

# Why and How to Upgrade Your Headlamp Circuit

By Daniel Stern

## Thoughtful Care and Careful Thought Required

The success or failure of your lighting upgrade efforts rides on the [quality of your parts](#) and the quality of your work. It matters how carefully you route wires to avoid chafing insulation. It matters how—and how well—you make connections. It matters how well you shield added wiring from road spray and splash. It matters that you use fuses in the new wiring to protect against vehicle damage due to a new or old electrical fault. It matters that you use high-quality parts designed and built to stand up to the rigours of automotive usage. Such components must be resistant to a wide range of temperatures, road splash, fumes found under the hood of every car, severe and prolonged vibration, etc. It will pay you to select only the products of companies with well established reputations for quality and durability; a no-name or off-brand relay could easily kill you when it fails on a dark road somewhere, leaving you with no lights. Price isn't the same as cost!

The techniques described in this article will yield excellent results if the work is carried out carefully and to a high standard, with quality parts and materials and without corner-cutting or sloppy work.

This guide focuses on the general principles and techniques involved with good headlamp wiring. There are many variations in original-equipment headlamp circuit design, and it will be worth your while to examine your vehicle's setup thoroughly, aided as necessary by wiring diagrams applicable to your specific vehicle.

## **Why Bother With Relays?**

Power for the headlights is controlled by (wait for it) the headlight switch. In almost all vehicles built through the late '90s, and quite a few built after that timeframe, all headlamp current runs through the switch. That is: long lengths of thin wire to and from the switch, which contains

tiny contacts. All of this adds up to a surprising amount of resistive voltage drop, which takes a big bite out of headlamp output.

In many cases, the thin factory wires are inadequate even for the standard original-equipment headlamps. There's a large element of automaker cost-cutting involved; it might sound like a joke to say they figure headlamps are only used at night, so that's a 50% usage duty, so they cut the wire gauge in half, but it's actually pretty close to how these kinds of decisions are often made in the auto industry where just about every last fraction of a cent that can be shaved from the build cost, will be.

And science has yet to give us the wiring, connections, and switch contacts that improve with age; in fact they do the opposite.

Headlamp bulb light output is severely compromised with decreased voltage. The drop in light output is not linear, it is exponential to the power 3.4. For example, let's consider a bulb with a rated output of 1000 lumens at 12.8 Volts and look what happens when it is operated at different voltages:

10.5V	: 510 lumens
11.0V	: 597 lumens
11.5V	: 695 lumens
12.0V	: 803 lumens
12.5V	: 923 lumens
12.8V	: 1000 lumens ← <b>Rated output voltage</b>
13.0V	: 1054 lumens
13.5V	: 1198 lumens
14.0V	: 1356 lumens ← <b>Rated life voltage</b>
14.5V	: 1528 lumens

