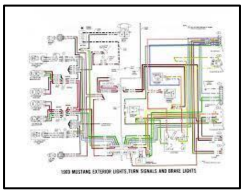
Fundamental Electrical Principles and Fault Diagnosis

+

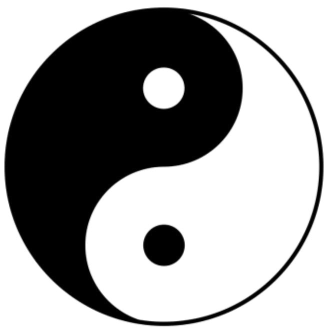
+



+

Fault Finding Guide

=



When it comes to vehicle repairs electrics is by far the area that most people struggle with, not just the weekend enthusiast but also dealership technician alike. Often referred to as “alchemy” or “the devils work” as you are working with something you cannot see and often don’t understand.

It is common for people (including dealerships) to “guess a fix” or spend many hours poking, prodding and pulling things in the hope that an answer to the problem will be forthcoming, which usually it isn’t.

It is my hope that the following information will help keep your blood pressure under control and reduce the number of dents in your garage door from flying hammers and the like. The key to successful electrical diagnosis and repair is to **be logical and always follow a process**, at the end of the day electricity itself follows the rules of physics and always acts in the same way (although sometimes it doesn’t seem like it)

Glossary:

Throughout this tutorial I will use the following terms when explaining diagnostic process etc.

Consumer: - This is any electrical component which has a “live” and a “ground” connection. Called a consumer as it will consume voltage (lights, motors, coils, relays, horns etc).

Component: - Any electrical component that is not a consumer (switch, fuse etc)

Reference voltage: - This is the battery voltage measured across the battery terminals.

Voltage Drop: - This is the difference in voltage between the “reference voltage” and the voltage present at the component/consumer being tested.

Measurements

There is a variety of methods to take measurements in electrical systems, the most common are below

- Multimeters (analogue or digital)
- Ammeters (with or without inductive current clamps)
- Oscilloscopes (this is the only way to measure “data bus” signals in modern electrical systems but can also be used to see ignition coil performance etc)

The key to productively using these measurements to aid accurate diagnosis is to understand

- **What readings you are expecting to get?**
- **What the information you get is telling you?**

Ultimately this is no different to taking mechanical measurements with a micrometre or dial gauge and interpreting the results you get.

The common units of measurement used in electrical systems are below (page 4), remember electricity is a flow of electrons within a closed circuit (it is sometimes easier to visualise what is happening by thinking of the circuit as a heating system where the pump is the battery, the radiator is the consumer and the pipework is the wiring – if there are broken pipes or blockages, the radiator doesn’t get hot)

Multimeter Basics

One of the most common mistakes people make when using a multimeter is to have the leads in the wrong locations. This is easily done but will give very random results leaving the user deeply confused

In the unlikely event you want to measure “Amps” the red lead **MUST** be moved to the 10ADC location.

If you try and measure “Amps” with the red lead in the V-R-Ω location you will blow the meters internal fuse (which is a pain to change) and may damage the meter

With the red lead in the 10ADC location you can measure up to 10amps only. The meter is fused above this value.

If you want to measure “Amps” the easiest way to do this is to connect the meter in place of the fuse as current does not change anywhere in the circuit and this is the easiest access point

Regardless of what you want to measure, the black lead should always be in the “Com” position

For all measurements with the exception of “Amps” the red lead should be in the V-R-Ω location

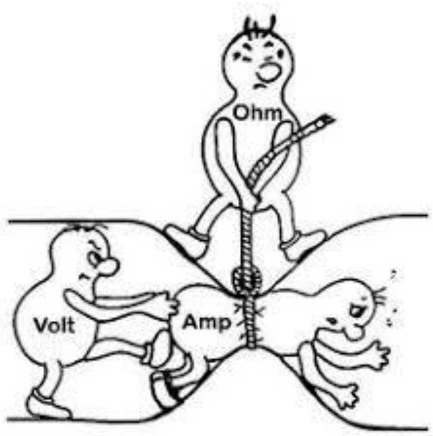
Voltage (Volts) – this is “pressure” which drives the electron flow. Voltage will diminish as you move further from the source (battery) and through each consumer in the circuit. By the time you reach the ground side of the last consumer you should have no more than approx 0.3v

Current (Amps) – this is the volume of electrons “flowing”. Current is constant throughout the circuit (what leaves the positive side of the battery will return to the negative side of the battery)

Resistance (Ohms) – this is the resistance to the electron flow. With regards consumers this is pre-determined during manufacture. With regards to the rest of the circuit this will be influenced by cable size, corrosion and also the condition/security of connections

Power (Watts) – this is the output of the consumer (this is usually calculated rather than measured) Power is a constant determined by pressure x flow

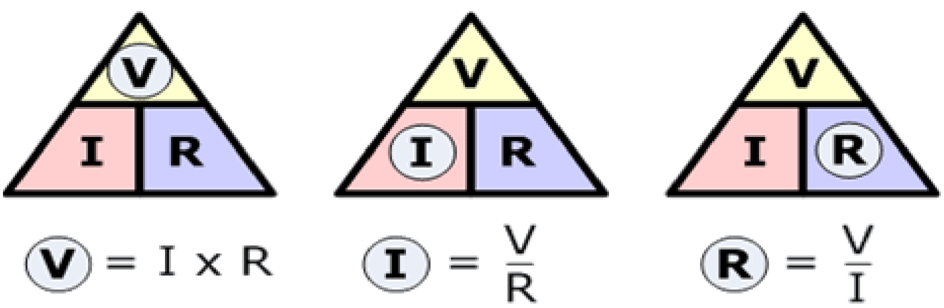
Frequency (Hz) – this is predominantly used in modern electronic systems where “Can” or “Lin” bus data transfer systems are used for communication between control units, “self-diagnosis” or to vary brightness of lights and speeds of radiator cooling fans etc. Frequency can only be measured with an oscilloscope. Frequency remains constant throughout the circuit.



When trying to establish what readings you are expecting to get it can be useful to use either “ohms law” or “watt’s law” to calculate your expectations. This is straightforward as long as you have at least 2 of the criteria required

Ohms Law

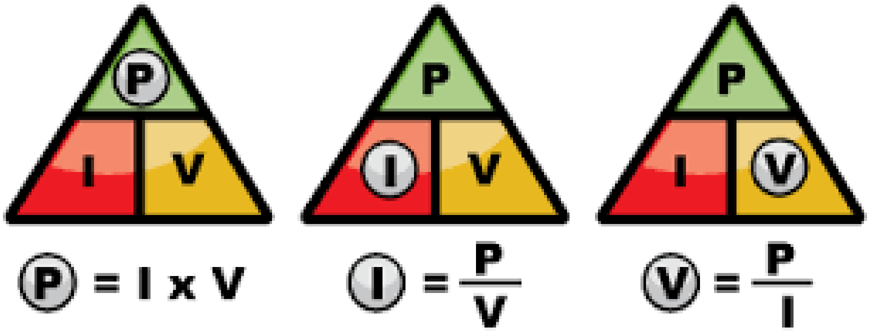
V = volts I = amps R = ohms



EG: 12v system with a 2Ω consumer - 12v/2Ω = 6amps

Watts Law

P = watts I = amps V = volts



EG: A 60w headlight in a 12v system - 60w/12v = 5amps

Fault identification

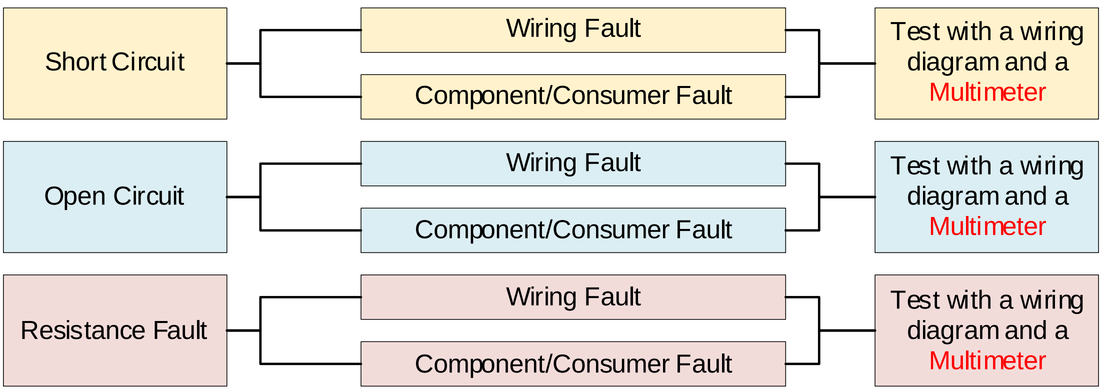
All electrical faults will fit into one of three categories (although it's not always obvious which one) Remember electricity is lazy and will always look for the "path of least resistance"

Short Circuit: This is when the current flow finds a path to ground without passing through the consumer. This will result in a blown fuse if the fault is after the fuse or smoke and fire if before the fuse (this is why the fuse should always be as close as possible to the power source)

Open Circuit: This is when the closed loop of the circuit is broken so there is no current flow, this could be a broken wire or a displaced connector or indeed an internal fault in a consumer/component. An open circuit will not blow a fuse, the consumer/component will simply not work.

