

EARTH LOOPS AND HUM

When you're connecting up various pieces of audio equipment like amplifiers, tape decks, CD and DVD players, vinyl record turntables and so on, it's not unusual to find that the final system produces an audible humming sound from the speakers. This hum is usually at mains frequency (50Hz in countries like Australia and New Zealand, or 60Hz in countries like the USA) and/or its harmonics, and it can occur even though the individual pieces of equipment may have excellent circuitry, and be performing entirely as they should be.

As you may have heard, this kind of hum can be caused by an **earth loop** in the overall system, created simply as a result of connecting the pieces of equipment together. And to remove the hum or at least reduce it to an acceptably low level, you generally need to track down the earth loop that's causing it, and if possible prevent it from occurring. This can sometimes be surprisingly difficult.

To have the best chance of solving this kind of problem, though, you need to understand what an earth loop is, how they can be set up, and how to remove them. That's what we'll try to achieve in this data sheet.

Hifi and home theatre or 'AV' amplifiers/receivers generally have a significant amount of exposed metalwork such as speaker terminals, line input and output connectors and so on, connected directly to the internal circuitry. To ensure that they're as safe as possible to use, they are accordingly provided with a protective mains earth — in other words, a three-wire mains cord which includes an earth connection.

Other audio equipment like tape decks, turntables, CD players and so on may also be provided with a protective earth, for the same reason. As it happens the most common situation where an earth loop can be set up, and the easiest to understand, is when you connect two or more of these earthed pieces of equipment together. Let's see how, and also how such a loop can produce hum.

The diagram in Fig.1 shows a very basic audio system with a cassette tape deck connected to a hifi amplifier (we've only shown one channel, for simplicity). As you can see both the amplifier and the tape deck are provided with protective mains earths, so this means that the earth connections ultimately connect together via the building's power wiring, at the building earth point. And if the common or 'earthy' side of the signal circuitry inside each piece of equipment is also connected to mains earth in each case, to maximise safety, this means that the common side of the signal circuits are also connected together via the building earth.

Now when you connect the amplifier's line input to the tape deck's output, via the usual screened audio cable, look what happens: there's now a **second** connection between the signal earths at each end, via the screen of the audio

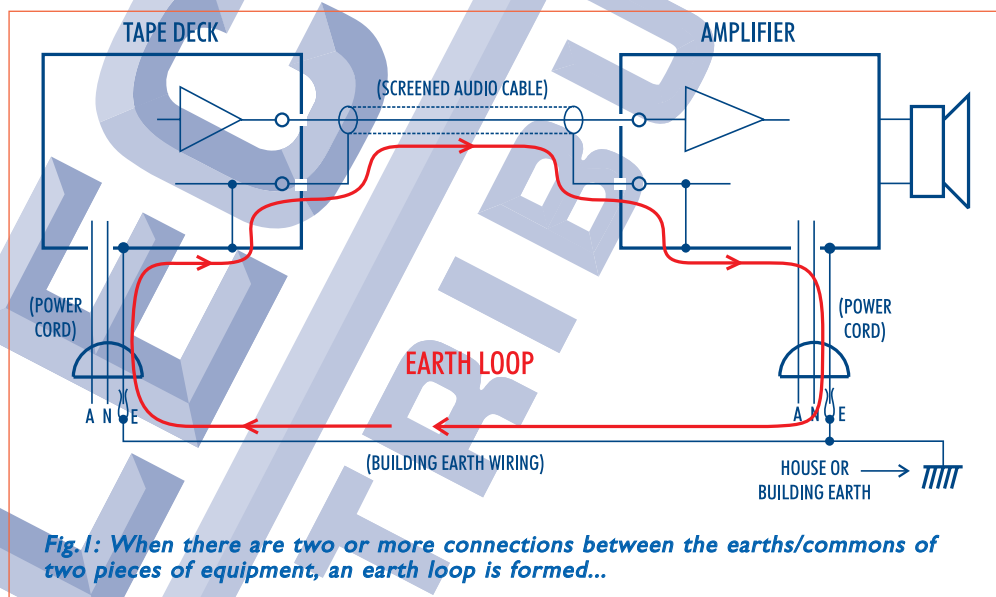
cable itself. So we now have a continuous loop in the system's earthing — an **earth loop**. But how does such an earth loop produce hum?

