Chapter 15: Grounding

Ground refers to the common 'reference node' that is shared by all the parts of a circuit. For all the circuits in this book (and most others) ground is zero volts, or earth, and is normally represented by one of the circuit symbols in fig. 15.1. All four are more-or-less interchangeable, though that in **a.** is normally reserved for direct connections to the chassis or mains earth.

Many of these symbols may appear in a single schematic, but in reality they are all ultimately connected together. However, when physically building a circuit it is important to adopt a suitable **ground scheme**, particularly in the preamp. We must not simply connect all the ground wires to each other randomly, even though it might appear on paper that one bit of ground wire is much the same as another. They are not. A good ground scheme will:

- Minimise series impedance in the signal ground
- Avoid ground loops
- Prevent 'noisy' ground currents from flowing in quiet signal grounds

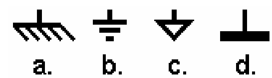

Fig. 15.1: Ground or earth symbols.

Confusion concerning 'ground' probably begins when we start learning electronics, since we necessarily start with very simple circuits. So simple, in fact, that grounding is not a problem. We can make the ground connections to any old bit of metal or wire and, as long as they are all ultimately connected together, the circuit works quite satisfactorily. So we don't bother to think or learn about grounding until we have already developed bad habits which, when we progress onto more advanced and high-gain circuits, suddenly become important.

Bad habits may also be reinforced by our familiarity with circuit diagrams that show components terminated with ground symbols. This makes for tidy diagrams, but it is easy to forget that current actually flows in a loop, so if it comes from some power source or generator then it must somehow find its way back again, via ground. Ground is, therefore, 'the other half of the circuit', and not some electrical black-hole into which current disappears never to be seen again, even though some diagrams seem to imply this.

Valve amplifiers are fairly noisy even at the best of times, but bad grounding is a serious contributor, even in many commercial amps. Sometimes it is difficult, practically, to follow an ideal ground scheme, and there is always the temptation to connect something to whatever bit of ground wire or chassis happens to be nearest, and hope for the best. Sometimes we will get away with this, especially in small, low-gain amplifiers, but readers of this book are probably beyond that level and will want to do things properly.

The principles behind grounding should actually seem quite straightforward once explained, but readers who only think about circuits in terms of voltage (another bad habit) are warned that they will have to start thinking in terms of current if it is to make any real sense. It is also worth noting that the rules we follow when grounding analog audio circuits are not always the same as those used for high-frequency radio and digital electronics, so the reader must be careful about which textbooks he uses for advice.

15.1: Safety Earth

Most guitar amps are built in a metal chassis. Even if it is enclosed in a wooden box, it is still possible for the user to touch the metal somehow, via fixing screws or when replacing valves, etc. Thus for the appliance to be safe it must be completely impossible for the metal chassis (and anything else the user might touch) to become live. This is achieved by physically connecting the chassis to planet Earth via the mains earth wire. Once the chassis is earthed it will be at the same potential as the person using it, and if any live wire were to touch the chassis it would immediately be shorted to earth and cannot shock the user, whether or not a fuse blows.

Where the mains cable enters the chassis –usually via an IEC inlet– a heavy-gauge wire should be soldered to the earth tab (do *not* use a push-fit connector for this), and then connected to the chassis with a solder tag, as shown in fig. 15.2. The chassis area should be cleaned with emery paper beforehand to ensure a good electrical connection. The wire should be short and should have the same colour scheme as the local mains supply, which is green-and-yellow striped in Europe, or green in the US.

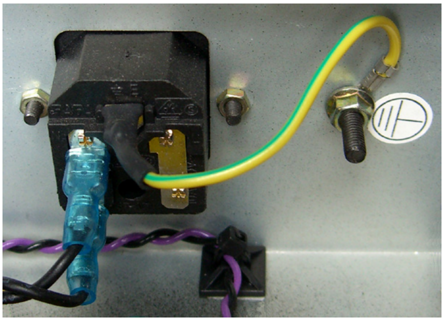

Fig. 15.2: The safety-earth bond should be made to a dedicated screw, close to the mains inlet.

Where this wire is bolted to chassis is known as the **safety-earth bond**, and it should be a dedicated screw/bolt, *not* a screw which is used to fix some other piece of hardware which might become loose over time. A nyloc nut should be used, or else a shake-proof or star washer should be used, with two ordinary nuts, well tightened. This wire is the most important connection in the amplifier and is legally required, and it must be completely sound.

This earth bond is for safety only; it plays no part in circuit operation and no current flows in it except under fault conditions. It can be regarded as just another part of the chassis. Although the terms ‘earth’ and ‘ground’ are often used interchangeably, the *audio* circuit ground does not necessarily have to be connected to planet Earth. The entire amplifier circuit *could* be built ‘floating’ inside the metal chassis, with no connection to the chassis at all. However, in reality the circuit *will* be connected to chassis at some point since this ensures the amplifier’s working voltages are properly defined with respect to zero volts, and that the chassis acts as a shield against electric fields. However, once we have accepted that our circuit exists inside a metal box which has been safely connected to earth then we can forget about the chassis, for the time being at least.