High Resistance: This is the most common type of fault in older vehicles and is usually the result of corrosion or connectors which have lost tension over the years and become loose. These faults will normally present as a consumer/component that either does not work or works with a reduced output (dull lights, sluggish starter motor etc)

In all cases a permanent fault is usually fairly straightforward to diagnose, an intermittent fault can be much harder to find and in some cases can only be diagnosed accurately when the fault is present. It is also worth noting that in the case of "resistance faults" simply disconnecting and reconnecting components/consumers during the testing process can remedy the fault by scraping the connector surface during the process of disconnecting and reconnecting. These are the least satisfying repairs as you don't conclusively know what you did to rectify the fault and it is likely that it will re-occur at some point in the future.

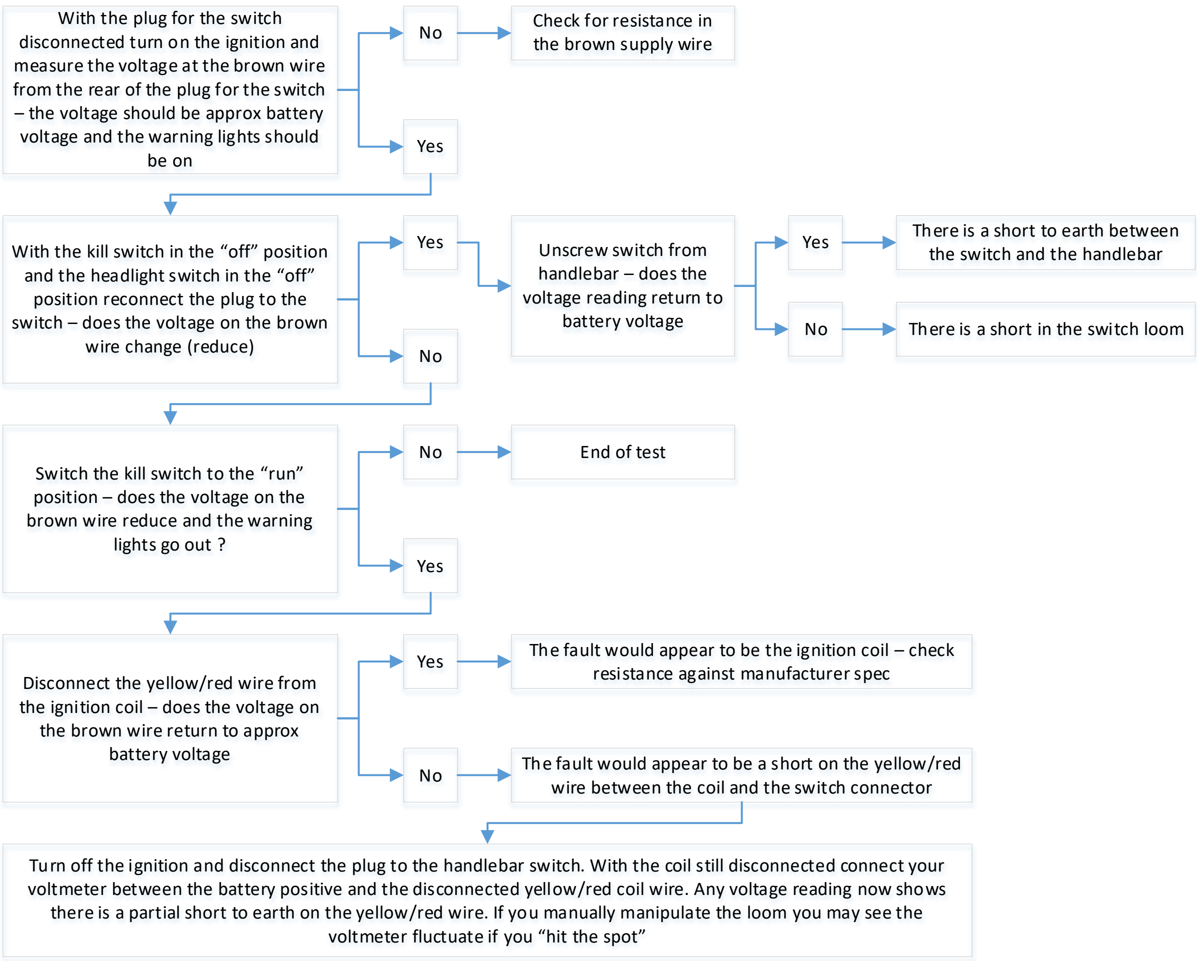


Fault Diagnosis

In all cases the approach I take to fault finding is as below

- Gather the information (what is the fault, when does the fault occur, is anything else being affected by it)
- Look at the wiring diagram (if you apply the information you have gathered to the wiring diagram you can narrow down the possible cause before you go anywhere near the bike)
- Grab a piece of paper and write a test plan (this will help you stay logical in your approach and you can note down the readings you expect to obtain from your tests)
- Grab your multimeter and coffee and get stuck in to sorting your problem.

Below is an example of a test plan I wrote for a forum member (this was done from “the information” in their post and “a wiring diagram” as I am several countries away from the member with the issue) This may look complicated but is only about 20 -30 minutes work to carry out the full test plan.



Short Circuit:

A short circuit can be a “short” to positive or the more common “short” to ground/earth.

- Short to positive will usually mean a consumer is working when it shouldn’t because you have operated another system (EG: you switch on the lights and the turn signal comes on as well)
- A short to ground will normally result in a blown fuse or smoke!!

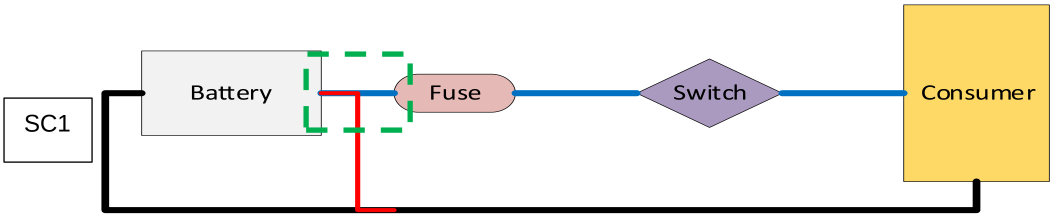
<u>Short Circuit to Positive:</u>

This will normally occur within a component/consumer that can effect multiple circuits (multi-function switch, fuse box etc) alternatively the wiring loom may be damaged allowing multiple wires to contact each other. If you suspect a component to be the fault disconnect it and carry out continuity tests on the component itself to see if there is continuity between circuits in the component that there shouldn't be. If it is a wiring issue you will need to visually inspect the wiring for damage. You could also switch on the system so the fault is present and then manually manipulate the wiring to see if anything changes, this will often help to identify the location of the problem as bending and pulling the wiring will most likely disturb the short circuit

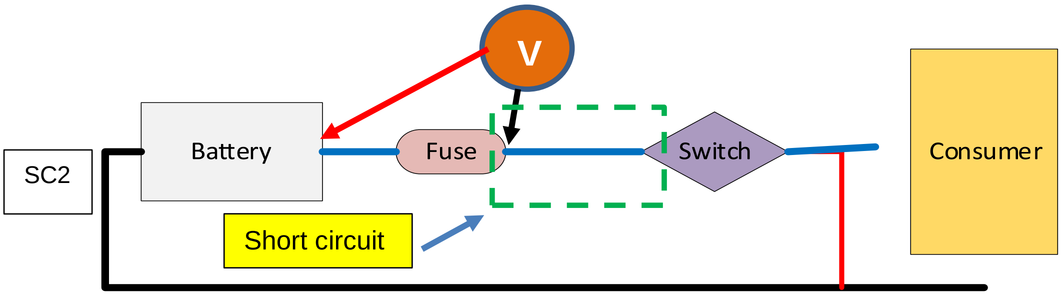
<u>Short Circuit to Ground:</u>

A "short" to ground should be diagnosed with a **"voltmeter".** I have regularly seen guys go through dozens of fuses in an attempt to diagnose a "short" **You should only need 1 replacement fuse**

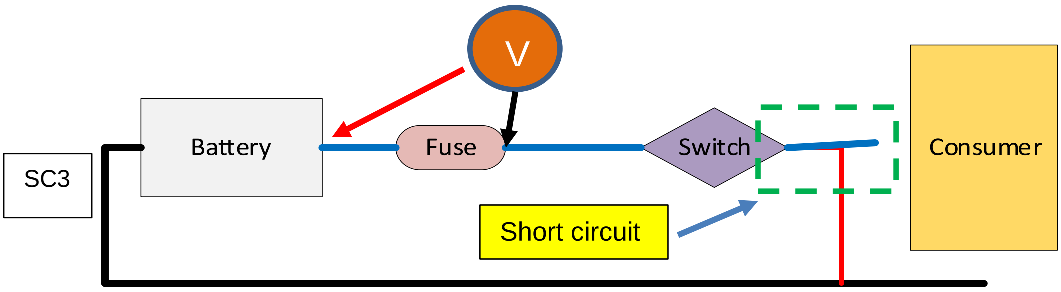
A short to ground before the fuse will be easy to visually diagnose as the fuse will be intact but there will be lots of smoke and if you are lucky the wire will melt before anything catch's fire



Next step is to **<u>disconnect the consumer</u>** and connect the red voltmeter lead to the battery + and the black lead to the output side of the blown fuse. A voltage reading will indicate a short to ground between the fuse and the switch.

