optic link. Bussing things together speaks more to a concept than to a piece of hardware.

Buses discussed in this work are more narrowly confined to discussions about power distribution. We'll speak of battery busses, main busses, essential busses, auxiliary busses and ground busses. In some cases we may have need to fabricate a lighting bus. In each of these cases, the bus is simply a technique by which a number of loads can receive distributed power or a number of ground returns can come to a common point. The bus may be a strip of metal drilled at intervals to accommodate interconnection of a row of circuit breakers. In our favorite fuse blocks, the bus is a part of the purchased device that runs down the center of the fuseblock and provides power distribution for a suite of plastic fuses. The symbology you will find in this work is illustrated in figure 1-13.

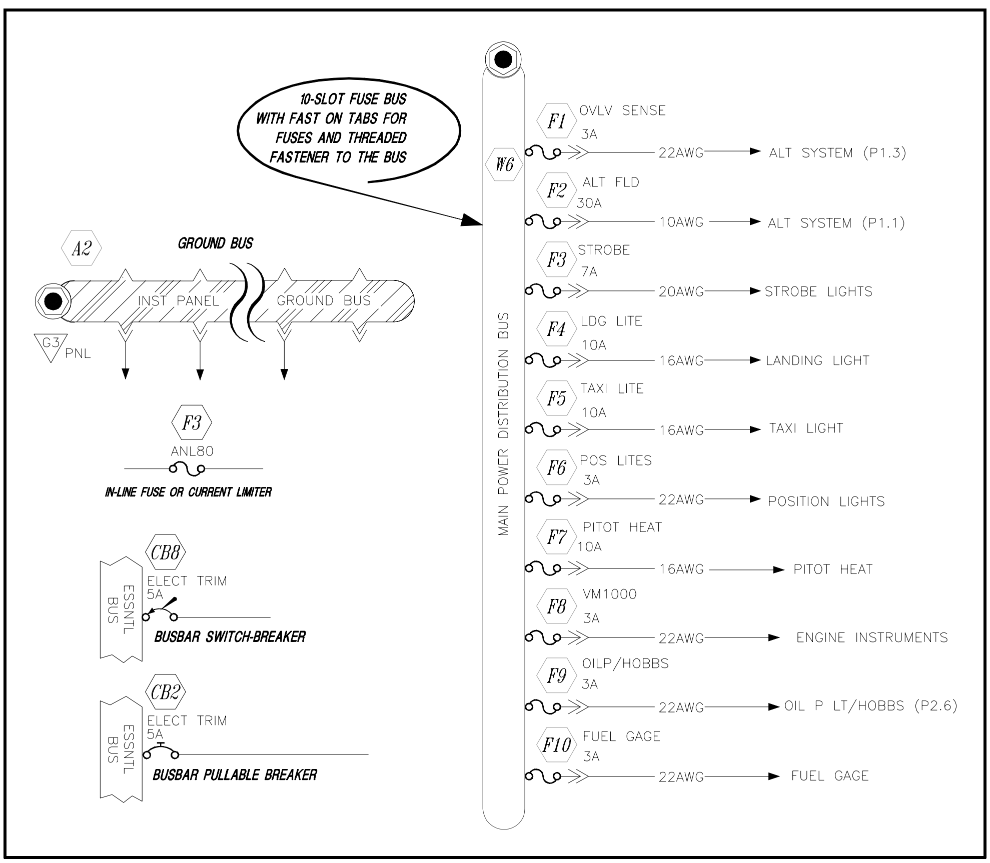


Figure 1-13. Fuses Breakers and Bus Bars

The first thing I do when planning an aircraft's power distribution system is to draw up the busses. Whether distributed to breakers or fuses, it doesn't matter. Every device needing power in the airplane has to pick it off of some protected circuit and that circuit is generally fed by a "bus".

