The Importance of a Good Earth . . .

Jo Atkins tells us why all those volts and amps have to get back where they started, even if they have been mangled in the wiper motor on the way . . .

ONE OF THE EASIER WAYS TO describe an automotive electrical system is to compare it to a simple water recirculating set-up. Don't switch off, it really is simple. Imagine, if you will, a water tank. A large pipe from the bottom of this tank leads downwards and splits into several smaller pipes. At the end of each of the smaller pipes you'll find a tap which corresponds in size to the pipe leading to it.

When any of the taps is turned on, the water flows out of the tap(s), through more pipes, into a reservoir, or catch tank, right at the bottom of the whole system. If you leave the taps running, the top storage tank will run dry and the flow will cease. Because there's a set amount of water in the system, the only way to keep up the flow is to return the water from the bottom tank to the top tank.

To fulfill this purpose, there's a pump which takes water from the lower tank and feeds it, through another large pipe, up to the top tank. This pump must automatically adjust itself to return the correct quantity of water to the top of the system and at the right pressure. Too much and the top tank will overflow, too little and it will run dry. In order to achieve this, the top tank has a basic ballcock valve and the pump has its own, more accurate, flow sensor into the bargain.

Now comes the clever bit. The top tank, with its ballcock valve, represents the car battery. The water itself represents electricity. (Volts represent the pressure of the water and amps represent the total volume of water flowing at a given point). The large and small pipes taking water from the top tank to the taps represent different sizes of cable in the wiring loom.

As it happens, the pressure of the water, the voltage, remains mostly constant in a car system between the battery and the loads (top tank and taps), if the cables are up to the job. When the volume of flow has to be larger, the cable has to be bigger. Hence the bigger pipes carry more water and therefore more 'amps'.

The taps at the end of the pipes represent the electrical loads in a car — any of the components which directly require electricity to work. Presume that the pressure of water above the majority of these taps is actually the same (around 12V). The pressure of the water leaving each tap, though, is nearly negligible (nearly zero volts). When a tap is turned off, nothing flows through it at all.

So, when you switch on the lights, for instance, the various switches used represent the tap controls. The power requirement of the filaments themselves will dictate the required size of cable — the diameter of the pipe and the tap.

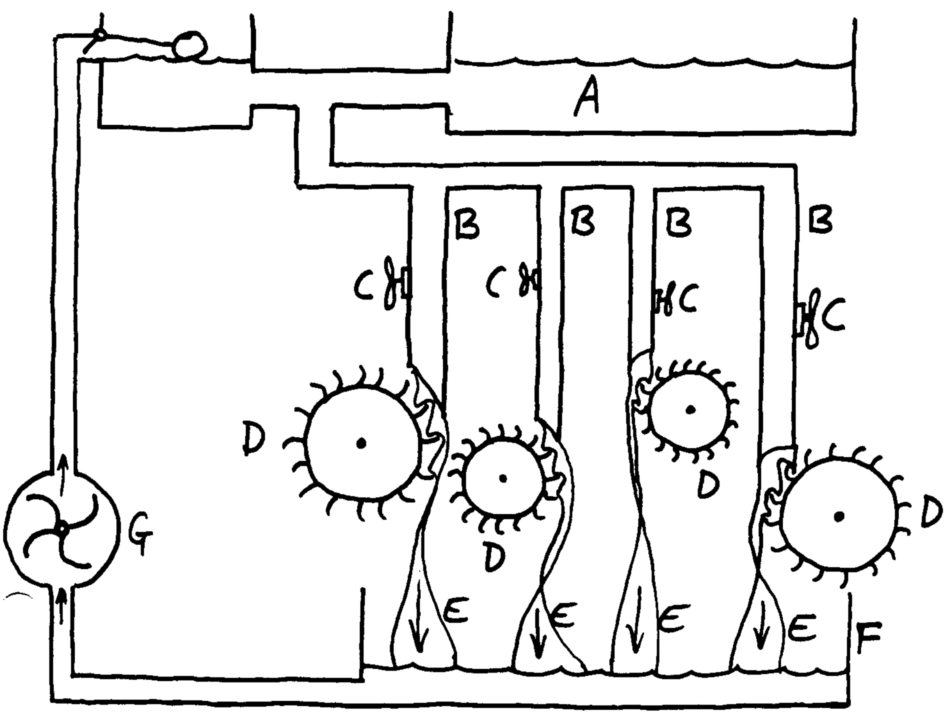
Having been through the taps, the water will flow out of the tap nozzle pipes, at low pressure, and all the water will mingle together in the bottom reservoir or tank. This represents the earth side of your electrical system.