15.2: Ground Loops

A ground loop is created when two or more grounded circuit nodes are connected together by more than one path. This might occur due to careless layout, accidental or unexpected ground connections, or when two or more appliances are connected together (see section 15.9). Vintage amps often inadvertently created ground loops by using non-insulating jack sockets, bending over the ground tab on a potentiometer and soldering it to the case, soldering a ground bus to the backs of the control pots, or using the chassis as a more-or-less 'random ground'. Many amplifiers got away with this without gross hum, but it is still bad engineering no matter how convenient it may appear.

A ground loop becomes a problem when unwanted noisy currents flow in it, and there are two ways this may occur:

- Alternating magnetic fields produced by transformers and high-current carrying cables will induce an EMF in a loop, according to Faraday's law. This will in turn drive a noise current around the loop.
- Noisy power supply or power-amp ground currents may find an alternative return path via the loop (see section 15.9).

Once a noisy current is flowing around a ground loop it may induce hum in two ways:

- Noise voltages will be set up across the unavoidable series impedances of the loop, which may add directly to the audio signal voltage.
- The current will induce noise EMFs in nearby signal conductors via mutual inductance or, in other words, by transformer action.

Interference by magnetic induction can be reduced or eliminated by breaking the loop, reducing the area of the loop, reorientating the loop to reduce the amount of magnetic flux flowing through it, or simply by moving it further away from the source of the magnetic field.

Interference by transformer action occurs when a ground-loop wire and signal wire run parallel and in close proximity so that there is mutual inductance between them, such as in a shielded cable. This can be reduced or eliminated by grounding the shield at only one end (breaking the loop), by adding series resistance in the loop to reduce the ground current, or by using balanced connections to reject the induced hum signals, as used in pro-audio equipment.

Fig. 15.3 shows a particular case that often arises in valve amps. The circuit in **a.** shows a simple input stage that uses a shielded cable to screen the grid input from parasitic feedback. However, the circuit has been inadvertently connected to chassis at both ends of the shield, creating a ground loop. Both signal current and ground-loop current flow in the shield as indicated by the arrows, so the ground loop current will generate a noise voltage across the resistance of the shield that adds directly to the audio voltage, and transformer action in the cable may also couple noise into the grid wire. To correct this, the loop should be broken by disconnecting one of the chassis connections as in **b**. Alternatively, the circuit in **c.** shows an even better solution. The grid wire and signal ground are now *both* screened by a completely independent shield. The shield is now effectively just a tubular extension of the chassis, and is grounded at only one end to prevent a ground loop and hum by transformer action.

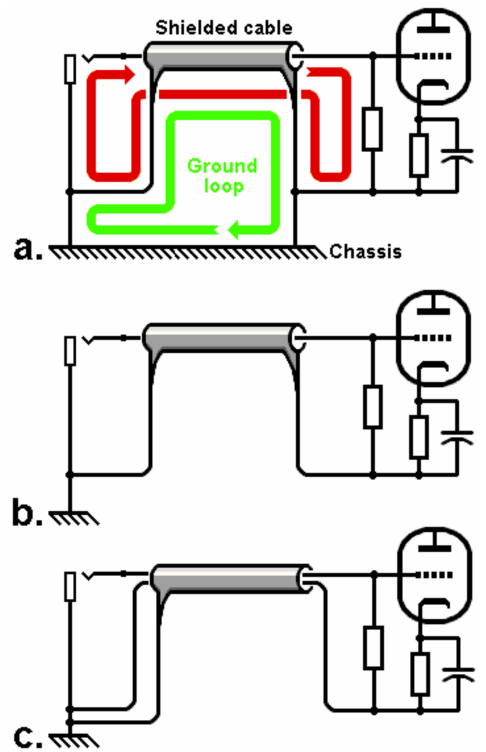

Fig. 15.3: **a:** Simple circuit showing ground loop created with a shielded cable. **b:** The ground loop is eliminated by removing one of the chassis connections. **c:** Ideal situation where a completely separate and independent shield is used.

15.3: Power-Supply Ripple Current

This book has assumed throughout that a suitable power supply is available. It is not the intention of the author to discuss the intimate details of power supply design here, but when it comes to grounding we must have at least some idea of how and where all that power comes from. In most valve amps the power supply consists of a power transformer, rectifier and reservoir capacitor. The rectifier may be a two-phase type or a bridge rectifier (or even half wave), and it may be solid-state or a valve; it does not matter as far as grounding is concerned. The reservoir capacitor then feeds the amplifier proper, usually via a chain of RC smoothing filters, each of which progressively smoothes the DC voltage and supplies one or two valve stages.

DC load current is drained off the reservoir capacitor at a more-or-less steady rate, but current from the transformer does not flow into the reservoir capacitor in the same steady fashion. Instead, the reservoir is 'refilled' twice every mains cycle. In other words, the current in the transformer, rectifier and reservoir flows in short, heavy pulses, and even though the *average* value of this current is the same as the

DC load current, its peak value will typically be about five times the load current. This is represented by the thick arrows in fig. 15.4 (for clarity only one diode is shown conducting whereas in reality they take turns). This is called **ripple current**, and because it occurs in heavy pulses it can easily introduce buzz into an audio circuit unless a sensible layout is adopted.

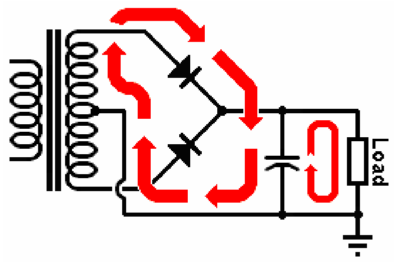

Fig. 15.4: Current flows around the transformer-rectifier-reservoir in short heavy pulses that may be a source of buzz.