Make a drawing for each bus and list every breaker or fuse attached to it along with the fuse's reference designator, size, function, size of wire attached to it and then some lead-off label that tells you what page the system will be found on. The first pages of your wirebook become the basis for planning a load analysis for your electrical system's various sources. These pages also become an index for the rest of the book - find the breaker that supplies the system of interest and follow the lead-out label to find the page were the system is described.

On each system page, the bus and circuit protector are repeated with just a segment of the bus illustrated. The segment needs to be labeled as to which bus the protection is fed from which leads you back to the "index" page.

This figure also shows a ground bus . . . no breakers or fuses, just a place where the suite of grounds assigned to that bus can be brought to a single location. Later in the book we'll discuss the importance of "single point ground systems".

So, there's nothing magic about a "bus" . . . in early Pipers, the bus was simply a piece of solid copper wire soldered to a row of fuseholders. Any distribution or commoning bus should be built such that no single failure along the bus will disconnect the rest of the loads. For example, I have a bus bar and circuit breaker assembly removed from a "certified" and many times annualed single engine Piper. The "bus" is fabricated from three separate pieces of aluminum strip that runs along the row of screws behind the circuit breaker panel. Loosening of any screw at the joint between the three pieces would cause electrical continuity to the remaining downstream loads to be lost as well. I've also seen builders crimp terminals on a handful of 2-inch wire segments and then daisy-chain them down the row of breakers . . . these multi-piece fabrication techniques negate the purpose of a bus. Insofar as you can, busses should be cut from single pieces of metal. Even in a multi-row breaker panel, you can cut strips of brass or copper to build the bus structure and then solder the strips together where they would otherwise be held together by a threaded fastener.

RELAYS and CONTACTORS: Just about every airplane will have at least two contactors. One for the battery and one for the starter. Contactors (and relays) are remotely controlled switches that operate because you apply power to a coil of wire (see the inductor symbols) which in turn creates a strong magnetic field. Magnets attract magnetic materials and in this case, the magnetic material is mounted on the movable contacts of some form of switch.

