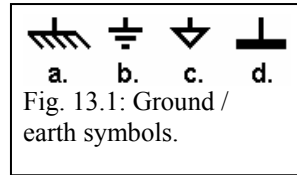


Grounding

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.



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.
- Prevent heavy power-amp and power-supply currents from flowing in the audio ground circuit of other parts of the circuit, 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 as those recommended in digital or high-frequency electronics textbooks.

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 it must be completely sound.

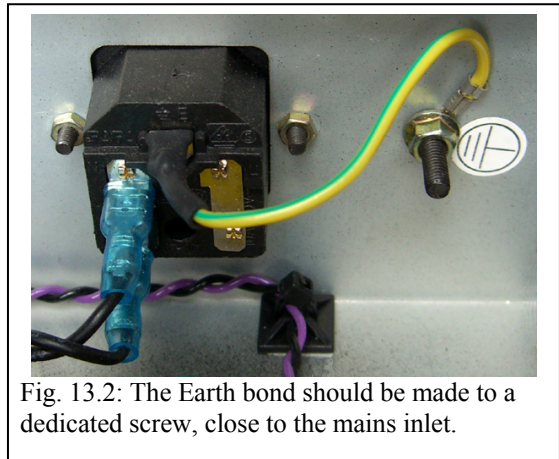


Fig. 13.2: The Earth bond should be made to a dedicated screw, close to the mains inlet.

The Earth bond is for safety only; it plays no part in circuit operation. 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 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, and so that the chassis will also act as an electrostatic-noise shield. 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 the field 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.

For example, fig. 13.4a shows a simple circuit where a shielded cable feeds the grid of a valve. One end of the shield has been connected to the chassis. If the circuit is completely enclosed by the chassis then it will be shielded from any external electromagnetic noise.

In *b.*, however, both ends of the shield have been connected to the chassis, creating a ground loop. External EM fields can now induce ground currents which flow in exactly the same wires as the signal current, as shown. Since the ground loop will have some inevitable resistance, this ground-loop current will create a voltage which is added to the signal voltage, giving us unwanted noise. The chassis has become a noise antenna rather than a noise shield!

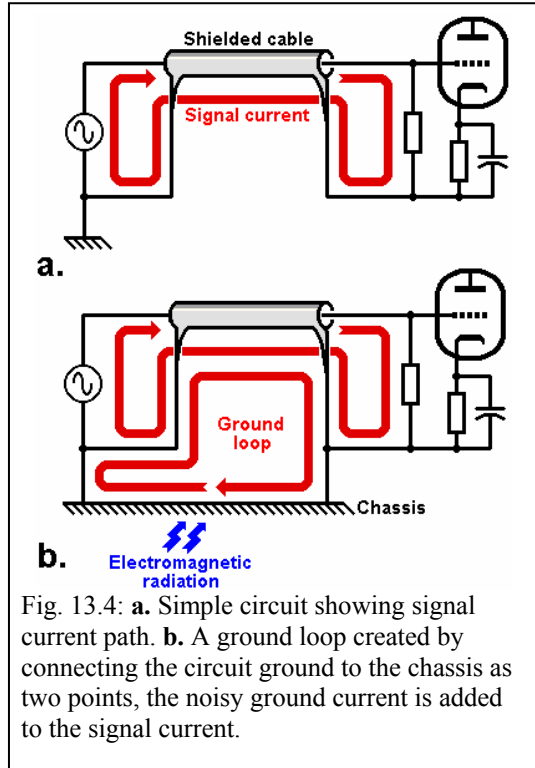


Fig. 13.4: **a.** Simple circuit showing signal current path. **b.** A ground loop created by connecting the circuit ground to the chassis as two points, the noisy ground current is added to the signal current.

This is just one example of a ground loop. It is all too easy to accidentally create multiple loops if we connect various parts of the audio ground to the chassis. It was once common practice to use uninsulated jack sockets, to bend over the ground tab on a potentiometer and solder it to the case, or to solder a ground bus [see later] to the backs of the control pot's, or to solder several star grounds to the chassis. Some amplifiers did get away with it without gross noise, but in the 21st century such practice is embarrassingly old fashioned, no matter how convenient it may appear.