Current flows out of electrical equipment and has to have somewhere to go if there is to be a flow. This somewhere is through an earth wire, or contact, to the steel chassis and/or body. The chassis/body/engine block represent the lower water tank.

How does all this used water get back up to the top tank? It's because of the pump. Take the pump to be the alternator or dynamo. It has equipment for sensing what the pressure of the water is (volts) and what volume of water is coming from the top tank (amps).

It will do its level best to send water back to the top tank (battery) at the correct pressure and rate. Needless to

A simple car electrical system represented as a water flow diagram. A is the top water tank with a self-regulating 'ballcock' valve to prevent overfilling — this represents the battery. B are pipes of varying diameters taking water away from the top tank — they represent live feed wires of different gauges. C are taps and their size relates to the size of pipe to which they are attached — they represent the various switches on the dashboard. D are water wheels driven by the flow of water past them — these represent electrical loads (such as motors) driven by the live feed. E is the flow of water which has driven the wheels and is on its way back to the lower tank — they represent various earth wires taking current from the load to earth (body or chassis in a negative earth car). F is the bottom collecting tank where all the water must flow to eventually — this is the vehicle's earth. G is a self-regulating pump which sends water back to the top tank via a large pipe — this is the alternator.



say, the alternator, or pump, has a damned good connection with earth, the bottom reservoir. This is because it sometimes has to collect and pump up large amounts of water (amps).

In effect, the water drains out of the top tank at a very low rate if the tank is in good condition. The pump's main work is to refill the tank after a large amount of water has been used. This, translated, means that cranking your engine over is the main battery drain and the alternator has to work to recharge the battery after starting the car.

Other than that, the battery looks after itself and the alternator provides current to the loom while the engine is running. Only when the loads on the system require more current than the alternator is capable of producing does the battery step in to lend a hand. If this state of affairs continues, the battery will run flat and there's a good chance that the car will stop.

There are a lot more parallels to be drawn from this image. If the pump starts to work badly and can't return enough water to the tank, the tank will eventually run dry unless a certain amount of taps is turned off. That's what happens when the alternator starts to go bad and can't keep the battery charged.

It can be a little misleading to talk about electricity in terms of positive supply and negative earth. Some have the impression that electrical equipment which is deemed powerful requires big wires taking current to it from the battery, or alternator. Fewer are sure as to what to do with the wire taking electricity from the component to earth.

True enough, the electrical equipment with the bigger loads tend to be earthed directly through a structure and not via wires. Such things as the starter motor, which is the biggest load in almost any car electrical system, earths to the engine block via its body. Remember that the block itself is earthed to the battery via one or several lumping great bonding straps. These could hardly be termed 'wires' as they have a huge section area.

The alternator, which is the primary source of current, needs a big earth because the current flows through the entire car structure back to the alternator via the engine block. An alternator is usually earthed through its mounts but some require an additional bonding strap to the block due to the large current flow involved.

So, when you're wiring up a car, or trying to fix general wiring problems, what are the kind of symptoms you would expect from a bad earth? In the first instance, try to think of our water diagram. The bad earth is something preventing the water from flowing out of the tap and into the reservoir. If you've got a bad earth, then there's a little gremlin somewhere with a finger stuck into one or two of the tap nozzles.

That tap, the electrical component, can't get rid of water fast enough, so it will work less efficiently. If it can't get rid of any water at all, or very very little, it's as if it had been turned off completely. If it was just water you were dealing with, then there wouldn't really be any safety problem.

When electricity is the subject matter, though, restricted flows can cause heat in the guilty connectors and sometimes in wires too. Heat can cause insulation to melt, sometimes dramatically catching fire. It's time to abandon ship and fill in insurance forms. (Don't tell them about the recent re-wiring)!

