Avoiding EMI by Maximising EMC

TONY WALDRON IS AN EMC EXPERT WITH CONSIDERABLE EXPERIENCE IN PRO AUDIO INSTALLATIONS. HERE HE EXPLAINS THE MECHANISMS THAT CREATE ELECTROMAGNETIC INTERFERENCE, AND HOW THE EU EMC DIRECTIVE IS HELPING PROVIDE SOLUTIONS

Electromagnetic interference (EMI) reminds me of Monty Python's *Spanish Inquisition* sketch. Nobody expects interference from equipment that is not designed to transmit electromagnetic waves, and nobody expects equipment designed for audio reproduction to be able to receive electromagnetic waves. It turns out that the unexpected should indeed be expected, so the main purpose of this article is to help hi-fi enthusiasts identify equipment that has the best chance of interference-free sound reproduction.

International regulations have been in force since 1996 to assist equipment designers, manufacturers and installers in ensuring that all of the electronic systems in use in the average home can coexist without interfering with each other, or with equipment outside the home. This is known as Electromagnetic Compatibility (EMC). Unfortunately, much of the audio industry regards the regulations as a handicap to business, rather than a series of practical solutions to the environmental electrical noise problems caused by computers, switch-mode power supplies, motorised domestic gadgets, and variable lighting controllers. Moreover, these days we are all walking around with transmitting equipment that can deliver electric field strengths of 3V/m (and possibly more) into the surrounding air: mobile phones. (By comparison, FM or DAB signals are 30 times smaller.)

These multiplying new transmitters mean that we are forced to re-think many of the accepted design and wiring techniques that we have grown up with. Unfortunately, the modern good practice necessary to ensure satisfactory electromagnetic immunity in audio equipment is at odds with many of the traditional audio design doctrines we grew up with. This means that much of the equipment available today is either found to be sensitive to, or indeed the cause of electromagnetic interference. I hope to be able to explain why users and designers should consider good design for EMC is a major advantage both for audio signal integrity and customer satisfaction.

Basic Electronic Circuit Facts

Tracks (traces) on printed circuit boards, interconnecting wires inside equipment & cables used to interconnect audio components can act as an aerial or antenna.

For an antenna, one end of a wire is connected to the electronic circuit and the other end is free. The resulting aerial becomes most effective when it is resonant – that is when the *radio-frequency* current is *in phase* upon reflection from either end – thus maximising the effect of the original current. An antenna designed for radio transmission/reception is commonly a *quarter of a wavelength* long, so that the reflection leads to a current distribution along the structure that ensures a current maximum at the input end, and zero current at the free end (from where it has nowhere else to go). For any track, wire or cable, we also need to be aware that resonances also occur at approximately 3, 5, 7, etc. multiples of the basic quarter wavelength of a possible interference frequency.

While the antenna behaviour of PCB tracks and internal wiring inside equipment needs to be taken into account, the interference environment tends to be dominated by external interconnect cables. These constitute a conductive link between two relatively massive objects, both of which may be seen as *ground mats* when considered in antenna terms. This gives us the potential resonance for two antennae (as already discussed), but now joined at their ends (see *Fig1*). Resonances occur when the cable has an electrical length equal to any multiple of a *half* wavelength. And in general, the only place where we may be sure to find a current maximum at all resonant frequencies is adjacent to a low impedance connection to a substantial object, such as the output of one device connected to the input of another. Examples include: turntable output to pre-amplifier input; pre-amplifier output to power amplifier input; and AC or DC power output to AC or DC power input.

At every electrical resonance there is a current maximum at each end of the wire or cable, but other

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current maxima and zero's occur in various places at the various frequencies. It should be noted that the 'electrical length' of a cable is greater than its physical length because of the dielectric effect of the cable insulation.

Active components in electronic circuits have the ability to detect and be influenced by information or 'modulation' embedded in electromagnetic waves.

An electronic circuit (or the software in a computer program) designed to detect information embedded in electromagnetic waves is known as a demodulator. The simplest form of a demodulator is a simple diode – as used in early 'crystal set' radio receivers. Later, thermionic tube elements and transistors were used in more advanced radio receiver designs. When we compare radio receiver schematics with circuits designed specifically for our high performance audio world, we should be aware that all the necessary ingredients for the demodulation of electromagnetic waves are also embedded inside audio devices. This means that if electromagnetic interference can get inside the housing, there is every chance that these signals will be demodulated to some degree and the resultant contamination added to the audio output of the device, potentially impairing sound quality even if not directly audible as a spurious noise..

