



Another EMC resource
from EMC Standards

Terminating cable screens (shields)

Helping you solve your EMC problems

Terminating cable screens (shields)

By Eurling Keith Armstrong, C.Eng, FIET, Senior MIEEE, www.cherryclough.com

First published in *The EMC Journal*, Issue 82, May 2009, pp 19-24

This is the first in a series of *short* technical articles, dealing with practical EMC engineering issues – the ‘nuts and bolts’ of EMC, if you like.

This particular topic was very kindly suggested by John Woodgate, who pointed out that in my articles for product designers and system integrators, I always seem to be recommending 360° termination – sometimes called circumferential or peripheral bonding, for the cable’s screen – at *both* ends of the cable.

I will not go into the details of this technique here, or discuss its ramifications. If you are interested, see Chapter 2.6 of [1]; Chapters 13.1.4 through 13.1.7 (pages 344 to 352) of [2]; Chapters 3.7.5 through 3.8 of [3]; Chapter 7.2 of [4] (pages 164 to 175) or pages 32-11 through 32-16 of [5]. Many of these references also discuss the issue of the so-called ‘ground loop’ currents that flow in a screen that is terminated (conclusion: not a problem for correctly-designed electronics, and cables with symmetrical screens).

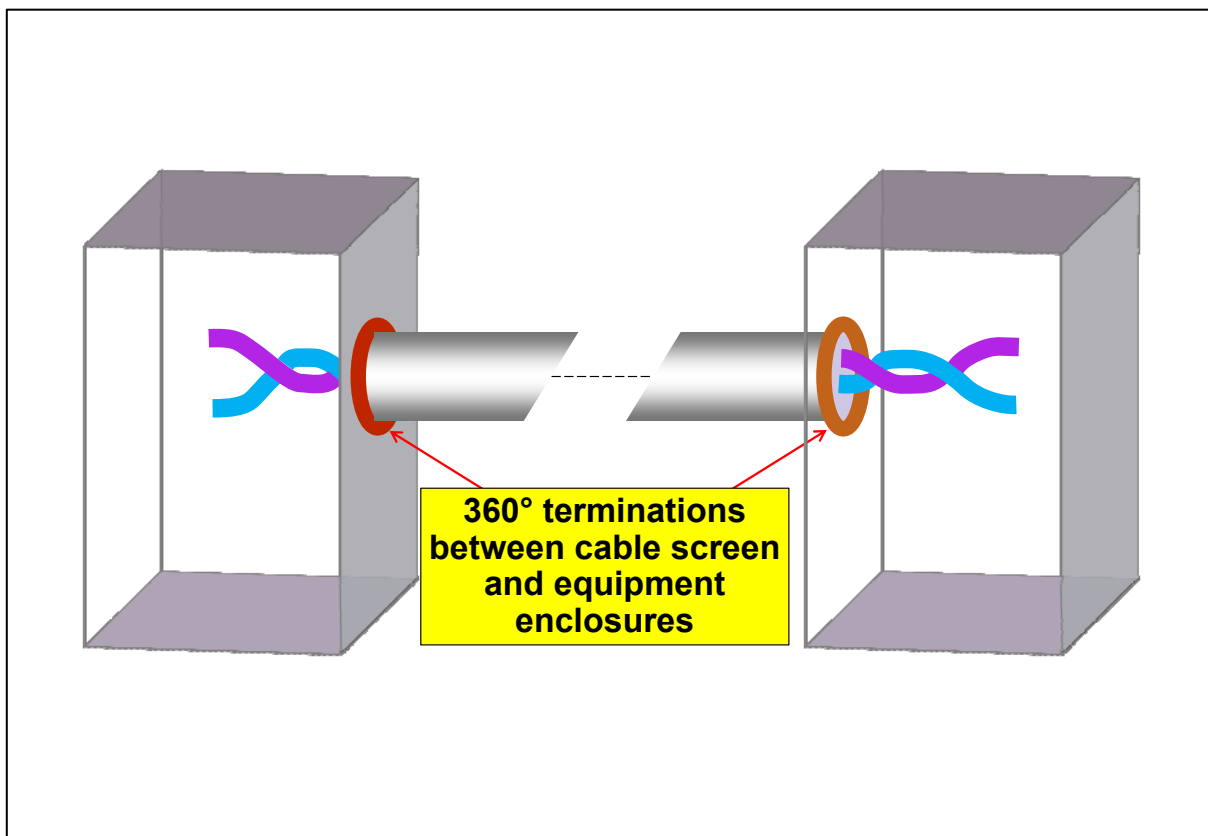


Figure 1 360° screen termination at both ends of the cable

When I am writing about good EMC engineering, I always make the point that to achieve the best shielding performance a cable is capable of, its screen must be 360° bonded to the RF Reference (usually the equipment’s connector panel, electrically bonded to its chassis) at both ends.

But – apart from chapter 7.2.4.3, on page 173 of [4] – I haven’t often written about how best to improve the cable shielding performance in a legacy installation where existing (poorly-

designed) equipment would suffer from excessive noise if screen currents flowed due to screen termination at both ends.

Such problems almost always occur at low frequencies, mostly related to the mains power frequency and its harmonics up to a few kHz, which is why an alternative name for 'ground loops', is 'hum loops'.

Low frequency – in this context – means frequencies for which the wavelengths are shorter than about 6 times the length of the cable (e.g., for a 10m cable, frequencies above 5MHz). At frequencies for which the cable is longer than a wavelength (e.g. above 30MHz for a 10m cable), much the same current flows in the screen whether it is terminated at one end, both ends, or at neither end.

In some situations, terminating a cable screen to the RF References at each end may not be enough, it may need to have its screen bonded to an RF Reference at one of more intervals along its length, see pages 32-11 through 32-16 of [5]

