Headlights Relays in Absurd Detail

Friday, May 29, 2020
4:15 PM

Introduction: This just grew. Writing this, I got to yack (in text) about a lot of tangentially connected topics. This seems really simple to me (probably because of my history), but it often comes up as a question or topic. A very nice man (now deceased) on one of the Wagoneer forums made and sold quite a few specialty harnesses to complete this same project. Apparently other companies sell specialty harnesse to do this for Chevy trucks or whatever. This is not difficult or complicated - once you get the idea, you can do it without any custom circuit boards or harnesses.

I will divide this into separate mini-articles.

1) Executive Summary
2) Some Basic Electricity
3) Electrical Components
4) Parts List
5) Wiring and Diagram
6) Assembly Including Splices
7) Tools
8) Fusible Link Instead?
9) Further Improvements?

Executive Summary

Headlight upgrades are a popular accessory for our Jeeps. The original incandescent bulbs are dim and yellow compared to modern replacements. These replacement bulbs often claim compatibility with original wiring, but this may be sales talk. Most owners add headlight relays to accompany their upgraded lights. Here's why and how.

Headlights have high-beams and low-beams. These are powered through separate wires (usually), via the headlight switch and a high-beam low-beam selector (dimmer) switch. The two wires go across the engine compartment to the front grille, powering the selected beam, and then are grounded to the body steel.

The objective is to power the lights from a relay, and control the relay with the original headlight wires. A relay is an electrically powered switch. We feed current to the relay with a big fat wire directly from the battery, which has both low voltage drop (more voltage to the bulb is brighter) and also relieves most of the original wiring from carrying the load of the new headlights.

This upgrade requires some assembly, but few components: two "Bosch Type" relays (one each for high-beam and low-beam), a length of big fat wire, a circuit breaker to protect the added wiring, and some connectors and other supporting bits. Once you gather all the parts, you should be able to do this in an afternoon easily.

Feel free to skip over anything that does not interest you.

Some Basic Electricity

These are the headlight bulbs I chose for my '75 CJ-6 that I own now: https://www.ebay.com/itm/332986701654
We don't need to get into a discussion of all the bulb options here. Suffice to say these are fine in my experience, they are a vast improvement over the original sealed beam incandescent bulbs, they are DOT legal (saving me hassle at my annual safety inspection for Massachussetts), and they are inexpensive; about $45 shipped to me.

When you choose your headlight bulbs, you need to have some idea of the current they will require. These bulbs are rated 60 and 55 watts for high- and low-beams respectively. I'm not going to run the high- and low-beams at the same time, so I'll use the 60 watt high-beam rating to evaluate my circuit.

Ohm's law tells us the relationship between resistance, voltage and current in a metal conductor. Note this is not a fundamental law of electromagnetism, since it depends on the properties of the material, here a metallic conductor. We use a formula V=IR or voltage V (the voltage drop) equals the current I times the resistance R from point a to point b. This is typically measured across an input and output (points a and b), like voltage to our bulbs compared to ground. Power (in watts, the units we care about here) is the transfer of energy per unit of time. A drop in voltage is a change in potential energy by the moving charges. The power is then the current I (the number of charges moved over a given time) times the potential change (voltage change) from point a to point b, P=IV. This is more general than Ohm's law, since it's no longer dependent on the properties of the material: it only requires moving charges and a change in potential. However, we often arithmetically substitute Ohm's law as V=IR and express power in any of three forms: P=IV or P=I*(IR)=I^2 R or P=(V/R)*V=V^2/R, the last two which are only valid in metallic conductors.

P=IV or P=I^2R or P=V^2/R, all the same in conductors.

We know what the voltage change will be: from pretty close to the operating voltage of the battery (say 13.5 volts) to ground or zero. Our potential change is 13.5 volts, and the resulting power is 60 watts (the bulb rating). This gives I (current) = P (power) / V (voltage) or 60 / 13.5 = 4.4444 or about 4.5 amps. Let's say 5 amps for each bulb. By this formula, the current will go up as the voltage goes down, but we know the bulb brightness will decrease with voltage, so that's not physically realistic - as the voltage goes down, the light output (and power consumption) will go down. Thus 5 amps per bulb seems like a reasonable estimate. (You could substitute illegal 100W bulbs, and that would use about 7.5 amps per bulb).

Back to designing the circuit. We want to protect this circuit with a fuse or circuit breaker. The steady-state current of this circuit is between 10 and 15 amps. A good rule of thumb is to double the current requirement and go up a bit from there. So a 20 amp fuse or circuit breaker is probably enough for this circuit, but I chose a rating of 30 amps. The circuit breaker (or fuse) protects from a short circuit, which could instantly go far above 100 amps. (Easy to calculate using Ohm's law. An exercise for the reader! Realize that the resistance of wire is not zero.) Thus a 30 amp breaker will be fine. You could go to a 50 amp breaker with 100 watt bulbs with no issues, though 30 should also be ok.

Let's look into the sources of voltage drop with relays compared to the factory headlight wiring. Here's the wiring path to the high-beams in my '75 CJ-6, showing the component and its source connection. Lengths found using a tape measure (not very accurate).

Battery to solenoid	battery cable
14 ga fusible link, 9"	crimp ring connector
10 ga wire to bulkhead, 84"	crimp butt connector
bulkhead pass-through	crimp to large Packard connector
10 ga wire to splice A, 24"	crimp to large Packard connector
12 ga to light switch, 12"	large butt crimp
light switch contacts	crimp push-on
14 ga to dimmer, 20"	crimp push-on
dimmer switch contacts	crimp push -on
14 ga to bulkhead, 12"	crimp push-on
bulkhead pass-through	crimp to Packard connector
14 ga wire to high-beam socket, 48-76"	crimp to Packard connector

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14 ga wire to high-beam socket, 48-76"	crimp to Packard connector

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Unfortunately I don't have any instruments that can measure the resistance of each of these components. At some point I may go back and take the wiring apart to measure the voltage drop for each complete configuration. That would be telling. But not now.

I do know that each connection has more resistance than wire and will cut the voltage some. Mechanical connections are much worse than runs of wire, and the larger the wire, the less resistance per unit of length. To make this better, we make the wire path short and of the largest wire practical. We also minimize the number of connectors, and maximize the quality of each connection.

