# Grounding

## Grounding:

Ground refers to the common 'reference voltage' that all the parts of a circuit share. For all the circuits in this book, which also applies to most existing guitar amplifiers, ground is zero volts, or earth, and is normally represented by one of the schematic symbols in fig. 13.1. All four are more-or-less interchangeable, though that in *a.* is normally reserved for direct connections to the chassis or earth.

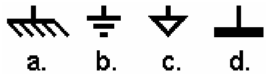

Fig. 13.1: Ground / earth symbols.

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 the resistance in the signal ground.
- Avoid ground loops.
- Remove the possibility for heavy power-amp and power-supply currents from flowing in the audio ground circuit of other parts of the amp, particularly the preamp.

Perhaps some of the confusion surrounding 'ground' arises because when we start learning electronics we necessarily start with very simple circuits. So simple, in fact, that grounding isn't 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. 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 circuits, begin to cause problems, much to our surprise.
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 a proper 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 it, 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 straight forward 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 analogue audio circuits are not necessarily the same for digital and high-frequency circuits, so be careful what texts you read.

## The Earth bond:

Most guitar amps are built in a metal chassis. Even if it is enclosed in a wooden box, it is usually possible for the user to touch the metal somehow, via fixing screws or when replacing valves etc. **For the appliance to be safe, it must be completely impossible for the metal chassis to become live. This is achieved by physically connecting the chassis to 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 be immediately shorted to earth and cannot shock the user, whether a fuse blows or not.

Where the mains cable enters the chassis, usually via an IEC inlet, a heavy-gauge wire should be soldered to the mains earth connection (do *not* use a push-fit connector for this), and then connected to the chassis with a solder tag, as shown in fig. 13.2. The chassis area should be cleaned with emery paper before hand to ensure a good electrical connection. The wire should be short and should have the same colour scheme as the local mains supply. The earth wire is green-and-yellow striped in Europe and green in the US.

Where this wire is bolted to chassis is known as the **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 must be completely sound.

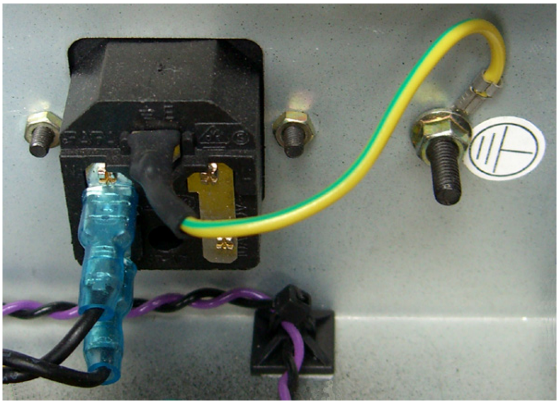

Fig. 13.2: The Earth bond should be made to a dedicated screw, close to the mains inlet.

*The Earth bond is for safety only; it plays no part in circuit operation* and may 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 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 that the amplifiers working voltages are properly defined with respect to zero volts, otherwise it might be possible for the user to receive a shock if he were to touch the guitar strings and chassis at the same time while an amplifier fault had occurred. 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.

## Ground loops:

If we place a loop of wire in a constantly changing magnetic field –such as that around a power transformer– a current will be induced in the loop. Since the loop will inevitably have some resistance (especially if part of it is a steel chassis) then the current will develop a voltage across the resistance, and this becomes a noise signal and can be amplified along with the audio signal.