Where 360° screen termination at both ends causes 'ground loop' problems for (poorly-designed) equipment, there are several possible solutions:

a) Replace the (poorly-engineered) equipment with products that don't suffer from excessive noise due to 'ground loop' currents in their cable screens.

Because of the perceived high cost and delay, not many people do this. However, looking back after the required EMC has *eventually* been achieved, they generally admit that they should have replaced the equipment, as it would actually have been the lowest-cost *overall* solution, and very much quicker.

b) Modify the (poorly-engineered) equipment to remove 'ground loop' problems.

This requires galvanic isolation of the troublesome inputs or outputs. Replacing the screened cable with a fibre-optic one is by far the best solution for galvanic isolation and EMC performance. Several suppliers offer connectors for standard digital interfaces, that convert to and from optical fibre, but custom designs might be needed for some interconnections.

Other galvanic isolation techniques include fitting opto-isolators or isolating transformers, usually in a separate shielded box. It may be possible to do this whilst maintaining 360° shielding integrity from the box containing the optos or transformers, to the equipment – but this generally means modifying the connectors or connector panels of the equipment.

Of course, modifying equipment invalidates its manufacturer's warranty. But I know of one London-based audio/video equipment hire company – the kind of company that can provide ten or more huge juggernauts filled with gear to provide a complete rock concert for an audience of any size anywhere in Europe – that modifies every item of equipment they purchase (if it needs it) so that they will not suffer ground loop problems in real-life installations.

Unlike an installation such as a theatre, office or industrial process plant, they cannot afford to spend any time hunting down 'hum loops' when they erect a touring system on a site. It must reliably function with acceptable quality immediately following its erection, because there is simply no time available for fiddling about to find the best solution for that particular set-up. Manufacturer's warranties are a very secondary financial concern to such companies.

c) Fit a 'Parallel Earth Conductor', PEC, as described in BS IEC 61000-5-2 [6].

Despite their name, PECs are not concerned with safety earthing. Detailed descriptions of how to use them in practice are given in Chapters 2.5 - 2.7 of [3], and Chapter 7.4.3 of [4] (pages 188 to 192).