Well, remember that in both of the mains cords, and also in a lot of the building power wiring, the protective earth wires are running very close to the 'active' mains wires, and thus sharing some of their surrounding AC magnetic field. That creates the opportunity for small AC voltages to be induced in the earth wires themselves, by transformer action. Also, there can quite often be small AC currents flowing in equipment earth leads anyway, due to 'leakage' through EMI suppression capacitors and so on. And these currents will set up small AC voltage drops in the earth wire of each piece of equipment.

Because of the very low resistance around the earth loop that has been set up, the resultant of these AC voltages will tend to produce a corresponding current flowing around the loop — and importantly, through the screening braid of the audio cable and the earthy side of the signal circuitry at both ends.

So we now have a mains-frequency AC current (or 'HUM current') flowing through the earthy side of the cable and signal circuitry. And because this side of the cable and circuitry inevitably has a small resistance of its own, this means that a corresponding hum voltage drop will be produced.

As far as the input of the amplifier is concerned, this hum voltage V_{HUM} is effectively added to the signal voltage V_{SIG} ,



as you can see from the equivalent circuit in Fig.2. So our amplifier is now being fed with not just the audio signal from the tape deck, but with a small hum signal as well. And the weaker the signal itself is, the more likely you are to be able to hear the hum.

That explanation may be a bit over simplified, but it shows the basic concept of earth loops and how they can inject hum into audio systems.

The idea, then, is that wherever we end up with multiple earth paths which set up an earth loop, there's the potential for hum to be injected into our signal path. (This can even happen INSIDE equipment, by the way, so equipment designers have to take great care with their

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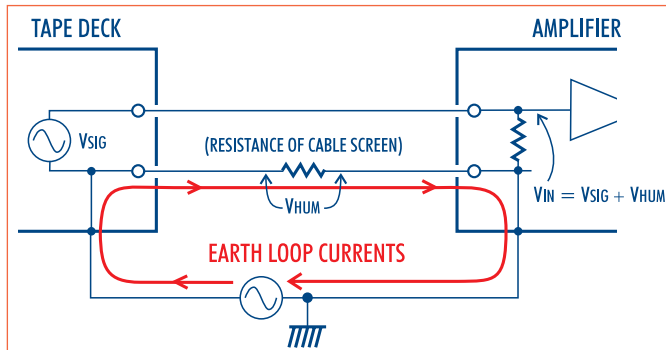


Fig.2: When there is an earth loop, AC currents induced in it can inject hum into the signal circuits via the screening braids of the interconnecting cables.

internal signal earthing techniques.) In theory, though, the solution is simple: be careful not to set up any earth loops. Unfortunately in practice it's often not that simple...

One approach that designers of low-level 'front end' audio equipment (like tape decks, CD and DVD players, turntables etc) have taken, in recent years, is to make this equipment effectively 'double insulated', so that it doesn't need a protective mains earth. Strictly speaking this isn't possible, of course, because truly double-insulated electrical equipment doesn't have ANY exposed metalwork connected to its active 'works'. However by carefully ensuring that there's a double layer of high quality insulation to prevent all possibility of the equipment's signal circuitry ever becoming 'live' (even in the event of fire or other drastic faults), the designers are able to ensure a very high level of safety without the need for a protective mains earth. So more and more of this equipment is designed to have only a two-wire mains cord, without the earth wire that can so easily set up earth loops.