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.

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 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, and it may be solid-state or a valve rectifier of course. This functional block then feeds a chain of RC smoothing 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 we break the system down into three types of current loop it is easier to see what ground connections should be made, and where.

First and most important, 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. 13.5 (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, so it is extremely important to keep this transformer-rectifier-reservoir circuit as short as possible, and to use relatively thick wire to keep the resistances small. In fact, it would probably be more obvious that this part of the power supply

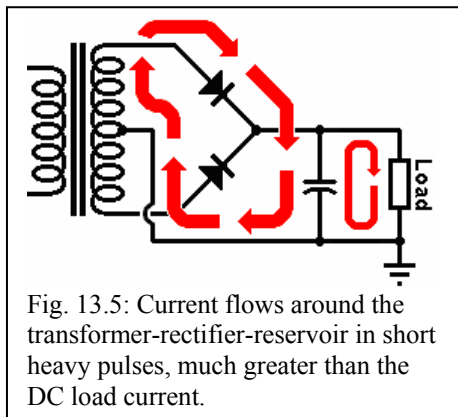


Fig. 13.5: Current flows around the transformer-rectifier-reservoir in short heavy pulses, much greater than the DC load current.

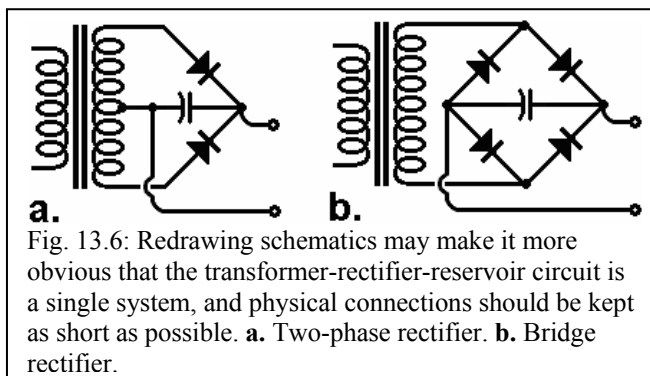


Fig. 13.6: Redrawing schematics may make it more obvious that the transformer-rectifier-reservoir circuit is a single system, and physical connections should be kept as short as possible. **a.** Two-phase rectifier. **b.** Bridge rectifier.

Grounding

is self-contained functional block if schematics were drawn as in fig. 13.6!

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.

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. Some very sensitive preamplifiers may even shield this part of the power supply from the audio circuit by a metal bulkhead or screening can.

Secondly, there is the steady charging current which flows from the reservoir capacitor and feeds the chain of RC smoothing filters, as indicated in fig. 13.7. Attentive readers will now have spotted that these power supply currents have to travel back along the ground connection.

Again, 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 *signal ground* to the *power supply ground*.

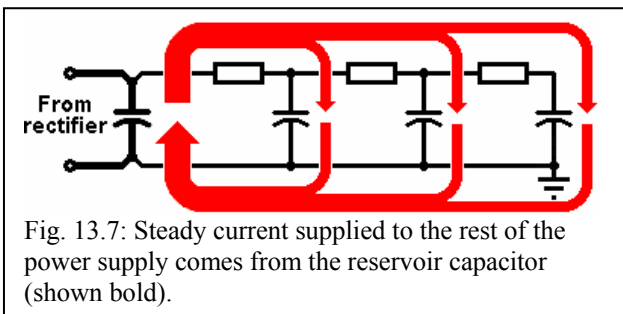


Fig. 13.7: Steady current supplied to the rest of the power supply comes from the reservoir capacitor (shown bold).

Fig. 13.7 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.