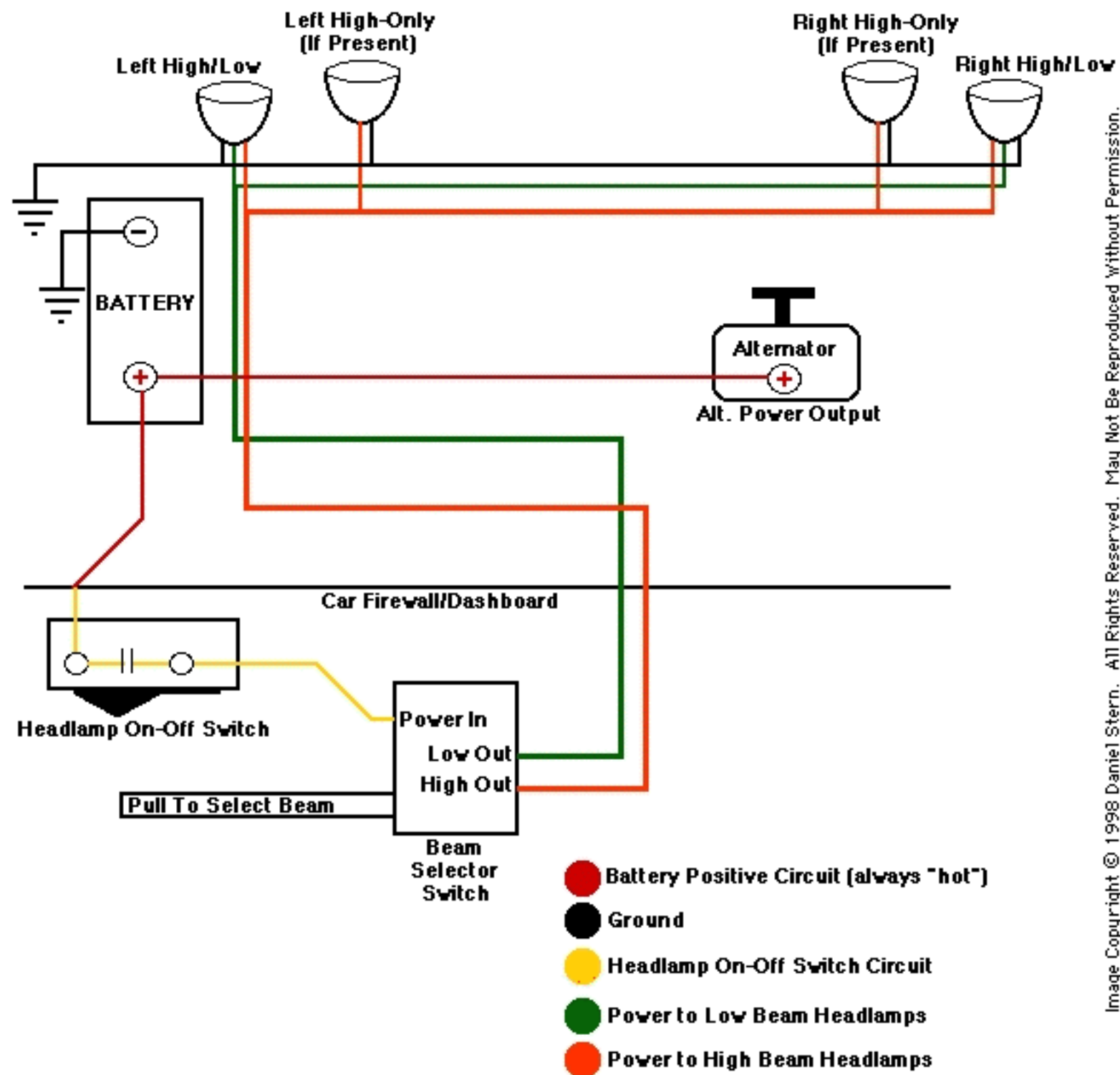
(Outside North America bulb output and lifespan are both rated at 13.2v, but the effect of voltage drop is the same).

When operating voltage drops to 95 percent (12.54v), headlamp bulbs produce only 83 percent of their rated light output. When voltage drops to 90 percent (11.88v), bulb output is only 67 percent of what it should be. And when voltage drops to 85 percent (11.22v), bulb output is a paltry 53 percent of normal! It is quite common for factory headlamp circuits to produce this kind of voltage drop, especially once they're no longer brand new and the connections have accumulated some corrosion and dirt. And even many newer cars where the headlamp switch tells a lighting control module to send power to the lamps have problems of this nature. The Ford Crown Victoria is just one of many examples; the lighting control module is underspecified; it starves the lamps until it burns out. Some modules can be repaired; others must be replaced—

sometimes at great expense and hassle—so putting in a low-loss circuit is well worthwhile not only to make it easier to see while driving at night, but to prolong the life of the module.

From the headlamp on-off switch, a single wire runs to the beam selector ("dimmer", high/low beam) switch. Two wires run from the dimmer to the front of the car: one for high beams, one for low.