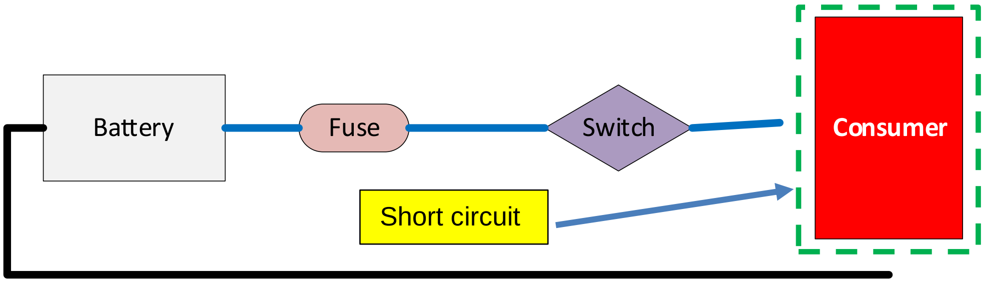


If there was not a voltage reading in the above step now operate the switch, a voltage reading now will indicate a short to ground between the switch and the consumer



If the above test did not indicate a voltage when the switch was activated then the fault is the consumer/component itself and this should be replaced.

SC4



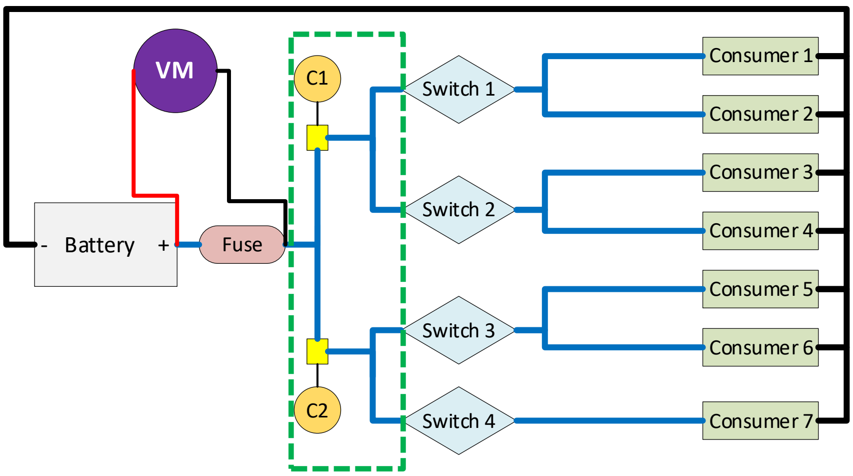
To find a fault in the wiring you should leave the voltmeter connected as in the above steps and manually manipulate the wiring in the area you have identified. Fluctuations on the meter will indicate the location of the fault

Having followed the four steps above and having found and rectified the "short circuit" (confirmed with your voltmeter) you can now install your **1 new fuse.**

I know the above circuit is very basic and I can hear guys saying *"that's all good but what about on my bike where the circuit is more complicated?"* – The short answer is that the principles and process are the same regardless of the complexity of the circuit. I have demonstrated this below:

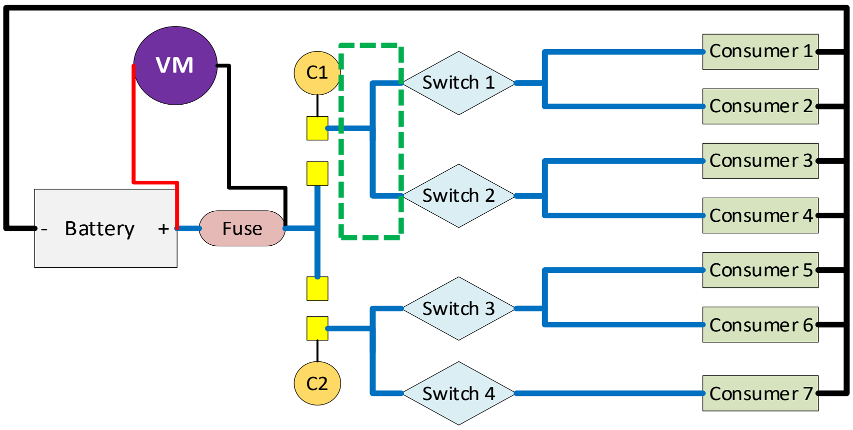
As before, connect the voltmeter between the battery and the output side of the blown fuse. A reading of battery voltage here (with all the switches turned off) would suggest a short to ground between the fuse and the switches

SC5



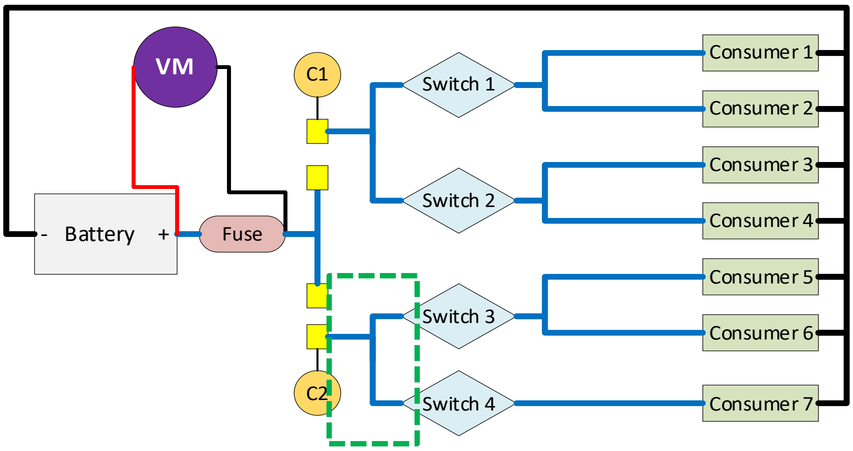
If there are any connectors between the fuse and the switches (C1 & C2) you can break it down further. Disconnect connect C1 – If the voltage reading drops to Zero the fault is between C1 and the switches

SC6



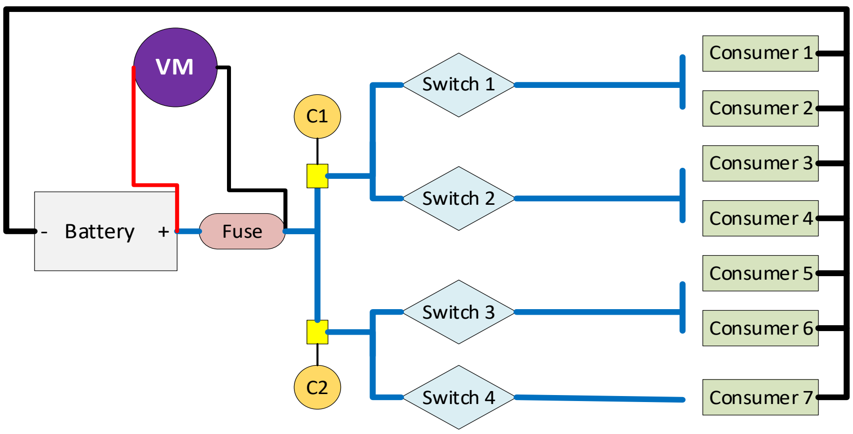
Disconnect connect C1 – If the voltage reading drops to Zero the fault is between C1 and the switches. If not disconnect C2, if the voltage now drops to 0v the fault is between C2 and the switches

SC7



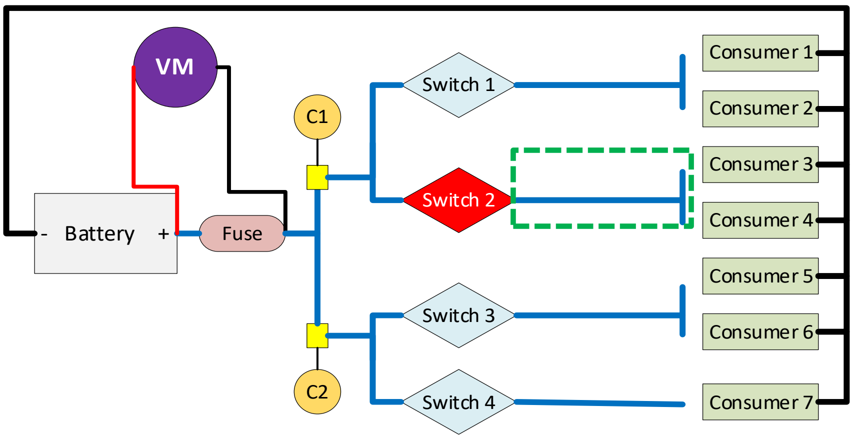
If your initial voltage reading with all the switches turned off was 0v you now need to disconnect all the consumers fed by that fuse. Now turn on and off each switch in turn until you get a reading of battery voltage

SC8



If your reading is battery voltage when a switch is operated then the short is between that switch and the consumer EG “switch 2” below

SC9



As before if none of the switches generates a battery voltage reading at the output of the fuse one of the consumers fed by that fuse is faulty.