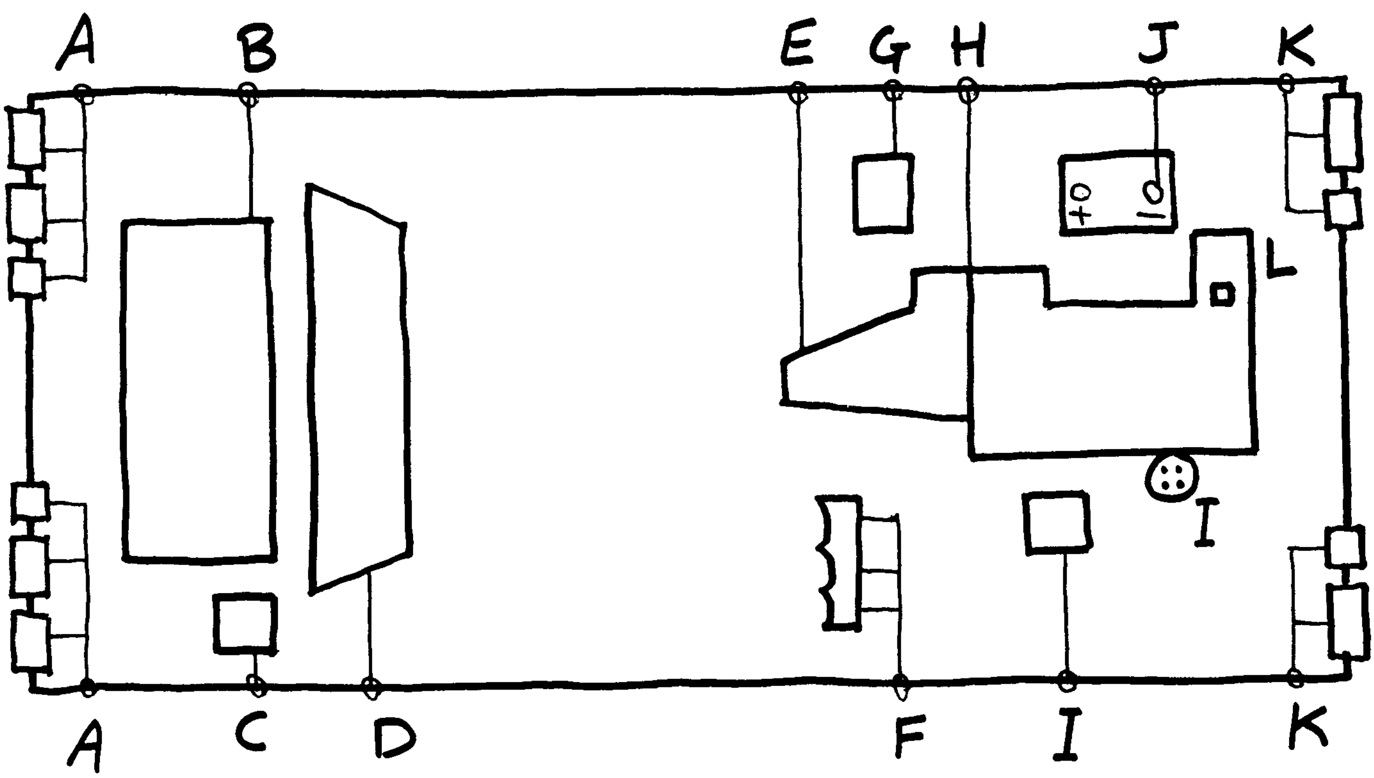
Most niggling earth problems seem very complicated to start with, as the symptoms can seemingly defy all logic. For instance, you have the sidelights switched on and when you apply the brakes, the sidelights go out when the brake lights are on. Similarly, all the sidelights and the brake lights go out when the brakes are applied.

What about the stiff or smouldering choke, throttle and clutch cables? These control cables are always a favourite route for earthing the body/chassis to the block if the main bonding strap earths are dirty or loose. Because these cables can create a high resistance themselves, they get hot and their plastic coating and/or lubrication may start to smoke!

Everyone's got a tale of mystical occurrences concerning car electronics. Sometimes the windscreen wipers will self-activate when you sound the horn. Maybe the indicators all come on at the same time when signalling left. What about smoke coming from one of the battery terminals when cranking the motor?

The two main reasons for unwanted

This is a very general plan representing the main earthing points in a steel-bodied, negative earth car (to be checked when operating anomalies occur). A is the earth for the rear light clusters, B is the earth for the fuel tank, C is the earth for the electric fuel pump, D is the earth for the rear screen demister, E is the gearbox earth strap, F is the instrument pod earth, G is the wiper motor earth, H is the main engine block earth strap, I is the earth for the electronic ignition box or the points/distributor, J is the main battery to body earth, K is the earth for the front lights and L is the solid earth connection from the alternator to the engine block.



heat generated by an electrical connection or by a cable are bad (or underrated) connectors and/or excess current flow. Generally speaking, if the wires taking current to and from a component are of insufficient gauge, then they will get hot. If there's a hot connector, whether or not this is an earth, then it's the connection which is at fault.