Thirdly there is the *signal current* which is actually delivered to the valves or other audio circuitry, and this is supplied by each smoothing capacitor. In fig. 13.8a 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

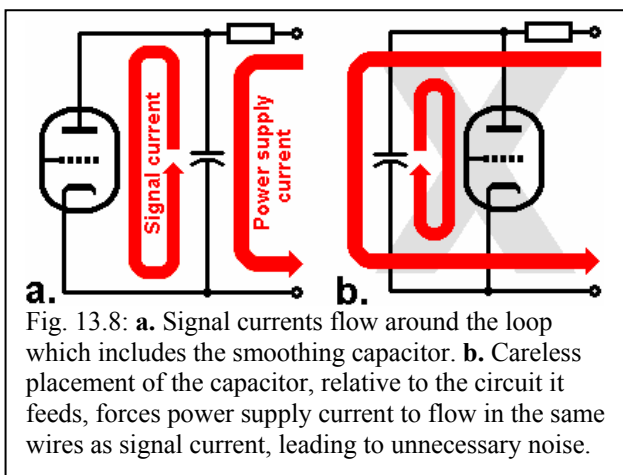


Fig. 13.8: **a.** Signal currents flow around the loop which includes the smoothing capacitor. **b.** Careless placement of the capacitor, relative to the circuit it feeds, forces power supply current to flow in the same wires as signal current, leading to unnecessary noise.

Designing Valve Preamps for Guitar and Bass

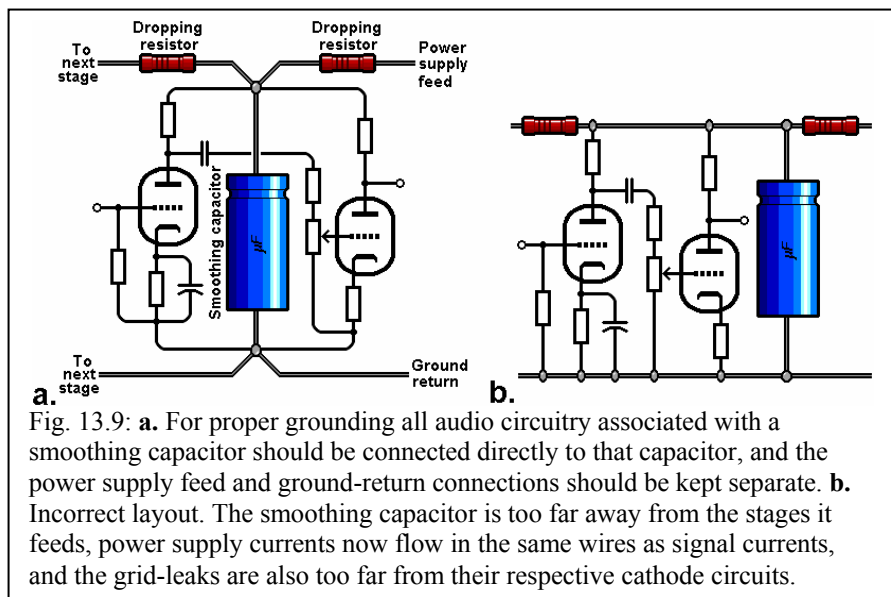
of the components as in *b*. we have forced the power-supply charging current to flow in the same wires as the signal current, immediately creating places for power supply noise voltages to interact with the audio; we have mixed the power supply's ground with the signal's ground.

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. 13.9*a*. Each end of the smoothing 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 a single ground, whereas in the correct example all the 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!).

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 there 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. 13.8*a*. and *b*. are functionally identical. But we now



Grounding

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 at a single point.

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) followed by 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. 13.10. A good ground scheme will do its best to minimise this resistance, as well as eliminate ground loops.