It's much harder to do this with hifi and AV amplifiers/receivers themselves, by the way, so they're generally still provided with a protective earth (i.e., a three-wire mains cord). But you'd perhaps expect that this shouldn't cause any problems, because if an earthed amplifier is used with a set of front end equipment which all uses this kind of 'double insulation', there should still only be one connection to mains earth — and hopefully no chance of an earth loop.

To a certain extent that's true, too. However even in this kind of system, without any obvious earth loops, you can still get a small amount of hum. So where does *this* hum come from?

Well, there can be more subtle *minor* earth loops set up. For example in modern stereo and multi-channel surround sound systems, there are often multiple audio cables connecting various pieces of equipment — like the amplifier and a CD or DVD player. As you can see from Fig.3, the screens of these multiple cables can themselves set up small earth loops of their own. And with the fairly high level of AC fields present in many modern homes and office buildings, even this sort of earth loop can again have small AC voltages induced in it.

The simplest way around this particular problem is to ensure that stereo or other multiple audio cables are run very closely together, so there's very little chance of different AC voltages being induced in their screening braids. That way, any induced voltages will tend to be identical and cancel each other

out. Another option is to remove the earth connection from *one end* of one lead's screening braid, in each stereo pair.

In difficult cases it can help to run stereo connections in 'twin screened' wire, with both signal wires enclosed in a single common screen which is possibly only connected to the earthy side of one connector at each end (Fig.4). Then there won't be a minor earth loop, but there *may* be a small increase in signal crosstalk between the two channels — probably not significant.

Another kind of earth loop that's more subtle again, and can be more difficult to solve, is a 'virtual' earth loop. This can occur even with audio equipment that's nominally 'double insulated', and with no salient connection to earth. It tends to happen more often when this equipment is fitted with a 'switch mode' power supply, which is more and more common.

The cause of the problem is that inside the equipment, there's inevitably a small amount of capacitive and inductive coupling between the common side of the signal circuitry and the incoming 'active' mains wiring. This happens through EMI suppression capacitors, stray capacitance and the 'stray' magnetic field from the mains wiring itself (Fig.5). Now there's also a link back from the active mains wiring itself to the building earth, both via magnetic and capacitive coupling again, and usually because the mains neutral lead is ultimately earthed itself, as part of the MEN (mains earthed neutral) system. This means that even though the signal common of the equipment has no nominal connection to earth, there can still be an earth connection of sorts — albeit a fairly high impedance one, and mainly via capacitance and magnetic coupling. So when this equipment is connected to an earthed amplifier, there is still the potential to set up a 'virtual' earth loop, and again inject a small amount of hum.

There's no easy way to remove this kind of virtual earth

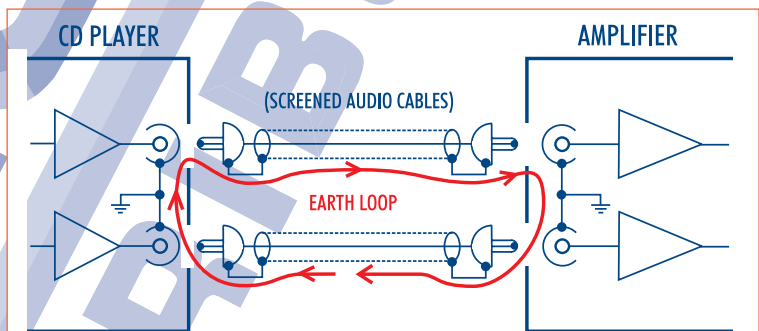


Fig.3: Even a pair of stereo interconnecting cables can create an earth loop...

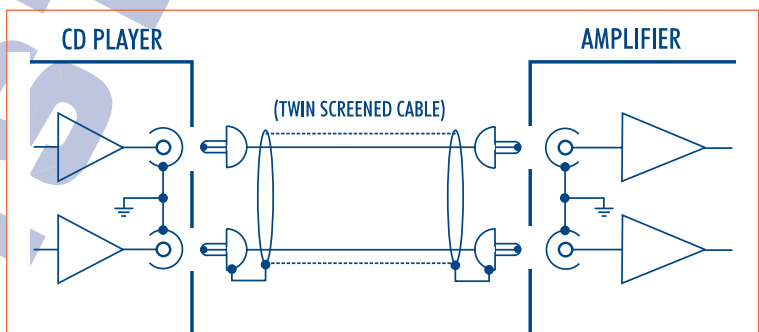


Fig.4: One solution is to use 'twin screened' leads with a single earth connection.