To minimise the interaction of ripple current with the rest of the circuit, the transformer-rectifier-reservoir must be treated as a single, self-contained circuit block. In some schematics this is emphasised by drawing the circuit in a more compact fashion, as in fig. 15.5, and the circuit should be physically built in a similarly compact way.* The rest of the amplifier will then be connected directly to the terminals of the reservoir capacitor. Connections to any other points on this noisy current loop are not allowed, and no part of this network may be connected to the chassis if a quiet ground scheme is to be maintained! Some very sensitive preamplifiers may even shield this part of the power supply from the audio circuit with a metal bulkhead or screening can.

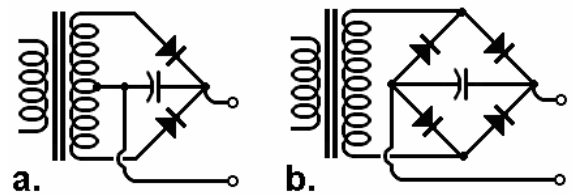

Fig. 15.5: The transformer-rectifier-reservoir network should be considered a single circuit block, and physical connections should be kept as short as possible. **a:** Two-phase rectifier. **b:** Bridge rectifier.

15.4: Power-Supply Smoothing Filters

Having built the transformer-rectifier-reservoir circuit block in a tidy, compact way, we now turn our attention to the power supply smoothing filters. These form a chain (or branching chain) that is fed from the reservoir capacitor. Each filter progressively smoothes the power supply voltage, scrubbing away residual ripple. The amp's input stage will always be supplied by the last filter in the chain since this valve is the most sensitive to any noise on the power supply.

Now, it is essential to appreciate that load current flows down the chain of the filters and *returns back again along the ground connections*. This will cause small voltages

* At least a few centimetres distance should be kept between the reservoir capacitor and any hot valve rectifier or transformer, however.

to develop across the unavoidable impedances of the ground wires. If the load current were *pure* DC then this would not matter much, but in practice there is still some residual ripple from the rectifier, as well as fluctuations in load current due to the audio signal being amplified, so the voltages developed along the ground circuit will be noisy. It is, therefore, important how we connect the *signal ground* to the *power supply ground*, and a good ground scheme will naturally minimise the interaction of the two.

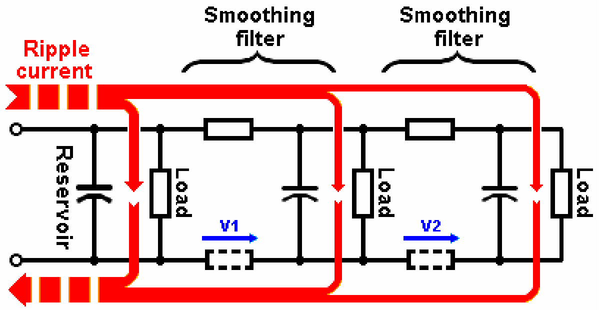

Fig. 15.6: Diagram illustrating the flow of power supply currents and the noise voltages developed across any ground impedances (shown dashed).

Fig. 15.6 attempts to illustrate the flow of power supply currents and the noise voltages developed across the ground impedances, which are shown dashed. Although we may be used to seeing power supply smoothing filters drawn as simple RC (or possibly LC) filters on circuit diagrams, we should really see them as balanced filters made from one capacitor and *two* series impedances, where one is the intentional dropping resistor or smoothing choke and the other is formed by the impedance of the ground circuit, as shown. Also note that ground currents accrue as we get closer to the reservoir, so in this case V1 is produced by only one noisy current whereas V2 is produced by the sum of *two* noisy currents.

In general we would try to minimise the ground impedance, but there is a useful exception to this rule. In stand-alone preamps and low power (usually single ended) amps there may be one or more additional stages of smoothing after the reservoir capacitor, before supplying the audio circuit. In such cases it is beneficial to split the usual dropping resistance into two parts (usually but not necessarily equal) and so deliberately create a real balanced filter, as illustrated in fig. 15.7. The added resistance in the negative side of the circuit helps isolate the noisy rectifier/reservoir circuit from the amplifier proper, and will keep ripple current out of the audio ground. One or both of the dropping resistors could be replaced by a smoothing choke, and there is the added advantage that a choke in the negative side of the circuit is subject to less voltage stress between the coil and frame than one in the ‘traditional’ side of the circuit. There must be no connection between transformer-rectifier-reservoir and chassis, of course, but that is always true of a proper ground scheme.

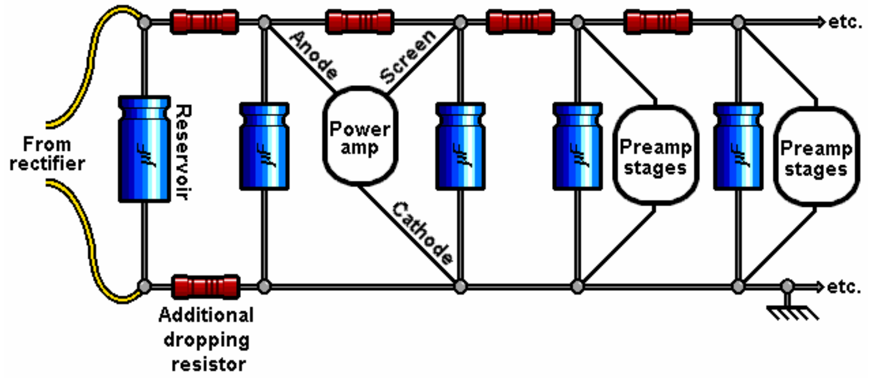

Fig. 15.7: If there is an additional stage of smoothing immediately after the reservoir capacitor then it is beneficial to split the dropping resistance into two parts to create a balanced filter, which will retard ripple current from entering the audio ground. Although resistors are shown, any or all of them may be replaced by smoothing chokes.