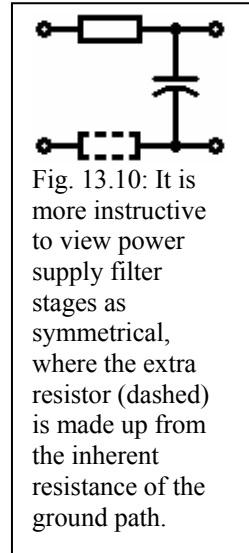
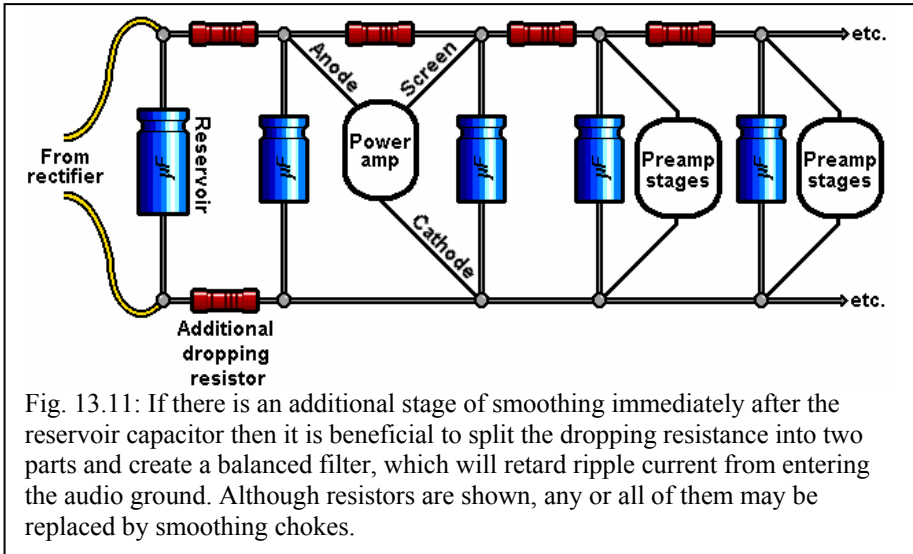


Fig. 13.10: It is more instructive to view power supply filter stages as symmetrical, where the extra resistor (dashed) is made up from the inherent resistance of the ground path.

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 highly beneficial to split the usual dropping resistance into two parts (usually, but not necessarily equal) and create a symmetrical or balanced filter, as illustrated in fig. 13.11. The added resistance in the negative side of the circuit considerably reduces the amount of ripple current which might ever find its way into the audio ground. (There must be no connections between rectifier/reservoir and chassis of course, but that is always true of a proper ground scheme.)

In practice one or both of these 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 much less voltage stress between the coil and frame, than one in the ‘traditional’ side of the circuit.



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.

To make 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 Britain. In the US, 14AWG solid-core may also be readily available. Ideally it should be tinned in a bath of solder to prevent corrosion, although this is not always within the means of hobbyists.

Many old amplifiers adopt a sort of pseudo bus ground by using the chassis as the bus ('ground plane' is perhaps a better term), but as discussed earlier, this is no longer considered acceptable practice. 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.

* This is short for omnibus.