Here's a schematic of what we have to start with:



Those are long lengths of thin wire between the battery and the headlamps! Typically we find 16 gauge wire (1.5 mm<sup>2</sup>) at best, more

commonly 18 gauge (1.0 mm<sup>2</sup>) and in some cases even 20 gauge (0.5 mm<sup>2</sup>). Many such circuits produce unacceptable voltage drop.

### **How to Measure the Voltage Drop**

This test must be made with the lamps switched on and all bulbs connected, so you may have to work to get access to the correct bulb terminal. In some cases, it may be easiest to remove the bulb from the headlamp and (carefully) operate it outside the headlamp with your voltmeter connected. Or, you can "backprobe" the headlamp socket: fetch a couple of straight pins, safety pins, or unbent paper clips. Don't use them to pierce any wires, just insert them into the back of the headlamp socket, alongside each wire, until the end of your pin makes contact with the metal terminal inside the socket. Then you can easily touch your meter probes to the pins with the socket connected to the bulb.

Connect the positive (red) test lead of a voltmeter to the car battery positive (+) terminal, and the negative (black) test lead to the + terminal of whichever headlamp filament (beam) you're testing—use the bulb farthest away from the battery. Your voltmeter will give a direct reading of the voltage drop. Write it down.

Then, connect the positive (red) voltmeter lead to the ground terminal of the headlamp bulb, and the negative voltmeter lead to the negative (-) terminal of the battery. Your voltmeter will again give a direct reading of the voltage drop. Write it down. Add the two voltage drop figures obtained, and this is the total circuit voltage drop.

### **How to Solve Voltage Drop**

To bring full power from the electricity producer—the battery or alternator—to the electricity consumer—the headlamps—we must minimise the length of the power path between the producer and the consumer, and we must maximize the electrical current carrying capacity, or wire gauge, of that power path. But we still want to be able to control the headlamps remotely (from the driving seat), so how do we do that? Install relays!

A switch is a device that completes ("makes") or opens ("breaks") a circuit, sending or interrupting current to whatever device we wish to control. A relay is simply an electrically-operated switch. When we send power to the relay with the headlamp switch, the relay completes a circuit between the the battery or alternator's positive (+) terminal and the headlamps. Unlike headlamps, relays require only a tiny amount of power to operate, so the thin wires that are inadequate to power

