ELECTRICAL 101

Learning basic electrical theory is part and parcel of Jeep ownership and upgrading

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An electrical system can make or break a Jeep, but many people overlook the importance of understanding basic electrical theory and hookup procedures when making upgrades—particularly when upgrading a trail rig. We add lights, winches, compressors and all manner of aftermarket electrical doodads, sometimes without thinking about the big picture. Now there's a recipe for problems.

In this article we will undertake an elementary discussion of electrical theory that will give you the basics you need to work through many common upgrades. We'll start with some simple electrical principles, focus on our vehicle systems, move on to DIY tips and finish with suggestions on where to find common supplies. Here, we will focus on electrical systems from older Jeeps since they are typically simpler and easier to get a handle on. We can apply the same principles to pretty much any vehicle system.

First, let's start with some rudimentary knowledge and a common vocabulary. You'll find it easier to think of electricity in terms of water...

VOLTAGE (electromotive force or E): Voltage is the amount of "pressure" required to make electrons travel through a circuit. Voltage determines how big a pipe you have. You can have a 6-inch pipe with a little trickle in it (we'll come back to this in a moment). This is expressed in volts. Most civilian domestic vehicles run on a 12-volt common ground system. Some exceptions to this rule of thumb are military vehicles, which commonly run on 24 volts, and older VWs, which run on 6 volts.

AMPERAGE (current or I): Amperage is the amount of current, or electrons, flowing through a circuit. A 10-amp circuit has twice as much current flowing as a 5-amp circuit. Think of this as water pressure. You can have a 1-inch pipe with 100 psi of pressure, and it will move more water (electricity) than your 6-inch pipe in the example above with only a couple pounds of pressure behind it. This is expressed in amps.

POWER (reserve): This is usually expressed as P=I*E. Think of this as "how big is your bucket?" Power is generally expressed in amp/hours, or watts. For example, you can maintain 700 amps at 12 volts for X number of hours.

When you are talking about an electrical system in a Jeep, you have three questions to answer:

1. How big of a bucket do I want?

This is how much battery you buy. Dual batteries mean a bigger bucket, so you can drain off more power for a longer period of time before you hit bottom. If you isolate the batteries, you have the option of maintaining a "separate bucket" dedicated to running the engine and other critical systems, while another battery can run add-on auxiliary systems.

2. What are my power needs?

As you consider your power needs, understand that your system needs to have some volume to spare. This means that under normal circumstances and under full load (lights, stereo, heater, etc.), your alternator needs to put out enough energy to run all your goodies AND still charge the system. For example, a stock CJ alternator is about 60 amps. If you figure running the engine takes 10 amps, the heater takes 10 amps, the lights take 20 amps, the radio takes 10 amps... You're already at 50 amps before you even hit the battery with a 400-amp load from the starter or the winch. This means you will be able to replace the charge at only 10 amps per unit of time. In situations where your load exceeds 60 amps, you are running the system at a continual deficit, and it is only a matter of time before your battery is depleted. In other words, dead.

3. How fast do I want to be able to refill the bucket?

This is how much alternator you buy. The bigger the alternator the more overhead you can afford (more lights, bigger stereo, more winch use, etc.). You also can recharge any depletion faster with greater surplus from the alternator.

Now let's consider what "common ground" means. When we look at a battery, there is a positive (+) terminal and a negative (-), or ground, terminal. The ground is hooked to the chassis of the vehicle. With Jeeps, we have distinct groups of components that must be grounded—specifically the tub, the dash, the fenders, the clip, the engine and the frame. Typically, manufacturers designed these to ground by touching via the bolts that hold them together. As vehicles age, corrode, rust or are repainted, grounds become problematic. It is highly advisable to run separate ground straps to each individual group. As grounds become flaky, a whole host of seriously weird problems start cropping up—everything from blown fuses to faulty gauge readings to overheating components.