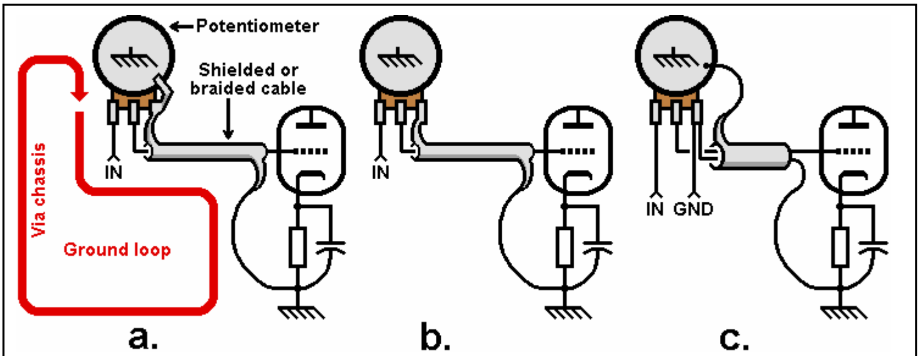


Fig. 13.4: **a.** A ground loop caused by too many chassis connection in a single circuit will lead to hum. **b.** Breaking the ground loop; there is now only one chassis connection. **c.** Improved layout with a completely separate shield.

For example, fig. 13.4*a* illustrates a case where one end of the shield on a shielded cable has been soldered to the tab on a potentiometer, which is also bent over and soldered to the body of the potentiometer (which is in contact with the chassis). The other end of the shield is connected to circuit ground, which has inadvertently been connected to the chassis somewhere else; a ground loop now exists, as indicated. If there is sufficient resistance in this loop then any induced currents will develop a voltage directly in series with the audio signal, creating hum, noise and even radio interference.
For this reason, the tabs on potentiometers should not be bent over and soldered to the back as this inevitably leads to ground noise, and the connection between potentiometer and chassis can become loose or corroded over time too. Fig. 12.4*b* shows the corrected circuit. Better still is to avoid using the shield as part of the circuit at all. Instead, the 'hot' signal and circuit ground each have their own wires, and both are then encased in a shield or braid as in *c*. This braid should be connected to the chassis or circuit ground at one end only. It therefore acts simply as a metal tube –an extension of the chassis– and is not part of the electronic circuit itself. Twisting the ground and signal wires together also aids in hum rejection.

In America, un-insulated jack sockets seem to be prevalent, which immediately force the builder to make a chassis connection where he may not want one. Now that we are in the 21st century these un-insulated sockets should be abandoned, and insulated jack sockets used instead*. These have been more-or-less standard in British amplifiers for decades.

Ground loops can also be accidentally created if two pieces of equipment are connected together (such as an amplifier and slave amp say) if each appliance has its own connection from circuit-ground to chassis. The resulting ground loop can lead to power-supply ground currents flowing from one device into the other [see fig. 13.12]. Some appliances will offer a **ground lift** switch that allows this connection to be broken, defeating the ground loop. This is illustrated in fig. 13.5; note that the Earth bond between chassis and earth must *never* be broken. Such switches are usually included in low-level preamps and mixers, rather than power amps.
The best way to avoid ground loops is of course to adopt a logical ground scheme. But if for some reason we can't avoid a loop, then other ways to minimise the effects are:

- Reduce the area of the loop by using short wires, kept close together.
- Reduce the magnetic flux normal to the loop by reorientating the loop or the source of magnetic field.
- Reduce the source of magnetic field by moving it further away or screening it.

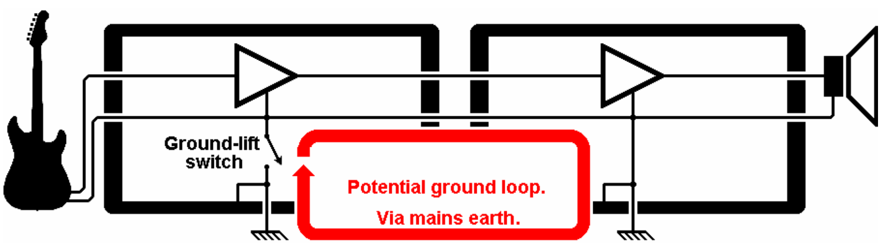


Fig.13.5: A ground loop caused by connecting two pieces of equipment together via interconnecting cables. The potential loop is broken by the ground-lift switch in one of the appliances. The Earth bond must *never* be broken, however.