Here's the upgraded wire path and its source connection:

Battery to solenoid	battery cable
10 ga to breaker, 6"	crimp and solder ring connector
breaker contacts	crimp and solder ring connector
10 ga to relay, 59"	crimp and solder ring connector

14 ga to relay socket, 2"	crimp and solder butt connector
relay and socket	crimp push connector
14 ga to high beam wire, 2"	crimp push connector
14 ga to high-beam socket, 12-40"	crimp and solder butt connector

Battery to solenoid	battery cable
10 ga to breaker, 6"	crimp and solder ring connector
breaker contacts	crimp and solder ring connector
10 ga to relay, 59"	crimp and solder ring connector
14 ga to relay socket, 2"	crimp and solder butt connector
relay and socket	crimp push connector
14 ga to high beam wire, 2"	crimp push connector
14 ga to high-beam socket, 12-40"	crimp and solder butt connector

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Looking at this, we can conclude that the new path must have a lower resistance, even if we can't quantify the change. We have eliminated the bulkhead connection, which removes two push-style connections. Both of the switches are gone, replaced by the relay. Ampacity (amperage capacity) of contacts depends mostly on their contact resistance. The relays I chose are rated 40 amps at 12VDC. That's 480 watts, which has to be way more than either of these switches can handle. There are contacts in the circuit breaker, which may be detrimental (more about this in the final article comparing a circuit breaker to a fusible link). I understand the instantaneous contact resistance is much higher than the steady-state resistance, and normally the circuit breaker contacts never open … not enough data.

The new wire path has fewer connections than the old path, 7 versus 11. I believe the new connections are also much higher quality than the old, but that can be debated somewhere else.

Electrical Components

The first component to analyze is the wire. We can find the resistance difference in the wire easily. These values are widely tabulated. Let the largest wire be the standard value of 1, and compare. 10 ga is 0.9988 ohms per 1000 ft, pretty close to 1. 12 ga is 1.5882 ohms / 1000 feet and 14 ga is 2.5254 ohms/ 1000 feet, 250% of 10 ga! Why are our Jeeps wired with all those lossy 12, 14, 16, 18 ga wires? Clearly, because the voltage drops over the short lengths of these wires is not significant.

Original wiring: (84 + 24) + 12 / 1.5 + (9 + 20 + 12 + 48 + 14) / 2.5 = 157.2" of 10 ga wire.
Upgraded wiring: (6 + 59) + (2 + 2 + 26) / 2.5 = 75.4" of 10 ga wire, or a 52% reduction in wire loss.

Our new wire path definitely has lower wire loss. Why not go to larger wire still? Cost and diminishing returns. 10 ga automotive wire can be found easily, is affordable (compared to much larger wire) and gives us most of the benefit we are going to get from larger wire. You need expensive instruments to measure these very small resistances, but I would guess that the dominant contributor to loss in the revised circuit is now the connectors. Also, since there's not much loss to recover now, as we approach zero, any additional gains get harder and harder: "The Law Of DIminishing Returns."

If the circuit breaker detected a short, that's like (roughly) 7 feet of 10 ga wire going directly to ground. We found that 10 ga wire has about an ohm of resistance every thousand feet, so 7 feet has 0.007 ohms. At 12.3V with the engine not running, Ohm's law says I = V /R = 12 / 0.007 = 1,714 amps. So basically the CCA of the battery will limit the current in the wire. This is the answer to the exercise above (you could have guessed a resistance of less than 1/10 ohm). Toasty!

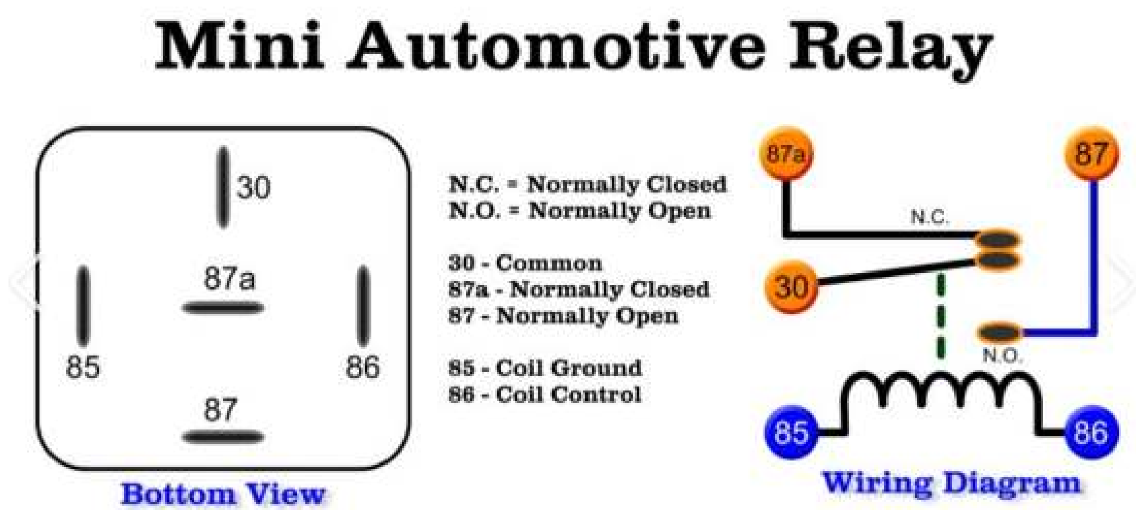
Here is the center of the action, the relay.

We need two of them, one for high-beam and one for low-beam. These are SPDT (single-pole double-throw) automotive relays, with the internal parts inside a waterproof cube. You can buy cheaper relays that are not waterproof, but I think going waterproof is cheap insurance for something that will live under the hood of our Jeeps. These relays include a metal bracket so they can be mounted on a penel or such. The bracket can be removed, but I used it.

A relay works magnetically. There is a coil of many turns of fine wire around an iron core inside it. When energized (electricity applied), the coil becomes a powerful electromagnet. An arm with switch contacts is positioned to experience the attractive force of this electromagnet. When energized, the electromagnet pulls on the arm and throws the switch "on." When the field is turned off, a spring inside the relay pulls the arm back to its at-rest position, throwing the switch "off."

This relay is rated for switching 40 amperes at 12 volts DC. Regarding SPDT, there is a convention for switches and relays that describes their action. This relay has a single pole, which means that it controls one wire. Double throw means that it has two sets of contacts, in this case one that is closed when the relay is not energized (NC, normally closed) and one that is open when not energized (NO, normally open). When the relay coil is energized, the NC contact opens and the NO contact closes. For switching the headlights, we will only use the NO contact. There is also a switched terminal that alternately connects to the NC or NO contact with the coil off and on respectively.

