The correct way to bond cable shields

Recent coverage of the topic in the pages of this magazine have begged explanation of the whole double-ended shield bonding issue. The knowledge base and the substantiating proof exists, according to KEITH ARMSTRONG and TONY WALDRON.

WHEN WE WERE LEARNING how to do pro audio decades ago, we learnt that experienced engineers minimised the noise in a mixing console by spending a great deal of time 'fiddling about' with the terminations of its cable shields and its internal bonding.

Despite the fact that the console's electronics modules worked satisfactorily on the bench, they behaved quite differently when connected together in a console frame – and differently again when finally installed on the customer's site. The main problem was interference known as 'hum' or 'buzz' and the purpose of the lengthy fiddling about was to 'eliminate the hum loops' (sometimes called ground loops).

In recent years we have discovered this expensive 'fiddling about' was all unnecessary. Because of a design decision made many decades ago, possibly even for no very good reason, and repeated as if it were gospel ever since, single-point grounding techniques and single-ended cable shield bonding became the standard for equipment design. As a direct result of this poor decision pro audio equipment and systems were condemned to suffer hums and buzzes requiring costly devices with high common-mode rejection ratio (CMRR) and/or time-consuming 'fiddling about' to solve.

It took the introduction of digital technology and the EMC directive with its EMC standards EN 55103-1 and -2 to force us to abandon our decades-old practices. Now we use mesh-bonding techniques and bond the shields of our cables to chassis at both ends – a process of discovery described [1] by Tony Waldron.

Tony Waldron and Cadac R-Type

We were surprised and gratified to discover that our new design techniques eliminated all the usual 'fiddling about' with cable shields and grounding – saving substantial amounts of time and money. They simply reduce the ground potential differences between items of equipment – which are the cause of hum and buzz problems.

We were also very pleased to find that our new techniques considerably improved audio performance; avoided the need for expensive high-CMRR devices; and improved equipment reliability and safety. Many new and legacy pro audio installations have already benefited greatly from the use of our new techniques.

Equipment should be designed so as to bond the shields of every cable (digital or analogue) to its local chassis or frame – ideally to the surface of its Faraday cage enclosure shield, if it has one. This is not a recent revelation – the Audio Engineering Society devoted a full issue of its Journal to it in 1995 [5], and John Watkinson described its benefits in Studio Sound in 1995 [2], in 1996 [3], and most recently in the July/August 2002 issue of Resolution [4].

Next, both ends of every cable shield should be bonded directly to their local chassis or Faraday cage as specified by IEC 61000-5-2 [6]. Of course, this causes ground loop currents to flow in the cable shields, but we have recently shown [7] that this cannot cause significant audio noise – even in the very highest quality systems – even with shield currents large enough to heat the cables.

Our article [7] in the EMC Compliance Journal describes tests on a variety of balanced audio cables nearly 30m long to determine the effects of power-frequency shield currents on audio noise. Several types of balanced cables were tested, including an extremely poor quality cable with untwisted signal conductors and a capacitive imbalance exceeding 20% – representing the worst legacy cabling that can be expected.

No properly managed pro audio system has ground potential differences large enough to drive damaging currents in cable shields, although they can occur in heavy industry and during ground-faults. In any case, the solution is simply to run a parallel earth conductor (PEC) between the offending items of equipment, as described in IEC 61000-2-5 [6].

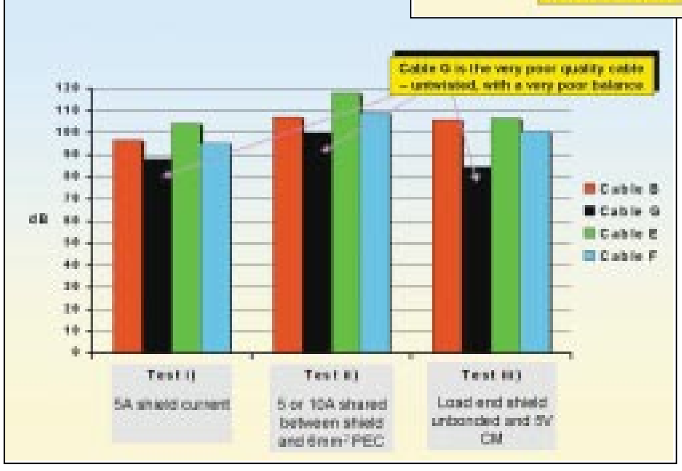

Figure 2. Cable CMRRs for a floating 75 ohm source

Figure 2 shows the results from one of the tests described in [7], simulating a floating 75 ohm signal source. The CMRR performance of an audio system when using four different types of cables (B, G, E, F) is shown, cable G being the extremely poor quality cable.