If you know the manufacturer resistance spec for the consumer you can measure the **disconnected** consumer’s resistance (a reading **lower** than spec would suggest that consumer is faulty) **you cannot identify a short in a consumer with a voltage test at the fuse because, with no current flowing in the circuit all consumers will show a varying path to ground**

This is where the initial pre-test steps are important to save you time (particularly where consumers are difficult to access)

At the beginning when you “gathered the information” if you identified that the fuse blew <u>when you switched on a particular consumer</u> then you can go straight to “**SC9**” as you know everything before the switch for that consumer is not the problem. Once you have narrowed it down to a consumer fault, for speed you could replace the fuse and re-connect one of the consumers fed by that switch, now power up the system and operate the switch. If the fuse blows the consumer is faulty, if not repeat the test with all consumers fed by that switch until you identify which one is blowing the fuse. (In this instance a second fuse would be required) and then replace the faulty consumer.

Open Circuit Faults

Open circuits can occur anywhere in a circuit either in the wiring on the “Live” or “Ground” side of a consumer, or can be a component fault (switch, relay or solenoid contacts etc). The fuse will be intact as there is no current flowing to cause it to fail. The symptoms of an open circuit fault are that one or more consumers will not operate when activated, This can present as an intermittent fault where going over bumps in the road, round corners etc may cause the consumer to operate intermittently (you know the old thing of “*it works if you give it a smack!*”)

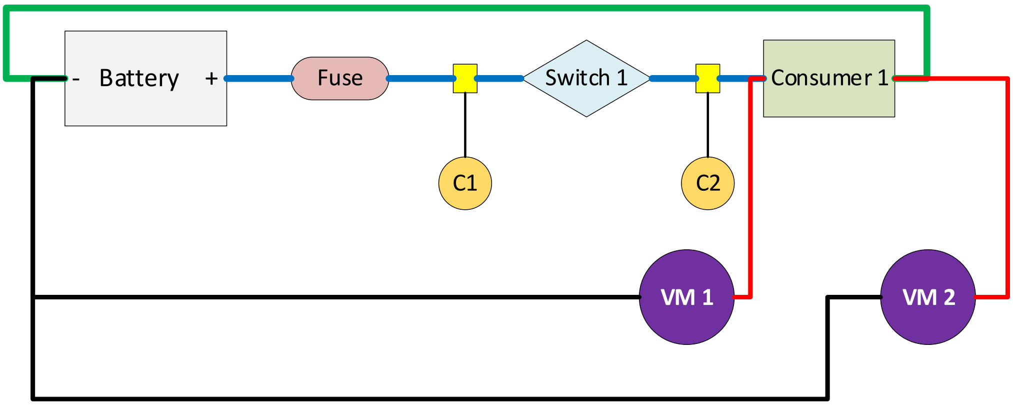
As with “short circuit” faults the most accurate diagnosis method is to use a voltmeter.

NOTE: check the fuse is not blown and that there is battery voltage on both sides of the fuse first before you start testing (a blown fuse is an “open circuit”)

The first step is with the circuit **"powered up and switched on"** measure the voltage at both sides of the consumer. A reading of approx battery voltage (VM1) on the positive side of the consumer tells you that the fuse, switch and wiring to this point are ok so the fault must be, the consumer itself or a ground fault.

Now measure the voltage (VM2) on the ground side of the consumer. This should be no more than approx 0.3v. If you have approx battery voltage on the ground side of the consumer then the open circuit is in the ground line (possible broken earth wire etc)

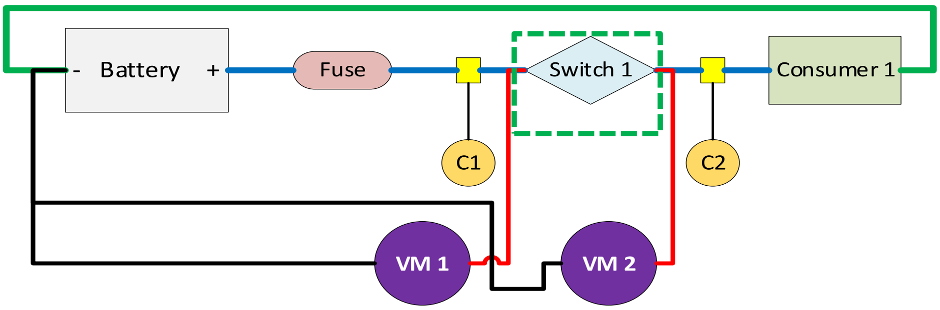
OC1



With open circuit faults the most time efficient way to diagnose is to break the circuit into sections (virtually) and to look at which points are easiest to access. If the fault is in the live side of the circuit (no voltage at the consumer) the next easiest point to check (in most cases) would be the switch.

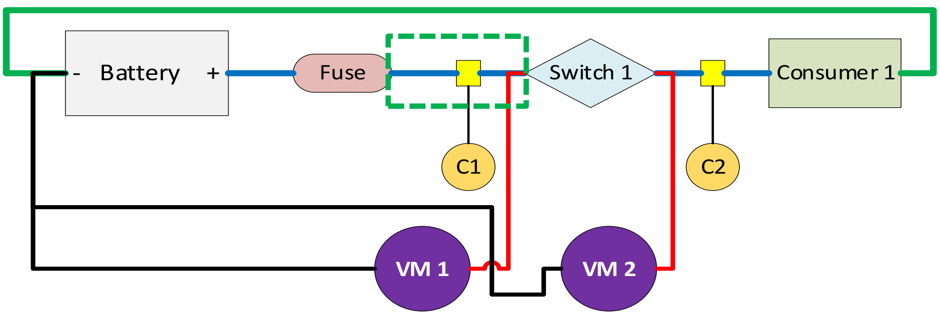
Take voltage readings from both sides of the switch (with the switch turned on) measure input first (VM1) and then output (VM2) you are expecting approx battery voltage on both sides of the switch. If the voltage at VM1 is battery voltage and the voltage at VM2 isn't then the switch is fault

OC2



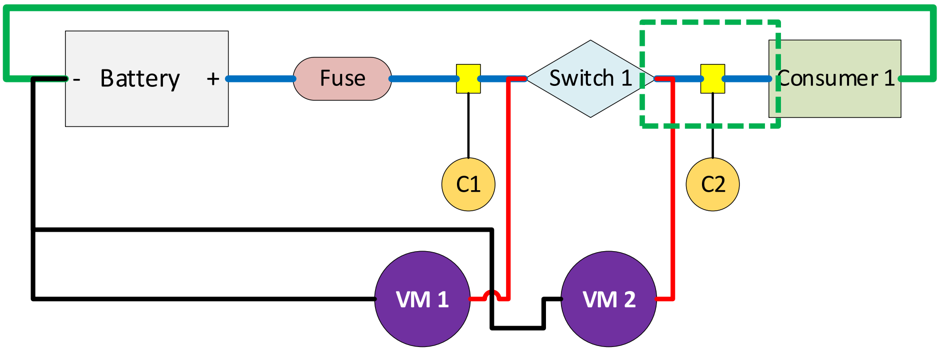
If there is no voltage at the input of the switch (VM1) then the fault is between the fuse and the switch

OC3



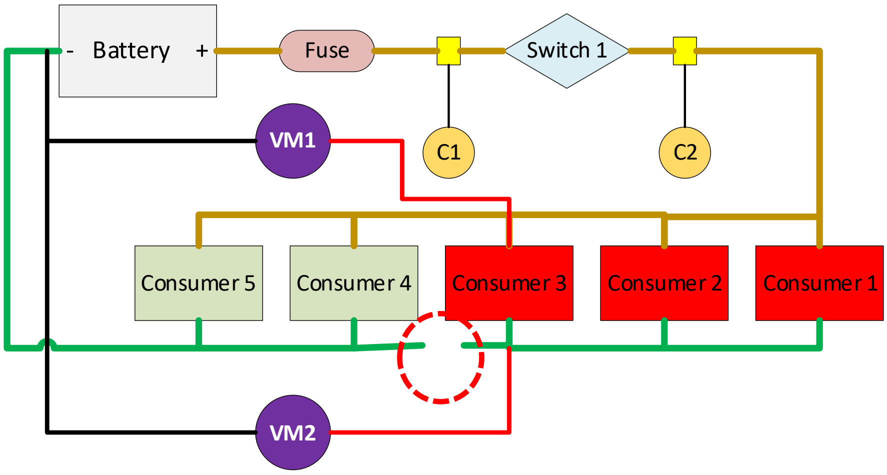
If there is voltage at the output of the switch (VM2) then the fault is between the switch and the consumer