Here's a couple of diagrams that apply to our relays.



You can see that the terminals are arranged on the base of the relay as a schematic representation of the relay function. Recognize this and you won't need to keep referring to the diagram. The two outermost terminals 85 and 86 are the relay coil, and are not polar. This relay works on 12 volts DC, turning on and off as voltage is applied. The coil has many turns of fine wire which will tolerate being powered on for a long time: 85 ohm coil resistance at 12 VDC is about 140 mA, dissipating about 1.7 watts. Bosch originally made these relays, then Tyco bought the relay division from Bosch, and now many companies make them. Here is the data sheet if you are interested:

PDF

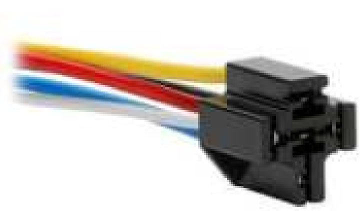
ENG_DS_V2
3234-X000...

The relay action happens at the switched contacts, the NO 87 and NC 87a. The switched terminal is 30, and is either connected to 87a (coil off) or 87 (coil on).

Back in 1973, when I owned a brand-new '73 CJ-5, I installed Cibié headlights and used this relay, specifically intended for these applications. Controls both high- and low-beams, and is labeled "SWITCH" and "LIGHTS."

Probably still works.

You can use push-on terminals with the Bosch relays, or a pre-made socket. Here's the one that I used - more about this when construction is covered.



We've covered wire and relays, and that leaves circuit breakers. These can be either thermally resetting (automatically resetting when they cool off) or manually resetting (with a button of some kind). For automotive use, you can get blade-type that plug into a fuse holder, though I have only used those with threaded studs and some type of integral bracket.

They protect your added wiring from the battery. Some discussion whether it's the best choice further on.

Parts List

All of these can be subsituted with equivalents at your discretion.

Major Components

2ea "Bosch" waterproof 5-pin type automotive relays; 12VDC 30/40A. $3.99 ea, Parts Express
https://www.parts-express.com/12-vdc-waterproof-5-pin-bosch-style-relay-spdt-30-40a-with-metal-bracket--330-079

2 ea 5-pin socket for "Bosch" type relays. $3.14 ea, Parts Express
https://www.parts-express.com/12-vdc-5-pin-relay-socket-for-bosch-type-relay--330-075

1 ea Sea-Dog resettable 30A circuit breaker with cover; $12.07 ea, Amazon.com[1]
https://www.amazon.com/gp/product/B00A5BO5Z0/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1

8' package Dorman 10 ga automotive primary wire, red; $4.30, RockAuto
https://www.rockauto.com/en/tools/electrical,wire,primary+wire,144

Connectors and Splices

4 ea 14-16 ga non-insulated butt connectors, brazed barrel; $0.0769 ea, 100 pcs minimum, Del-City[2]
https://www.delcity.net/store/Non!Insulated-Butt-Connectors/p_801870.h_801871

1 ea 12-10 ga non-insulated butt connectors, brazed barrel; $0.1370 ea, 100 pcs minimum, Del-City[2]
https://www.delcity.net/store/Non!Insulated-Butt-Connectors/p_801870.h_801871

2 ea 10-12 ga ring connector for a #10 stud; $6.85 for 50 pcs, Parts Express[2]
https://www.parts-express.com/10-(12-10)-ring-terminal-50-pcs--095-222

1 ea 10-12 ga ring connector for a 5/16" stud; $8.78 for 50 pcs, Parts Express[3]
https://www.parts-express.com/5-16-(12-10)-crimp-ring-terminal-50-pcs--095-226

1 ea 16-14 ga ring connector for a #8 stud; $4.79 for 50 pcs, Parts Express[3]
https://www.parts-express.com/8-(16-14)-ring-terminal-50-pcs--095-212

4' 3M 1/4" thin-wall adhesive lined heat-shrink tubing; $4.98, Parts Express
https://www.parts-express.com/3m-1-4-heat-shrink-with-adhesive-4-ft--080-112

Wire Dressing and Fasteners

10' 1/4" plastic split-loom tubing; $2.80, Parts Express
https://www.parts-express.com/1-4-split-loom-tubing-1-ft--080-523

1 pkg 4" black cable tie, 100 pcs; $0.64 Parts Express
https://www.parts-express.com/cable-wire-tie-4-18-lb-tensile-black-100-pcs--080-936

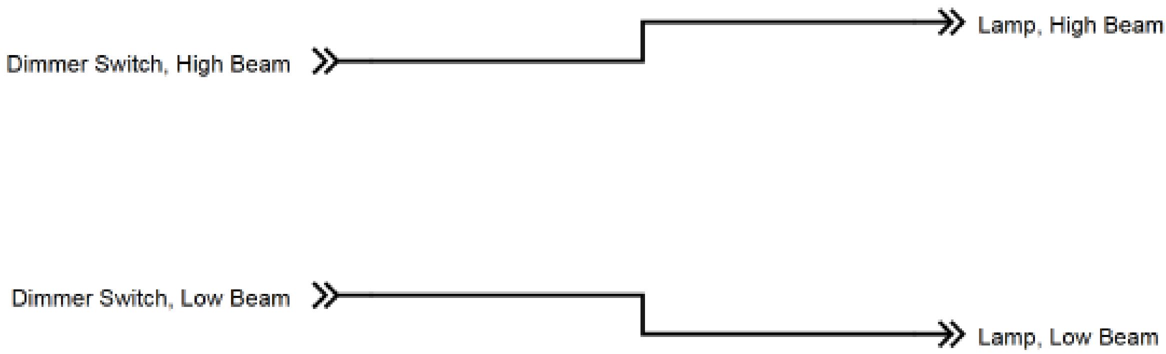
1 ea Zinc Plated Steel Loom Clamp; $0.2863 ea, 100 pcs min, Del-City[4]
https://www.delcity.net/store/Zinc-Plated-Steel-Clamps/p_800836.h_66685

4 ea 8-32 screws, nuts and lock washers; hardware store or this kit at Amazon.
https://www.amazon.com/gp/product/B07CKNGX1P/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1