When small currents are involved in an electrical component, then it's less likely that there will be heat generated anywhere. Either way, there are better ways of looking for a fault than waiting for something to melt.

If anomalous lighting activity is the problem, there's a very good chance that one or several bulbs are badly earthed in their sockets. If it's the brake and sidelamps that are affected, remove the lot, including the front sidelamps, and clean up the metal surfaces on each bulb with fine abrasive paper.

It's more difficult, but you'll also have to clean up the bulb sockets and the various live terminals deep within these sockets. For safety's sake, remember to turn off the lights and ignition before doing this and, to be totally sure, you might want to disconnect the battery positive terminal instead.

Bad earths in bulb clusters are commonplace as each lens acts like a greenhouse and there's condensation, let alone ingress of rainwater. Look closely at some cars and you'll see an inch of water resting innocently at the bottom of the light lenses!

Electrolytic corrosion also has a part to play and, at the end of the day, when the earth to each of your indicator bulbs offers a different resistance, some very interesting things can start to happen. Ever driven in a car whose indicators flash quicker on the right than on the left? It happens. Some brake and tail lights can also be seen to be brighter on one side than on the other etc. etc.

If cleaning your bulbs and sockets has done no good, you've then got to trace the route that the electricity takes from the bulb holder back to the car body/chassis and then to the engine block and alternator. Suspect connections and terminals more than runs of wire. Separate all push-fit, bolt-on or self-tapped contacts, clean them and refit them. This could even run to earthing straps which connect the engine to the body/chassis.

The way that lighting systems are often wired up, it's possible for a badly earthed filament to earth itself through another filament as the easy option. While that other filament isn't in use, then the badly earthed counterpart will still seem to work OK. When the second filament becomes live, though, the first really won't have anywhere to earth and will go out.

What's happening when your engine doesn't crank over properly or at all? Don't necessarily start by replacing the battery, starter and alternator. It could be a lot easier than that. Remember that while cranking your engine, it's using up one helluva current.

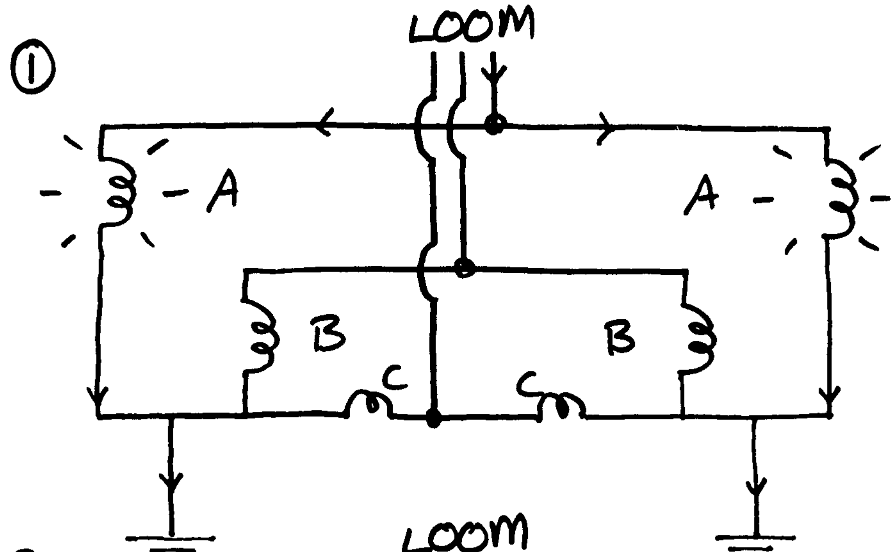
Back to the water diagram. The starter is the largest tap with the largest pipes. Treat it as its own little water system, as if it was the only tap. Obviously, it can only work correctly when all the water flows through the tap and back up to the top tank smoothly.