How to Maximise EMC (and Hence Audio Quality)

There are two reasons why we sometimes hear hum, buzz, clicks and other noises mixed with our audio signals. One is the demodulation of RF electromagnetic interference picked up by cables acting as antennae at both send and receive ends directly injected into the audio circuit electronics. The other is the directly audible low-frequency noise that lies within the audio band: hum and buzz are from mains 'ground loops'; clicks are caused by transients such as nearby lightning and also electrical loads being switched on and off.

There are now (or soon will be) increasing levels of new types of such lower frequency noise from the frequency-changing AC motor drives that are beginning to be used in domestic appliances (to help save the planet from overheating by reducing the energy consumption of fridges, freezers, water pumps, etc.).

Quite simply, we need to stop electromagnetic interference in the increasingly noisy environment from getting inside our equipment, and to stop any interference generated inside from getting out. We can do this in part by using two well established techniques: shielding, and also minimising the tendency of our cables to behave as antennae.

A Brief History

For the first 50 years of electronic and audio system manufacturing, equipment interconnection techniques followed rules set out by national and international telephone, broadcast, film, and recording institutions. However, by the 1950s, higher performance recording and reproducing equipment – once the preserve of audio professionals – started to become available to the general public.

The rapid growth of the resulting hi-fi industry meant an ever increasing demand to reduce production costs and use more economical connection practices. At the same time, the professional audio industry decided to change to an input/output connector that was primarily developed to control hum induction in long microphone cables, including low output ribbon mikes that could only deliver a few microvolts. Similar techniques for interconnections were adopted by the hi-fi industry for the low output moving-coil pickup cartridges used in the record playing equipment.

Within a few years, most of the audio industry had changed from input/output connectors that had a 360º common bonding, circular connection shell to signal ground to connectors (even insulated plugs and sockets) that had a single chassis insulated common pin. Worse was to follow: instead of the traditional single conductive structure for audio units built with a relatively large area (often referred to as the *chassis*), circuit designs were produced with multiple current return paths for their input and output topologies. In many cases, electronic practice was abandoned and replaced by a series of 'black magic' myths, for example typified by the concept of 'clean earth/ground', and 'technical earth' (assumed to mean 'perfect earth'). Now, instead of return currents being spread thinly at low current density across a large area of conductive structure, individual sets of ground and noise return currents were concentrated in individual insulated wires – acting as unwanted antennae as EMC specialists have discovered, due to the relatively large electromagnetic fields surrounding the wire associated with the concentrated current flowing in the wire.

Before the advent of computers and other electronic devices controlled by high speed clocking circuits, multiple current return paths inside audio equipment were only a problem for audio professionals working in theatre, broadcast, films or live sound. Here, the large currents flowing in stage lighting control and electric motor wiring produced high level electromagnetic interference across the whole system. When coupled with the audio wiring, the newer 'high performance' audio equipment faithfully demodulated and reproduced this additional information in the form of hum, buzz and clicks.

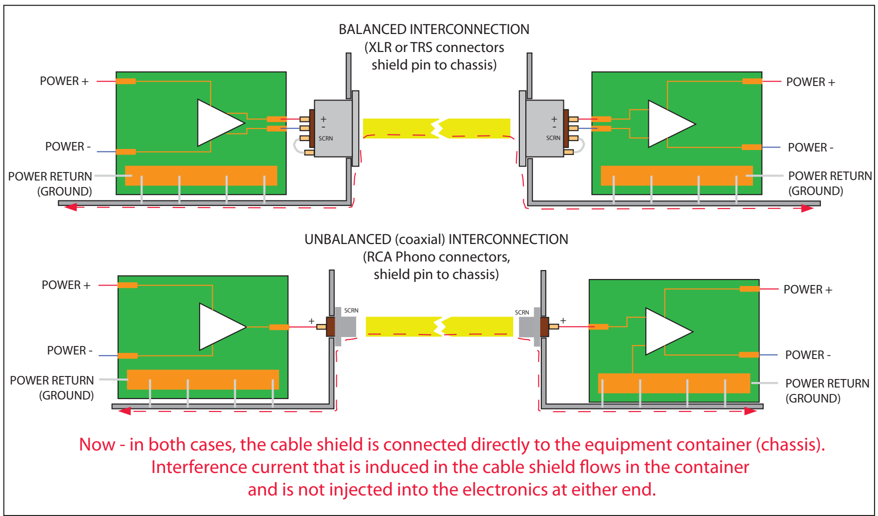

Fig 1 Shielding Methods for Balanced and Unbalanced (SE) Connections

Shielding

Enclosing the active electronics inside a conductive enclosure is a technique that has been in use for many years. Steel, aluminium and other related materials have been joined by a range of plastic materials with a conductive coating inside. For an enclosure to be effective as an electromagnetic shield, however, all surfaces must form a continuous conductive structure. Any material used for the decorative finish that has insulating properties (painting, anodising, etc.) must remain conducting at the interconnections. More recently, both conductive gaskets or seals and screening techniques for printed circuit boards have been developed to improve the shielding characteristics of enclosures and internal components. (Very high frequencies can even enter *via* a narrow slot.)