Grounding

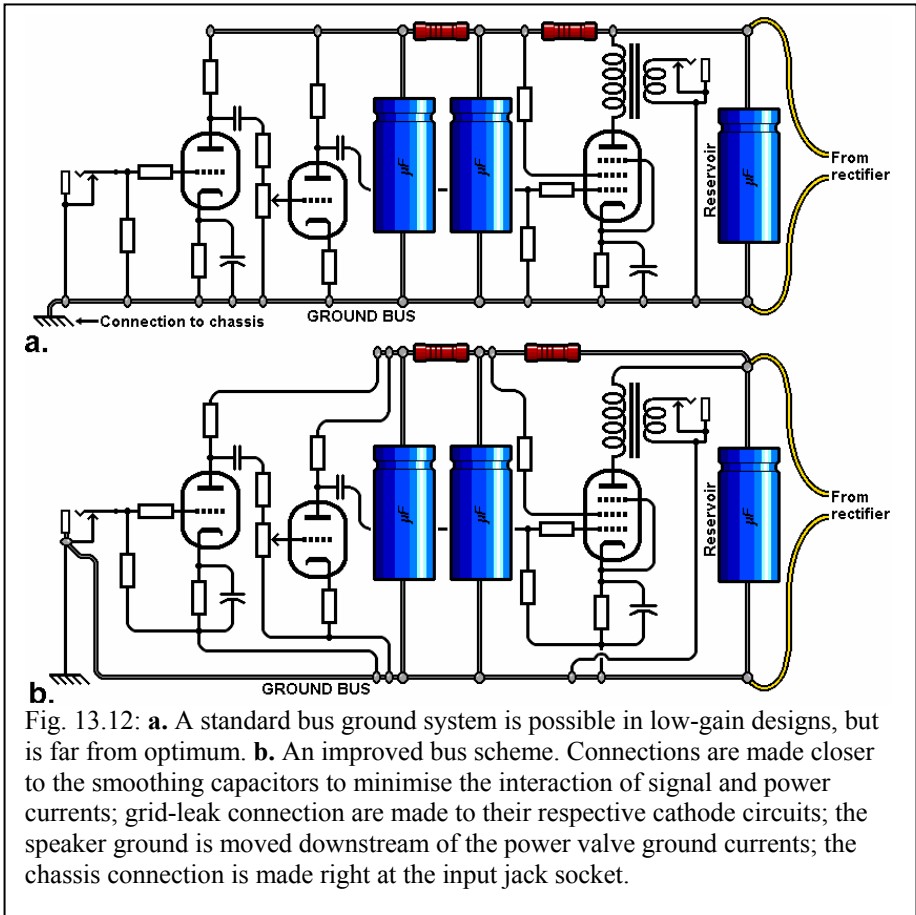


Fig. 13.12: **a.** A standard bus ground system is possible in low-gain designs, but is far from optimum. **b.** An improved bus scheme. Connections are made closer to the smoothing capacitors to minimise the interaction of signal and power currents; grid-leak connections are made to their respective 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.

An example of a bus ground is shown in fig. 13.12a. 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 [see fig. 13.15 for the reason]. However, this still looks rather like the example of bad grounding shown earlier in fig. 13.9b! 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. 13.12b from which it can be seen that the bus now runs from the reservoir capacitor to the input jack, and a separate wire runs from the negative jack connection to chassis. All power and ground connections are now made much closer to the smoothing 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, in accordance with the stream-river-sea concept.

Star grounding:

In more complex amplifiers, ordinary bus grounding becomes questionable, and the proper ground scheme will be the star method, and earlier text has already alluded to it. The ideal star ground would be one where every ground connection in the amp is brought via a very short wire to a single point. Since all these wires would radiate away from this point, the name ‘star ground’ becomes obvious, and this method tends to encourage a radial or horseshoe-shaped layout.

However, in anything but very tiny circuits the single star method becomes impractical as it will inevitably require lots of very long ground wires leading to the star, which completely ruins its ideal nature. Therefore, the very best ground scheme for ordinary amp circuits is the multi-star ground, as this is the only method which minimises the interaction of power supply and signal ground currents in the most efficient manner, and allows the circuit to be freely arranged in whatever pattern is required (e.g., U-shaped, long and thin, etc.).

The multi-star ground is essentially a more flexible and improved version of the idealised bus ground in fig. 13.12*b*. As usual, the transformer-rectifier-reservoir circuit should be built first, as a single block. Every smoothing capacitor forms a ‘local star’, and all circuitry associated with a given capacitor is grounded directly to it, in exactly the same way as shown earlier in fig. 13.9*a*. All the local stars are then daisy chained together in exactly the same order as the ‘positive side’ of the power supply.

Fig. 13.13 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 hinted at in fig. 13.11 earlier). In this case a push-pull amplifier is shown, and connections to it are kept as symmetrical as possible to maximise CMRR.

In a fixed bias amp the 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 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. 13.13*b*.

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.