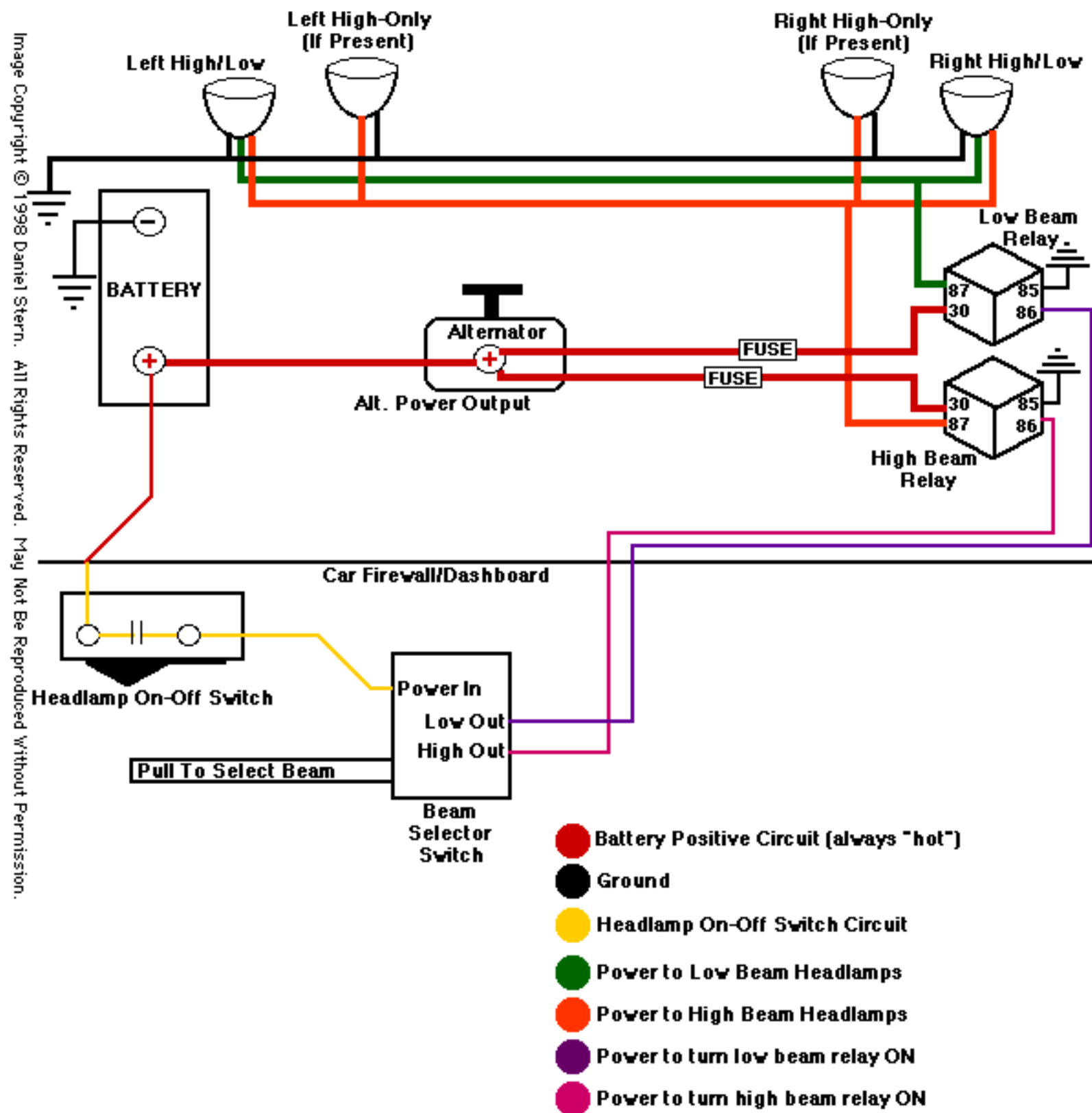
headlamps are more than sufficient to power relays. We will simply use the existing headlamp wires to switch the relays on and off, and let the relays do the heavy lifting, the big job of sending or interrupting current to the headlamps. We use relays with plenty of current-carrying capacity, which enables us to use heavy-gauge wiring that also has plenty of current-carrying capacity. This way, we can bring full current to the headlamps, with virtually no voltage drop.

A relay only needs a watt or two of power to activate it. On the other hand, even many old-fashioned sealed beam headlamp systems' total power is over 100W on low beam (even more on high beam), which means they need over 10 amps of current. Power (in watts) equals current-squared (in amps) times the circuit's total resistance (in ohms). So if the headlamp switch or beam selector switch has a resistance of only 1 ohm due to underspecified contacts and age-related deterioration, and we have a 10-amp load, that means 100 watts' worth of heating in the switch. Ever put your hand on a 100-watt light bulb? Ouch! Keep in mind you can solder with as little as a 15-watt soldering iron, and you begin to see the issue here.

So what does the headlamp circuit look like when we install relays?

There are several things to notice in this diagram:

## Upgraded Headlamp Circuit With Relays, Fuses, Heavy-Gauge Wire



Those seemingly random numbers on relays and sockets are more or less universal designations, by German industry decree. You'll find a reasonably complete list of their meanings [here](#). On relays, we have:

**86**, the relay switching/control circuit "in" (+)

**85**, the relay switching/control circuit "out" (-)

**30**, the power circuit "in" (from power source)

**87**, the power circuit "out" (to lamp or whatever other electrical device is being powered).

The best relays to use in setting up a headlamp circuit have dual 87 terminals. That lets you use one 87 terminal to power the left filament, and the other 87 terminal to power the right filament in whatever circuit you're building (low beam, high beam, fog lamp, etc.), so there's no need to double up on wires going to a single terminal or mess with piggyback connections or other suchlike. Note that a terminal labelled 87a is not the same as an 87 terminal.