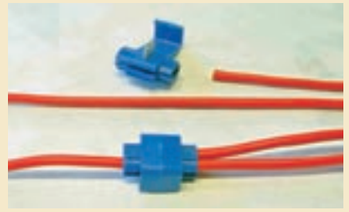
For electricity to flow it must complete a circuit. With most auto systems, we talk about that circuit in terms of flowing from positive to negative. We put the accessory, or "load," between the positive and negative terminals. When we have a line straight from positive to negative (***DO NOT TRY THIS***, but think of cross-connecting one wire to the other), we call that an overload, "short circuit" or just "short." When this happens, electrons flow too fast, and we see the wire heat extremely quickly, to the point of melting the metal. This is dangerous.

To protect our vehicles and ourselves from fires caused by overloaded wiring, we use some form of circuit protection—at the simplest, a fuse (one-time disposable). A circuit breaker works just like a fuse, except it can be reset. Both are designed to shut down the flow of electricity when a circuit is pulling too much power. Another common approach to simple protection in older vehicles is a fusible link, which is essentially a special wire designed to burn out like a fuse (except more slowly) and open the circuit.

As we start looking at heavier loads like starters and headlights, we see another type of protection. Normal switches cannot handle the load for many larger loads, so we add things like relays and solenoids. Simply put, these are both special types of "remote" switches designed to handle heavier loads. Let's look at an example of a common use for each.

When you turn the key on your Jeep (which is a switch), voltage goes down a very small wire to a solenoid. The solenoid "actuates," and a much larger wire delivers a huge surge of electricity to the starter (often in excess of 400 amps). A relay does the

The butt connector is the simplest of the available wire-to-wire connectors. Simply strip away just enough of the wire insulation so the exposed ends of the wires will seat flush inside the connector collar. Use a crimping tool to secure each wire end and you're done. You will find it easier to insert the copper strands into the connector if you first twist them, and then insert the wire as if you were screwing the connector onto it.



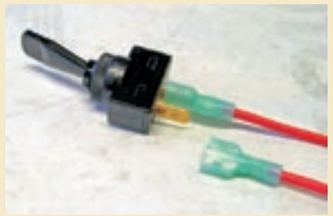
The quick-splice connector is the best way to tap one wire into another, such as when tapping into a power lead. One side of the connector fits over the main wire while the add-on wire fits into the other side (which is blocked off at one end). Once in place, you can use a pair of pliers to push the metal connector bridge over the wires (which cuts into the insulation to make the electrical connection). Lock the security tab in place to finish.

Bullet connectors are often used when wiring an electrical component that you want to install and remove as needed. The bullet end (right) would connect directly to the component, while the receptacle end (left) remains in the vehicle. These are crimped onto the wire ends the same way as the butt connector.

Basic spade connectors perform in much the same way as bullet connectors and feature a flat spade end and a receptacle end. This type of spade connector has limited use, as the connection is in no way shielded, which could lead to short circuits. They could be wrapped or sealed with heat-shrink tubing, but that defeats the purpose of the disconnect feature.

A better alternative to the unprotected spade connector is the shielded spade connector. The plastic shielding protects the circuit from shorts and can be disconnected as needed.

Ring terminals are used mostly for connecting to grounds, such as body bolts or other sheetmetal fasteners. They are also useful for adding a power pickup at or near a battery terminal.



In addition to making for great disconnects, spade terminals are ideal for connecting to blade terminals on an assortment of accessories, such as toggle switches.

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same thing but on a smaller scale. A common upgrade on earlier Jeeps is to hook relays directly to the battery and supply energy directly to the headlight. The headlight switch (which commonly has a lower voltage) turns on the relay, which in turn supplies full battery voltage to the headlights. This results in a double bonus—no more failed headlight switches and brighter headlights.

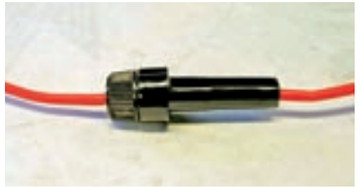
Now that we have established a basic understanding of how electricity flows and its necessary safeguards, let's talk about some common project goals for your future endeavors. As you build something new, remember that you are probably the only one who will understand it, and you will most likely have to fix it if it breaks—probably in the dark and, if it's really broken, in the rain. Build with the expectation that you'll have to troubleshoot at the worst possible time. Keeping this in mind, there is a certain beauty in simplicity. We should start by keeping things neat. It's a serious pain to have to wade into a bunch of spaghetti when troubleshooting a problem.