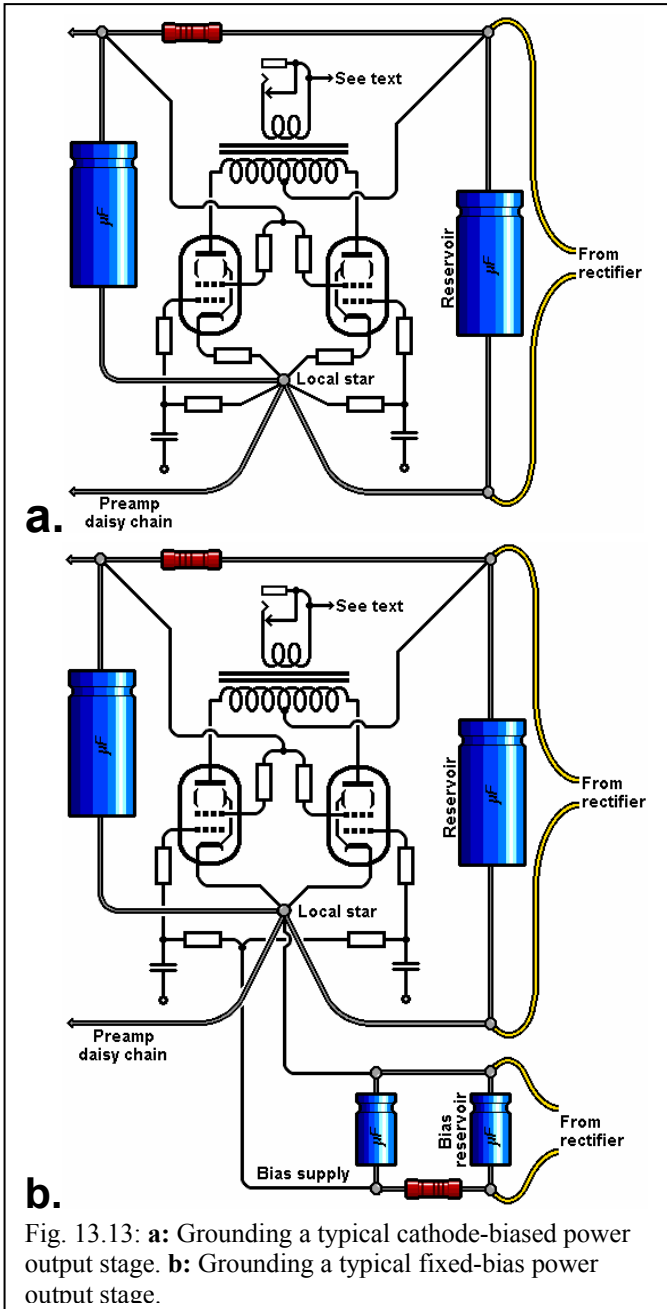


Fig. 13.13: **a:** Grounding a typical cathode-biased power output stage. **b:** Grounding a typical fixed-bias power output stage.

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 injected into, usually the phase inverter (e.g., fig. 13.14).

Fig. fig. 13.14 shows how a typical preamp would be arranged, and it can be seen that this turns out more-or-less the same as the idealised bus-ground from fig. 13.12*b*; the bus has become the daisy chain, though it might not be a continuous solid wire. Needless to say, all these connections should be as short as possible.

Any non-audio grounds such as switching

control etc., should be considered noisy and should *not* return directly to an audio star. Instead they should returned 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.

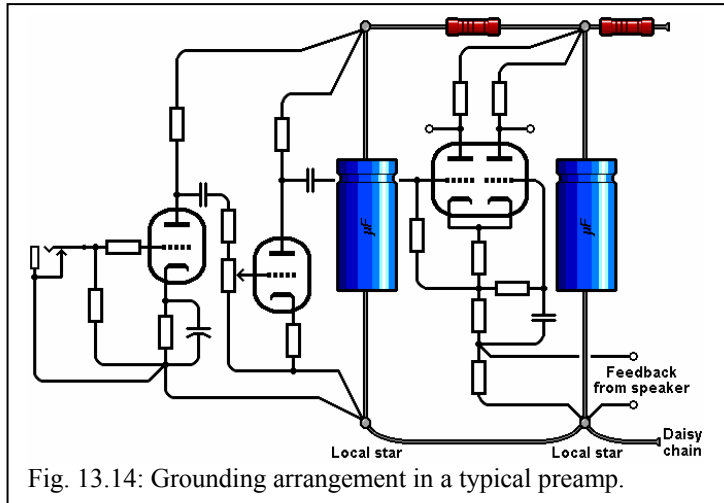


Fig. 13.14: Grounding arrangement in a typical preamp.

The ground-to-chassis connection and ground lift:

Having designed the 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 ground system to the chassis (which is bonded to earth) at *one* point only.

