Electrical Modifications II

Steve Maas
Long Beach, California, USA
October, 2009

My 1960 Austin Healey Sprite has a number of electrical modifications, including a radiator fan, electrical fuel pump, and electronic ignition. I had also made some modifications to reduce the current in the ignition switch. After several changes, the electrical system was rapidly becoming a kludge, so I decided to straighten it out a bit. I also wanted to convert it to modern automotive fuses and add relays for the headlights. An important aspect of the modification was to improve the circuit protection, and concomitant fire resistance, by making the fusing more sensible than the original Sprite design.

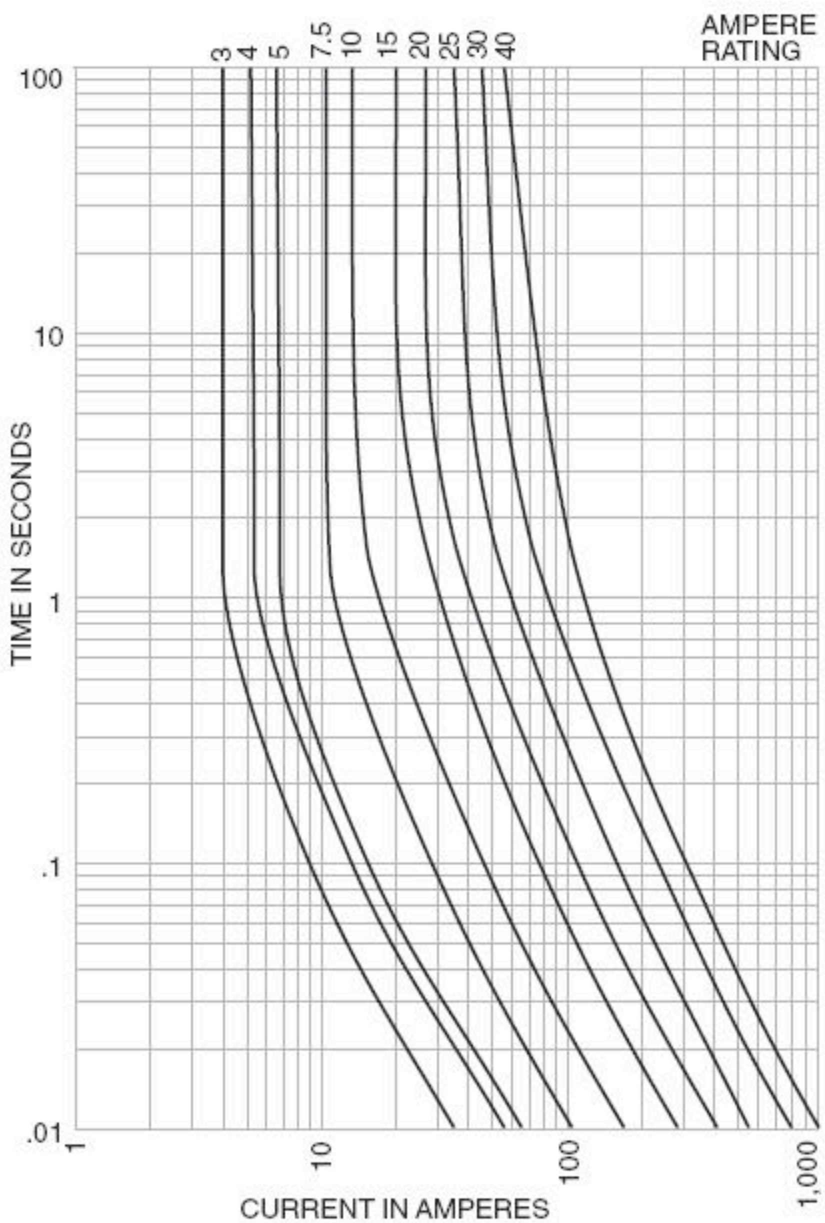
Fuses and Fused Circuits

Fuses seem simple enough, but they're broadly misunderstood. For this reason, I think that a brief tutorial is warranted.

A fuse consists of a short segment of a soft metal that heats up when current passes through it and melts if that current exceeds some established value. By limiting current in a circuit with such a device, a fuse prevents the possibility of a fire, or other circuit damage, caused by the excessive current. According to modern standards, a fuse's rating is the maximum current it can reliably carry without "fusing" (i.e., open-circuiting or "blowing"). Previously, other standards were used; for example, in the UK at the time the Sprite was built, fuses were rated as the the current that would cause "instantaneous" fusing. As we shall see, such a current is difficult to determine. Typically, it is approximately twice today's rating.