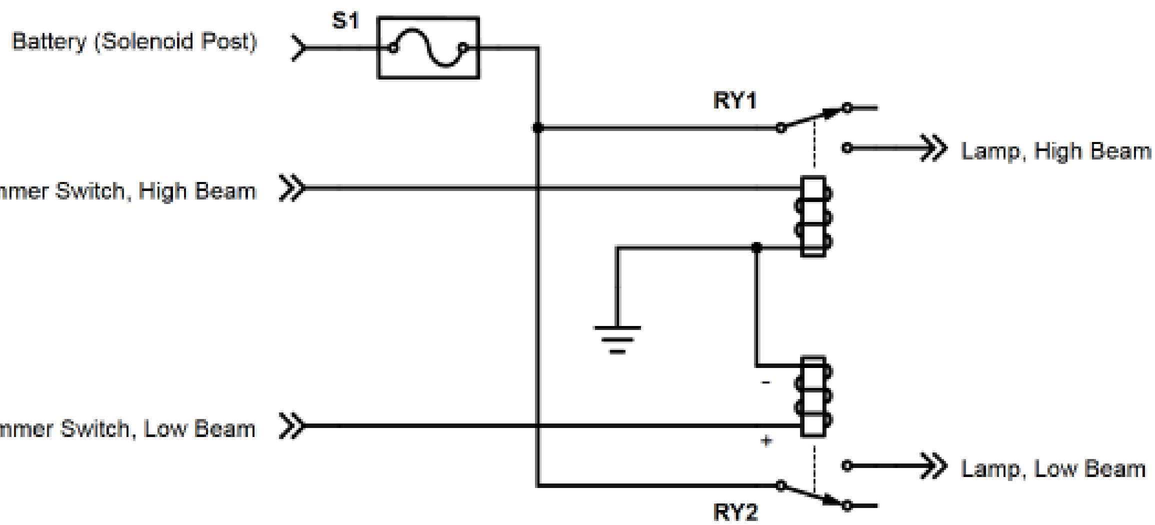
NOTES:
[1]The SeaDog covered breakers have gone up a lot since I purchased. Check RockAuto or your local parts store if you decide to use a circuit breaker. You can buy just the cover if you want that.
https://www.amazon.com/gp/product/B00KYYPDWW/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1
[2]It would be hard to buy just a few of these. Buying 100 is not terribly expensive, but you could go to the hardware store and buy small blister packs of insulted butt connectors of this size, and cut the plastic insulation off if you want to solder. The 10-12 ga connectors will be yellow, and the 14-16 ga will be blue.
[3]If you are willing to buy 50 of these connectors, the Parts Express price is good. My assembly instructions further on show how to pull the insulation off so you can solder, if you want to. You can also buy kits of many types of insulated connectors at Amazon or eBay, and have an assortment of connectors for future projects.
[4]You can probably buy one of these or something similar at the hardware store. I don't recall whether I got mine from eBay or at a hamfest. Look around and you'll find something suitable.

Wiring and Diagram

For those of you that are hip to this kind of diagram, this is a schematic of BEFORE the new wiring. Not much happening; the wires from the dimmer switch come up to the bulkhead connector, go through the bulkhead connector, go across the top of the finder, and into the grille to light the chosen element of the bulb.



Adding the new wiring, it looks like this.

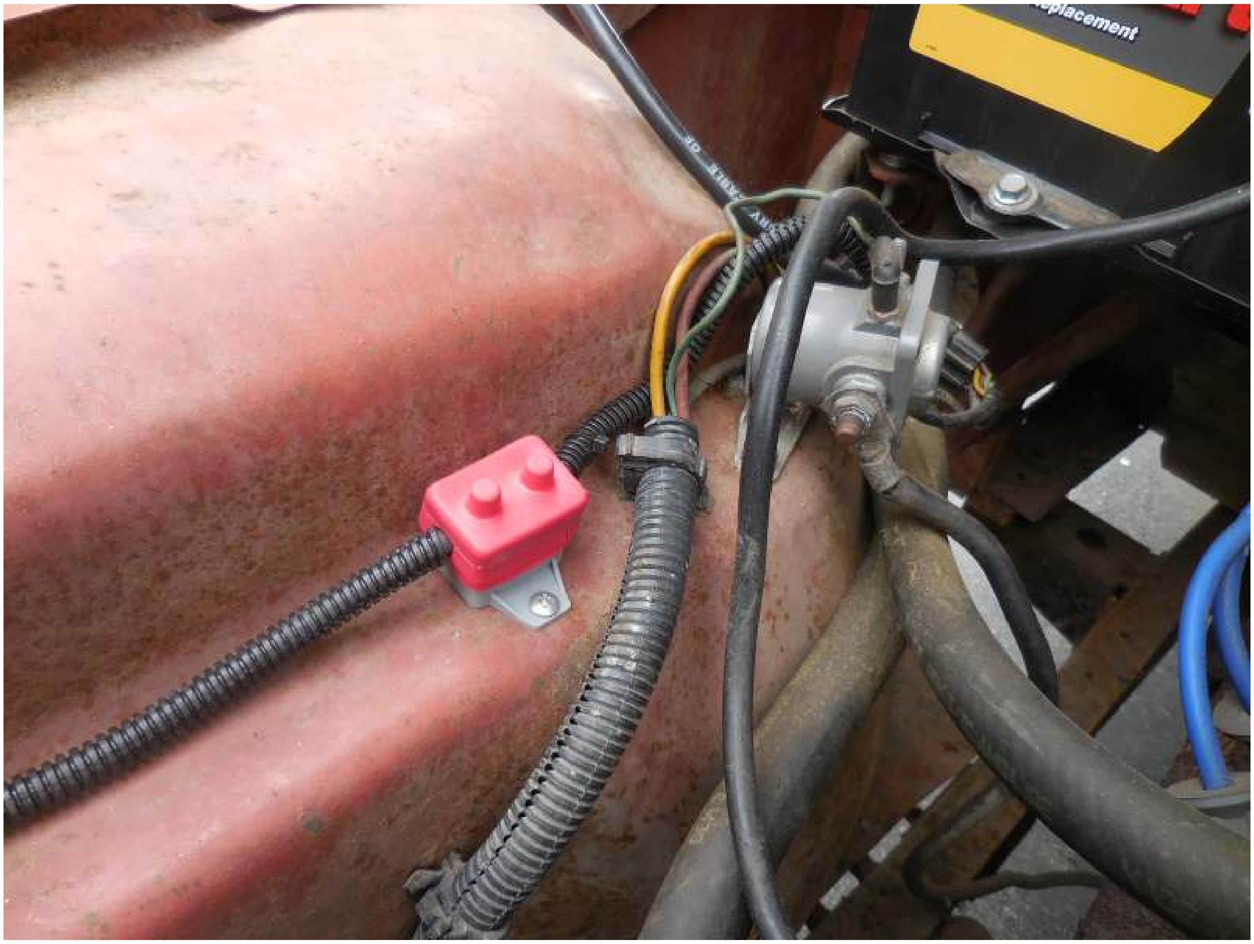


Now the dimmer switch only powers the relay coils. You turn the lights on, and depending on the position of the dimmer switch, either the high-beam or low-beam wire goes high (ie to 12V). RY1 is the high-beam relay, and RY2 is the low-beam relay. The 3 short lines in an upside-down triangle is ground, here the fender steel where the relays are mounted. Current from the dimmer switch goes through the relay coil and back to the battery, energizing the coil and closing the NO connection. This supplies current to the headlamp directly from the battery via our big fat wire. S1 is a fuse symbol, but it represents our circuit breaker or whatever kind of protection you want to insert to guard the new wiring.