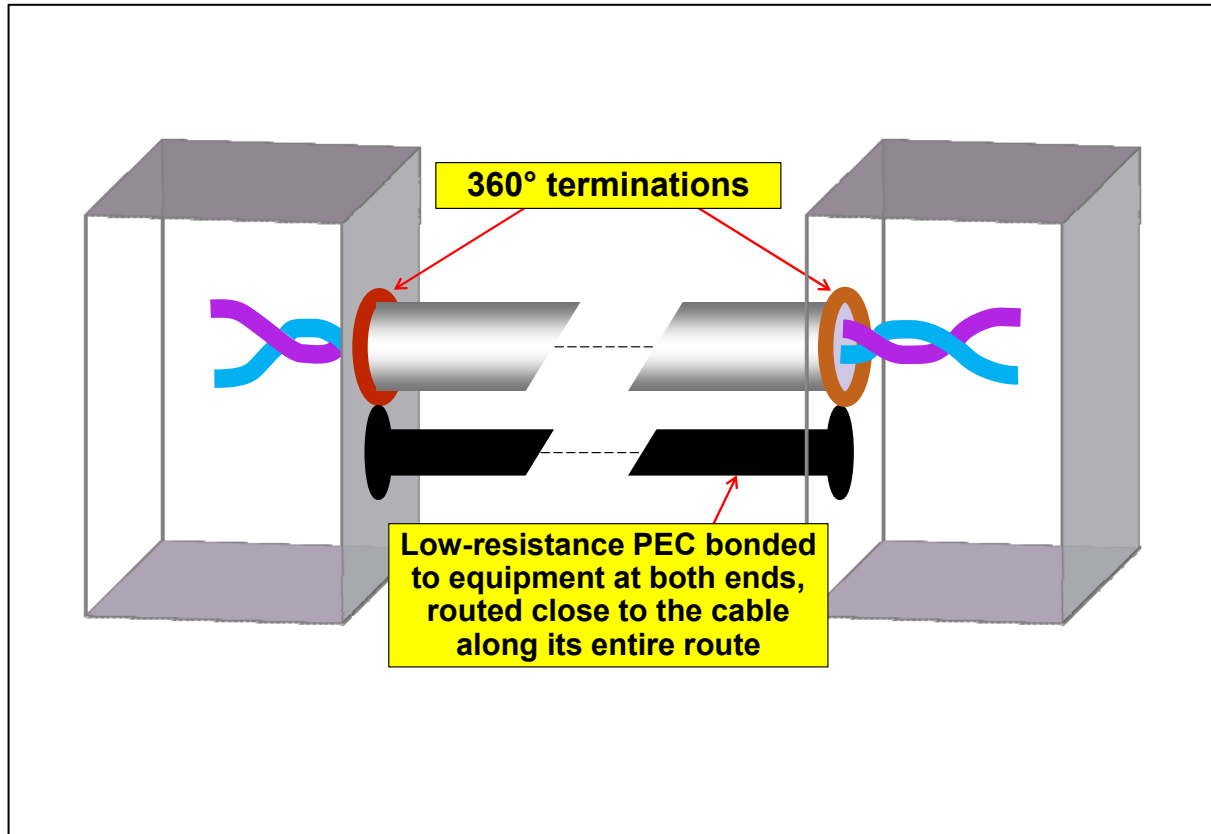


Figure 2 Adding a PEC

PECs divert the majority of the mains-related currents from the cable screen into themselves, because at such low frequencies they have a much lower impedance than the cable screen they are routed very close to. They have a very much lower *resistance*, inductance only becoming the dominant issue for cable impedance above a few kHz.

The 18th Edition of the IEE Wiring Regulations, BS7671 – expected to be published in 2011 with a new EMC requirements clause – calls PECs "bypass conductors". But a better term than either would be 'parallel bonding conductor', suggested by John Woodgate.

A common problem with using this technique in legacy installations, is that there may not be the physical room in the cable ducts to add all the PECs required.

As the above references show in some detail, so-called 'natural metalwork' such as cable support systems, steel girders, etc., can be very effective PECs. Where adequate natural metalwork exists, all that might be needed is to electrically bond all the pieces together along the entire cable route. Plus, of course, bond the resulting PECs at both ends to the frames of the equipment the screened cables connect to.