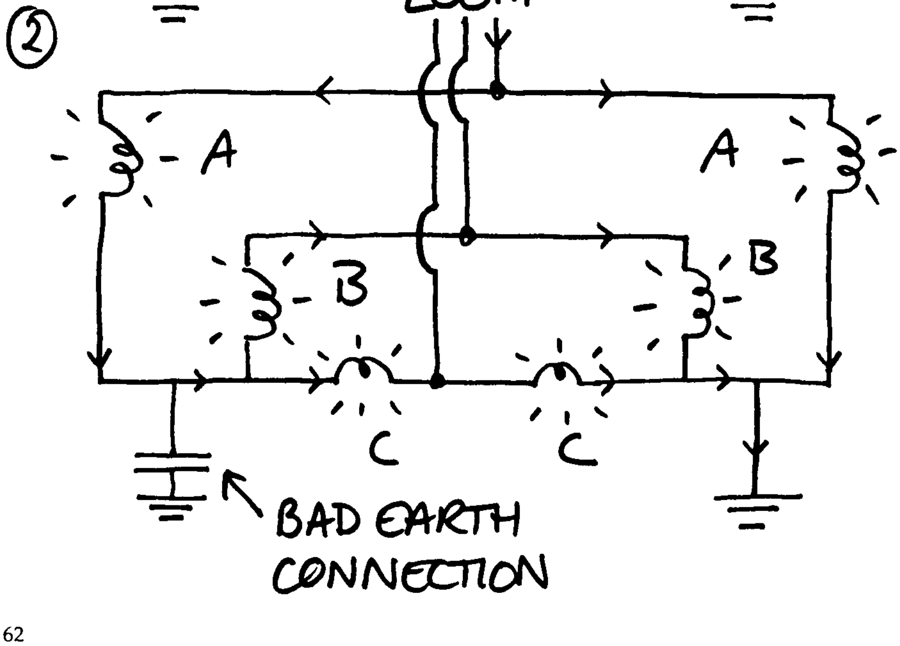
Anything stopping that water flow from or to the starter will make it work slower or not at all. Again, you've got to consider all the connections involved in this circuit. Clean up the battery terminals and clamps. (Bear in mind that a connected battery usually runs a permanent live to the starter solenoid whether or not the ignition is off).

No difference? Try the main cable connections from the battery to the solenoid and from the solenoid to the starter itself. What about the bolts holding the starter to the block?

Is the solenoid itself in need of an earth and, if it's body-mounted, is there corrosion behind it? Again, clean up the main straps from the body/chassis to

In these two diagrams, the bulbs A, B and C are all rear lights sharing the same earth point. Presume them to be brake, tail and reverse lights. Version 1 shows normal operation of brake lights A. Current comes from the loom, across to each bulb A and then to earth each side. Lights B and C are off. Version 2 shows the effect of a bad earth at the left side. Current flows to each brake light bulb A. On the right, the current flows through the filament and earths as normal. On the left, the current flows through the filament A but cannot reach the closest earth due to a bad connection. While bulbs B and C are switched off, though, the left side bulb A can earth through them to the good earthing point on the right side. It goes via all filaments B and C on the way and may well light up all or some of them when the brakes are applied. However, when lights B and C are also on, it's probable that all the left side bulbs will go out as they won't be able to earth back to the right side. If B and C are on and A is off, it's possible that left side bulbs B and C will earth back through bulbs A to the right side earth point, so all the bulbs may well light up.





the block and the earth connections to and from the battery. You could well save a lot of money by checking these things out.

When you start playing with looms so as to adapt them for a different car, as with many kit cars, you may well find that there is a multitude of earthing wires poking out of the loom and ending in flat rings. These rings would normally self-tap or bolt to a car body at selected points to earth the lower-powered components such as interior lights, exterior lights etc.

There might be a temptation to tidy this all up, especially in the case of a GRP-bodied car, by running a single earth wire in with the loom and connecting each or some of these original earths to it. Be very careful. Here's where we start playing with sums to add up currents.

Water flowing out of many small taps through many small pipes is OK. Water flowing out of many small taps and into one or a few small pipes isn't OK. The latter pipes will restrict the volume of water flowing but the equivalent wires will get hot.

Somewhere down the line, a designer designed the electrical system of the car whose loom you're using. The cables attached to those earth tabs aren't that size by accident. Several factors affect the size of the cable in terms of both diameter of its section and its length.

The main thing is the size of current it must carry. Another factor is whether that current is only sporadic or whether it's pretty much permanent. A certain size of current through a certain size of cable will start to generate heat. Six small cables cooled by the air around them might safely carry a certain current but, when these cables are bunched together, the cumulative heating might cause a meltdown.

So, if you're taking several earth cables and connecting them to a 'master' earth cable running in the loom, you'll know that if the master earth is the same size cable as each of the earths you're picking up, then it will probably be too small. It could create too much resistance, too much heat and thus a meltdown. How do you know how big your master earth should be?

Happily, there's a mathematical way around the problem and it's not high-flown theorising either. What you need to know is what each of your tributary earths is earthing. You need to find out what current rating is attached to the equipment being earthed by each tributary. Trace the earth cables back to whatever they're earthing and establish, probably through the Haynes manual or a dealer, what that equipment's power output is in watts.