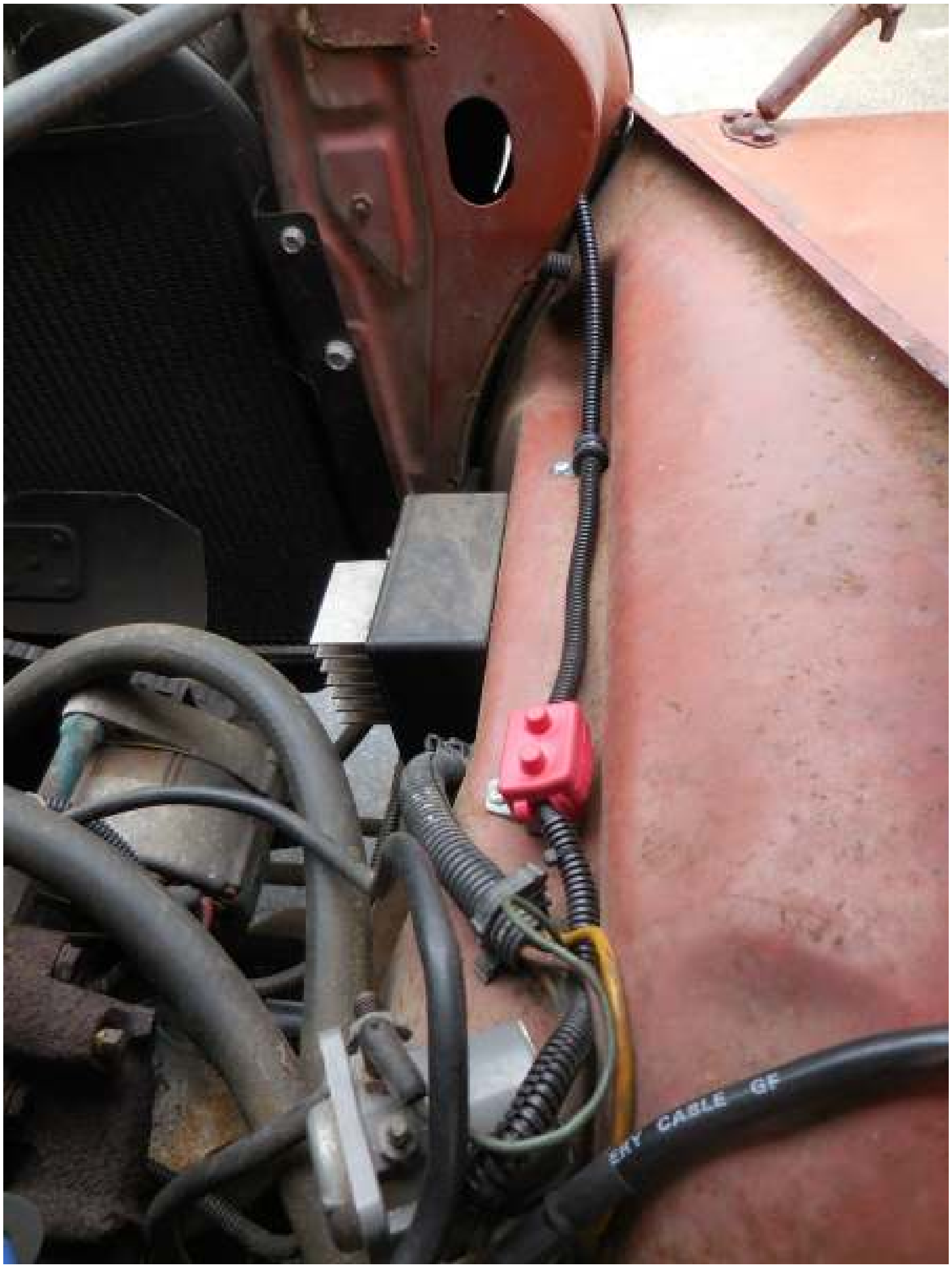
Assembly Including Splices

We start with an overview of everything assembled. These are the relays mounted on the fender.

I suppose my '75 is more like a '76-on, looked at from here. You see the two clearly labeled relays and their sockets. The black corrugated plastic tube is called "split loom" and it's used on cars a lot. Not surprisingly, it is split down its length, so you can pull wires out and push them back. Very tidy. All the wire you see here came with the sockets; the original wire is inside the loom. We will see that later. The smaller loom protects the big fat wire that comes across the grille to feed the relays.