OC4



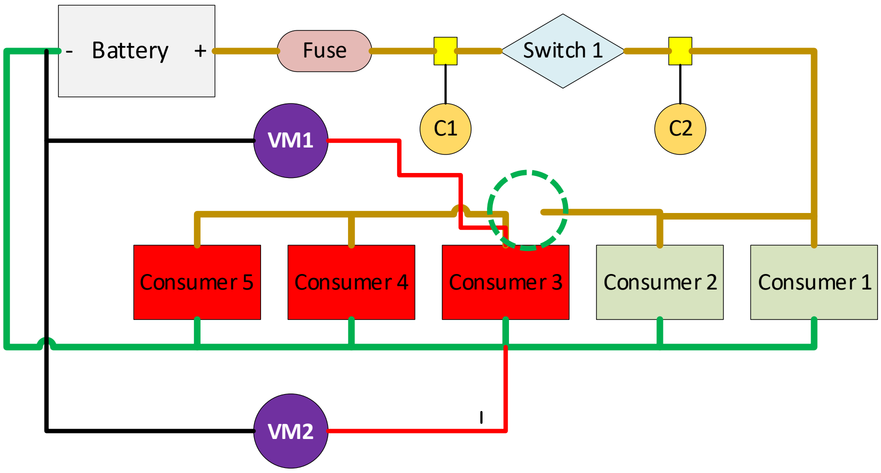
As with a "short circuit" fault the process and principles for a circuit with a single or multiple consumers is exactly the same and the process of "gathering the information before starting testing can save a significant amount of time (see below) In this case when you gather the information you would know that consumer1, 2 & 3 don't work but consumers 4 & 5 do VM1 Would read approx battery voltage. VM2 would also read approx battery voltage showing an open circuit earth. Because you know consumer 4 & 5 work the fault can only be where indicated

OC5



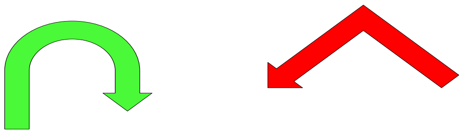
Below only consumer 1 & 2 work, VM1 and VM2 will both show 0v so the fault can only be as indicated

OC6



When checking wiring for breaks there are a couple of ways to locate the problem

- Visually check for signs of green powder on the insulation, this is common on older vehicles and is caused by the insulation cracking and allowing water ingress. The green powder is the corrosion from the copper wire inside (I recently had this problem with an ABS sensor wire on my car which is only 4 years old!!)
- Gently work along the wire bending it as you go along, where the wire is good it will bend with a uniform radius, when you get to the point where the wire is broken it will “fold” at that point



If you are planning to cut out the break and splice in a repair section (which is a perfectly acceptable repair if done correctly) make sure you cut the bad wire back until you reach clean copper before jointing your repair section (blackened wire won’t take solder properly)

<u>Resistance Faults</u>

As the heading says, these are faults caused by resistances in the circuit that are over and above the design spec. High resistance faults are probably the most common type of fault you will come across working on older vehicles, and can be the hardest to diagnose as the amount of resistance will vary based on operating time (resistance generates heat, the longer the circuit is switched on the hotter it will get. Heat itself generates resistance so the hotter it gets the greater the resistance becomes. When the circuit is switched off no current flows so, the point of resistance cools and the resistance reduces). A resistance fault will not cause a fuse to fail as the resistance reduces the amount of current flowing in the circuit. Common symptoms of a high resistance fault are

- Consumer doesn’t work
- Consumer works with a reduced output (dull lights, sluggish motors (starter etc) weak spark)
- Consumer stops working after a period of operation, then works again after a cool down period when switched off

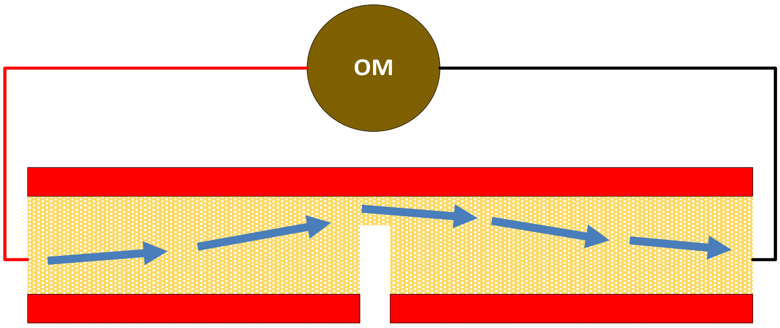
The most common cause of resistance faults (particularly in older vehicles) are

- Switch, relay or solenoid contacts that have oxidised or burnt over time (remember when you operate switches etc as the contacts close current will try and flow before full contact is made causing arcing)
- Corroded wiring (were insulation is damaged and the wire has corroded but not yet become an “open circuit”)
- Corrosion at connector points, this can be between connector contacts or between the wire itself and the crimped on connector (therefore cleaning the connector points may not resolve the issue) Bikes of the age favoured by this forums members use multi-pin connectors that are not weather proofed like those used in modern automotive applications so this is a very common cause of problems 40 years on.

When talking about resistance faults your first reaction is to reach for an "ohmmeter" however these faults should be diagnosed in a "live" circuit with a VOLTMETER. I will explain the reason for this below:

An "ohmmeter" works by sending out a very small current (a few milliamps) from it's internal battery and measuring the resistance to flow. Imagine the below is a cross section of you main starter or battery cable. As you can see it is cut through approx 80% but the few strands that are left would still show an acceptable resistance reading on an ohmmeter because of the small current, this would leave you believing the cable was good and looking for a problem elsewhere.

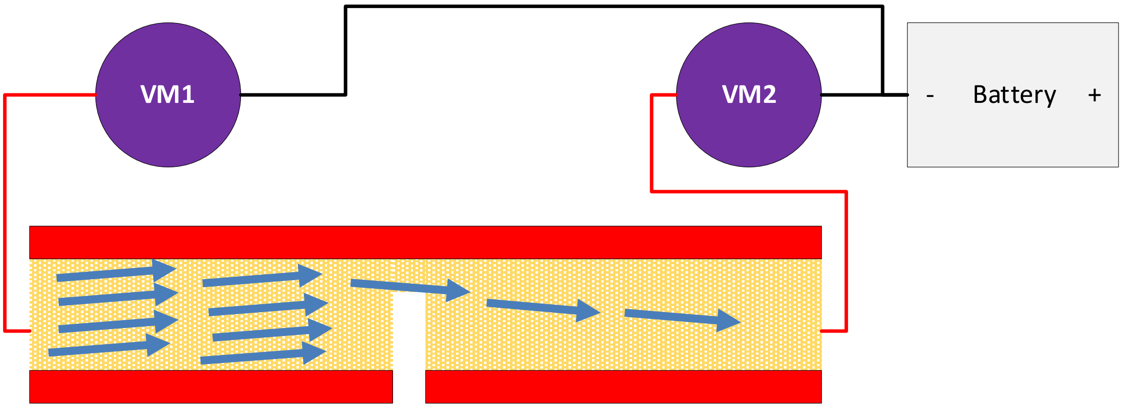
HR1



With the circuit fully connected, if you operated the consumer you can see below what would happen to the current flow (in the case of a starter this level of resistance could start a fire due to the excessive heat build-up)

Using a voltmeter check the voltage at VM1 when operating the consumer and you would expect to see reference voltage (approx battery voltage) when you checked the voltage at VM2 while operating the consumer the voltage reading would be significantly lower than at VM1 because of the resistance.(**an ohmmeter would not have diagnosed this fault**)

HR2



Whilst the above may seem like an extreme example the principle is relevant to any damaged or partially broken conductors.

Note: Just because a relay or solenoid "clicks" it doesn't mean it is working correctly. Always carry out the required input and output voltage checks before declaring that component "good". It will save you looking elsewhere for a fault you have by-passed and may save you buying replacement parts you don't need.