Another part of keeping things neat is proper positioning of your wiring. Bare wires cause problems. At worst, they have the potential to cause a fire. Minimize chafing by installing grommets in all holes (particularly sheetmetal) where wire passes through. Reduce the strain on wires by providing enough slack so they don't pull too hard. Last, but certainly not least, position your wiring so it doesn't get overheated. Route everything away from exhaust components and anything else that could melt the insulation on your wiring.

One of the first things you will notice as you start looking up under the dash of your Jeep is that everything is color-coded. Wiring schematics help us decode what each wire does or where it goes. When adding new electrical components, using monochrome wiring doesn't cut it. Maintain at least some basic color coding, adding in enough variation to be able to figure out what goes where later on. At its simplest, red wire is used for positive 12V connections, and ground is black. Don't change this standard on your projects or you could get into a real problem.

You can't do good electrical work without the proper tools and supplies. Investing in a quality set of cutter/strippers and crimpers will prevent huge headaches in the future. We highly recommend the products from Klein Tools. You can't get any better. A basic digital multimeter or test light is also an essential tool. A simple kit to get started can be put together from your local home improvement or auto parts store for $50 or less.

Of course, to go with your new tools, you want to make sure you have the right supplies. For that we need to consider the typical Jeep environment—outside,



Some electrical systems require that a fuse or breaker be installed in the circuit to prevent overload and either damaging the component or causing a fire hazard. One way to accomplish this is with an in-line fuse holder. This two-piece unit comes with a wire pigtail on each half. These wires bridge a wire in the circuit, and the circuit is completed when the fuse is installed. When or if the fuse blows, simply separate the holder and install a new fuse.

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sometimes wet, often dirty, in direct sunlight and highly corrosive at the worst of times. Does this sound familiar? While some of the products are pricey, marine electronics can be quite at home in a Jeep, as they are designed to withstand the worst of elements and conditions. Keep that in mind as you pull together your supplies. If you can afford to go marine, do it.

Wire, of course, is one of the key ingredients in any electrical project. As we already discussed, keep a color code in mind when you are making your wire purchases. There are a couple other points to think about when you're looking for wire. Quality wire should be rated for automotive use and include the proper type of sheathing. Furthermore, wire that has many thinner strands is more desirable than wire that has fewer, thicker strands. The thinner, multi-strand variety is a better conductor and is more flexible. Most important, wire should be appropriately sized for the application. Heavier loads require larger wire. As a rule of thumb, there are three main sizes of wire you will be dealing with—battery cable, which is anywhere from 2 to 4 gauge; primary wire, which is 10 gauge; and cross-connect wire, which is 12-14 gauge. These are certainly heavier than factory standards, but it never hurts to over-engineer a little.

Other primary ingredients of DIY automotive electrical projects are the terminals used to connect wires together and to the various electrical components.

There are two basic types of wire-to-wire connectors: permanent and detachable. Permanent connectors are often used for wires designed to bridge long gaps, such as between an electrical component pigtail and a direct connection to a battery or ground. Many components you will install, for example, may have only short 4- or 6-inch "pigtail" wires, which must be attached to a length of stock wire to complete the circuit. Often, you will use permanent connectors for this.

On the other hand, you may have situations where you do not want a permanent wire connection. Say you've installed an electronic trailer brake controller for use when towing. When not towing you don't want the controller in your cab. Detachable wire-to-wire connectors allow you to remove an electrical component, and then reinstall it without the pain of making new connections. Some examples of these include bullet and spade-style connectors, where one side is male and the other female. The accompanying photos illustrate the common connector types used in automotive electrical projects.