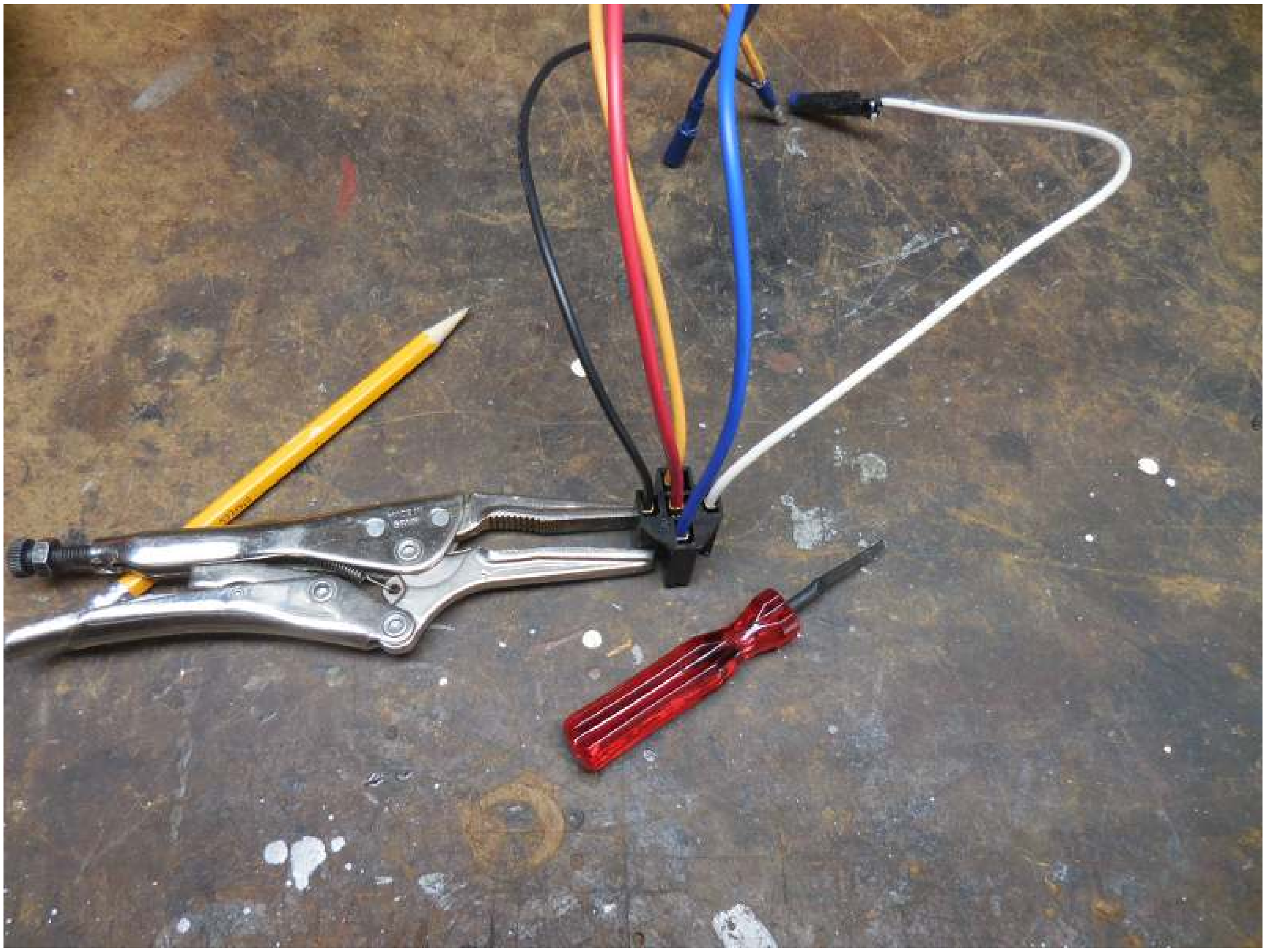
This is the opposite side. You can see that the big fat wire is protected here by loom, from the solenoid, to the circuit breaker, and across the fender. Another view -



You can see one wire clamp and the loom disappearing into an existing hole in the grille. The wire and loom go across the underside of the grille (behind and above the grille bars), supported by the existing loom that contains the factory lighting wiring.

Preparing The Sockets

You don't have to, but I remove the unused wires from the sockets.



Remember that you can look at the pins of the relay (or the back of the socket) and know what each pin is by their schematic layout? Black and white are the 85 and 86, the coil connections. Yellow is the NO connection 87 that goes to the headlights. Blue is the connection from the battery, 30. The red wire in the center is 87a, the NC connection. We won't be using it, and it's in the way. The tool you see here is used to release if from the plastic shell of the connector. You can also use a sharp, thin probe like a dental pick or jewler's screwdriver, but this tool fits exactly.

Put the tool in from the front (relay) side, push on the tab and out it comes.

Here's the tab.