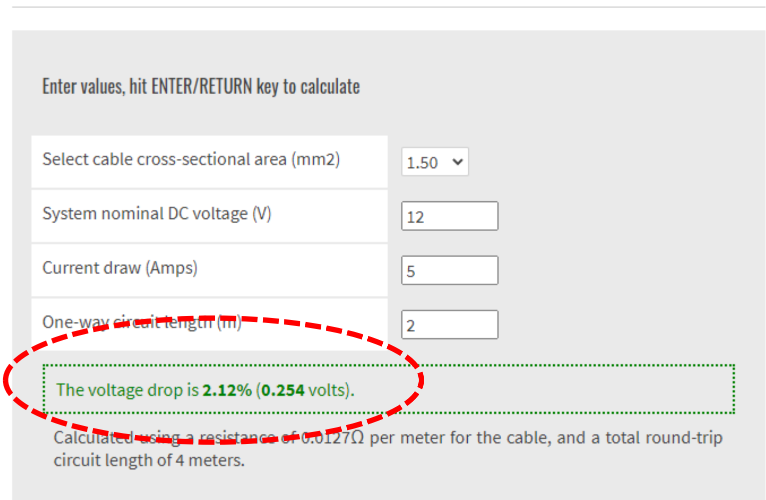
Resistance Fault Testing:

Always check "reference voltage" prior to starting testing and re-check periodically if the testing process is taking a while. Remember to diagnose a resistance fault you are looking for a voltage difference between the source (battery) and the consumer, this is sometimes referred to as PD (potential difference)

Don't forget that a certain amount of volt drop is normal between the source and the consumer (up to approx 0.5v total between the source and the furthest consumer is acceptable)

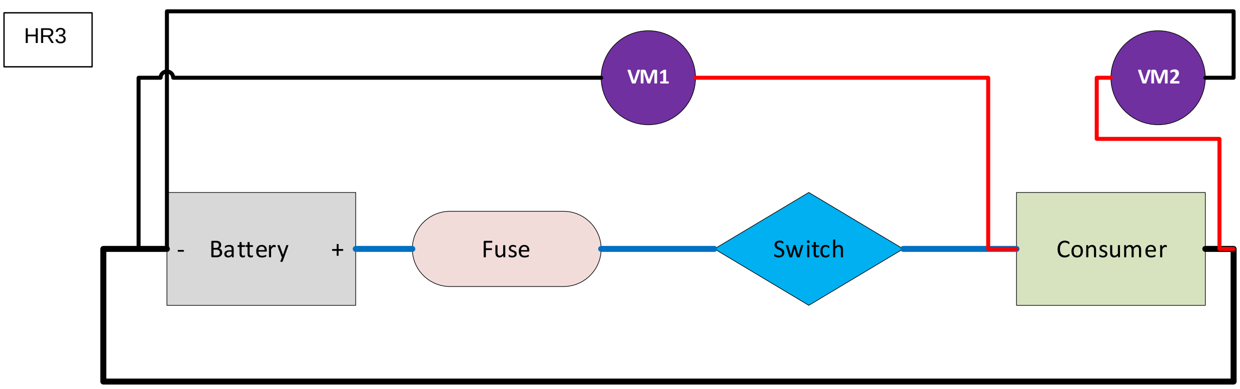
The calculator below on the below link can be used to calculate what level of volt drop you could expect in the wiring of a healthy circuit (this calculator can also be used to decide on the best size cable to use if replacing or adding additional wiring)

https://www.12voltplanet.co.uk/cable-sizing-selection.html



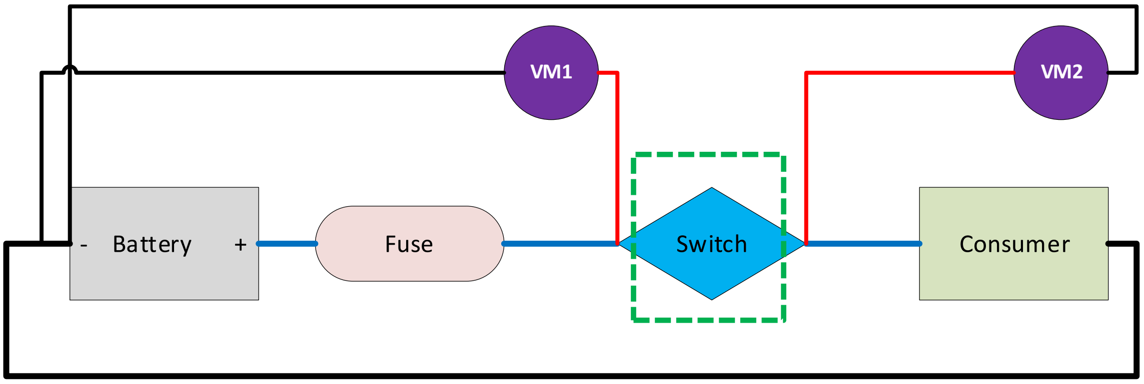
Having decided that you have a resistance fault the first step is to measure the voltage at both sides of the fuse (should be reference voltage) then if fuse ok both sides of the consumer with it live and turned on – VM1 should read within 0.5v of your reference voltage and VM2 should read no more than approx 0.3v (you need a nominal voltage to push the current back to the battery)

A reading more than 0.5v smaller than the reference voltage at VM1 shows a resistance in the supply, a reading of more than approx 0.3v at VM2 indicates a resistance in the earth/ground line.



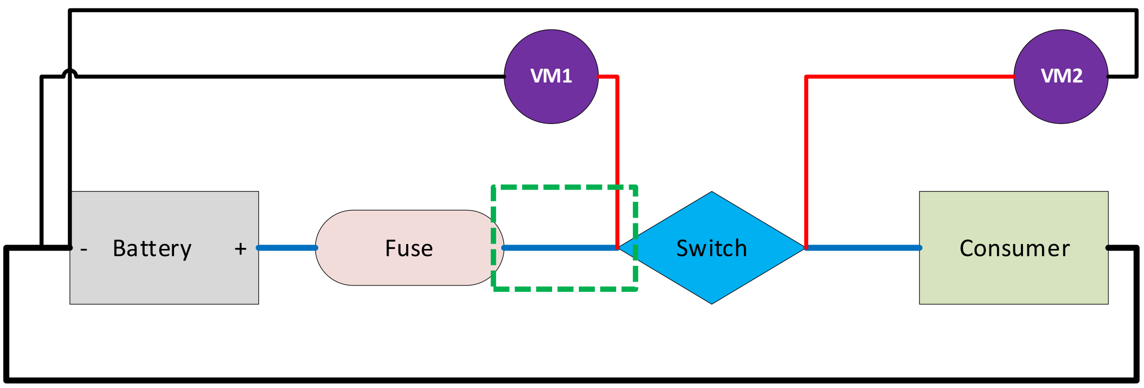
Having found that your resistance is in the live supply side the next step is to check the voltage in and out of the switch, VM1 should read approx reference voltage and VM2 should read the same approx reference voltage as VM1. A lower reading on VM2 would indicate a faulty switch (or the connections to it)

HR4



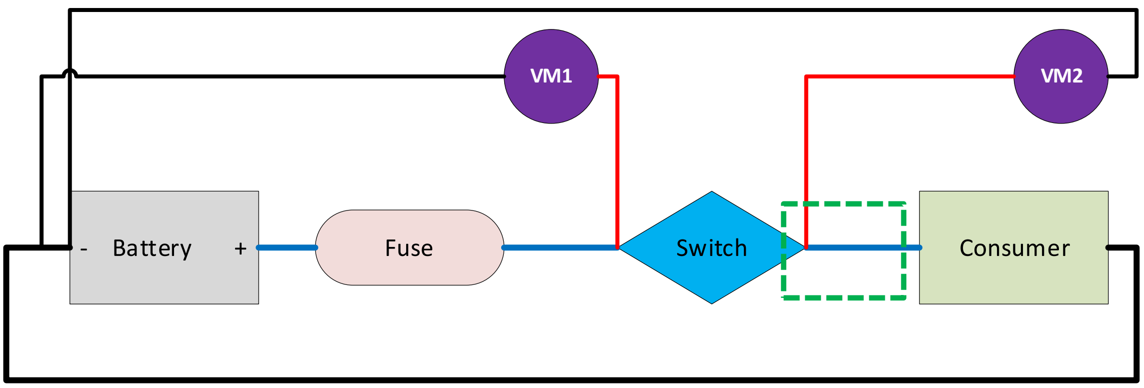
A reading of more than 0.5v less than reference voltage would indicate a resistance between the fuse and the switch (or the connections to them)

HR5



A reading within 0.5v of the reference voltage at VM2 would indicate a resistance between the Switch and the consumer (or the connections to them)

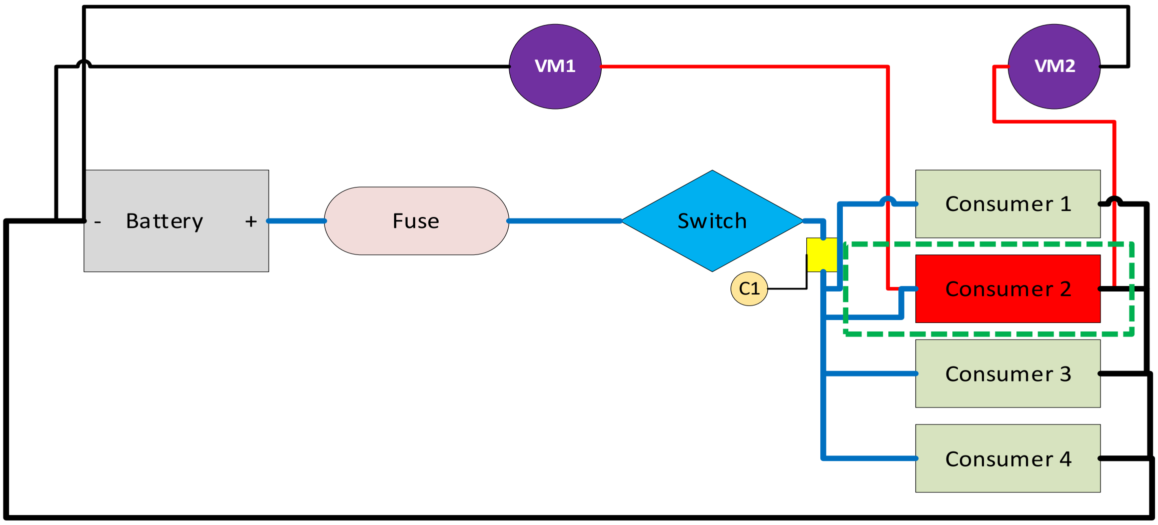
HR6



As with the other fault types, when applied to a multi consumer circuit the principles are the same and the importance of gathering the information as this will again aid speedy diagnosis

If when you gathered the information you noticed that only consumer 2 was effected and that consumers 1, 3 & 4 work correctly, then the fault can only be in the indicated area and the rest of the circuit must be good so you can limit your testing to this area.

