



Everything you always wanted to know about....

Vehicle Wiring

but were afraid to ask.....

by
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*The way electronics are wired in mobile equipment plays a major role in their performance.
This paper highlights points that should be considered when wiring vehicles.*

Introduction

The problem with Wires

The primary problem with using wires for conductors is that they are not perfect conductors. All wires have some level of resistance, capacitance and inductance, which varies and is based on the physical construction or composition of the wire.

Resistance in the wire causes a voltage drop across the wire that is directly proportional to the current going through it, multiplied by the wire's resistance. The higher the current, the higher the voltage drop will be, across the wire. Larger gauge wires, more conductive wire and shorter lengths can reduce this resistance.

The simplest way to think of wire capacitance, is that it transfers energy to and from nearby wires or components. This transfer of energy is not the same at all frequencies. Typically the higher the frequency, the better the transfer (coupling). A voltage spike is much more likely to effect nearby wires than a DC voltage. This coupling is also dependent on proximity and distance. The closer the wires are and the longer they run next to each other, the better the coupling.

Basically, a wire's inductance increases its resistance. This is due to the magnetic field that every conductor creates. The magnetic field resists any change in itself and the effect is more pronounced at higher frequencies. This effect slows down and attenuates higher frequencies, but is virtually invisible if the current level does not fluctuate.

An extension of every wire is the connector used to attach one wire to another. Connectors also increase resistance in the overall wire harness. This occurs due to the surface resistance between the contact pins and between the wire and the contacts. Although connectors increase serviceability, they will also increase noise and decrease the overall performance.

Resistive Effects

In this section, we will ignore the capacitive and inductive nature of wires, and assume that they are purely resistive. We will also ignore the connectors. If all electrical devices used a constant current, then there would be no noise problems. However, that is not how the real world works. Lights need to be turned on and off, coils need to be activated and deactivated, etc. Thus the current through wires rarely remains constant. Ground wires are a particular problem, since most electronics are tied to ground, everything effectively funnels down into the ground lines.

Ground Bounce

The term “Ground Bounce” describes the condition when the voltage of a ground point or wire changes with respect to the (–) BATTERY terminal (reference point). This is usually due to a change in the current through the ground wire. This is illustrated below, as a simple battery, switch, and coil circuit.

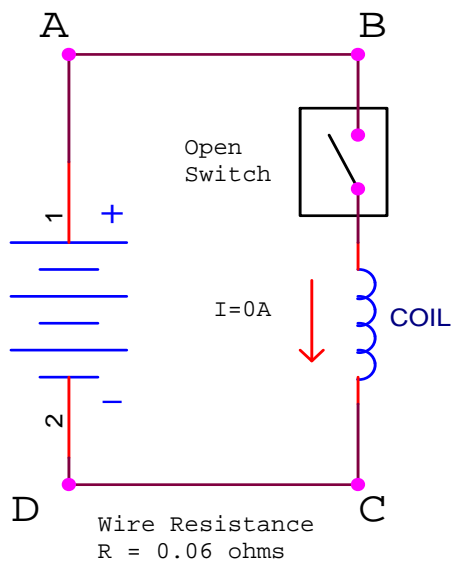


Figure 1

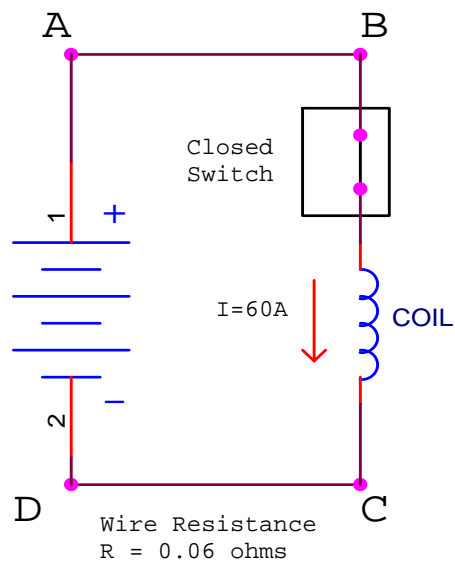


Figure 2

If we assign point D as the 0V reference point, then all voltages are determined with respect to point D. Point D is where the Common lead of a volt meter is attached. In figure 1, since the switch is open, no current is flowing. Thus there is no voltage drop across the ground wire. The voltage at point C is the same as the voltage at point D, which is 0V.