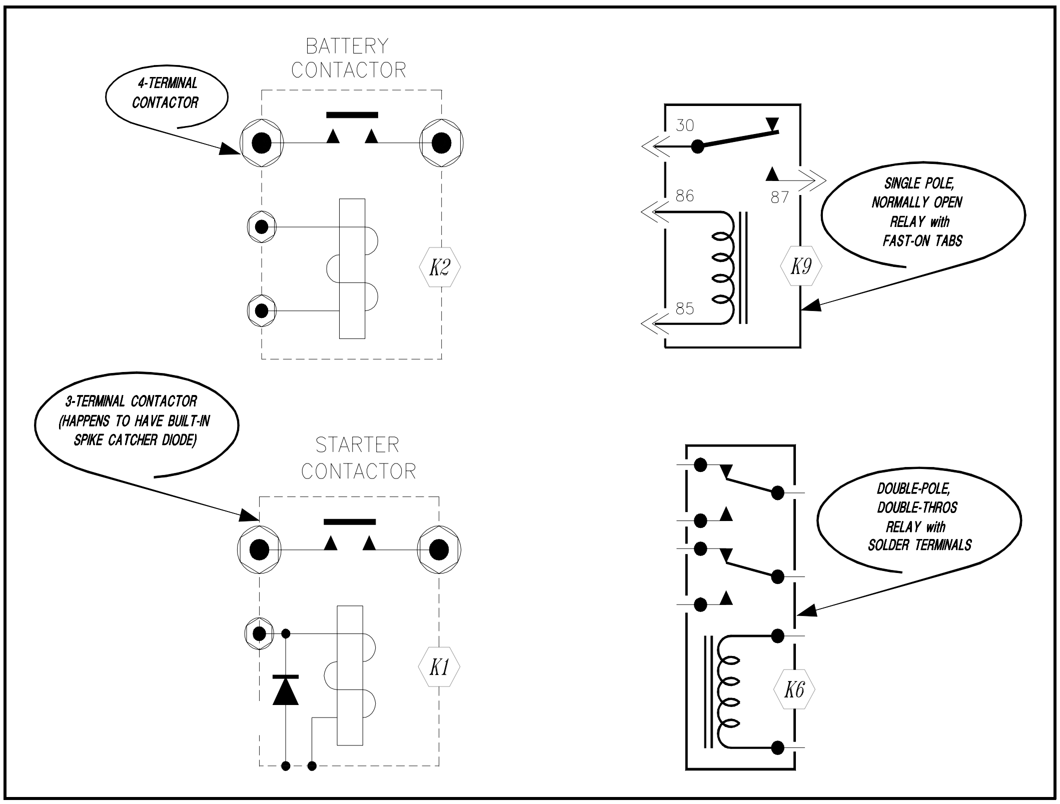


Figure 1-14. Relays and Contactors

The schematic symbols for contactors and relays are strongly suggestive of their construction. Relays are generally smaller and designed to switch currents of up to 30 amps. Contactors are much beefier devices and rated to switch loads of 50 to hundreds of amps and carry loads in the hundreds of amps. You can see how the starter and battery contactor symbols suggest that a magnetized coil of wire pull down on a shorting bar to make electrical