The noise performance of the cables with 5 amps of shield current is much the same as when their shields are one-end bonded. Adding the 6mm2 PEC reduced the noise by about 10dB, so it can be beneficial to employ a PEC even when shield currents are low. Similar results were obtained for a variety of other signal sources.

Real pro audio systems have large numbers of cables, and when their shields are all bonded at both ends their combined impedance is very low. Since the source impedance of ground potential differences is finite, the more shields are bonded at both ends and/or the more PECs that are employed, the lower is the resulting ground noise potential. This is shown by Figure 3 for a floating 75 ohm signal source, taken from a series of such graphs in [7].

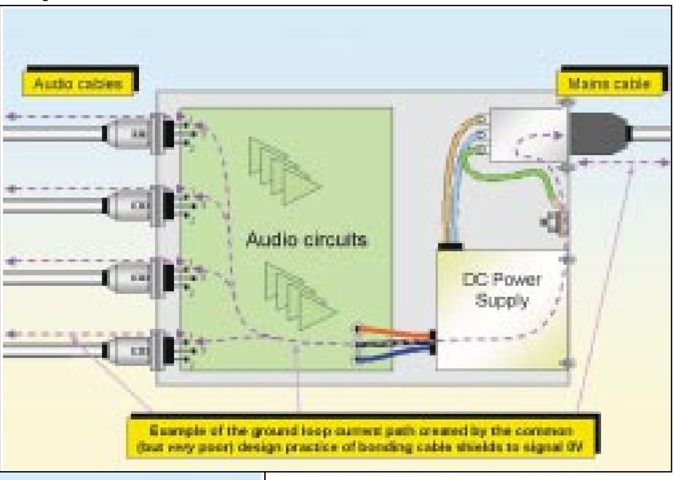

Figure 3. System CMRR versus ground system impedance

Figure 3 shows the overall system CMRR for four different configurations of the same four cable types as Figure 1. It shows that in real life, bonding cable shields to chassis at both ends usually gives much higher system CMRR (lower system noise) than the traditional technique of bonding cable shields at only one end.

Note that although the amplifiers used in [7] had a CMRR of well under 100dB, the overall system CMRR can exceed 140dB. This is one reason why pro audio systems achieve better quality sound when bonding shields to chassis at both ends, without the need for costly high-CMRR devices such as special transformers.

Bonding cable shields to chassis with ‘pigtails’ (a length of wire and/or a connector pin), as XLR and many other standard audio connectors often force us to do, is sufficient for eliminating hum and buzz interference caused by mains frequencies, but useless at preventing radio-frequency (RF) interference.

Controlling the emissions of, and susceptibility to, interference is known as EMC. Most readers will know that all pro audio, video, and entertainment lighting equipment and systems supplied in Europe must by law meet the EU’s EMC Directive by applying the harmonised standards EN 55103-1 and EN 55103-2, affixing the CE mark and having a signed Declaration of Conformity. (An alternative is known as the Technical Construction File route.)

Designing equipment to employ RF shield terminations at both ends of typical shielded audio cables helps achieve EMC compliance at the lowest cost, by considerably reducing the size and cost of the filters that would otherwise be needed at every input and output. Happily, some audio connector manufacturers can now supply products that use reasonable RF shield bonding techniques.

Some people have been recommending capacitive shield bonding at one cable end to help achieve good EMC, but this would still require ‘fiddling about’ and the use of expensive high-CMRR devices for the highest quality. For good EMC performance to 1000MHz as required by EN 55103-1 and -2 the special capacitive connectors required would be costly, and will often need to be fitted at both ends of the cable to permit the traditional time-consuming ‘fiddling about’.

Poor equipment design is the real cause of ‘hum loop’ noise. Shield currents have got such a bad reputation for causing noise because most legacy equipment was designed using very poor shield bonding practices, such as the method shown in Figure 4.