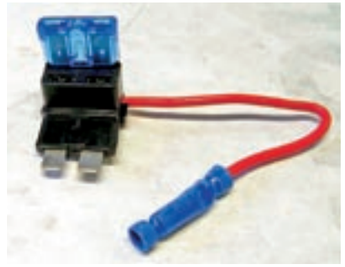
In addition to the wire-to-wire connectors, electrical work often requires the use of end terminals. These are the pieces that allow you to connect a wire to something like the posts on a switch or even a grounding bolt. Naturally, there are a variety of terminal ends to satisfy various applications.

Regardless of which type of connectors and end terminals you may use, it is imperative that you keep your wiring properly shielded. In other words, bare wire should never be exposed unless it is at a grounding point where it must be, or in

Wire Gauge Selection Chart

The size of wire you require for a particular electronic installation should be determined by the manufacturer of the product in question. Wire size will be dependent on the load to be carried by the circuit. Without specific guidance, however, you can make an educated guess as to what size wire you might need for a particular circuit you are working on. This is dependent on the amperage the circuit is required to carry, and the length of the wires needed. The following chart offers a good rule of thumb for selecting the proper gauge wire given a specific use length and amp load on a 12-volt circuit.

Circuit Amps (12V)	Wire Guage (for desired length)						
	3 ft.	5 ft.	7 ft.	10 ft.	15 ft.	20 ft.	25 ft.
0-5	18	18	18	18	18	18	18
6	18	18	18	18	18	18	16
7	18	18	18	18	18	18	16
8	18	18	18	18	18	16	16
10	18	18	18	18	16	16	16
11	18	18	18	18	16	16	14
12	18	18	18	18	16	16	14
15	18	18	18	18	14	14	12
18	18	18	18	16	14	14	12
20	18	18	18	16	14	12	10
22	18	18	18	16	12	12	10
24	18	18	18	16	12	12	10
30	18	16	16	14	10	10	10
40	18	16	14	12	10	10	8
50	16	14	12	12	10	10	8
100	12	12	10	10	6	6	4
150	10	10	8	8	4	4	2
200	10	8	8	6	4	4	2



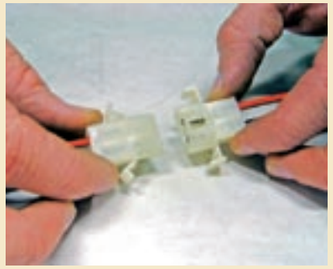
Here's a slick product for tapping 12V power from an existing fuse block, called an add-a-line fuse. Simply connect the lead from the electrical component to the holder's pigtail, and then insert the holder into a slot in the fuse block. Add the fuse and you're set. If you don't have an active, empty fuse slot in your block, you can remove a fuse that matches the amperage rating of the add-a-line holder, insert the holder, then add the original fuse plus the fuse of the component you are powering.

It doesn't require a lot of expensive or fancy tools to work basic automotive electrical systems. The key ingredients are a quality wire stripper/crimper tool (one that denotes wire gauge for stripping insulation and crimping connectors), followed by a test light or two and a decent multimeter—preferably one capable of measuring DC voltage, DC amperage, milliamps and ohms (resistance).

An even simpler fuse setup is the blade-type fuse holder. Again, the pigtails bridge the circuit wire, and the circuit is completed once the blade fuse is installed. These are great if the fuse must be located outside of the cab and be exposed to the elements because the integrated protective cap seals the connection.

Of particular interest to those installing CBs or other in-cab communications equipment is the 2-conductor connector. These are desirable when you wish to install a system that requires "hard-wired" power and ground wires, but you want the flexibility of removing the unit from your Jeep.

The supplied male pins are secured to one side of the circuit while the female pins are secured to the other side. The pins are then inserted into the plastic plug (male) or receptacle (female). The only trick is to make sure that the power and ground wires correspond to each other on each side of the connector.



The connector then snaps together and can be disconnected whenever you need to remove your transceiver from your Jeep.