In figure 2, the switch is closed. Now the current (I) is flowing through the ground wire that now has a resistance (R). This causes point C to be IR volts above point D. If the coil is a starter solenoid rated at 60A and the wire is 10 feet of 18AWG stranded copper wire, the voltage at point C will be about 3.6V. Decreasing the current, shortening the wires or using larger gauge wires would reduce this effect.

Supply Droops

For the lack of a better term, “Supply Droops” are the same as “Ground Bounces”, but in supply lines. Thus in the above example, if 10 feet of 18AWG wire was used to connect the battery to the switch and the switch to the coil, there would also be a 3.6V drop from the battery to the high side of the coil (from point A to point B). Thus, if the battery is 12VDC, then the voltage at point A is 12V. The voltage at point B is 8.4V ($12V - 3.6V = 8.4V$). This leaves only 4.8V across the coil, from point C to point B, with the other 7.2 volts across the wires themselves.

Cross Talk

If more than one electronic device or electrical load shares the same wires, then the Ground Bounce and Supply Droops generated from one of the devices or loads, will effect the others. Consider an example of an electronic controller being attached in parallel to the coil in the previous example.

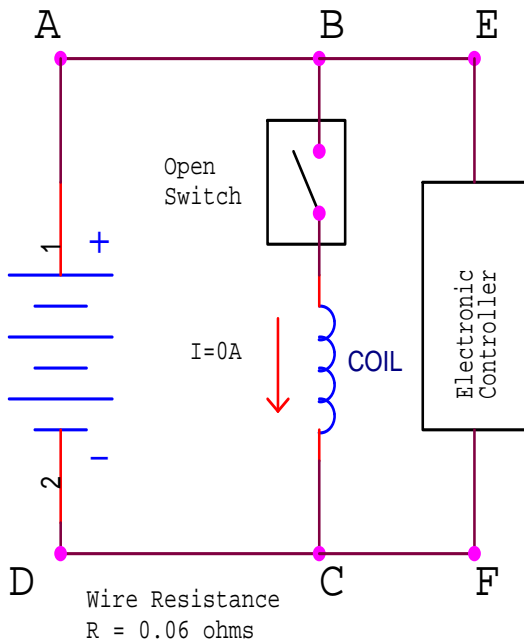


Figure 3

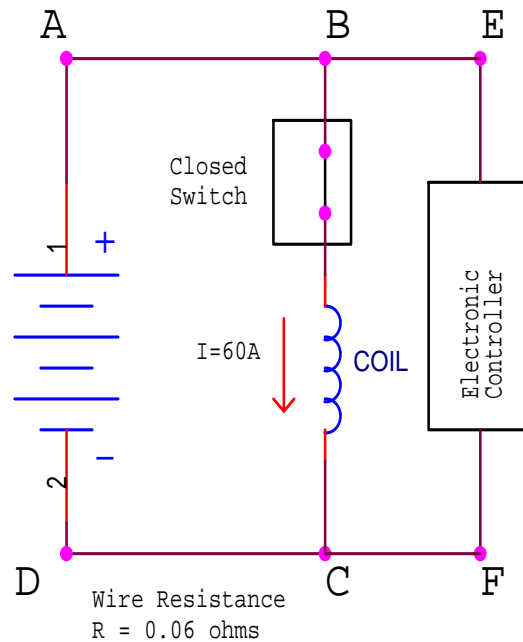


Figure 4

When the coil is off (figure 3), the electronic controller has the full battery voltage across it. That is, the full voltage minus what the wire resistance drop is for the Electronic Controller's current. However, when the switch closes (Figure 4), to turn on the coil, the picture changes. Now the Electronic Controller sees less than the 4.8V as calculated in the Supply Droop paragraph. The more current the Electronic Controller draws, the lower this voltage will be.

Star Pattern Wiring

The best way to reduce cross talk is to run separate wires to the battery, from each device. This wiring arrangement is called a star pattern. This basically separates the individual wires so they branch out from one central location.

Figure 5 and 6 shows the same circuit as in Figure 3 and 4, except that there are separate wires for the coil and Electronic Controller to the battery. Assuming that the battery is capable of maintaining a constant voltage (i.e. 12V) when the coil is ON, then the Electronic Controller is not effected by the status of the switch and coil. That is, if the voltage at Point A is 12V in both Figure 5 and Figure 6, then the voltage at Point E and Point F are also the same in both figures. The Electronic Controller is essentially isolated or de-coupled from the coil.