15.5: Signal Currents

When the amp is at rest the current drawn from the power supply is steady, but when it is amplifying a signal the current demands are continually changing. This can alternatively be viewed as an AC signal current superimposed on top of the steady 'background' current. In a valve stage this signal current flows in the loop formed by the valve and the smoothing capacitor which supplies it, as illustrated in fig. 15.8. For the quietest operation the signal current should be kept separate from the power supply current that keeps the capacitor topped up, because this current contains residual ripple. The smoothing capacitor should therefore be positioned close to the valve stage, and the connections to it should be kept as short as possible (radial capacitors are sometimes preferred for this reason).

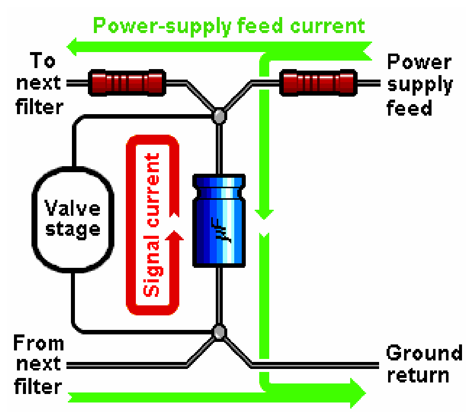

Fig. 15.8: Diagram illustrating how signal and power supply currents should be kept separate, as far as possible.

Conversely, the connections that supply current to the smoothing capacitor from the rest of the power supply are not critical. After all, we normally put a dropping

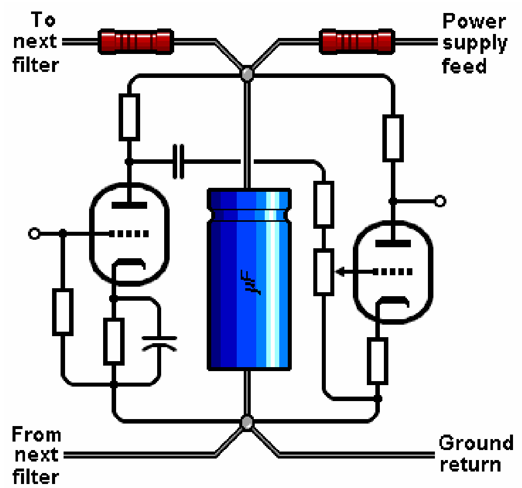

Fig. 15.9: Ideal layout for two valves operating from the same smoothing capacitor.

resistor or choke in this path anyway, so the extra impedance of a long wire is of no consequence. On the other hand, a long feed path implies a long ground return path, which is not what we want. Good planning should produce a layout that achieves a reasonable compromise between these things (and planning costs nothing but time). The habit of placing all the power supply capacitors in one place and running long wires from there to the amplifier stages is the exact opposite of what we want, and is bad engineering.

When two valve stages are cascaded, components which come after the coupling capacitor 'belong' to the following stage's grid-leak circuit and should be returned directly to the following stage's cathode circuit. Fig. 15.9 shows an example of this where the two cascaded stages are also supplied by the same smoothing capacitor.

15.6: Ground Planes

Many electronics textbooks talk about ground planes, so it is perhaps worth clearing up any confusion here. A ground plane, as the name suggests, is a wide grounded area, often formed by a single layer on a printed circuit board. In high-frequency equipment operating in the megahertz region, components are often grounded directly to such a plane, which creates the tightest possible layouts. This is acceptable only because, at these frequencies, ground return currents do not flow evenly throughout the whole plane but will naturally find the path of least inductance, that is, smallest loop area. The ground currents will therefore flow directly in parallel with their associated conductors above the plane and will not readily interfere with the ground currents of other parts of the circuit.

Many old guitar amplifiers use more-or-less random grounding to the chassis and beginners may confuse this with the deliberate ground plane approach adopted in high frequency equipment. But it must be emphasised that at audio frequencies the use of a ground plane is generally *not* good engineering practice, since ground currents will flow more-or-less uniformly in it and will interfere with one another. The chassis should be considered nothing more than a metal box which protects the user from the circuit, shields the circuit from interference, and provides a solid support for the construction. Allowing it to become part of the audio circuit by treating it like 'one big fat wire' is asking for trouble.

15.7: Bus Grounding

One logical ground scheme is the bus* ground. This is involves routing a single, heavy-gauge wire –called the **bus wire** or **bus bar**– through the chassis. The path of the bus wire should follow the natural path of the amp circuit from the reservoir capacitor, to power amp (if present) to preamp, to input stage, and all ground connections are made progressively along it in the same natural order. The bus bar should be connected to the chassis at *one point only*, at the input end of the amplifier (see section 15.9). This tends to encourages a long thin layout, but it can be bent into any convenient shape of course.