On headlamp sockets, the terminal designations are as follows (not shown in diagram):

**56a**, the high beam feed.

**56b**, the low beam feed.

**31**, ground (or "common").

### **How to Route the Wires**

You'll need to choose a place to draw the power for the headlamps. The two most common choices are the alternator output (B+, BAT) terminal, or the battery positive post. Some cars with remote-mounted batteries or underhood fuse panels have underhood power points, and these can be a good selection as well. So, which is the best power point?

On cars with full-current ammeters (mostly pre-1976 Chrysler products) it is best to pick up your power from the alternator output terminal, rather than at the battery positive terminal. This so that when everything is in its normal state—engine running, battery charged—the power for the headlamps doesn't go thru the car's existing wiring at all. That's the wise way to do it on cars with full-current ammeters, because such gauges must carry **all** current for the entire car. Keeping heavy current loads out of this area reduces stress on the entire wiring system, and eliminates much voltage drop on the charging side of the wiring. That said, if you have such a car, it's an excellent idea to improve on this setup for reliability and safety. As with anything else, there are good and bad ways of making such improvements. Shoot me an email if you're curious, and I'll advise.

The vast majority of cars, however, do not have full-current ammeters, so take your choice of alternator or battery positive terminal (or power point terminals, on cars so equipped) based on access and convenience. These points are all electrically common, and any of them will serve pretty much equally well. If you have a General Motors vehicle with a side-terminal battery, you'll need to grab a couple of special new battery cable terminal bolts like [these](#) so you can easily and securely attach your harness + and - wires to the battery.

You may have heard that it's not good to take headlamp power from the alternator output because of "voltage spikes"; this is not quite true. The voltage might be a little higher at the alternator B+ (output) terminal than at the battery positive terminal—and if so, it's probably a little higher than optimal for feeding lamps—but no voltage spikes are present in an electrical system with good voltage regulation, and any spikes that are present in a system with bad voltage regulation are present more or less equally across the entire system. If your charging system is "spiky", indicated by vehicle lamps that flash brighter and dimmer with the engine running at a steady speed, then you need to fix the problem that is causing the spikes!

When picking up your power at the battery, particularly with a conventional (all makers except GM) top-terminal battery, mind the potential for corrosion. Keep those terminals clean-clean-clean, and once you've added the harness power and ground wires to the positive and negative battery cables' terminal clamps (with a ring terminal on each) and reinstalled your cables, be sure to overspray the assembled terminals with [the appropriate sealer](#) to guard against any such trouble—this is good practice even if you're not adding any new wires to the battery.

Every make and model of vehicle is different, and you may find yourself without easy access to any of the power pickup points mentioned so far. In that case, a little creativity might be called for. You don't have to use the battery end of the positive cable, you could hook up at the other end, where it connects to the starter, the starter solenoid, or wherever else it attaches. If you're working on a big motor home or other vehicle with the powerworks at the back, nowhere near the headlamps, then you might best run new power and ground cables forward to the front of the vehicle—make sure they're adequately sized, and well protected against abrasion, chafing, snagging, and all other damage.

Note: The illustrations below use the alternator as the power takeoff point. This doesn't mean that's better, it's just how the drawings were made.

### **Protecting the Circuit**

A properly-configured relay harness has fuses in the power supply side of the headlamp power circuit, as close as possible to the power pickup point—within inches of the battery + or alternator B+ terminal. This is *very* important! When you add wires that weren't there by the vehicle's original design, you must properly protect the new circuits you're building. Fuses are first choice. Manual-reset circuit breakers are second choice. **Don't** use self-resetting/auto-reset circuit breakers, and here's



why: some kinds of electrical loads, like motors, can sometimes draw just *somewhat* more than their usual current, usually for a short time due to an unusual condition. An example might be a power window motor that must overcome a bit of ice sticking the glass to the doorframe on a cold day. In that case an auto-reset breaker is a fine choice; it'll open the circuit for awhile and by the time it resets the transient overload condition will probably have passed. **Lamps and their circuits aren't like that.** Either they draw about the amount of current they're designed for, or there's a short circuit that pulls a giant amount of current—and if that happens, you want the circuit to stay dead until the problem is fixed. A self-resetting breaker in that condition would keep sending power to the short circuit every time it would reset, worsening the damage and danger each time. That's why we use fuses or manual-reset breakers in a properly-configured lamp harness.