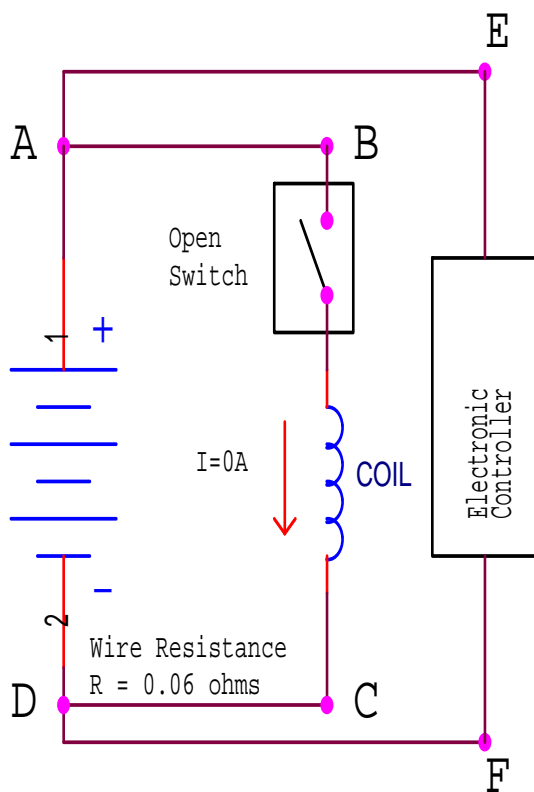


Figure 5

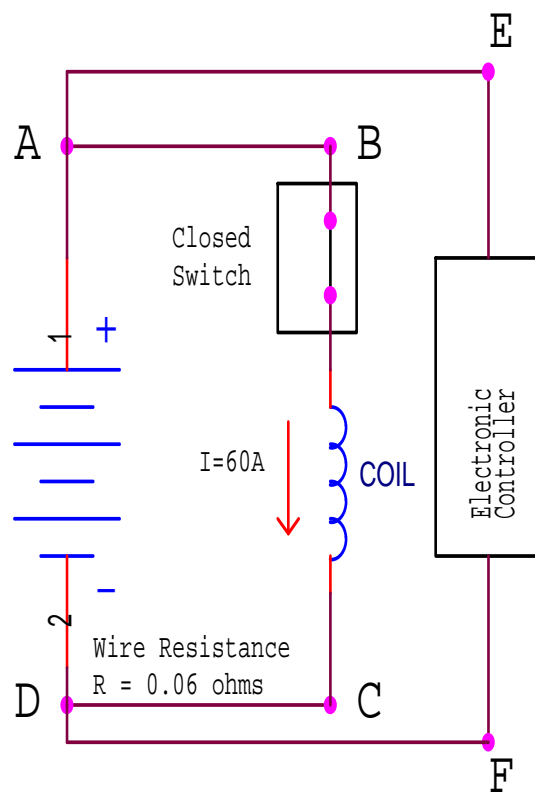


Figure 6

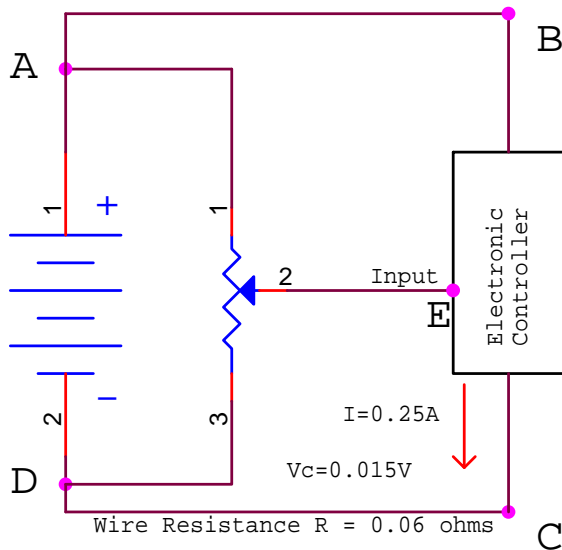


Figure 7

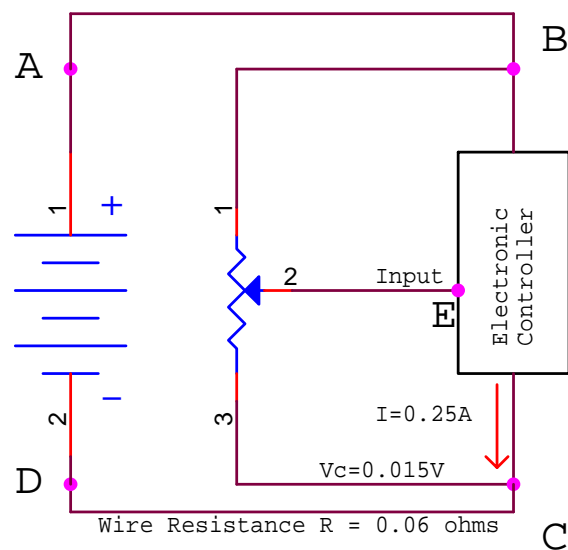


Figure 8

Sensors

The way sensors are wired can create problems. Consider a circuit with a battery, an Electronic Controller, and a potentiometer, point E is an analog input to the controller that is measuring the position of the potentiometer's wiper.