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loop entirely. All you can do is try to reduce its effect. One approach that can often work quite well is to connect the 'double insulated' equipment to the mains via an isolating transformer, rather than directly. This can reduce the coupling back to earth via the mains wiring, and can reduce the hum quite significantly. Unfortunately mains isolating transformers are not cheap, though — even those with a low power rating (which is all you need, in most cases).

Where it isn't feasible to use an isolating transformer, it sometimes helps to connect the metalwork of the 'double insulated' equipment back to that of the system's only earthed item (i.e., the amplifier/receiver). This assumes that there is no direct connection already, of course, via the signal common. The extra connection may 'short circuit' the virtual earth path back via the mains wiring, and the hum voltage induced in it, and thus achieve an improvement.

What NOT to do!

Now that you know how earth loops tend to be set up, and how they can cause hum to be injected into an audio system, you might be tempted to try solving such problems in an unsafe way. For example if you have a system with a number of pieces of equipment that are fitted with mains earths, and you're getting hum, you might think that a simple solution would be to simply disconnect the earth wires on every piece of equipment except the amplifier.

Don't do it. Tempting though it may seem, simply disconnecting the mains earth can be very dangerous in equipment that has been designed and built to be earthed. At the very least you might get a nasty 'tingle' when you're connecting the equipment up to the earthed amplifier, because of capacitive and inductive coupling; at the worst, either you or a loved one could easily be killed if the equipment should develop a fault.

In the long run, a much safer approach is to have the equipment properly and safely modified inside by a qualified technician, to remove the direct connection between the signal common and mains earth — or at least reduce its

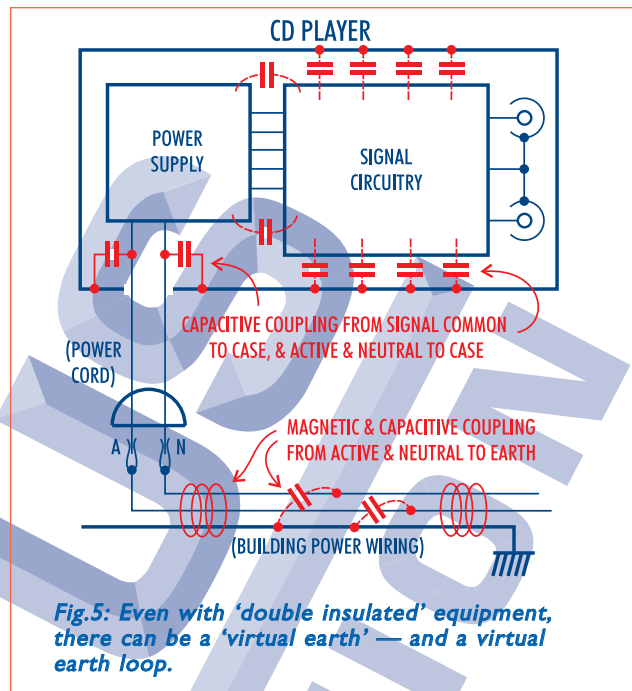


Fig.5: Even with 'double insulated' equipment, there can be a 'virtual earth' — and a virtual earth loop.

effect, via a higher-impedance link. Alternatively, you can replace the piece of equipment concerned with a newer model of the 'double insulated' type. This might well be cheaper than having it modified, anyway.

Remember, though, a hum may be annoying when you're listening to music or watching a movie, but an electric shock can be fatal. Don't be tempted to 'solve' an annoying problem by creating a potentially tragic one.

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