Minimising the Tendency of Cables to Behave as Antennae

In order to protect audio signals from electromagnetic interference, conductive shielding needs to be extended between each different piece of equipment in the system. This can be achieved by using shielded interconnection cables. Indeed - we already use shielded cables to link one device to another. Unfortunately, it has become audio design practice to use connectors with a shield contact that is usually insulated from the shielding enclosure, itself present to enclose and protect the electronic circuits from electromagnetic interference. Thus, interference that couples to a cable shield, that unfortunately does behave like two antennas connected at their ends, can now get directly injected into the electronics at either end of the cable. In order to minimise the antenna behaviour, we need to bond the cable shield to the outside of the shielding enclosures *at both ends*.

Fig2(a) shows a method that solves the problem, adapted from the techniques employed in the early days of electronic equipment design. Radio frequency (RF) interference currents induced in a conductive structure tend to travel on the outside surface of the material. (This is known as the 'skin effect'.) Therefore, RF current flowing on the outside of a cable shield produces very little mutual inductive coupling with the usually balanced signal conductors inside. However, to minimise the possibility, filter techniques have also been developed for both audio and digital signals [*2*].

Cable Properties at Frequencies Lower than RF

A cable used to connect audio signals between two electronic devices requires at least two conductors. We refer to one as 'hot' (or signal, live, positive, etc.), and the other 'cold' (or common, ground, neutral, negative, etc.). All conductors have properties of resistance and inductance, while the insulation between the signal and ground conductors gives rise to some stray or 'parasitic' capacitance between them. When multiple conductors are used together in a cable for connecting two electronic devices, a complex structure is formed, as shown in *fig2(b)*, and we become aware of the stray mutual inductances and capacitances between the shield and the conductors. At lower frequencies, and related harmonics, where the skin depth effect does not keep enough of the cable shield noise current flowing in its outer surface, out of the way, the inherent parasitic inductive component in each conductor of the cable tends to couple some unwanted shield signal in much the same way as the two windings in a transformer – but in this case electrical noise.

Concerning mains power, and earth potential differences, unlike much larger Pro-audio installations, most hi-fi system installations derive power from a local power outlet, or are designed with double insulated power supply techniques and so tend not to suffer from earth potential differences. However, double insulation does mean that there's an inevitable residual leakage coupling from the mains circuits to the chassis (typically 0.25mA of current). This means that the chassis/earth terminals of different audio units are at slightly different voltages with respect to each other. Here is a source of 'ground loop current' which has nothing to do with any protective earthing conductors, and this causes unwanted 'hum' currents to flow in the interconnection cable's common conductor.

In tests that I was involved with back in 2005 [*1*], it was found that low frequency power currents flowing in either metallised foil or braided outer shields did not induce significant noise on the internal conductor(s) of the cable. The voltage induced on the inner conductor(s) by inductive coupling from the ground loop currents flowing in the cable shield exactly matches the voltage created on the shield itself – so the electronics at the termination 'sees' a common-mode voltage at the end of the cable. It is easy to design audio electronics to reject such common-mode noise voltages using balanced circuitry, and bonding the cable shield to the outside of the shielding enclosure is a necessary first step.

Ground loops have become the 'bogeyman' of audio electronics, precisely because many designers did not understand this. The connected shields are an essential requirement if the cable's screen is to do what it is designed for and help protect against RF interference.

Why EMC Design Techniques are Good for Us

When one considers the specifications of electronic equipment, we note that most of the measurements for frequency response, noise, distortion, and crosstalk etc are done within the constraints of the accepted audio bandwidth of 20Hz to 20kHz. These are known as weighted and band-limited measurements, of which there are many, with very different looking response curves. Performing wide-band measurements (say, up to 500kHz) on the same equipment can result in different numbers, and not just because there is more inherent noise from a wider spectrum. The reason for this is clear when one connects a spectrum analyser to either end of a cable used to connect two audio devices, allowing us to observe the high frequency electromagnetic energy associated with a pair of antennas joined at their ends. The electromagnetic energy present cannot be detected directly at audio frequencies, but if the noise gets into the electronics at either end of the cable, demodulation of the signals in the audio electronics will make the audible noise worse, and/or generate other audible by-products such as hum, buzz, clicks. I find the unwanted 'chirping' on the audio caused when a call is received by a nearby mobile phone deeply annoying. And audio manufacturers ought to find it deeply embarrassing! Even when the signals may not be audible directly there can still be a loss of quality in hi-fi terms.