To make the bus bar, tinned-copper wire can be bought on the roll, but a piece of stripped 24A or 32A solid-core mains wire is a cheap alternative in Europe. In the US, 14AWG solid-core may also be readily available. Ideally, bare copper should be tinned in a bath of solder to prevent corrosion, although this is not always within the means of hobbyists.

A 'first principle' bus ground is shown in fig. 15.10a and it can be seen that it closely follows the way a circuit diagram would normally be drawn. In a very simple circuit like the one shown, no problems should be encountered with this arrangement. However, by taking more care over the exact positions of the ground connections it is possible to closely approximate a more ideal multiple star ground (see next section), and this is to be preferred when building more complex or high-gain amps. The necessary changes are shown in **b.** from which it can be seen that the bus now runs all the way from the reservoir capacitor to the input jack, and is connected to the chassis at the input jack itself. All power and ground connections are now made much closer to their relevant smoothing capacitors, thereby minimising the interaction of audio and power currents. The speaker ground has been moved to the quieter side of the ground currents flowing from the power valve, and all grid leaks are now connected to their respective cathode resistors, rather than directly to the bus.

This method of grounding is highly recommended as it offers near-ideal performance while being straightforward and intuitive. If the path of the bus bar is carefully planned from the beginning then the component layout should follow quite naturally, and mistakes will be difficult to make. It is well suited to hand-wired designs and once all the components are soldered to it, it can form a pleasingly rigid structure. Do not be tempted to wrap component leads around the bus bar multiple times before soldering, however, as this will make later modifications extremely difficult!

* This is short for omnibus; the alternative spelling 'buss' is wrong.

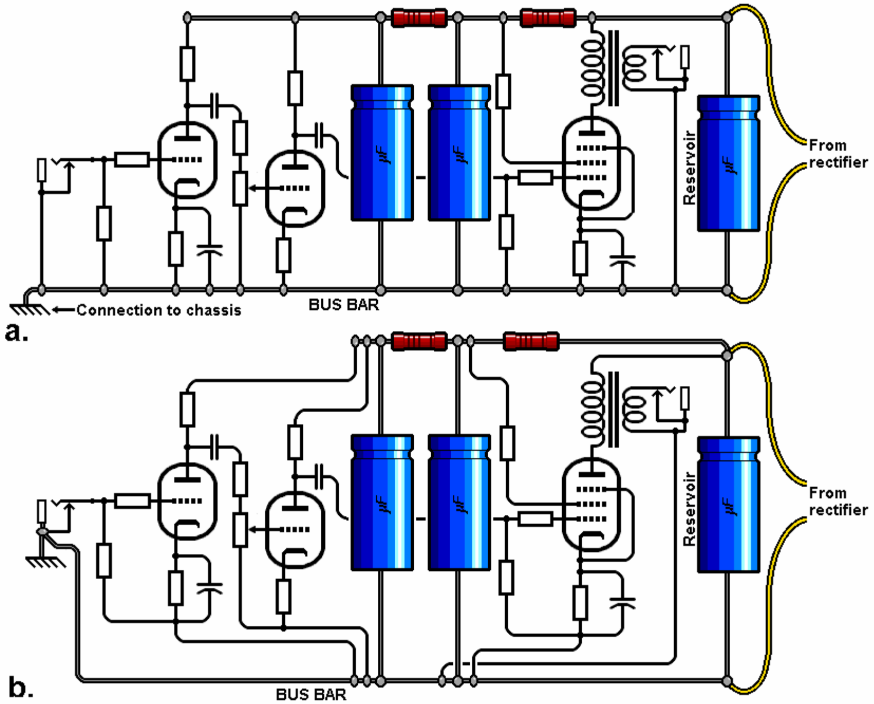

Fig. 15.10: **a:** First principle bus ground suitable for low-gain designs. **b:** Improved bus ground that closely approximates a multiple star ground.

15.8: Star Grounding

The ideal star ground is one where every ground connection in the amp is brought via a very short wire to a single point, which is then connected to the chassis. Since all the wires radiate away from this point the name 'star ground' becomes obvious, and this method tends to encourage a horseshoe-shaped layout, as illustrated in fig. 15.11. With a single star, ground loops and interaction of ground

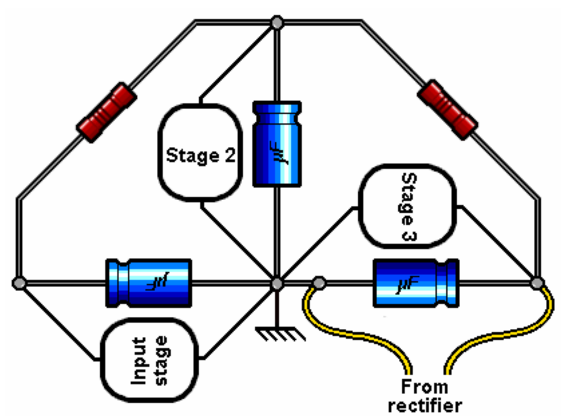

Fig. 15.11: A single star ground is theoretically ideal, but impractical in a complex circuit.

currents would in theory be completely eliminated, but for anything other than simple circuits it is difficult to keep the connections short, and long ground wires would defeat the ideal nature of the single star ground by introducing lead resistance and inductance, not to mention being plain ugly.