The time required for a fuse to blow depends on its current. The figure below shows the fusing time vs. current for a number of Buss ATC automotive fuses. (Buss is a major fuse manufacturer, and the ATC fuse is the type most commonly used in modern cars.) The values on this graph should be interpreted as the *maximum* time to open-circuit at a given current. From this graph, it is clear that there is a "no man's land" between the rating and the current at which the fuse blows in a reasonable time; say, less than 100 seconds. If, for example, the 3-amp fuse were to carry 3.5 amps, it might last forever, or it might blow in a few minutes. The behavior at this level is not at all certain. On the other hand, the time required to blow the fuse decreases rapidly at 4 amps, and, above 4 amps, it will blow in less than a second. All the fuses of 20 amps or less, described by the chart below, will blow in less than one second at double their rated current. The larger ones take a little longer, but even the 40 amp fuse will blow in less than 3 seconds at double the rated current. This is the basis for the idea that fuses blow "instantaneously" at twice the rated current, and the justification for using modern fuses rated at half the old, British rating.

We should note that the fusing current varies with temperature. The higher the ambient temperature, the less heating is necessary to bring the fuse element to its melting point. Thus, the curves below shift somewhat to the left as ambient temperature increases. The curves are for 25C (77F) ambient; at 60C (140F), a common under-hood temperature, the rated current decreases approximately 10%. This point is important to remember for selecting fuses mounted in an engine compartment.



A fuse should be selected according to the maximum current expected in the circuit, including consideration for ambient temperature. It is customary to allow a margin of approximately 30% for uncertainties in the current load, the possibility of current surges at turn-on, and similar phenomena. For example, suppose the maximum current in a circuit is expected to be 7 amps. A 30% margin gives 9.1 amps, and allowing for an approximate 10% decrease in rating due to a high ambient temperature, a 10-amp fuse would seem appropriate. Of course, fuses are available in only a limited set of values. If this calculation had called for, say, a 12-amp fuse, it would be necessary to use a 15-amp fuse and to size the wiring appropriately.

There's nothing holy about the 30% margin used in the above example. In many cases, where the maximum current can be determined precisely, the margin can be decreased. Conversely, when the current is less certain (e.g., it might vary with temperature or might include a turn-on surge), that margin, or even more, may be necessary. One good reason to reduce the margin is that the next fuse rating is simply too high. Consider a case where the maximum current is 9 amps. A 10-amp fuse is only 11% over the maximum, so one might be tempted to use a 15-amp fuse instead. From the chart above, the 15-amp fuse might not blow at all until the current reaches 20 amps, however, and it may require 30 amps to blow in less than a second. That might be too much for the wiring in the circuit, so, all in all, the 10-amp fuse, even with minimal margin, may make more sense.

Wiring

While the fuse is selected to allow the maximum current in the circuit branch, the wiring must be sized so that it can handle any overcurrent condition until the fuse open-circuits. The greatest concern in wiring is for insulation damage, not melting of the copper wire itself. If the insulation overheats, it could catch fire, and if it melts, a dead short might result. That would draw enormous current, and, unless a fuse blew quicky, the wire could get hot enough to start a fire somewhere in the car, or even to melt the copper conductor. Heating would be greatest near connections, where the resistance is higher, and any flammable material near a connection could ignite. On the other hand, as long as the circuit is properly fused, high currents blow the fuse rapidly, so as long as the circuit is fused and the wiring is properly sized, even high currents are not a great concern. The real worry is for high currents, resulting from a failed component, that do not blow the fuse or do so only after some period of time.