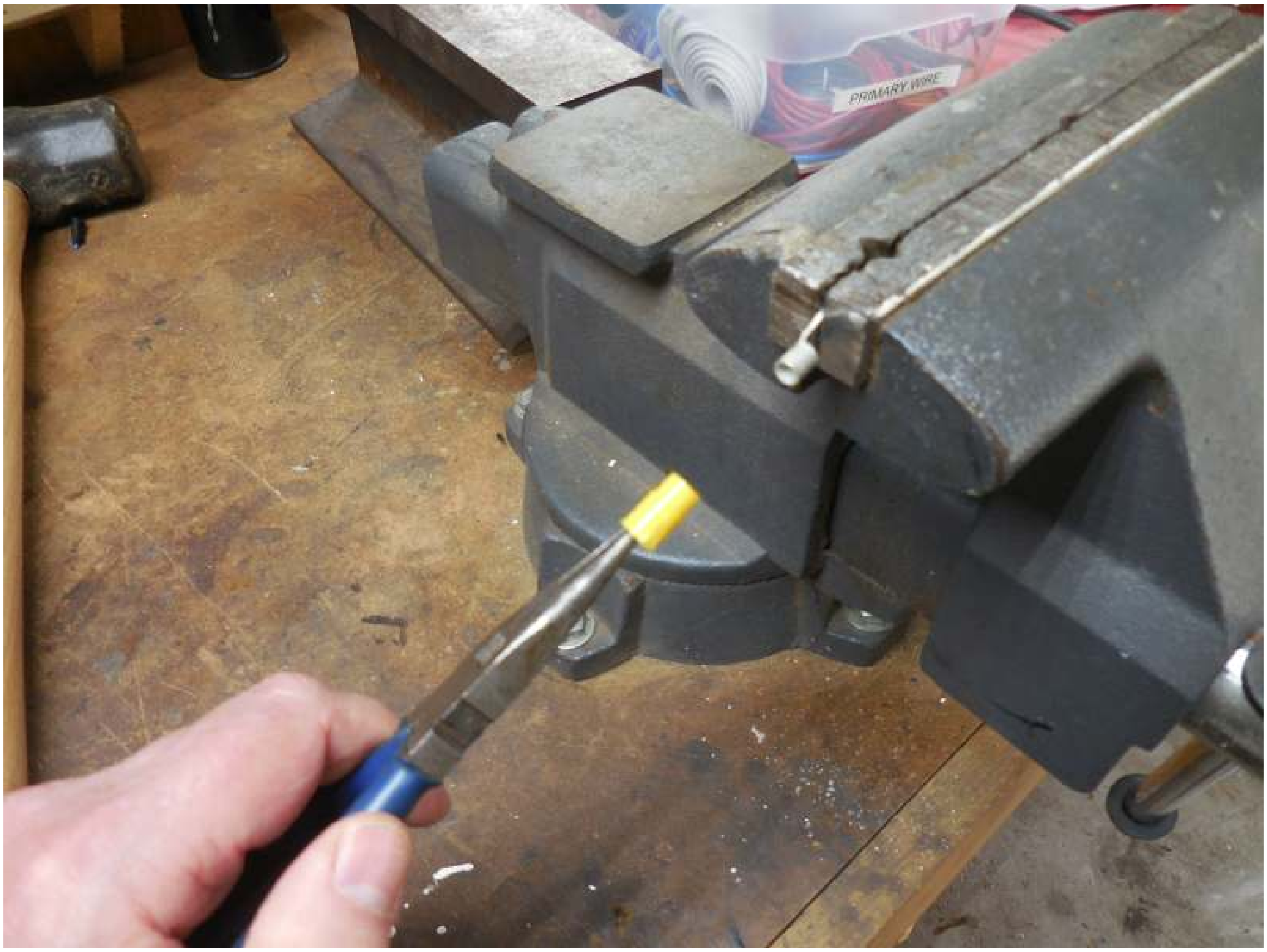
Making Connections

I always crimp and solder. First you strip the ends - I find that the automatic stripping tool makes this go very much faster. I have this Klein in the garage, and I also have a Gardner-Bender that is very good on my indoors bench (links below).

These butt connectors seen below come in different sizes for different sizes of wire. I always cover with 3M adhesive-lined heat-shrink tubing - linked above in the parts list. Once the two ends are bare and you have selected the proper size connector, cut a length of heat shrink about twice the length of the bare metal joint and place the length of heat shrink tubing over one end of the wire (don't forget this!) and slide it far away from the joint so it won't be affected by the heat of soldering. Don't forget to put the heat shrink over the wire before you crimp! If the wire is old and not shiny, use extra flux. The brand of liquid flux I like is shown here - link below. I have a little squeeze bottle that looks like a blunted hypodermic needle glued on a medicine bottle (maybe I will link below - it has a story). Crimp and solder - hot iron, get in, get out. Let the work melt the solder while you apply heat. Aim your solder wire for a gap or a hole in the connector to let solder wick into the joint. The butt connectors have a little divot in the middle that goes in.

These joints are nice and slender and usually you can get them back into the loom just like they were before. The tubing also grips the wire (adhesive!), is waterproof (adhesive!) and sort of rigid-like when it cools. A really solid joint, electrically and mechanically.

You can convert insulated connectors into non-insulated and solder them. Connectors like ring terminals are easy - just pull the insulation off.

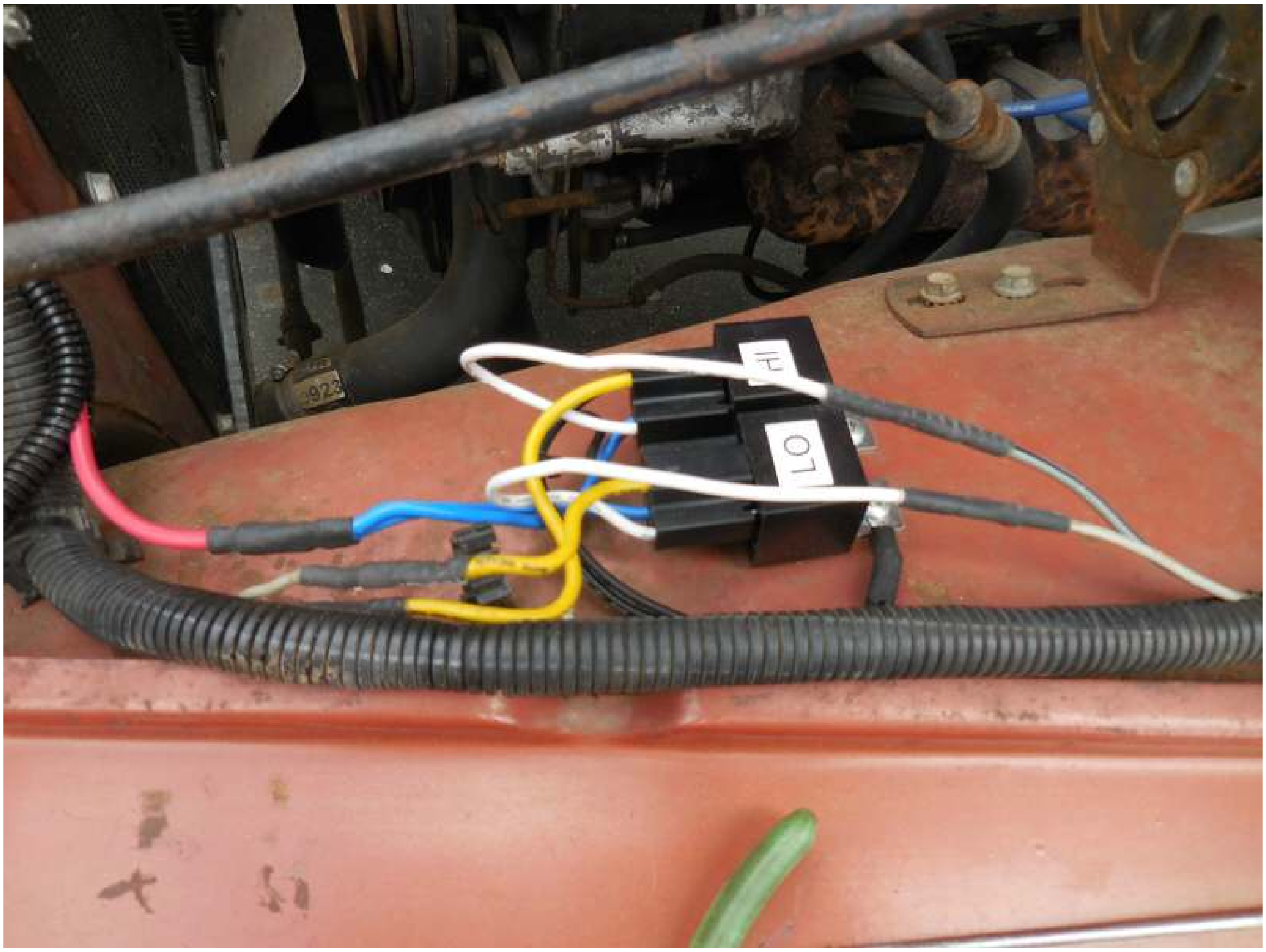


Connectors where the insulation covers the metal like butt connectors or the female side of bullet connectors are harder - I alternately score the plastic with my utility knife and peel at the plastic with my pliers till it comes off.