A more practical ground scheme is the **multiple star ground** that was alluded to in the previous section. This has most of the advantages of a single star ground but allows the circuit to be freely arranged in whatever pattern is required, and is really just a more flexible version of the improved bus ground in fig. 15.10b, since it dispenses with the rigid bus bar.
As usual, the transformer-rectifier-reservoir circuit should be built first, as a single circuit block. Every smoothing thereafter forms a local star, and all circuitry associated with a given capacitor is grounded directly to that star, in exactly the same way as shown earlier in 15.9. All the local stars are then daisy chained together in the same order as the positive side of the power supply.

Fig. 15.12 shows an example of star grounding in a practical power output stage. In most guitar amps the power valves are pentodes or beam-tetrodes, and it is more important that their screen-to-cathode voltage remain noise free, rather than the anode-to-cathode voltage. Therefore, the local star is made at the smoothing capacitor which supplies the screen grid (this was also seen in fig. 15.10b). In this case a push-pull amplifier is shown and connections to it are kept as symmetrical as possible to maximise CMRR.

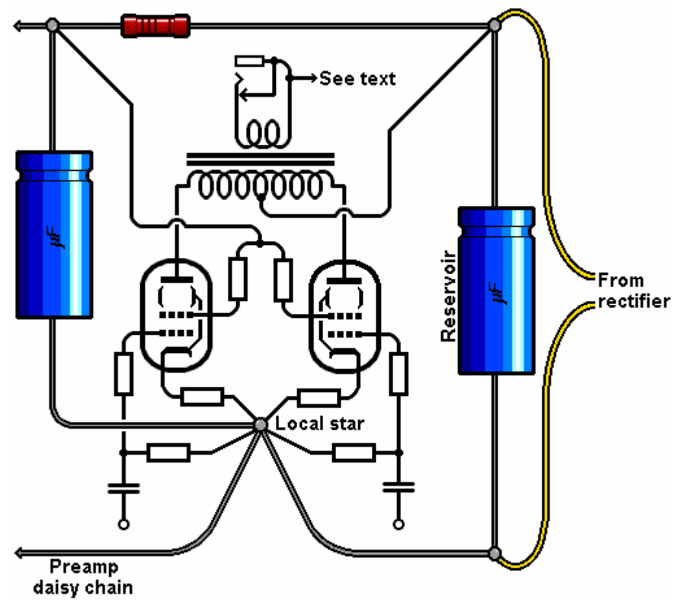

Fig. 15.12: Grounding a typical cathode-biased power output stage.

In a fixed-bias amp the negative bias supply should be considered to be a tiny power supply in its own right, so the same grounding logic can be applied. The whole bias

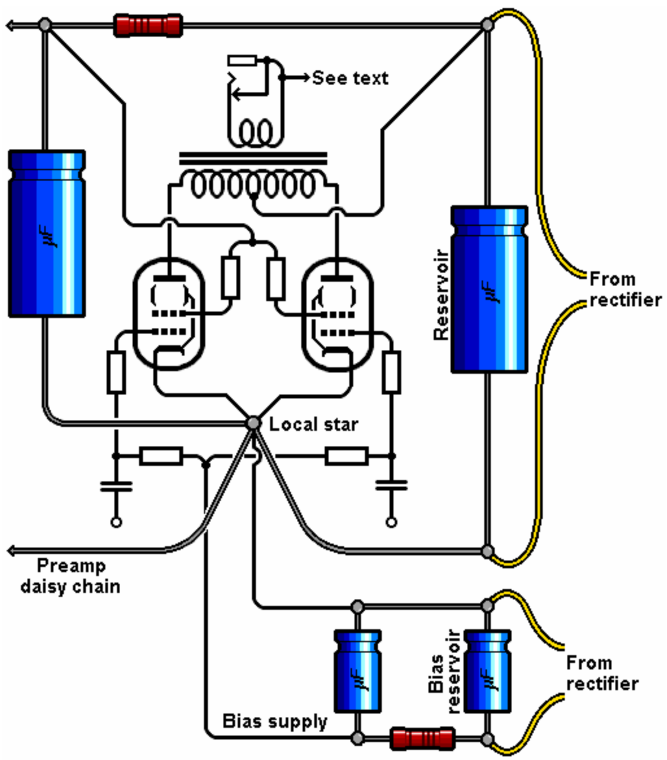

Fig. 15.13: Grounding a typical fixed-biased power output stage.

supply is built with its own star (or possibly bus) ground scheme, and the last stage –often a bias adjustment pot– is finally connected to the audio circuit, as in fig. 15.13.

The secondary side of the output transformer (if one is used) should always be wired directly to the speaker jack using heavy-gauge wire. This is true no matter what ground scheme is used. A separate wire (which does not need to be heavy gauge) should then run from the negative connection of the speaker jack back to an appropriate star. If global feedback is not used then this speaker ground wire should be returned to the power-amp star. If global feedback *is* used then the speaker ground should be returned to the local star of whichever stage the feedback happens to be applied to, which is usually the phase inverter (e.g., fig. 15.14).

Fig. 15.14 shows how a typical preamp would be arranged using multiple star grounding, and it can be seen that this turns out more-or-less the same as the improved bus ground from fig. 15.10b; the bus bar has become the daisy chain. Needless to say, all these connections should be as short as possible. Any non-audio grounds (e.g., for channel switching) should be considered noisy and should *not* return directly to an audio star but to the reservoir capacitor.