For things like bulbs, that's easy because they've usually got it stamped on them somewhere. Use the equation amps (current) equals watts (power output) divided by volts (take this to be 12V in most circumstances). Hence a 3-watt interior bulb in a car will be drawing (3 divided by 12) amps current. Around 0.25 amps.

So, if your master earth cable is earthing four interior bulbs at 0.25A each, two 0.42A tail lights, two 1.75A brake lights, one 1.75A fog light, one 1.75A reverse light, two 0.42A number plate lights and two 1.75A indicator lights, it's sporadic maximum current will be 13.18 amps. Call it 14A if all these bulbs happen to be on at the same time — however unlikely.

When buying multi-strand, insulated copper cable, you have to make sure that they are proper automotive cables with a current density of at least 6.975 Amps/mm.sq. You would expect most

Cable Sizes (Strands/strand diameter in mm)	Current Rating in Amps.
9/0.3	5.50
14/0.3	8.75
28/0.3	17.50
44/0.3	25.50
65/0.3	35.00
84/0.3	42.00
97/0.3	50.00
120/0.3	60.00
37/0.9	170.00

All of the above current ratings should be reduced by 40% if the cable is to be bound into a loom. Cables of 28/0.3 and bigger should be downrated by 40% if they are continuously loaded.

cables designated 'automotive' would comply with this requirement and probably exceed it safely.

Because your master earth cable will probably be running in a loom and not in a cooling air space, you will need to make it bigger than just 14A-rated. That 14A should be about 60% of the cable's amp rating. You'd therefore need cable rated at about 23.4A. Looking at our reference chart, the closest we can get in readily available sizes is 28/0.3 metric.

That metric identification of the cable means 28 strands of copper, each of which is 0.3mm in diameter. It might seem like a fairly hefty cable to you but it gives the requisite safety margins for the sporadic use in hand.

If that 14 amps was a permanent load on the cable in the loom, then another safety margin would mean that you'd regard the 23.4A as 60% of the required cable rating. You'd use something like 39.2A cable. Then you might have to buy the closest equivalent which appears to be 42A and a size of 84/0.3

Pretty big stuff but you can't buy a cable too big — you can buy a cable too small! Remember the consequences of a meltdown compared to the price of cable.

What happens when you have to connect the end of the earth cable to earth itself? The best theoretical earth is the engine block, as that's what the alternator itself is attached to. Sometimes, though, it would be impractical to run all the earths directly to the engine/gearbox.

If you're lucky enough to have a full monocoque steel body, then your earth wire's flat ring terminal can be bolted or self-tapped to a cleaned steel surface out of the way somewhere. Bear in mind that paint, grease, vaseline and general dirt are bad conductors. Rub the contact surfaces clean with abrasive, fasten them together and then coat the lot afterwards.

Paint, underseal or high temperature grease are suitable protectors once the mating faces have been joined. Such things as vaseline, oil and standard grease can melt away due to high engine or interior temperatures.

If you have a monocoque GRP body, then you'll be at pains to put in a damn good earth from all the components to the engine and/or the battery. That's because any of the body-mounted electrical components will be isolated from earth unless they are earthed through the loom.

Maybe it would be better to forget the cable calculations and run a length of copper water pipe (flattened or otherwise) to the extremities which require an earth. It offers the advantage that you can readily solder wires to it and it really won't melt! Don't try to earth to steel or kunifer fuel/brake lines, although it's a good idea to run a separate cable from the fuel filler cap to earth.

Perhaps the best prospects for earthing at the extremities of a vehicle are when that vehicle has a tubular steel chassis. Earth wires with ring connectors can be bolted to convenient chassis tabs. In the case of a round-section steel chassis, it might be convenient to solder earth wires to a section of braided earth strap and then fasten the strap to the chassis with stainless jubilee clips.

One small note of caution relates to steel chassis with aluminium body panels. Electrolytic action can accelerate corrosion in both alloy and steel. Passing a current from the alloy to the steel or vice versa won't help things much. Try to keep all the earths connected to the steel chassis in this case.

Pop-rivets, which are usually aluminium, can also present a high resistance problem if you are earthing through them. For instance, if you're earthing to a steel panel which is fastened to the chassis with pop rivets, don't expect it to be a good earth. There might also be that problem with accelerated oxidation due to electrolysis.

That, in a nutshell, is the rough guide to earthing requirements. Now, the pedants will say, what about electron flow, (from negative to positive)? Well, for the purpose in hand, the only answer to that can be 'beam me up, Scotty'.