Unfortunately, the criteria for selecting an appropriate wire size are not at all clear. Residential electrical wiring has specific standards for current loading, including the well know requirement of no. 12 wire for the ubiquitous 20-amp branch circuit. These standards were developed after extensive testing and require that the insulation on the wire itself meet certain standards. Because house fires cause expensive damage and can result in fatalities, those standards are extremely conservative. In cars, however, the criteria for wire selection are much less clear. Automotive wire varies in quality, and much of the wire available in auto-parts stores does not meet any standards for the melting point of its insulation. Additionally, the ambient temperature is often high and the wires are often bundled into a wiring harness, where they cannot dissipate heat easily. This seems to imply that cars should have even larger wiring, for a given current, than residential wiring. However, since the consequences of wire heating in cars are not as great as in a house or commercial building, smaller sizes are actually used. Typically, no. 14 or occasionally even no. 16 wire is used for 20 amp circuits in cars. In this installation, I used no. 10 wire for the high-current branches (e.g., alternator output), no. 14 for 20-amp branches, and no. 16 for all else. I left existing wiring in place wherever it made sense; usually, the current in that wiring was reduced relative to the original design.

It is possible to find published charts of wire size vs. current for automotive wiring. These are usually based on limiting voltage drop in circuits, not on preventing overheating. If a chart lists wire size vs. length of run, it is based on the voltage-drop criterion, not heating. The temperature increase in the wire does not depend on the length of the wire run: doubling the length of the wire, for example, doubles the power dissipation in the wire but also doubles the area available for dissipating that heat, keeping the temperature the same.

Automobiles should use stranded wire, not solid. Connections are subject to vibration, which would work-harden solid wire and lead to its breakage. Stranded wire is much more flexible, and thus is more resistant to this problem.

Design of the Fused Branches

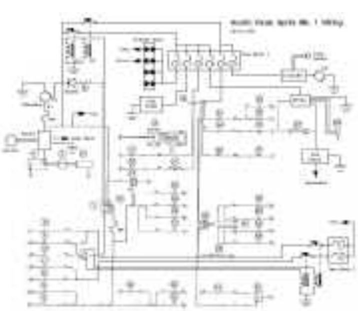
Inevitably it is necessary to assign the electrical components to a number of fused branches. This requires some thought. Some of the considerations are as follows:

1. A large number of low-current components should not be protected by a single fuse. In this case, a failure could draw enough current to create a fire danger in the component where it occurs, without blowing the common, high-value fuse. In such instances it may be necessary to fuse low-current components individually, as well as fusing the entire branch.
2. The larger the number of electrical components powered by a single branch, the more difficult it is to determine the cause of a blown fuse and the larger the fuse value has to be, relative to the individual component currents. Ideally, each component would be assigned its own fused branch circuit, but this is usually impractical. Sensible trade-offs are in order.
3. A failure in a nonessential component should not shut down essential functions. For example, it makes no sense to put the fuel pump and the tachometer in the same fused branch. In that case, failure of the tachometer might blow the fuse, shutting down the fuel pump and disabling the car unnecessarily. On the other hand, putting the ignition and the fuel pump on the same fused circuit might make sense, as failure of either component has the same consequences.
4. It's always best to have all the fuses in one location (say, a single, large block) but sometimes, especially if existing wiring has to be modified, that is not practical.
5. Even though a certain amount is unavoidable, unfused wiring still should be minimized.
6. It's important to distinguish between wiring and components that are always "hot" and those that are powered only when the car's ignition switch is turned on. The former deserve much more consideration, as a failure potentially leading to a fire might occur when no one is around. When the car is in use, however, the smell of burning insulation is unmistakable, and the driver can attend to it immediately.

As with all things in engineering, some of these requirements result in competing trade-offs. This is where good judgment is necessary.

The Revised Wiring

The revised electrical wiring circuit is shown in the figure below, as is a photo of the installation. (Click on the thumbnail to open a larger version of the diagram.) The picture may not correspond perfectly to the wiring diagram; I made some minor changes after the picture was taken.




The original Bugeye electrical system had only two fuses. One protected the switched part of the circuit (i.e., components that are turned on and off by the ignition switch) and a second fuse protected the unswitched part, which consisted only of the horn. Parts of the circuitry, including the ignition circuit and the headlights, were not fused at all. These parts were presumably left unfused to prevent the failure of a fuse from creating a dangerous condition.

To determine the electrical load on each branch, it was necessary to measure the current required by each component. Lights are easy to estimate, as their currents are listed in the bulbs' specifications. The 1156 uses 2.1 amps, and the two filaments of the 1157 use 2.1 and 0.6 amps. Other components had to be measured. I found that the heater fan, for example, uses 3.5 amps and the wipers 4 amps. The horn requires an average 6 amps, although its current varies rapidly between 0 and 12 amps.