While doing experiments on shielded cables back in 2005, (see reference [*1*]), wide-band weighted noise differences of 20dB were found between connecting the cable screen directly to the circuit board (insulated ground pin method), and the shield bonding techniques shown in *fig2(a)*. In my view such large differences in the noise that gets demodulated by the electronics are easily detected by the human auditory system. Indeed, loudness differences of just 0.1dB are detectable by professional audio engineers and hi-fi enthusiasts.

There should be no mystery about such extraordinary sensitivity. Mammalian hearing has developed over tens of millions of years to hear predators (*eg* snakes in the dark), and as a result has become very sensitive and discriminating.

Conclusions

It can be demonstrated that EMC design techniques improve the signal integrity of our equipment by minimising the RF noise demodulation artefacts, which in turn reduce the overall noise floor of the electronics and enhance the accuracy of audio reproduction.

Similarly, equipment designs that have circuit elements likely to produce electromagnetic emissions, can be made compatible with other system devices by the same engineering good practice, preventing RF noise from getting out. This is a major advantage, since poorly designed equipment often interferes with itself.

So, designing audio equipment to meet the EMC EU Standards Directive is good news for the manufacturer, as well as the user. I have also found that good EMC practice can simplify audio system design and integration by reducing the time taken to test a product or complete an installation.

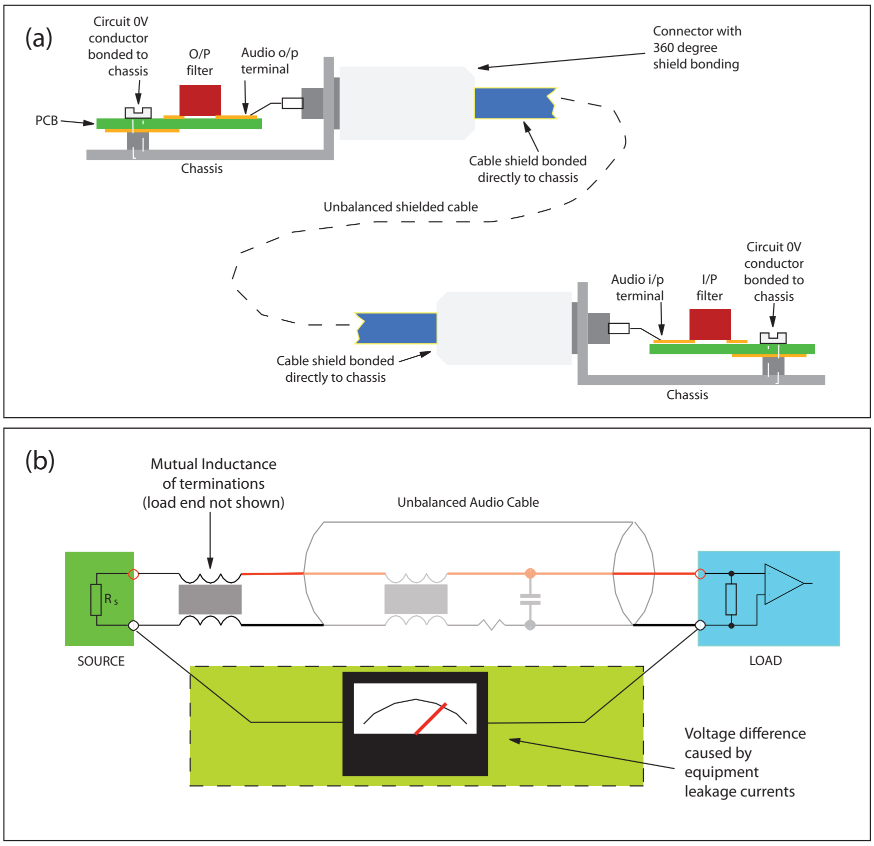

Fig2 (a) Cable shield bonded 360° to chassis by a suitable shielding connector
(b) Cable properties at low frequencies

References

[1] Bonding cable shields at both ends to reduce noise – by Tony Waldron & Keith Armstrong – published by EMC Journal 2005

[2] A practical interference free audio system, part 1 – by Tony Waldron - published by EMC Journal 2009