**Grounding and power supplies:**

This book has assumed throughout that a suitable power supply is available. It is not the intention of the author to discuss the intimate operation or design of power supplies, but when it comes to grounding we must have at least some idea or 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, and it may be solid-state or a valve rectifier of course. This functional block then feeds a chain of RC filters, and each stage of the amplifier will be fed from a smoothing capacitor (in complex amplifiers there may be more than one chain of RC filters). If

* They are sometimes known as Cliff jack in the US, after the popular manufacturer.

we break the system down into three types of current loop it is easier to see what ground connections should be made, and where.

Firstly there is the current flowing around the transformer, rectifier and reservoir capacitor. This current flows in short, very heavy pulses at twice the mains frequency, when each diode switches on. This is represented by the thick arrows in fig. 13.6 (for clarity only one diode is shown conducting). This is called **ripple current**, and the pulses can easily peak at ten times the DC current that we feed the rest of the amplifier with! Such heavy currents can develop noise voltages across even small resistances and so it is very important to keep this transformer-rectifier-reservoir circuit as short as possible, and to use relatively thick wire to keep the resistances low. In fact, it would probably be more obvious that this part of the power supply is self-contained functional block if schematics were drawn as in fig. 13.7! Further power supply connections should then be made directly to the reservoir capacitor itself, and not to any of the wires which feed the reservoir.

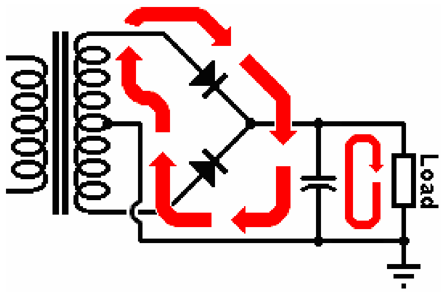

Fig. 13.6: Current flows around the transformer-rectifier-reservoir in short heavy pulses, much greater than the DC load current.

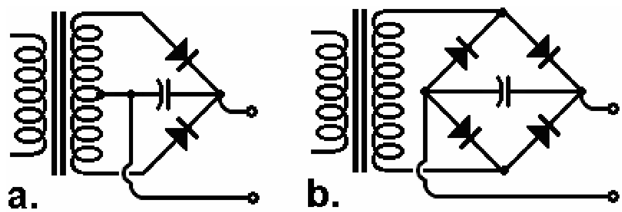

Fig. 13.7: Redrawing schematics may make it more obvious that the transformer-rectifier-reservoir circuit is a single system, and physical connections should be kept as short as possible. **a.** two-phase rectifier. **b.** bridge rectifier.

The heavy ripple current also generates a strong magnetic field, so audio circuitry should not be placed too close to any wires carrying this ripple current.

Next, there is the steady current which flows from the reservoir capacitor and feeds the chain of RC smoothing filters, as indicated in fig. 13.8. Attentive readers will now have spotted that these power supply currents have to travel back along the ground connection. Again, since there will always be some unavoidable resistance in this path across which noise voltage will appear. If the current were pure DC then this would not matter too much, but in practice there will be residual ripple from the rectifier and also variations in load current, which will cause similar variations in these voltages. It is therefore important how we connect the *amplifier ground* to the *power supply ground*. Fig. 13.8 also illustrates how the current flowing closer to the source is the sum of all the current further down, so the closer we get to the reservoir the more noisy things become.

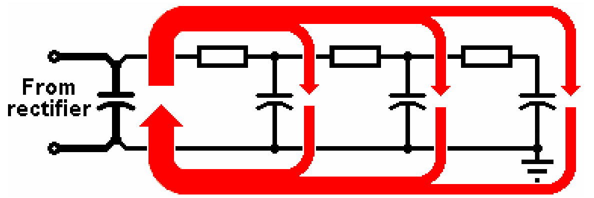


Fig. 13.8: Steady current supplied to the rest of the power supply comes from the reservoir capacitor (shown bold).