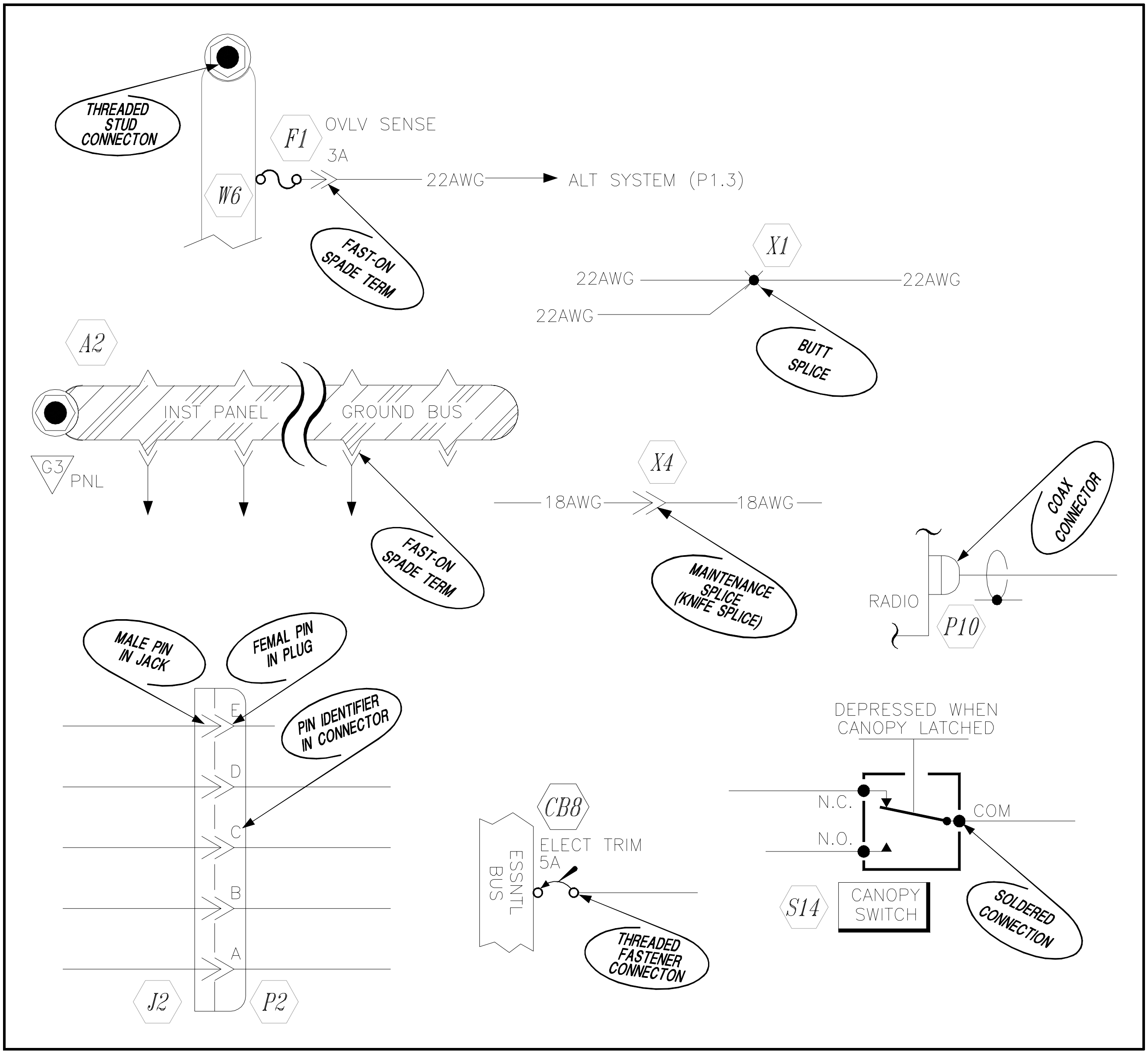


Figure 1-15. Connectors and Connections

connection between two main terminals. Note that the starter contactor symbol shows a built in diode . . . NOT ALL contactors have this feature . . . but if the contactor you've selected includes the spike catcher diode, figure 1-14 suggests how to depict it.

There is nothing unique about the symbol for a contactor to differentiate a continuous duty contactor (for battery, crossfeed and ground power applications) from the intermittent duty devices (used on starters and some landing gear pump installations). This differentiation is described in your reference designator list or bill of materials.

Relays are more like switches in that they are available in multiple poles. If needed, you can easily acquire up to 4 poles of double-throw relay in a compact, single device. Your project may not need any relays but they can be useful in flap and trim motor control systems, over-voltage control implementation on small alternators and pilot-priority microphone selection.

CONNECTORS and CONNECTIONS: As the various wires wend their ways about your airplane, they have to start and stop somewhere and somehow. There are basically two ways to attach wires to things, crimp the buggers with some form of solderless connection or warm up the soldering iron and stick them together.

Wires will terminate either in some device that mounts the wire to a stud, a passageway through a de-mateable connector, or solder to the terminal provided on some device.

Figure 1-15 illustrates a range of connecting technologies and some symbols to help describe them. Note that the –>>– combination of symbols are universally used to depict pin/socket combinations in connectors, Fast-On spade terminations and maintenance joints using knife splices. It's sufficient to indicate that the joint in the wire exists and resolve ambiguities with hands-on observation of the part and/or referring to the bill of materials.

MISCELLANEOUS SYMBOLOGY: Ground symbols depicted in Figure 1-16 labeled in accordance with their optimum locations. Every airplane has three specific locations for instrument, electrical and avionics grounding. G1 is called out as the "engine" which automatically includes alternator, starter and any sensors that find their way to electrical ground by virtue of their mounting.

Permanent magnet motors are most common for trim actuators, flaps or fan motors. The PM motor will reverse its direction of rotation by reversing the two leads that attach to the brushes. There are a few articles of surplus aviation hardware that run a wound field, brush type motor. The motor's field flux is supplied by a wound-field . . . lots of turns of small wire. Both the field and armature (brushes) are supplied with bus voltage to make the motor run. Reversing either the field -OR- the armature supply leads will cause the motor to reverse direction.

Various appliances will be fitted with some kind of connector, screw terminals on a terminal strip. Perhaps you'll have to splice onto pendant wires. It's easy to visualize how one would draw a circle or rectangle, label it as to name or function and then describe the methodology by which wires are taken to and from the device.

It's not uncommon for some publishers to draw accurate pictures of various devices. recognizable as to name or function by observation. I've fielded a few complaints about our drawings from builders who have purchased one or more accessories wherein the installation drawings used "pictorials" to show how wire up the product.

These work well if the device is wired with very few wires but it's time consuming and tedious to develop this type of drawing and adds no more meaning than can be deduced from the simple graphic that concentrates more on wiring details than on the physical appearance of the device be wired.