Note that no part of this ground system is yet connected to chassis / earth. The whole audio circuit is still effectively floating inside the chassis. The next section specifies the one-and-only connection to be made between the circuit ground and chassis.

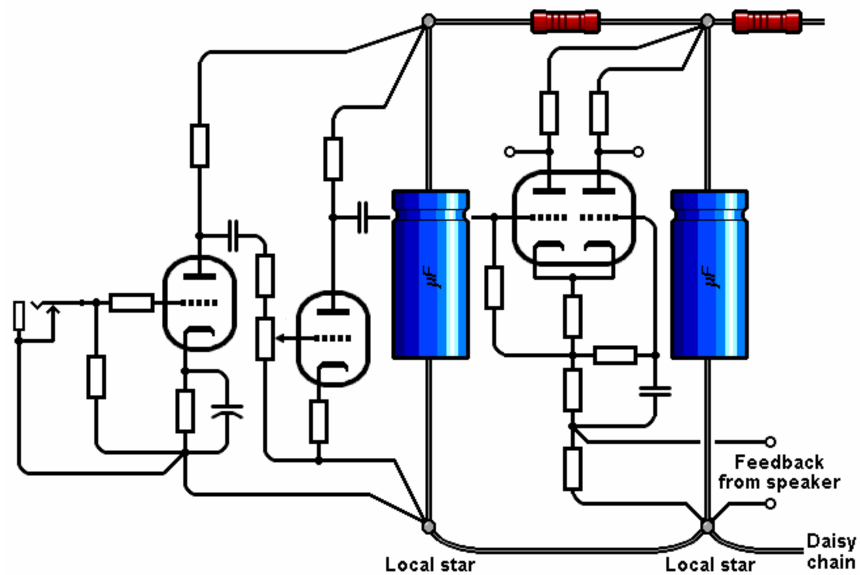

Fig. 15.14: Multiple star grounding of a typical preamp.

15.9: The Ground-to-Chassis Connection

Having designed the circuit layout on a PCB, turret board or even wired point-to-point, and having dutifully obeyed a sensible ground scheme, we must finally connect circuit ground to the chassis (which is bonded to earth) at *one* point only. This connection is purely for safety / shielding purposes; no circuit current flows in this connection under normal circumstances. It is merely a voltage *reference*, not a return for current.

The position of the ground-to-chassis connection is important because, inevitably, we will want to plug other powered devices into the amp, such as mains-powered effects pedals or external preamps. These appliances will have their own earthed chassis so connecting two together will create a ground loop via the audio interconnect and the mains earth. This loop will have a huge area so even fairly innocuous magnetic fields may produce significant noise currents in it, and power supply ground currents can also flow from one device into the other, which introduces another source of hum.

To illustrate the situation, fig. 15.15 shows a simplified diagram of two devices –in this case a separate preamp and power amp– connected together, and the resulting ground loop. In **a.** the ground-to-earth connection has been made at a sub-optimum position so power supply currents from each device can flow into the other, as

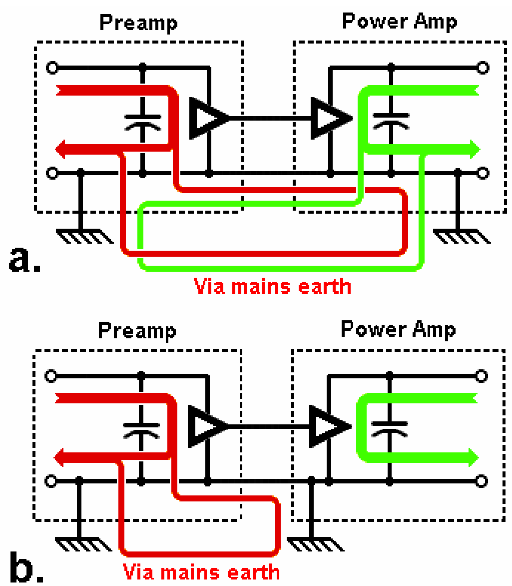

Fig. 15.15: **a:** Improper choice of ground-to-earth connection allows power supply currents to flow between devices. **b:** The correct place for the ground-to-earth connection is the input of the amplifier.

indicated by the arrows. Magnetically induced hum currents will also flow around the same ground loop. Altogether this is a poor situation.
By moving the ground-chassis connection to the very input of the power amp the situation is much improved, as shown in **b**. The loop area is reduced and with it any magnetically induced currents, and current from the power amp is now completely isolated from the preamp. Current from the preamp can still flow down the audio interconnect, but it at least does not flow around the whole ground circuit of the power amp.

Now, readers might point out that the situation could be improved still further by moving the ground-chassis connection of the preamp to its output, to make the ground loop even smaller. This is true, but if we had a third device plugged into the input of the preamp then we would have the same problem that we started with in **a**. And since devices towards the end of an audio chain handle larger signal levels and are less sensitive to noise than those preceding them, the arrangement in **b.** is always the one adopted. In other words, the ground-to-chassis connection should always be made right at the input jack of an amplifier circuit. Ideally this connection should run from the jack socket to a point near the safety-earth bond, but connecting it to some other part of the chassis is usually satisfactory.