Thirdly there is the *signal current* which is actually delivered to the valves or other circuitry, and this is supplied by each smoothing capacitor. In fig. 13.9*a* we see the signal current flows in the loop formed by a triode and the capacitor which supplies it. However, simply by altering the placement of the components as in *b.* we have forced the power-supply charging current to flow in the same wires as the signal current, immediately creating places for power supply noise voltages to interact with the audio; we have mixed the power supply's ground with the signal's ground. In this case only one stage is shown, but if this were just one stage in a series, so that the power supply current was also going on to supply the other stages, then the possibility for noise grows. Therefore, whatever audio circuitry is served by a smoothing capacitor should be connected *directly to that capacitor*, and the connections between the smoothing capacitor and the rest of the power supply should be separate, as illustrated in fig. 13.10*a*.

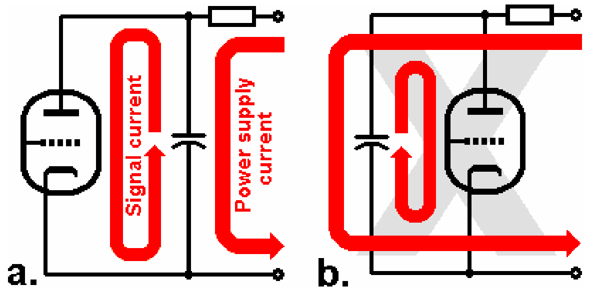


Fig. 13.9: **a.** Signal currents flow around the loop which includes the smoothing capacitor. **b.** Careless placement of the capacitor, relative to the circuit it feeds, forces power supply current to flow in the same wires as signal current, leading to unnecessary noise.

Each end of the capacitor is, in effect, a 'star point' to which the connections are made. Note that when two valve stages are cascaded, components which come after the coupling capacitor 'belong' to the second stage's grid-leak circuit. Fig. 13.10*b* shows an incorrect example. Notice here that there are multiple components connected to ground, whereas in the correct example there are actually only two connections, one for each triode. All the other components (grid leaks, cathode bypass capacitors etc.) feed like a network of tributary streams into a single river, which finally meets the sea (the smoothing capacitor!).

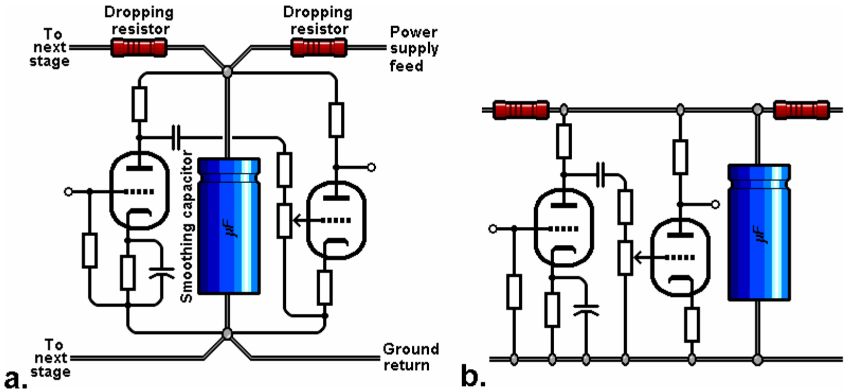


Fig. 13.10: **a.** For proper grounding all audio circuitry associated with a smoothing capacitor should be connected directly to that capacitor, and the power supply feed and ground-return connections should be kept separate. **b.** Incorrect layout. The smoothing capacitor is too far away from the stages it feeds, power supply currents now flow in the same wires as signal currents, and the grid-leaks are also too far from their respective cathode circuits.

The habit of placing all the power supply capacitors in one place (under a 'cake tin' in the case of some Fender amps) and running long wires from here to the rest of the amplifier is absolutely unacceptable, and should be derided in any modern amplifier.

Here we get at the heart of why good grounding and layout are important, because on a paper schematic, which shows only perfect components and zero-resistance connections, both fig. 13.9*a.* and *b.* are functionally identical. But we now appreciate that, in *practice*, they are not, and that *a.* will be the quieter circuit. Hopefully by now the reader will have spotted that there can actually be several 'grounds' in a circuit, as we have already starting talking about the 'power supply ground' and 'signal ground', and there could be more (such as digital ground). Some schematics will give them separate symbols to better indicate how they should be independent of one another, not sharing the same lengths of wire. Somewhere the different ground systems will connect together of course, but always only a single point.