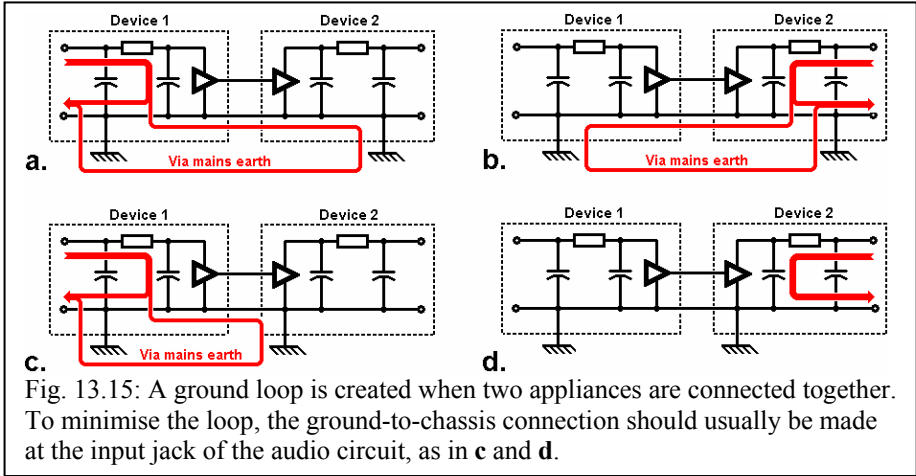
The position of the ground-to-chassis connection is important because, inevitably, we will want to plug some other powered device into the amp, such as mains-powered effects pedals, external preamps etc. These appliances will also have their own earthed chassis, so connecting two together will create a ground loop via the audio interconnect and the mains earth cable, as shown in fig. 13.15. Since both these wires are likely to be very long, the loop will have a huge area and be subject to strong induced hum currents. Additionally, power supply currents in one device can flow through the other.

Fig. 13.15*a* shows an example where the ground-chassis connection in device 2 has been made at a sub-optimum position, creating a fairly large ground loop which includes most of the ground wires of both units. A portion of the power supply currents in device 1 will flow into device 2, via the mains earth, which is obviously undesirable. Electromagnetically induced hum will flow around the same loop of course.

The same devices have been re-drawn in *b*. for clarity, to show how power supply currents in device 2 also flow into device 1 via the same loop! Altogether this is a noisy situation.

By moving the ground-chassis connection to the very input of device 2 the situation is much improved. Although power supply current can still flow from device 1 down

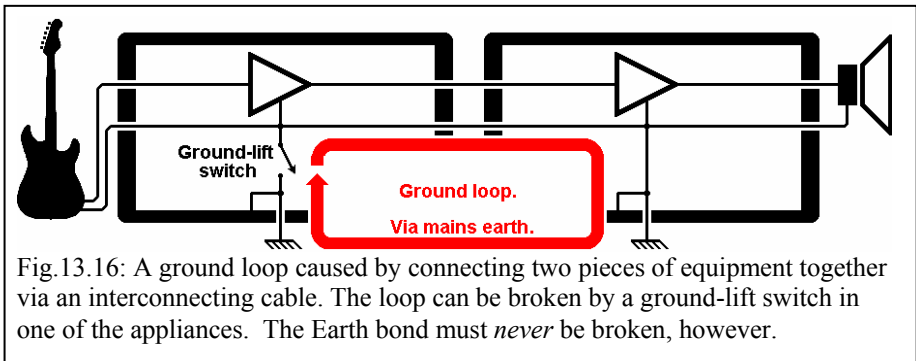
Grounding



the audio interconnect, it does not flow around the whole ground circuit of device 2, as shown in **c**. Better still, power supply currents in device 2 cannot flow into device 1 at all, as shown in **d**.

In nearly all cases then, the ground-to-chassis connection should be made right at the very input jack of the device. 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.

Some reader might point out that the situation in fig. 13.15 could be improved further, by moving the ground-chassis connection of device 1 to its output. This is true if device 1 is an independent signal source such as a keyboard or signal generator. In most cases, however, device 1 will have its own audio input too, and its own ground-chassis connection must be made there, for all the same reasons as discussed above, since the input of an audio circuit is always the stage most sensitive to noise.