15.10: Ground Lift

To combat the problem of creating a ground loop via mains earth when connecting two devices together, some appliances will offer a ground-lift switch. This disconnects the audio ground from the chassis, breaking the loop. **However, the connection between chassis and mains earth is NOT broken. The chassis must remains earthed at all times!**

Completely breaking the connection between audio ground and mains earth still has some safety implications, so a compromise is to use a hum-loop block network instead. This consists of a 10Ω resistor in parallel with a 100nF to 470nF capacitor.

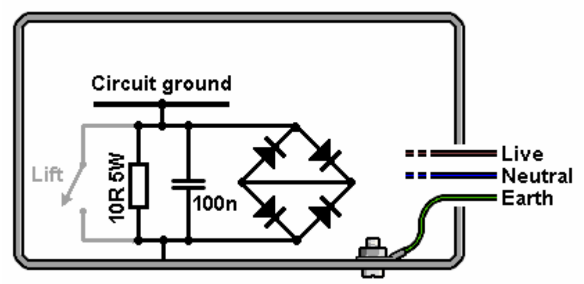

Fig. 15.16: Hum-loop block network and optional ground-lift switch. The chassis is always connected to mains earth for safety reasons.

When a ground loop is created it will now have a 10Ω resistance in series with it, which should reduce power-supply ground-loop currents to negligible levels. The capacitor ensures audio ground still appears to be connected directly to chassis as far as high frequencies are concerned, so we still have good shielding against radio interference.

The resistor should be a power device, say 5W, so that it can withstand fault currents. A pair of high-current diodes should also be connected in anti-parallel to bypass more serious fault currents, thereby ensuring any fuses will reliably blow. A >6 amp bridge rectifier package is quite convenient for this, as shown in fig. 15.16 (it does not need to be a high-voltage rectifier). A silicon diode will not turn on until the voltage across it reaches about 0.6V, so the ground loop still appears to be blocked as far as small hum voltages are concerned. In low-level preamps, mixers, and other noise-sensitive equipment, a switch may also be included as shown in the figure, but this is not necessary in a power amp.

15.11: Grounding Multi-Channel Amplifiers

If the amplifier has more than one channel then we must make a decision about where to make the ground-to-chassis connection. We must not connect *all* the inputs to chassis since this would create a ground loop between the channels. If one

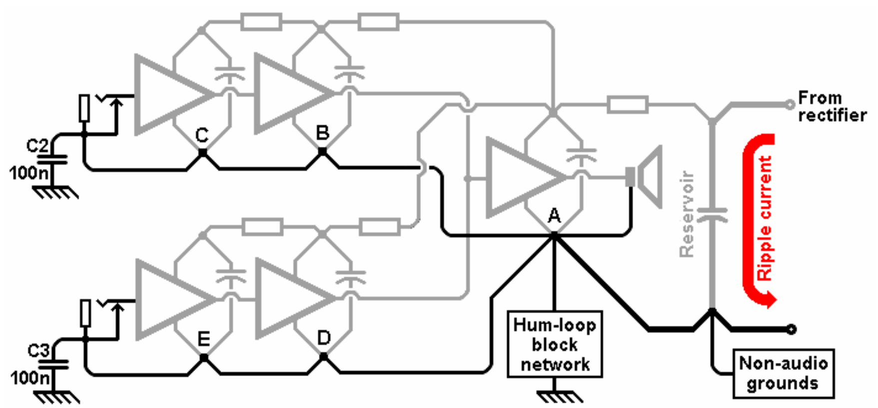

Fig. 15.17: A multi-star ground scheme applied to a two-channel amp.

of the channels has very much higher gain than the other(s) then that is the input we should connect to chassis, since the other channels will be less sensitive to ground loop hum.
If the amplifier has more than one high-gain channel then it may be better to make the chassis connection further into the amplifier where the two channels meet and become one. Since this increases the chances of ground loop hum when other pieces of equipment are attached, as fig. 15.15 showed, the connection should be made via a hum-loop block network.

A typical, two-channel ground scheme using this method is shown in fig. 15.17. The locals stars are at points A-E, and note that two separate daisy chains from A to C and A to E are used, mirroring the path of the positive side of the power supply. The point where the two join is connected to chassis, which might be at the phase inverter or power output stage. C2 and C3 may be added directly between the input-jacks and chassis to reduce any chance of radio pickup, but this is a rare necessity.

15.12: Miscellaneous Ground Connections

Some transformers have an internal screen between the primary and secondary coils to reduce stray capacitance between the two, and this should be grounded. Usually it can be connected to any convenient point on the chassis, often via one of the transformer mounting bolts. Otherwise it may be connected to the negative end of the reservoir capacitor like any other non-critical ground.

If the heater supply is not elevated but simply grounded then this connection can usually be made to any convenient point on the chassis, or else to a point close to the reservoir capacitor. However, heater hum is induced in many ways so it may be worth experimenting by making the connection to various points on the circuit ground to see if any particular place happens to give more favourable hum performance.

Older amplifiers often used multi-section capacitors commonly known as **can caps**. These usually contain two or three capacitors with a single, shared negative connection. These were convenient at the time since they saved space and presumably money. The obvious problem with them, however, is that by having only one negative connection they force us to adopt a ground star that may not be convenient. The best advice would be not to use can capacitors at all; like non-insulating jack sockets they are an anachronism. However, for readers who still insist on using them, a reasonable compromise would be to use a single, dedicated capacitor for the reservoir, and a can-cap for later smoothing stages. Nevertheless, the ground connections should always be kept as short as possible.