The main fuse block, Fuse Block 1, controls switched components. Power to the block is switched by two relays, R1 and R2, each of which controls approximately half the current. Two relays were necessary, as the maximum switched current would have been close to the maximum allowable for a single relay. The electrical load, including that of new components, has been divided into a number of branches, according to the criteria listed above. The previous switched branch has been divided between two fused branches. One branch powers the brake lights and turn signals. With this arrangement, the failure of that fuse is immediately obvious, since the turn signals won't work; if the brake lights were on a single circuit, the failure of a brake-light fuse would create a safety hazard with no immediate warning. The rest of the switched components (heater fan, wipers, and fuel gauge) are another fused branch.

One fused branch powers a terminal strip. This strip can be used to connect additional, low-current components. At present, the tachometer power and a cigarette-lighter socket (used for connecting a GPS or an iPod, not for a lighter!) are connected to this. If further high-current components are connected here, it may be necessary to increase the fuse rating and to fuse low-current components individually.

Connections to the fuse block use spade lugs, which are soldered. I prefer this to crimped connections. The spade-lug connectors are covered by heat-shrink tubing to prevent short circuits from inadvertent contact. The terminal strips use circular lugs, also soldered and shrink-wrapped.

A 1N4006 diode is connected in series with the D+ connector of the alternator. It was found that the D+ point on the alternator was not a simple, passive load; it could provide power to the relays, keeping them closed, when the ignition was switched off! The diode prevents this from happening. An alternative might be to connect the white wire from the ignition light to the terminal strip, but then it might still feed power back to the supposedly switched components. Even if this were not enough power to keep the car running, I don't like the idea of circuits remaining powered in any way when they are supposedly switched off. As it stands, this is a short, innocuous lead from the ignition switch to the lamp, which is, after all, unpowered when the car is off. The replacement would be much longer, albeit fused, but with more locations where shorts could occur.

A second fuse block, Fuse Block 2, distributes unswitched power. At present, it is used only for the headlights, which are now controlled by relays R3 and R4, and the horn. Separate relays and fuses are used for the low and high beams; this way, failure of one fuse does not shut down the headlights completely. If I were to add a radio, it would be connected to this block as well. Radios are usually run from unswitched power, so information in their electronic memories is not lost.

A 75-amp barrier strip is used as the common connection for the main 12V power. This is the "+12V" point on the circuit diagram. From this strip, the main electrical wiring fans out to the various relays and fuse blocks. The positive battery terminal is connected to this block, through the ammeter sensor, of course, as is the alternator output.

I was concerned that the car still had considerable "hot" (unswitched and unfused) wiring. A certain amount of this is inevitable, if only the connection from the battery to the fuse block. In the Bugeye, the main wire from the battery goes through the firewall into the area behind the dash, then back out to the high-current terminal strip. From there, a conductor returns to the ignition/headlight switch, whose outputs go to the switched-power relays, sidelights, and high-beam footswitch. So that long runs of wire like this would not be left unprotected, I added appropriate in-line fuses from the headlight/ignition switch to the high-beam switch and to the sidelight circuit. These are located under the dash, near the ignition switch. It would be preferable, from a practical standpoint, to locate these fuses in the same blocks as the others, but that would require longer unfused wiring runs, which is what the fuses are intended to eliminate. Another possibility would be to place a 10-amp fuse in the wire from the battery to the ignition switch, but this would kill the entire electrical system if only a small part (say, the license-plate lamp) short-circuited, a distinctly undesirable possibility. This illustrates the kind of dilemma one frequently encounters in modifying an existing installation. It would be possible to redesign this part of the circuit for better fusing, but it would require replacing the existing combined headlight/ignition switch with separate switches. That would detract from the original appearance of the car's dash, which would be unacceptable in many cases.

Disclaimer

I don't like saying this, but I suppose it's necessary, now that the lawyers have taken over American society. If you choose to do this, or something similar, but don't know enough about automobiles or electricity to be comfortable with it, get some help. The consequences of wiring errors in high-current circuitry, as exists in any automobile, can be serious. In any case, I'm not forcing anyone to make this modification, so if you choose to attempt it, you take full responsibility for the results. This is just a report on my experience with these modifications. It is not intended to be a set of instructions for duplicating my work or a recommendation to do it. It's entirely possible that some of the things I've done in this installation may not be consistent with existing automotive wiring standards and practices, or may even be unwise. You're on your own.

Return to the Sprite page...