HR7



Resistance diagnosis by measuring "**Volt Drop**"

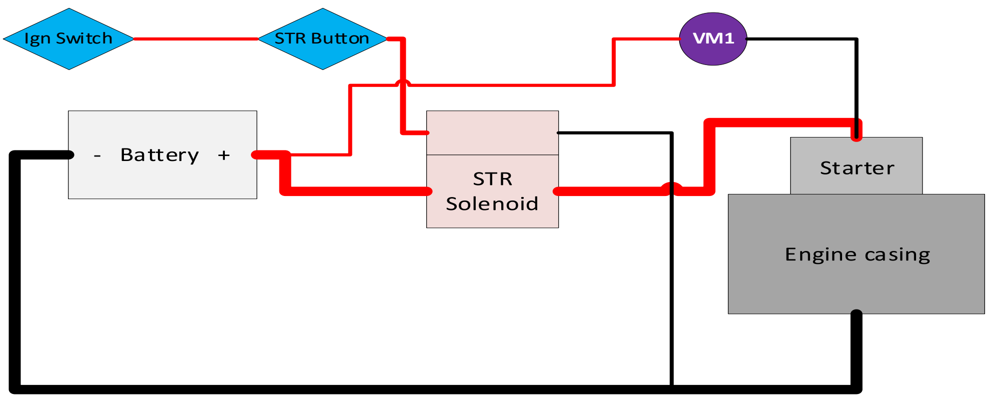
Dependant on your confidence levels and the circuit being tested it is possible to diagnose resistance faults by measuring "volt drop" at key points in the circuit. The benefit of this method is that you don't need to continually re-check your reference voltage for comparison (this is particularly useful when testing high consumption circuits such as the starter as repeated operation will significantly reduce the reference voltage quickly)

What you are doing here is measuring the PD (potential difference) between the reference voltage and the supply voltage at the point being tested

Below demonstrates how to test a starter circuit using the "volt drop" method.

Connect the red lead from your voltmeter VM1 to the positive terminal on the battery, now connect the black meter lead to the main positive terminal on the starter and operate the starter. You should have no more than approx 0.5v as a reading of PD. A higher reading suggests a resistance in the positive line.

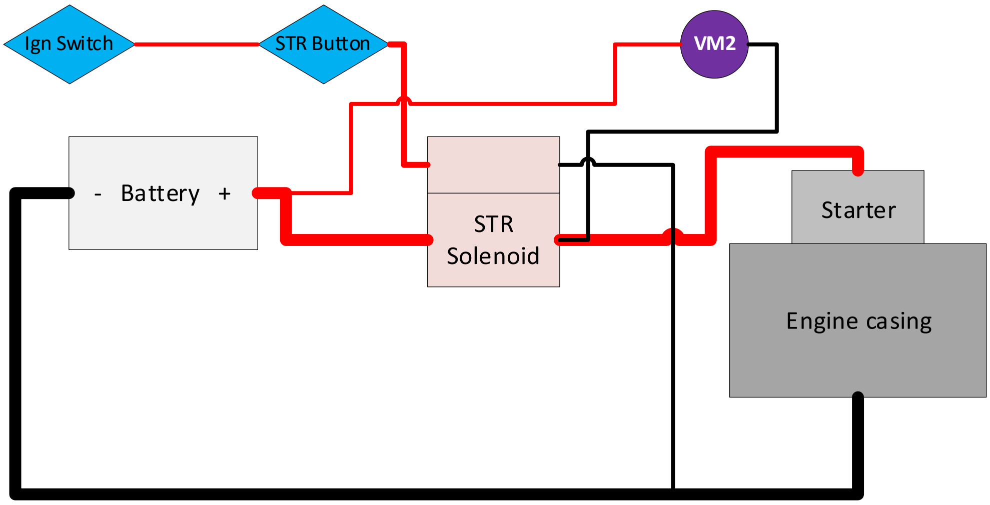
HR8



Classification:IN-CONFIDENCE

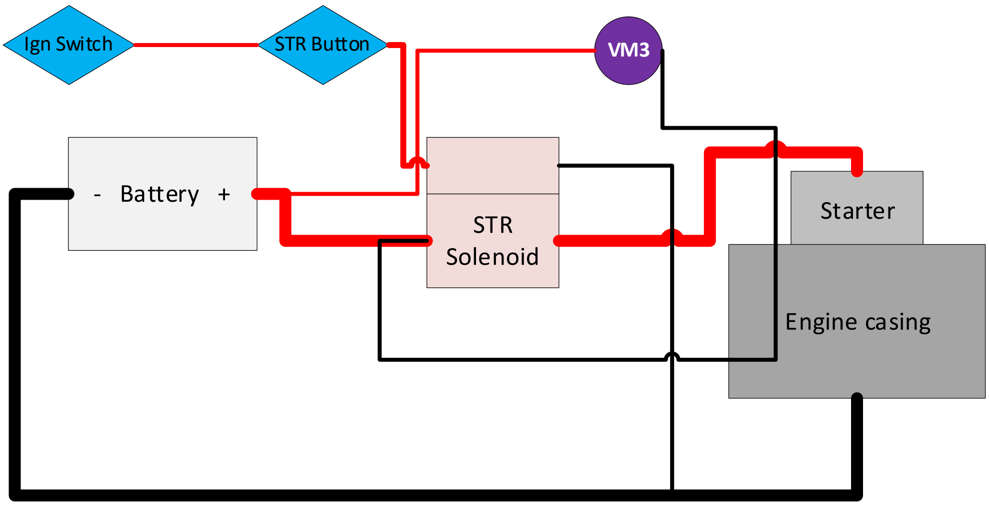
If the 1st reading was higher than approx 0.5v move the black meter lead to the output side of the solenoid and operate the starter again. A reading of approx 0.5v or less means the fault is between the solenoid and the starter (poor connection or damaged cable) if the reading is more than approx 0.5v move the black meter lead to the input side of the solenoid and operate the starter again

HR9



If the reading is now approx 0.5v or less the fault is within the solenoid (don't condemn the solenoid without testing the primary side as a weak pull won't press the switch contacts together properly. You can use the "volt Drop" method on the live from the starter button and test the ground as explained in resistance fault finding) if the reading is higher than approx 0.5v the fault is between the battery and the solenoid.

HR10

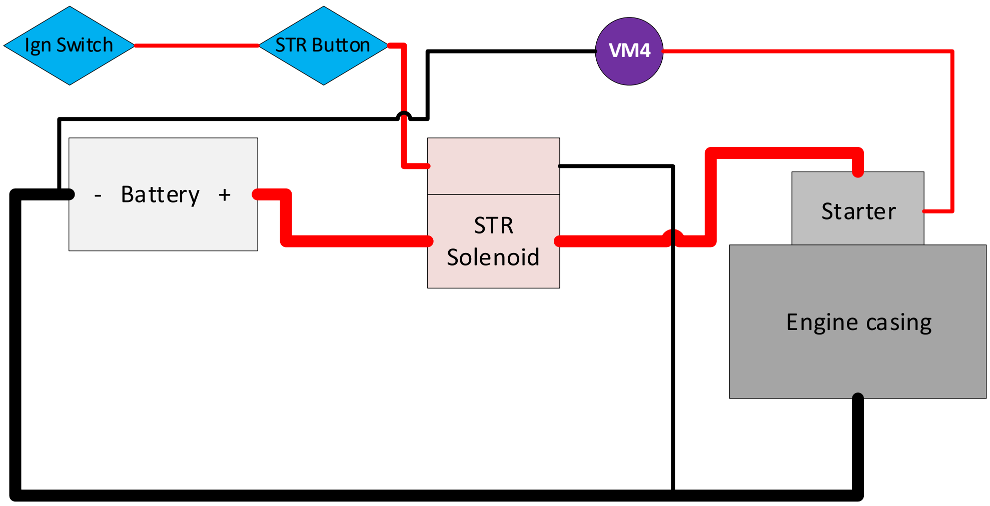


If the live at the starter main terminal was approx 0.5v or less then you should check the ground ref the below