To combat the above problem of connecting two devices which both have audio inputs and outputs, some appliances will offer a **ground lift** switch. This disconnects one audio circuit from the chassis, breaking ground loop, as illustrated in fig. 13.16. Ground-lift switches are usually included in low-level preamps and mixers, rather than power amps. Note that the Earth bond between chassis and mains earth must *never* be broken; the chassis must remain safely earthed at all times.

An alternative to the ground lift switch is a hum-loop block network, as shown in fig. 13.17. The ground to chassis connection is made via a 10Ω resistor in parallel with a 100nF to 470nF poly⁷ or ceramic capacitor. The resistance should reduce ground-loop currents to negligible levels and must be a power device, say 5W , so that it is resilient to fault currents which might occur. The resistor alone would make the audio ground more susceptible to radio interference, so the capacitor is added to reduce the impedance between ground and earth, at radio frequencies. Sometimes a pair of high-current diodes (shown faint) are also connected in parallel, to act as a bypass path for serious fault currents. A 25A (or more) bridge rectifier package is quite convenient for this.

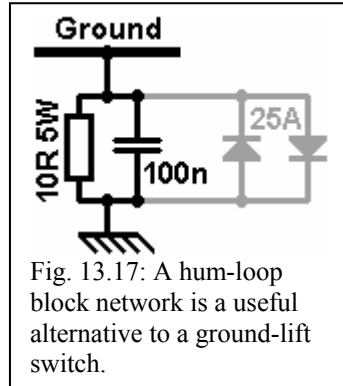


Fig. 13.17: A hum-loop block network is a useful alternative to a ground-lift switch.

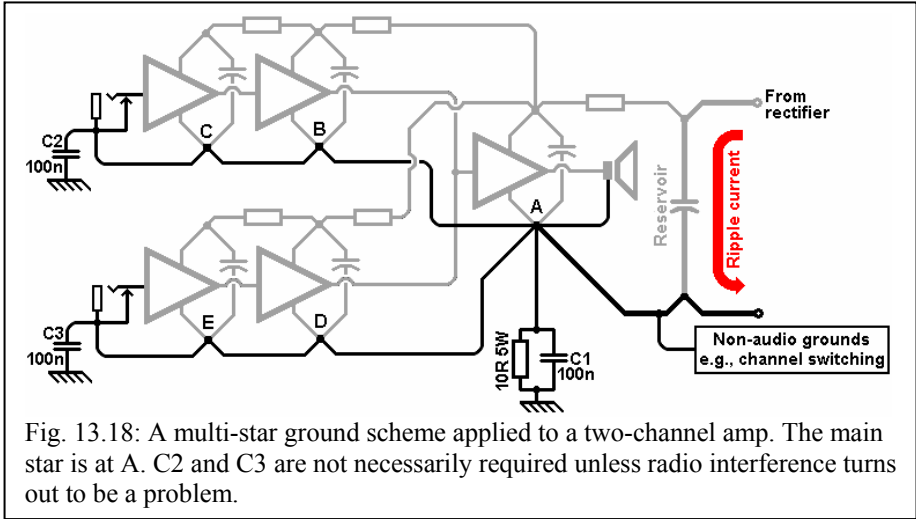
However, what if an amplifier has more than one channel, each with its own input? Then we must make a decision about where to make the chassis connection. We must not connect *all* the inputs to chassis since this would create a ground loop between the channels. If one of the channels has very much higher gain than the other(s) then that is the input we should connect to chassis, since the other channels are likely to 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 mix and become one. Since this increases the chances of ground loop hum when other pieces of equipment are attached, as fig. 13.15 illustrated, the connection should be made via a hum-loop block network.

A typical, two-channel ground scheme using this method is shown in fig. 13.18. 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, since this reflects the path of the positive side of the power supply. The point where the two join is connected to chassis, which in this case happens to be the power output stage star.

If radio interference on the ground circuit turns out to be a problem then adding C2 and/or C3 directly between the input-jack ground and chassis may help, but this is a rare necessity.

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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, 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 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 later smoothing stages. Nevertheless, the ground connections should still be kept as short as possible.