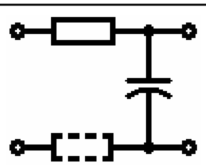

Fig. 13.11: It is more instructive to view power supply filter stages as symmetrical, where the extra resistor (dashed) is made up from the inherent resistance of the ground path.

Perhaps the best way to avoid grounding mistakes is to recognise that ground is actually 'the other half of the circuit'. It is not some electrical black-hole into which current disappears, never to be seen again. If current is drawn from the positive end of a power source, then that same current has to somehow find its way back to the negative end via ground.

We can look at a simple, conventional power supply as a charge pump (the transformer-rectifier-reservoir circuit block) and a chain of smoothing stages. Although we will be used to thinking of these as being simple RC (or possibly LC) filters, we should really see them as symmetrical filters in which the opposite resistor (or choke) is actually made up from the resistance of the ground connection, which is very small of course, but not quite zero ohms, as shown in fig. 13.11.
In fact, in some amplifiers, small resistors (about 10Ω) may be placed in the ground path between filter stages. This is to discourage power supply currents in the power amp from finding an easier path home through the preamp ground of any other piece of equipment that might be connected. This is shown in fig. 13.12 and helps reduce the need for a ground-lift switch in the other piece of equipment. Of course, by deliberately introducing resistance into the power-supply ground we must be even more careful where we connect the signal ground, and we should not use this method if we can help it.
Note that if the chassis connection were moved to the preamp input instead, the problem would be eliminated without the need for resistor R. For this reason, the connection between circuit ground and chassis should always be at the audio input of the circuit, where possible. This is expounded upon later.

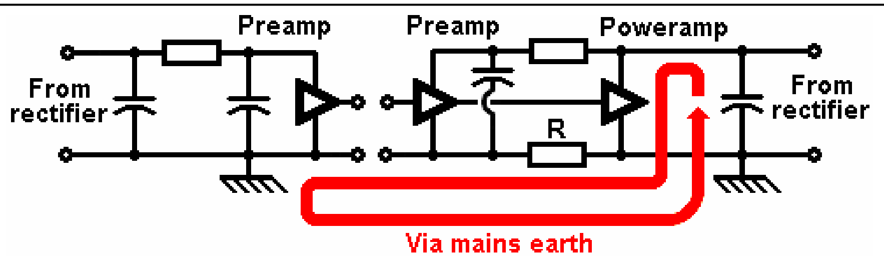


Fig. 13.12: If it is not possible to earth the input of the amplifier then adding a small resistor R in the ground path between preamp and power amp will discourage power amp currents from flowing around the ground loop when connecting to other pieces of equipment.

## Bus grounding:

A popular method of grounding is the bus ground. This requires a single, heavy-gauge wire or **bus wire** to be routed through the chassis, to which all the ground connections are made. This naturally encourages a long, thin layout, although it could be bent into any shape. The path of the bus wire should follow the natural path of the circuit from the reservoir capacitor, to power amp (if present) to preamp, and all the ground connections should be made progressively along it, e.g., a power-amp ground should not be connected amongst the preamp ground connections. For making the bus, 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 Britian. In the US, 14AWG solid-core may also be readily available.
Some amplifiers adopt a sort of pseudo bus ground by using the chassis as the bus ('ground plane' is perhaps a better term), but this will never work in anything but the simplest, low-gain, low-current circuit. The chassis must not be imagined to be 'one

big fat wire'. It is simply a metal box which protects the user from the circuit, screens the circuit from interference, and provides a solid support for the construction; no current should flow in the chassis.

An example of a bus ground is shown in fig. 13.13*a*. Note that that the various power-supply smoothing capacitors should be as close as possible to the stages they feed. The bus wire should be connected to the chassis at *one point only*, at the input end of the amplifier. However, this still looks rather like the example of bad grounding shown earlier in fig. 13.10*b*! Indeed, this kind of simplified bus grounding is only practical in fairly simple, low-current, low-gain designs. Nevertheless, it is straightforward (difficult to get wrong) and well suited to hand-wired designs, and once all the components are soldered to it, it can form quite a rigid, floating structure.