A headlamp relay harness connects to the vehicle's main electrical feed, either at the battery or at the alternator. If the new wiring (or a portion of the old wiring after the relay) shorts to ground, without a fuse you will have an expensive fire. The alternator can typically pump out 60 amps or more, and the battery can contribute another 80 to 100 amps before the vehicle main fuse or fusible link blows. That's on the order of 130A flowing through your wires, which will heat them to orange-hot immediately. Not to mention that if you do blow the main fuse, you are now stranded as well. Completing this unpleasant line of thought: if you own an old classic without any sort of main fuse, fusible link, or other main-circuit protection, the entire wiring harness can be quick-fried to a crackling, crunchy crisp in a matter of seconds. I have seen, smelled, and heard this happen, and it is not soon forgotten; if you drive such a car, **add a main fuse or fusible link!**

Notice that in the diagram of the upgraded headlamp switch, the wires to the headlamps themselves are heavier. If you are going to the trouble of fixing inadequate factory headlamp wires, do a complete job and run good wires all the way to the headlamps. The necessary pieces and parts to facilitate such an improvement, such as fuse holders and headlamp sockets compatible with large-gauge wire, can be difficult to find locally. Parts stores tend to carry the same inadequately-small-gauge stuff your car originally came with. Packages containing all these necessary parts, dual-87 relays, and all the rest of the juicy bits are available [here](#).

### **Choosing Wire**

Use only stranded copper wire, never solid (household type) wire, in automotive service. Reputable brands in America include (but aren't limited to) Belden/PowerPath, Deka, Ancor, Carol, Whitaker, and Standard. Ordinary automotive wire uses PVC insulation, and that's

usually adequate. Higher-grade crosslinked insulation (GXL, TXL, pretty much anything-XL) is more resistant to just about everything aggressive to car wires—heat, oil, repeated flexing, etc—and can be bought in [convenient multi-colour packs](#). Marine-grade tinned wire is super extra resistant to corrosion, and comes in a [good variety of colours](#) as well as convenient pre-made cables containing [two](#) or [three](#) different colours of wire—really nice for easy, tidy, well-protected installations. If you don't get that sort of cable, get some [wire loom](#) to protect your wire runs.

Wire gauge selection is crucial to the success of a circuit upgrade. Wire that is too small will create the voltage drop we are trying to avoid. On the other hand, wire that is of too large a gauge can make it difficult to get a good and durable connection at the terminal, and can cause mechanical difficulties due to its stiffness, particularly in hidden-headlamp systems. 14-gauge ( $2.5 \text{ mm}^2$ ) is usually quite adequate. 12-gauge ( $4.0 \text{ mm}^2$ ) is well more than adequate. 10-gauge ( $5.2 \text{ mm}^2$ ) is past the point of diminished returns and over into too-big/overkill territory.

Don't fail to use adequate-gauge wire on the feed *and* ground legs of your circuit; voltage drop occurs due to inadequate grounding, too. You will only sabotage your efforts if you run nice, big wires to the feed side of each headlamp, and leave the weepy little factory ground wires in place. Speaking of which, many factory headlamp circuits run their underspecified ground wires to a point on the car body conveniently near the headlamps. This is an acceptable ground (barely) on a new car. As a car ages, corrosion and dirt build up and dramatically increase resistance between the car body and the ground side of the vehicle's electrical system. It takes little extra effort to run the new, large ground wires directly to one or the other end of the battery negative (-) cable, or to the metal housing of the alternator, and this assures proper ground.