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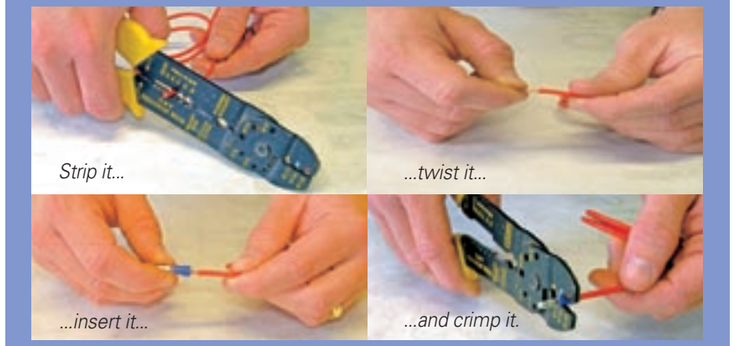
Making a Wire Connection



some situations when you are connecting directly to the battery positive terminal. A bare wire exposes your electrical circuit to shorts, which can damage fragile electrical components or, worse yet, cause a fire.

Most wire-to-wire connectors and end terminals are protected by plastic shielding, however, some folks don't bother doing things the right way and insist on using electrical tape to wrap an otherwise bare connection. This is not recommended in most cases, and the tape can deteriorate and unravel under certain conditions.

Rather than use electrical tape, the better bet is to apply heat-shrink tubing over exposed wiring connections. When properly applied, heat-shrink wrap puts a durable, safe and neat finish to any electrical upgrade.

Another slick product we recently discovered is liquid electrical tape. This is a liquid plastic-like material that brushes right over a connection and creates a fairly durable seal that is also neat and tidy.

Speaking of sealing, that's another reason to apply either liquid electrical tape or heat-shrink tubing to both bare connections and to finish off certain shielded wire-to-wire and end terminal connections. Sealing the wiring from water and the elements will help prevent corrosion. As you may know from dealing with old battery and starter cables, corrosion along copper wiring increases the resistance of the wire, thereby reducing the efficient flow of electrons in a circuit and minimizing electrical system performance.

Beyond the connectors and use of coded wiring to keep your electrical circuits clean, safe and organized, there's the issue alluded to earlier regarding neatness—a near-priceless asset when forced to diagnose or repair an electrical system in

Heat-shrink wrap is ideal for strengthening a wire connection and providing protection from the elements. Cut an appropriate length of tubing and slip it over your wire/connector. Carefully apply heat to the wrap and it will shrink and conform to the wire and connector, providing a tight, secure seal.

Another trick product we recently discovered is Brush-On Electrical Tape made by North American Oil Company. Shake it up, brush it on (a coat or two), let it dry and you're good to go. The connection is now sealed from moisture and corrosion.

less-than-desirable conditions. Wire looms are one way to keep your wiring from becoming a tangled mess. These single pieces of plastic secure a number of wires in a row, just like the looms found on ignition wires. Another simple organization tool is the lowly zip-tie. Use these to keep wiring snugged up and out of the way. They're also good for keeping together multiple wires of a single component or system in an otherwise cluttered engine compartment or under the dash, although the best thing for that is often electrical conduit. Finally, there are several types of push-mount, stick-on mount and screw-mount wire clamps available, just like those used by the OEM (the ones you almost always break or have to cut to remove). The push-mount clamps, for example, make use of those myriad holes in your Jeep's inner fenders, radiator core support and firewall to provide mounting points for wire routing.

Again, no matter what device or method you use to connect and route wiring, keep it clean, sealed whenever possible and organized.

In upcoming issues of *J Rations* we'll dig a bit deeper into custom electrical systems and solutions, so stay tuned.

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Electronic Supply Sources

Although you can purchases most of your common automotive electronic supplies at your local auto parts store, marine shop or Radio Shack, the following companies are great sources for more complete lines of products, including those specialty items that you can't seem to find in conventional brick-and-mortar establishments. And remember, marine-grade components, while typically more expensive, are ideal for use in a Jeep environment.

Electrical Supply Houses

www.delcity.net
www.waytekwire.com
www.grainger.com

Marine Supply Houses

www.boatus.com
www.westmarine.com
www.boatersworld.com