It is possible to improve the ground bus system somewhat, and at least approximate an ideal ground scheme. The necessary changes are shown in fig. 13.13*b* from which it can be seen that the bus now runs from the reservoir capacitor to the *input jack*,

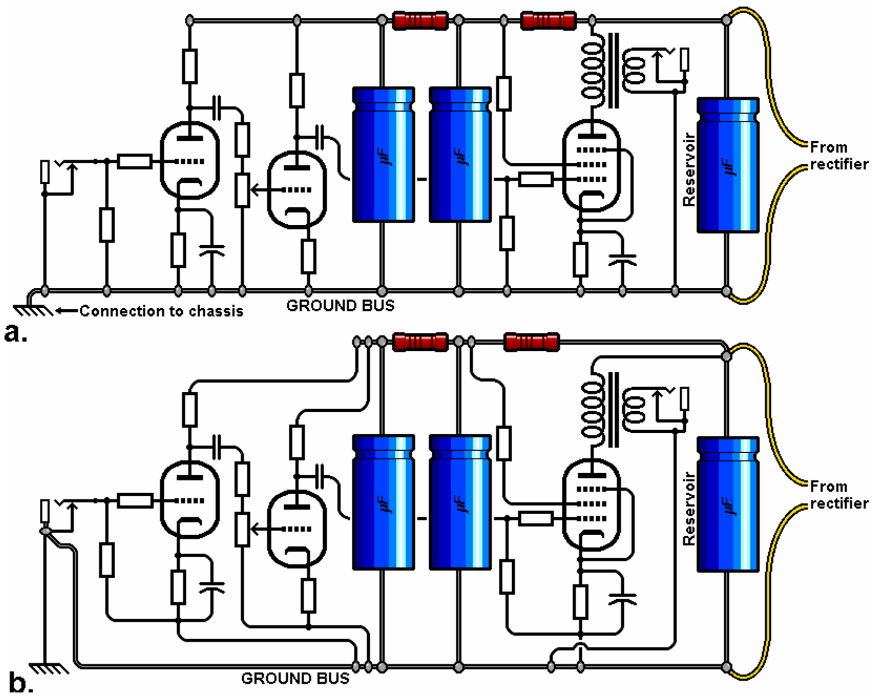


Fig. 13.13: **a.** A standard bus ground system is possible in low-gain designs, but is far from optimum. **b.** An improved bus scheme. Connections are made closer to the smoothing capacitors to minimise the interaction of signal and power currents; grid-leak connection are made to their respective cathode circuits; the speaker ground is moved downstream of the power valve ground currents; the chassis connection is made right at the input jack socket.

and a separate wire runs from the negative jack connection to chassis. All power and ground connections are now made much closer to the power supply capacitors, to minimise the interaction of audio and power currents. The speaker ground has been moved 'downstream' 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.

## Star grounding:

In more complex amplifiers, ordinary bus grounding becomes questionable, and the proper ground scheme will be the multiple-star method, and insulated jack sockets are *mandatory*. Again, the transformer-rectifier-reservoir circuit should be built first, with short, thick wire. A short spur (5cm to 10cm say) of thick wire should then be run from the negative end of the reservoir capacitor to a convenient point, which will form the main star point (this is not connected to chassis).

Fig. 13.14 shows an example of how this might look in a practical amplifier. In this case the power output stage is supplied directly from the reservoir, so does not return to the main star. Also note that in this case a push-pull amplifier is shown, and connections to it are kept as symmetrical as possible to maximise common-mode noise rejection. All the grid, cathode and screen-grid connections come to a common point which is finally returned to the reservoir, in accordance with the 'stream, river, sea' approach.