### **Working With Wire**

You will need a crimper better than the typical cheesy consumer-grade item you might already have. You *can* spend a couple hundred dollars on one, but it shouldn't be necessary; just go for a good one such as [this](#). You'll find it very useful for scads of other projects; it's a worthwhile purchase.

Perhaps you are skilled and talented with a soldering iron, and you're thinking of soldering your connections. A good and durable headlamp harness can be put together with soldering, but you may want to choose other techniques instead; see [here](#), [here](#), and [here](#).

Aside from properly-done crimps, there's another good technique for tapping and connecting wires. It's called the Posi system, and you can read about it [here](#). Get [this assortment](#) and you'll surely find uses for them; they're one of those products that you buy for a particular project, but then other uses for them keep popping up in front of you once you have them in the house. These are nothing at all like the horrid fold-over-and-crunch "Scotchlok" wire taps (please never use those).

### **Mounting the Relays**

Relays are very compact, about 1 inch by 1.5 inches. Because they take up so little space, it is relatively easy to mount them in an optimal location. Because the main idea with this upgrade is to minimize the length of the headlamp power circuit in order to bring the producer and consumer as close together (electrically) as possible, it is best to mount the relays at the front of the car near the power source (alternator, battery or power point) and near the headlamps. Don't sweat this too hard, though; pick a convenient and appropriate location for the relays without worrying about extra inches or feet of wire needed to reach them. Because you will need at least two relays—one for high beam, one for low beam—you will want to use relay mounts that incorporate a snap-lock feature to create tidy relay banks that can be made to look like factory installations if the wiring is done neatly. These relay mounts also serve as moulded terminal blocks so that all of the wires going to a relay come together into one socket, which is preferable to having individual wires without a supporting plug. These are the relays and mounts included in the installation packages available [here](#).