I like to package wiring like this using split loom and zip ties. Links are in the parts list above.

You won't get any pictures of me actually building this, since it was finished before the idea for this document. However, I have graciously pulled the wires out so you can see what it looks like sans culottes, so to speak.

This is the battery side, showing the BlueSeas circuit breaker and its rubbery cover. I suspect this is the WVE circuit breaker you can buy from RockAuto inexpensively. The rubbery cover is available on Amazon. Not much to see here.



More to see on this side. The split loom goes across the fender here, and the gray wires go to the headlights. Not surpising that the high-beam wire is 14 ga (gray with trace/stripe) and low-beam is 16 ga (gray). The white wires go to the positive side of the the coil of each relay. You can see how the black wires from each coil are gathered together into a single small ring terminal that is grounded to the fender through one of the attaching screws. These circuits allow the wires from the dimmer switch to turn the relays on and off. The big red wire has traveled inside the grille to the connection with the two blue wires here. These blue wires provide current to the relay when switched on by the respective coil. The yellow wires are the current output from the NO contact of the relay. These connect back to the gray wires going to the headlights.

The relays are here because this is a convenient place to put them, with easy access to the gray headlight wires. It is also advantageous to put the relays as close to the headlight bulbs as possible. See the above discussion of wire loading. On my '73 (back in 1973) I put the relay shown above on the right fender, because the headlight wires go to the headlights across that fender. A '73 does not have the fuse panel or the bulkhead connector of my '75. You will have to work out the best location and wire routing for your Jeep's design.

Ok, all back together and tidy.

Tools

Wire Crimpers - I use these
https://www.amazon.com/gp/product/B00004SBDI/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1
They are good for manual crimpers, and not expensive. A ratcheting crimper would be better if you don't solder.

Wire Strippers - These are great. I'm surprised so many struggle to strip wires without them.
These are the ones I like for electronics work -
https://www.amazon.com/gp/product/B00004WLL0/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1
This pair is what I show above and I keep in the garage -
https://www.amazon.com/gp/product/B00CXKOEQ6/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1

Electrical Connector Extractors
https://www.amazon.com/Extractor-Tool-and-Picks-0660PT/dp/B0002JMYKS

Heat Gun - You need something for heat-shrink tubing. Don't be a caveman and use a lighter or butane torch or such! Even a cheap heat gun will work fine.
https://www.harborfreight.com/power-tools/heat-guns-knives-seamers/heat-guns/1500-watt-dual-temperature-heat-gun-56434.html

Weller Soldering Gun - I have two of them; I bought a second one when I thought I'd lost the first, and then found it. I think they are great for automotive wiring. Keep the tip tight and they heat up fast, and deliver a lot of watts. Don't know why Amazon does not sell them, but they are apparently still available. Or pick up a used one for a few bucks.
https://www.homedepot.com/p/Weller-100-Watt-140-Watt-Soldering-Gun-Kit-9400PKS/301430491

Solder - You want quality rosin-core tin-lead solder, not lead-free. I use Kester; you want a wire size that's not tiny. This roll of 0.031" would probably be ok; I use 0.050" diam in my garage. Or order from Mouser or Digikey and get exactly what you want. Get 63/37 Sn/Pb (the eutectic mixture) or 60/40. They each melt at nearly the same temperature. Rosin core or self-cleaning.
https://www.amazon.com/Kester-24-6337-8800-Activated-Solder-No-Clean/dp/B00068IJOU/ref=sr_1_4?dchild=1

&keywords=kester+solder&qid=1590878073&sr=8-4

Flux - I like this
https://www.amazon.com/MG-Chemicals-Liquid-Leaded-Solder/dp/B005DNR01Q/ref=sr_1_2?dchild=1&keywords=MG+flux&qid=1590878891&sr=8-2

Flux bottle - this is what I bought, but I don't recommend it. The bottle does not look like the picture, and I complained and asked to send it back. The seller just refunded my money. Works ok, but not what I wanted. Caveat emptor.
https://www.amazon.com/gp/product/B00UG08QDC/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1

Fusible Link Instead?

After finishing this project, I had a discussion with someone on another forum about the relative merits of fusible links and circuit breakers. Jeep uses two fusible links in my CJ-6, and later models have even more of them. The objective of a fusible link is to protect the Jeep from the battery. In normal use, these links never come into service. Barring some mitt-fisted action by an owner, they would only be important in a catastrope, like a bad wreck. If you set off the fusible link, you are unlikely to need rapid repair, like resetting a circuit breaker.

https://www.amazon.com/gp/product/B001BXR9L8/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1

Today, I would likely use a 14ga fusible link in place of the BlueSeas circuit breaker. I took care to protect the wire and prevent an accidental short. The main reason I added the circuit breaker is because I always had, and that's how I was told to wire it up when I was a teenager (just barely a teen - I turned 20 in August of 1973). The fusible link would be simpler, less expensive, provide the same protection from electrical fire that the circuit breaker does, and extend the protected length of the wire all the way back to the solenoid. It eliminates two ring connections, replaced by a soldered splice. It eliminates any contact resistance in the circuit breaker. It adds the resistance of 9" of 14 ga wire in place of 9" of 10 ga wire… very likely much less than the connection and contact resistances that are gone.

Further Improvements?

What might we do to improve these lights? One might go to different reflectors (e-code, for instance), or higher wattage bulbs. I want to stay within the law, so I don't have to change out a bunch of stuff to pass state inspection. That's not for me.

If one wanted thes hotter bulbs, it might require a change to ceramic headlight bulb sockets instead of the hard plastic (phenolic?) sockets that come original equipment. You could also change to bigger gauge wire from the relays to the sockets, though on my CJ-6 the relays are already rather close to the bulbs. Better grounds might show some improvement. The headlights are grounded to the body steel, which has to go from grille to fenders to body shell to reach the battery. A heavy jumper from the engine ground to the grille might be worthwhile. I have wondered about this in the past - the steel body is a poor conductor compared to copper wire, but there is a lot of it. Does the shear mass of steel in the body make up for steel's inferior proerties as a conductor? Could we measure a voltage drop from the headlight grounds to the battery? Hmm.