The secondary side of the output transformer (if one is used) should always be wired directly to the speaker jack using heavy-gauge wire, and a separate wire (which does not need to be heavy gauge) should then run from the negative connection of the speaker jack, back to the main star, as shown. This is true no matter what ground scheme is used. Similarly, if global feedback is used, a wire should be taken from the positive connection of the speaker jack rather

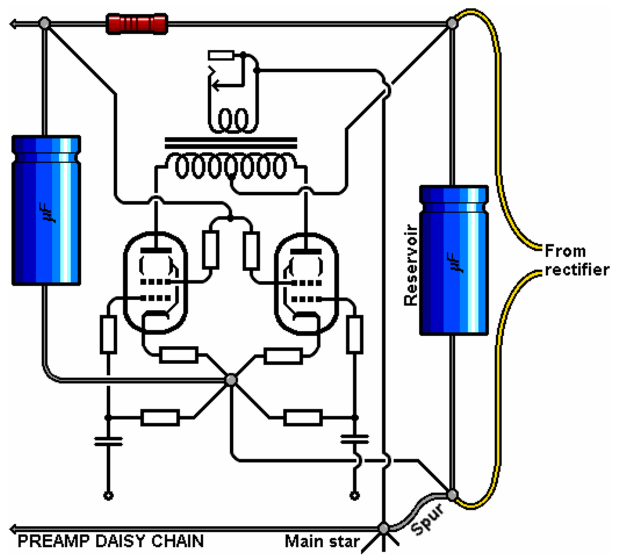


Fig. 13.14: The main star point should be distanced from the reservoir by a short spur. In this case the power output stage is supplied directly from the reservoir, so it does not have any connections to the main star.

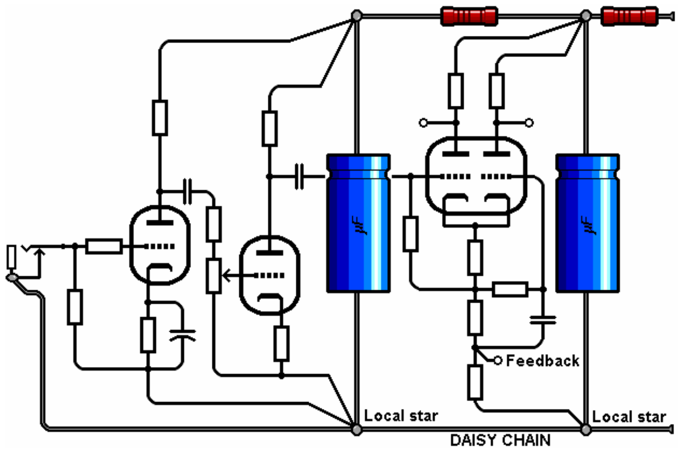


Fig. 13.15: Grounding in the preamp can follow an idealised ground-bus scheme (compare with fig. 13.13*b*).

than from the output transformer itself.

As the power supply then progresses through the amplifier, each smoothing capacitor defines a 'local star' for the stage/s it feeds, and all audio circuitry concerning a particular capacitor should be made directly to that local star, or in other words, we obey the system already shown in fig. 13.10*a*. Each of these minor star points can then be daisy-chained together in the same sequence as the positive side of the power supply (remember, we should think of this daisy chain as being the other half of a chain of *symmetrical* filters), and finally it will return to the main star. Looking at fig. 13.15 it can be seen that this turns out more-or-less the same as the idealised bus-ground from fig. 13.13*b*; the bus has become the daisy chain, though it might not be a continuous solid wire.
Amplifiers which use bipolar power supplies are superior in this regard, because the ground connections for the smoothing capacitors can actually be kept completely separate from the signal ground, all the way back to the main star. It is still desirable to keep all circuit-ground and daisy-chain connections as short as possible, so star grounding often encourages a radial or horseshoe-shaped layout.

Any non-audio circuitry such as heater wiring, switching control etc., should *not* return directly to the main star. Instead it should be connected somewhere on the spur between the reservoir and the main star. In fact, in this case very few connections are actually made to the main star, and one might wonder why it is called a 'star' at all. However, in multi-channel amplifiers it is more obvious, as the next section will illustrate. 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 ground system and chassis / earth.