### **Ground-Switched Systems**

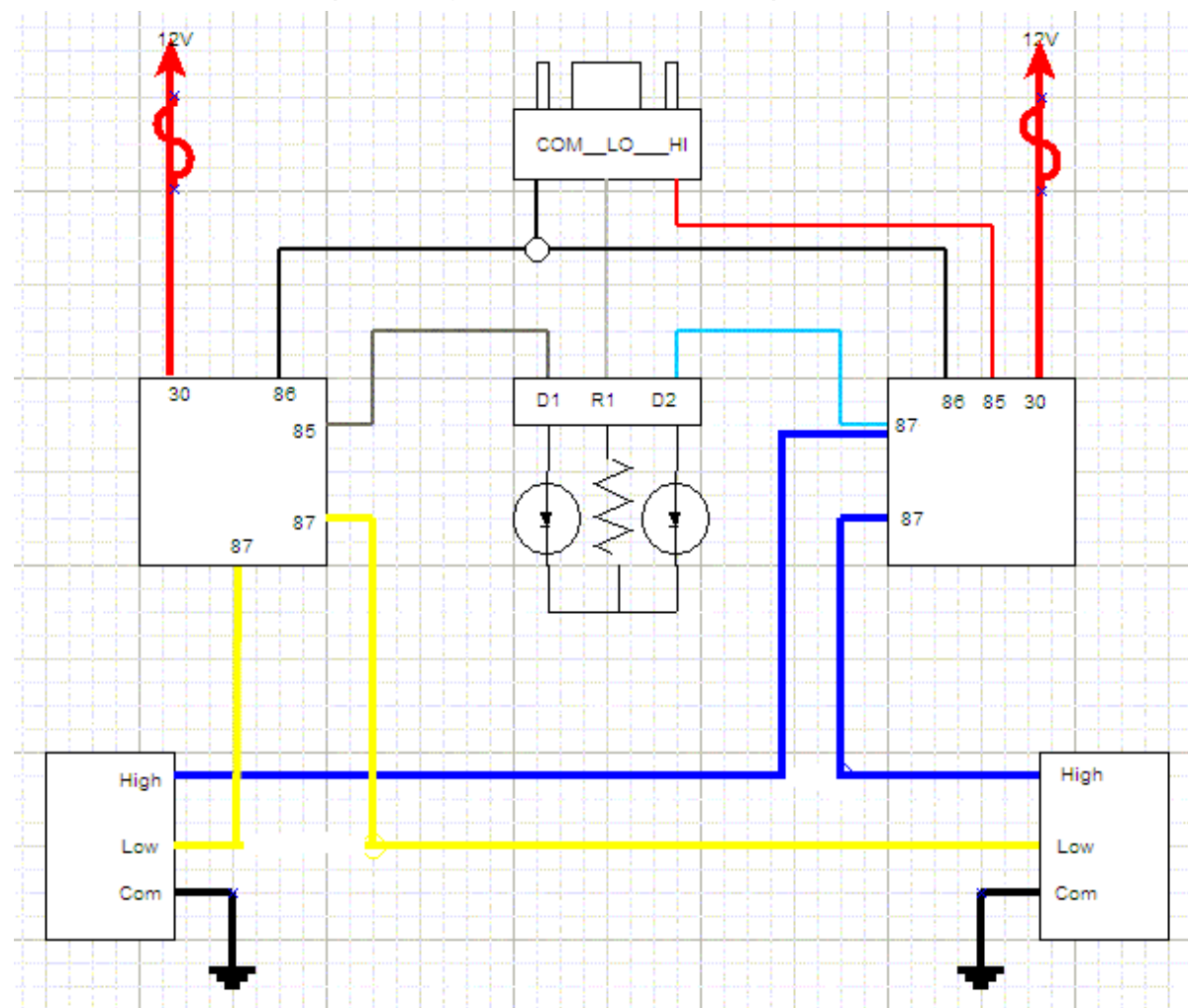
Many Japanese vehicles, as well as some others, use a "ground-switched" headlamp circuit: the headlamp and beam selector switches make or break the *ground* leg of the headlamp circuit, rather than the feed leg. On these systems, make sure to **use both the negative and positive** existing headlamp wires to trigger the relays. It is tempting to run the existing headlamp feed wire to relay terminal 86 (trigger feed) and simply find a convenient ground for relay terminal 85 (trigger ground). However, this will not work with ground-switched systems. Run the vehicle's existing feed wire to terminal 86, and run the vehicle's existing ground wire to terminal 85.

But what are we going to do now we've used our one and only ground wire on the 85 terminal of the low beam relay, but we still have to install the high beam relay? Go to the other side of the car and you have another ground wire! Remember, the relay trigger circuits can be as long as you like, because they take insignificant power. So you can extend

the vehicle's existing headlamp wires to your relay mounting location. It is fine to use this method regardless of whether you have a ground-switched system or not, so go ahead and use it if you're not sure.

### Toyota-Built Vehicles

Toyota's headlamp circuitry is unusual. It's usually ground-switched, but there's more to it than that. It's not wrong or bad or anything, it's just different to the way other automakers do it. If you don't account for these differences when configuring your relay installation, you'll get operational quirks and irritants. Your high-beam indicator light won't work correctly, the high beams won't switch off when you select low beam—that kind of thing. To avoid these problems, you'll need to include some diodes and resistors as shown in this next diagram (which is for a 2-lamp system, but the principle applies to any headlamp system configuration). Get them locally or online from an electronics supply house. **R1** is an 8-ohm, 2-watt resistor. **D1** and **D2** are silicon diodes with at least 2-amp rating and at least 50v peak inverse current rating.



### Lamp-Outage Indicators

Some cars have dashboard-mounted indicators to tell the driver when a headlamp has burned out. The function of such devices can be disrupted by the installation of headlamp relays. There are ways to maintain the function of a bulb-outage indicator while still using relays. On my own vehicles, I simply remove the bulb from the bulb-outage indicator...I like to think I will notice a burned-out headlamp!

Daniel Stern Lighting (Daniel J. Stern, Proprietor)

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