Most if not all of the devices discussed in this chapter will be covered in more detail in later chapters of this work. This introduction to the language and symbology of aircraft electrical system analysis, design and documentation should assist your travels into this new venture.

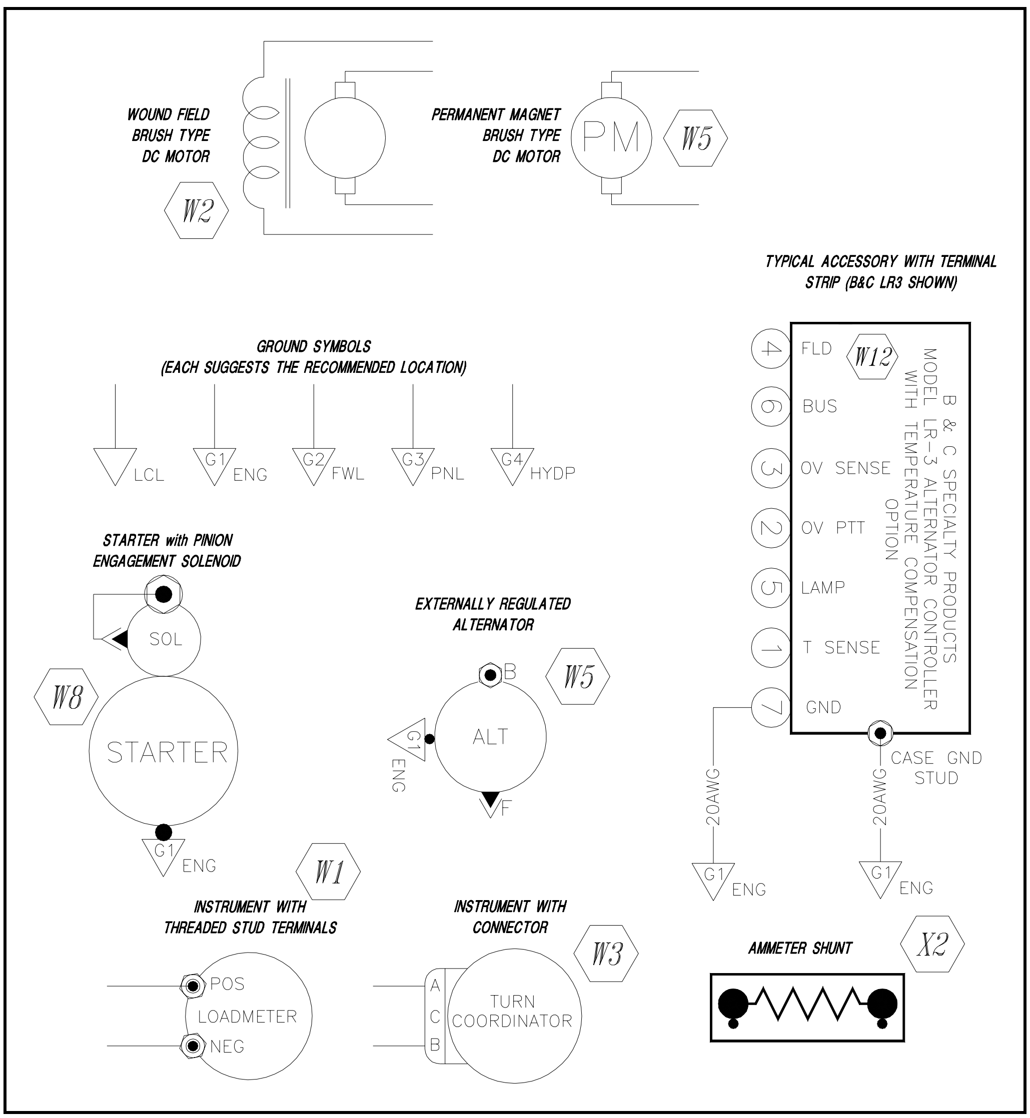


Figure 1-16. Miscellaneous Wiring Symbols