## The ground-to-chassis connection:

Having designed our circuit layout, either on PCB, turret board or even wired point-to-point, and having dutifully obeyed a star-ground system, we must

finally connect the circuit ground to the chassis (which is bonded to earth) at *one* point only.
When other pieces of equipment are connected, ground loops are minimised if we make the ground-to-chassis connection at the amplifier's audio input, right at the jack socket. Ideally this connection should be a wire which runs from jack socket to a point near the main Earth bond, but connecting it to some other part of the chassis is usually good enough. There may of course be more than one input jack feeding the input valve, but this should not matter if they are all close together, only one earth connection is required.

However, if the amplifier has more than one channel, each with its own input, then we must make a decision. We must not connect *all* the inputs to chassis since this would create a ground loop between the channels. If one 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 a ground loop.
But what if we have more than one high-gain channel? In such cases it may be better to make the chassis connection further into the amplifier where the two channels mix and become one, close to the main star.
However, making the connection here increases the chances of ground loop hum when other pieces of equipment are attached, as fig. 13.12 illustrated. This can be reduced by connecting ground to chassis via a 10Ω resistor instead, which should be large enough to prevent such ground currents flowing. It should be a power resistor, say 5W, so as to handle any fault current that might occur. Although this can reduce ground loop noise, it actually *increases* the likelihood of radio interference being picked up on the signal ground instead! Therefore a poly' or ceramic capacitor of about 100nF to 470nF should be connected in parallel with it, so that the impedance is much less than 10Ω at high frequencies (it can be a low-voltage type of course). Alternatively, similar capacitors may be connected between ground and chassis at the input of each channel.

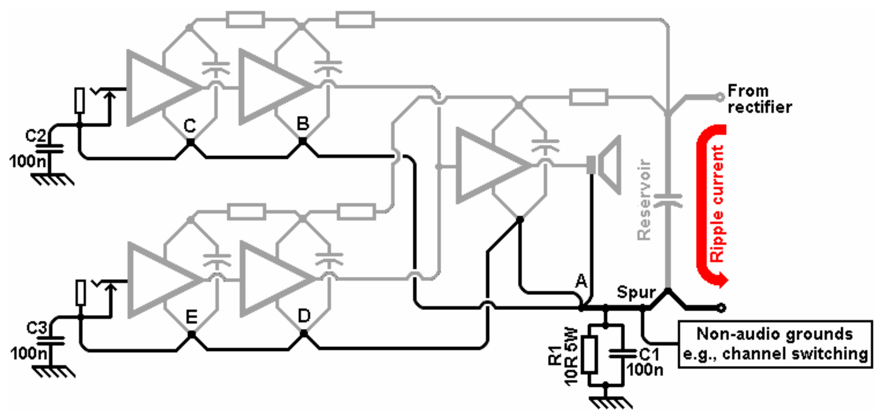


Fig. 13.16: A multi-star ground scheme applied to a two-channel amp. The main star is at A. C2 and C3 are not necessarily required unless radio interference turns out to be a problem.

A typical, two-channel ground scheme using this method is shown in fig. 13.16. The main star is at point A, again this is on a thick spur from the reservoir capacitor. Additional, local stars are created by the smoothing capacitors for each gain stage, at B, C, D, E, and each channel has its own daisy-chain which follows the path of the power supply back to the main star. Non-audio grounds should *not* be brought directly to the main star, but should be made to the spur. C2 and C3 are not necessarily required unless radio interference turns out to be a problem, in which case including one or both may help.

## Additional considerations:

Some transformers have an internal screen between the primary and secondary coils, 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.

If the heater supply is not elevated but simply grounded, then this ground connection can usually be made to any point on the chassis (as above) or else to the ground spur. 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 point happens to give the most favourable hum performance.

**Can capacitors:**

Older amplifiers –particularly American ones– 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 ideal.

The best advice would be not to use can capacitors at all; like un-insulated jack sockets they are an anachronism. However, for American readers who still insist on using them (hopefully not in a high-gain design) a reasonable compromise would be to use a single, dedicated capacitor for the reservoir, and a can-cap for the other smoothing stages; the can would then become the main star. Nevertheless, connections between the audio circuitry and the star should still be kept as short as possible.