Classification:IN-CONFIDENCE

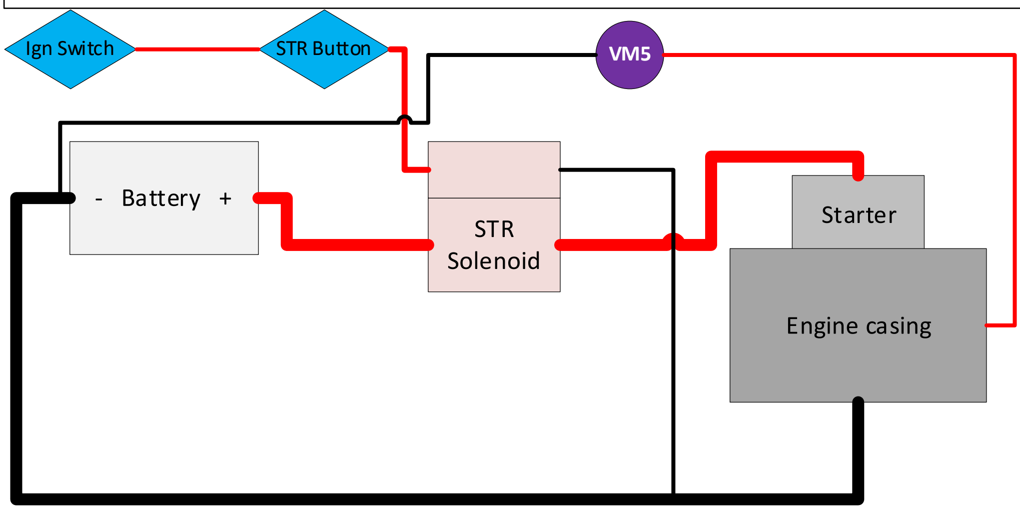
Connect the black meter lead to the battery negative terminal, hold the red lead on the starter casing and operate the starter, a reading of 0.3v or less is what you are looking for and this would confirm the fault is the starter itself. E reading higher than approx 0.3v would suggest an earth problem.

HR11

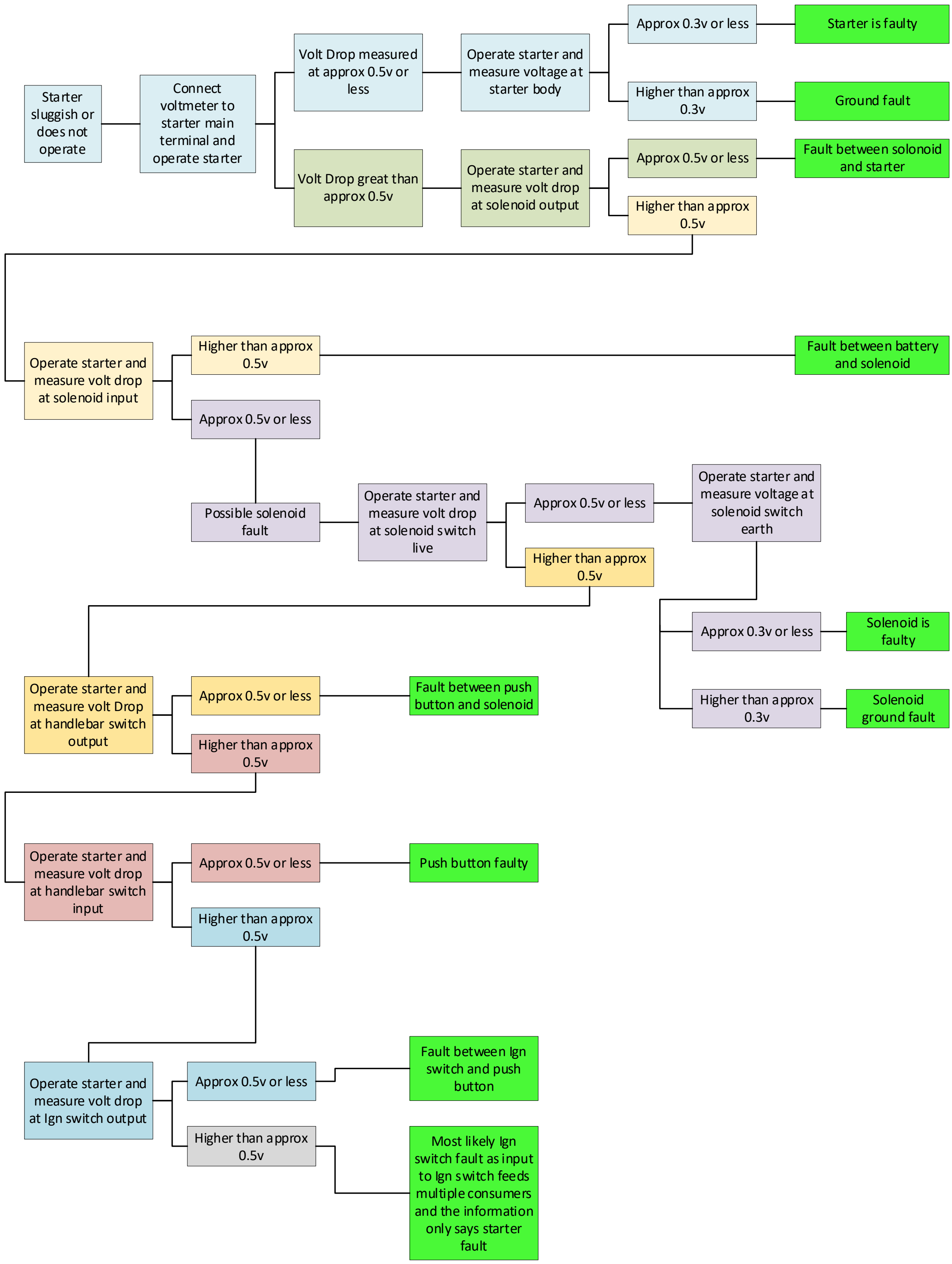


If the above reading was higher than approx 0.3v move the red meter lead to the engine casing and operate the starter. A reading of approx 0.3v or less now would suggest a build-up of dirt or corrosion between the starter body and the engine casing causing a poor ground. A reading higher than approx 0.3v would suggest a faulty ground between the engine and battery negative terminal

HR12



This process can be used to diagnose any resistance fault in any circuit, it looks long winded but below I have converted the above into a test plan for the starter circuit which once you have access to the solenoid, starter and battery would take approx 10 - 20 mins to accurately diagnose your starting fault (if electrical, not mechanical)



Now that you have diagnosed your electrical fault I will run though some repair methods that should give the best results for a long term “fix” below.

Broken, Damaged or Corroded Wires:

It isn't practical or cost effective in most cases to completely replace a length of wire which has a local defect at some point along the run. It is perfectly acceptable to repair a wire if done correctly**! (Wiring heat damaged by a "short circuit" should be replaced completely)**

Once you have located the source of the fault disconnect the power source and decide how best to repair based on the fault location and the condition of the cable,

- If close to the consumer cut out the damaged cable (go back far enough to reach clean copper, connecting to wire blackened by corrosion will grow into a new resistance fault over time) Extend the cut back wire to the consumer and install a new connector for the consumer, The best way to join the new section of cable is to twist it along the length of the repair with the original cable and solder (make sure there are no sharp points on the soldering which could pierce the insulation) then apply "heat shrink" sleeving or insulation tape to cover the joint. **(Ensure the new piece of wire is the same gauge as the section cut out)**
- For wiring faults mid-way along a run the jointing process is the same as the above to replace the faulty section with joints at both end (don't for get to slide your "heat shrink" onto the cable before completing the second joint)

If original appearance is important to you when replacing a damaged section of wiring you can splice in your repair section and slide the original wiring along so that the visible connection to consumer or multi-pin connector will still be the original wiring.

If due to damage you have multiple wires to repair at the same location then stagger the repairs (this will help prevent ending up with a loom that looks like a Python that has swallowed a sheep!!)

Replacing Broken or Corroded Connectors:

The majority of connectors are "crimped" to the cable in a variety of ways. When replacing "crimped" connectors it is essential to be fitting the connector to clean copper (if necc cut back the wire and splice in a new piece) Crimping a connector to "blackened" wire will at best be a temporary fix as that corrosion process will continue and resistance will build between the connector and the wire bringing a new fault to diagnose.

Replacing Connector Pins in Multi-Plugs:

If you are going down the "restoration" route and want everything original you can still source replacement pins for the connector plugs and sockets **(Before disassembling a multi-pin connector take photos or draw a diagram of the wire locations, the more pins there are the easier it is to get locations crossed especially given that colours can change either side of a connector – the hardest faults to diagnose are the ones you create yourself)** When replacing connectors in a multi-pin always replace the corresponding "male" or "female" that the new pin will engage with and if possible solder rather than crimp the new pin to the wire (this will help "future proof" the repair)

If originality is not a concern a much better repair would be to replace the original multi-pin connector with a modern weather proof version which are readily available. The connectors have a seal between the two halves and also every wire has its own seal where it enters the connector block making them much less likely to suffer with corrosion issues in the future.

My own build will use these connectors for everything as the intention is to use an M-Box, so will require a new loom making.

I hope this guide will be useful to those of you who struggle with electrical fault identification and diagnosis and that you persevere with keeping more classic “Z” model Kawasaki’s on the road.