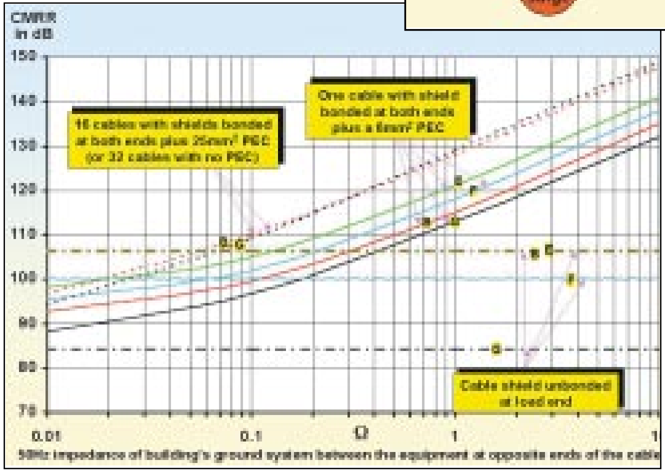

Figure 4. It is poor equipment design that causes ‘ground loop’ noise

Ground loop currents in cable shields are injected into the finite impedances of a sensitive audio circuit’s 0V system, causing noise voltages to arise in the 0V references of the unbalanced audio circuits and making their signals noisy. Very careful use of single-point grounding can go some way to reducing this problem, but the stray magnetic coupling between wires and PCB traces means that shield currents will always cause unacceptable hums and buzzes.

Another traditional but very poor technique is to use a ‘chassis’ trace (or wire) to connect all the shield pins together and (eventually) connect them to the chassis. These ‘chassis ground’ traces are isolated from 0V but magnetically couple with any nearby signal or 0V traces or wires, giving rise to noise voltages.

All these noise problems would be eliminated if cable shields were connected directly to the chassis/frame/enclosure at the point where their cable enters the equipment (as recommended by [2], [3], [4], [5] and [6]) and this is also best for EMC. A surprising proportion of new equipment still uses long-discredited shield bonding methods.

Although grounding system resistances are usually less than 2 ohms, their inductance makes their impedance to lightning and other types of voltage surge much higher.

Reference [8] shows that the effect is to apply most of the surge voltage to the electronic devices at cable ends where shields are not bonded to chassis, and this

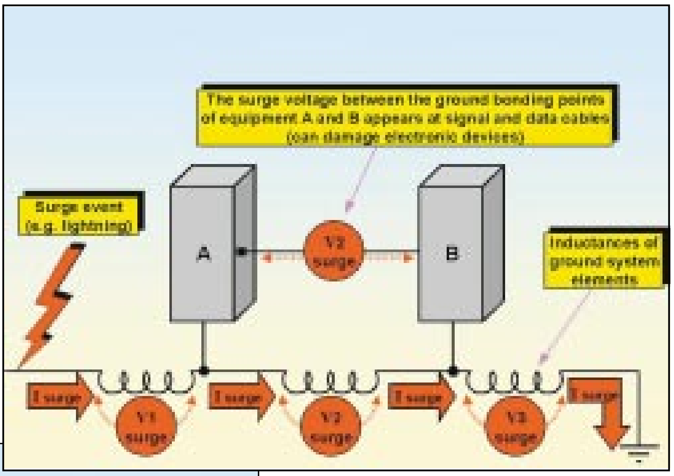

Figure 5. Surge overvoltages caused at signal inputs and outputs

is very bad for reliability (Figure 5). Bonding cable shields at both ends and using PECs where appropriate considerably reduces the inductance of the grounding system, reducing the surge voltages that develop as well as helping to protect input and output devices from overvoltages.

The ends of cables that have unterminated shields have occasionally been seen to flash-over during thunderstorms, so there are clearly significant shock and fire hazards associated with bonding cable shields at one end. Finally, it is a common practice in the pro audio industry to disconnect the protective ground conductors from items of equipment to help ‘cure’ hum loops quickly and at low cost. This is a very bad practice indeed, and is illegal under health and safety legislation in many countries. When cable shields are bonded at both ends this traditional (but unsafe) remedy is not required.

In conclusion, bonding the shields of balanced cables at only one end only achieves good noise performance for complex installations after a great deal of costly ‘fiddling about’, and also wastes a low-cost EMC resource.

Concerns about ‘hum loop’ noise when bonding both ends of the shields of balanced audio cables are without basis for correctly designed equipment. Correct equipment design need cost little more and helps achieve EMC compliance at lowest cost by using the EMC performance of existing cable shields. As the number of cable shields bonded at both ends in an installation increases, and/or as more PECs are used, the noisy ground potential differences in an installation fall and so do the resulting CM noise voltages. The large number of shielded cables available in a typical pro audio installation make it easy to reduce ground noise potentials dramatically – substantially increasing the system’s overall CMRR.

Even where EMC compliance is not a necessity, bonding cable shields at both ends saves large amounts of time and cost by totally eliminating any need to ‘fiddle about’ with hum loops. It also improves sound system quality, reliability, and safety. ■

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