In figure 7, the parts are wired using the Star Pattern. From the previous examples one might think that this is the proper method of wiring. However, for sensors that is not the case.

In this example, the Electronic Controller draws 0.25A. With the 10 feet of 18AWG copper wire, that makes the voltage at Point C equal to 0.015V. In Figure 7, the Electronic Controller will think that Point E is 0.015V less than it really is. This is because the zero point for the Electronic Controller's input is 0.015V above ground (Point D). For some sensors this might be negligible, but for others this might be a substantial error.

If the potentiometer was wired as in Figure 8, with its supply and ground wires connected as close as possible to the Electronic Controller, this error goes away. If Point E is at 2.5V, the Electronic Controller will also see 2.5V. If the Electronic Controller has them, sensor grounds and supplies should be run directly to the Electronic Controller's connector. However, due to size constraints, not every Control can have three pins per sensor. If it does not, try to connect the sensor's ground wire and supply wire as close to the Electronic Controller as possible.

Inductive and Capacitive Effects

This section discusses the effects of wire capacitance and inductance. These two effects create coupling from one wire to another. The coupling happens when there is a change in voltage or current in one wire, with respect to nearby wires. How and where wires are routed can effect the whole system's performance.

Coupling

The term coupling means that current or voltage in one wire can induce current or voltage in another. Every wire generates an electro-magnetic field when current flows through it and when the wires are close enough in proximity, these fields can interact with each other. This can cause an increase or decrease in the current or voltage in coupled wires.

Consider a high current pulsing wire (i.e. running to a Pulse Width Modulated valve), near a lever signal wire (i.e. output from an Electronic Joystick). The lever might be sending a smooth 2.5VDC signal out to the controller, but at the other end of that wire at the Electronic Controller, there is a little pulsing added to the signal. This superimposed pulsing is caused by the other wire coupling some of its energy to the lever signal wire. If there is enough coupling between the high current wire and the signal wire, the signal wire could appear to have a higher or lower voltage than expected. This could make the Electronic Controller think the lever is moving, which could create a highly hazardous situation.

Spacing

The effects of wire coupling decrease with distance. Therefore, the further apart wires can be spaced, the less the coupling. The coupling effect is also cumulative. This means that the greater the distance that two wires are running along side of each other, the greater the coupling. Two wires, six inches apart, for ten feet will have only half of the coupling effect as two wires, six inches apart, for twenty feet. If wires need to be crossed, do so in a perpendicular fashion, as this will reduce the coupling down to a minimum.

Sensitive Wires

Some wires, due to their function, are more sensitive to noise coupling than others. This includes wires to and from sensors, levers, potentiometers and other analog sources. These wires should be kept as far away as possible from noise sources, particularly the problem wires.

Noisy Wires

Some wires will be worse noise sources than others. Thus their coupling to other wires should be considered. The main wires to consider are the main Battery and Ground wires, along with any high voltage, high current, or pulsing (PWM) wires.

Battery and Ground wires are notoriously noisy, since everything on the vehicle tends to be attached to them, so they collect and transmit a lot of electrical noise.

By high voltage, we generally mean signals that swing all the way from battery to ground. The greater the voltage swing, the greater the coupled noise. Typically, any output from a controller that provides power to coils, solenoids or other high current loads can be a substantial noise source due to this effect.

The higher the current change in a wire, the greater the coupled noise. That means high current and inductive loads, like valve coils, solenoids, relays, starters can produce a lot of noise. Signals that change frequently create more noise than other signals. Pulse Width Modulated (PWM) signals that drive proportional valves are typically noisier than most on/off signals. For example, a 100Hz valve when active will have 100 pulses per second.

It is always preferable to route these noisy wires away from others.

Shielding

It may be possible to decrease the coupling in wires, by shielding individual wires, pairs and cables. This shielding is often braided copper and should be grounded at one or both ends of the wire, depending on the application. Shielding is not completely effective at preventing coupling and is not a substitute for good wire routing and proper harness design.



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