- d) **Fit a connector or gland that uses an annular capacitor to terminate the screen to the chassis *capacitively* in 360° at one end only.**

The screen at one end of the cable enjoys 360° termination, and when a capacitor is used to terminate the *other* end it is often called hybrid screen termination. An annular (i.e. ring) capacitor maximises the shielding effectiveness of this technique.

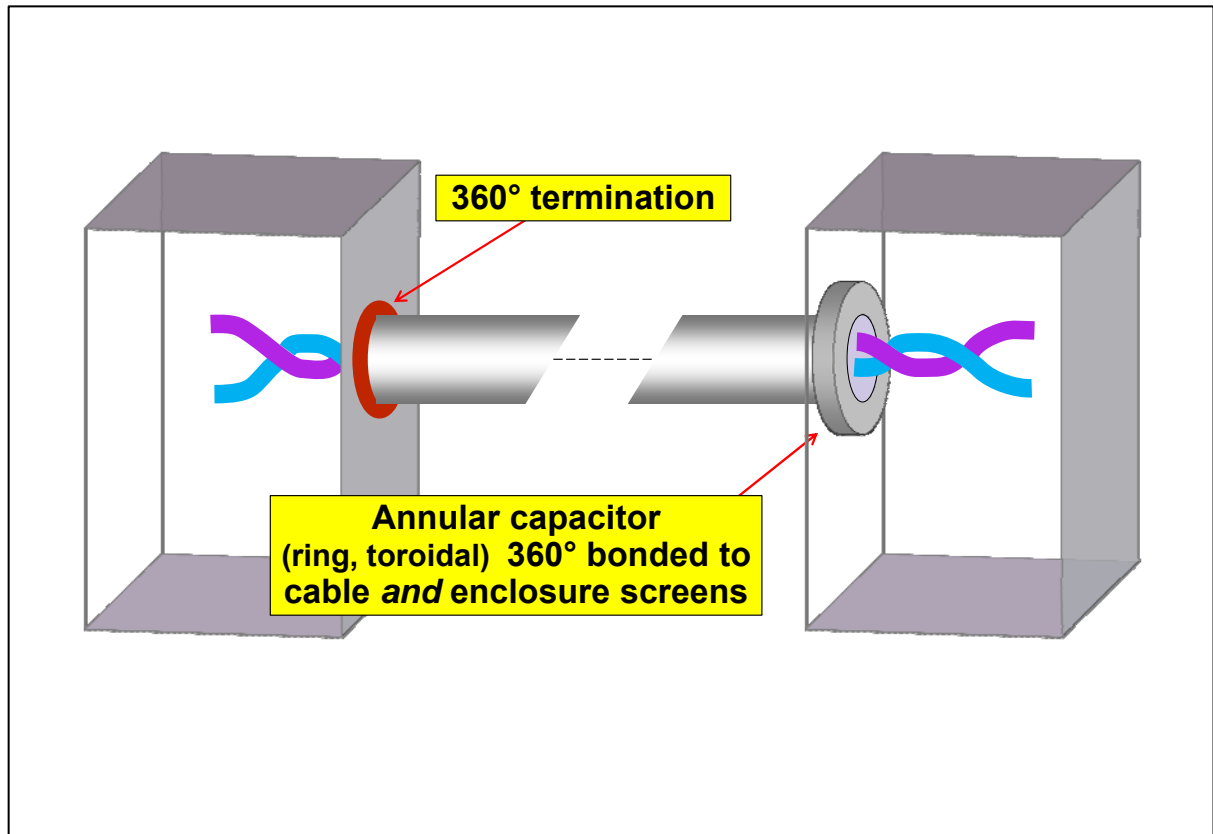


Figure 3 Hybrid termination with an annular capacitor

When using annular capacitors, the equivalent series inductance is vanishingly small, so good shielding effectiveness is maintained over a very wide range of frequencies.

Unfortunately, screened connectors or glands that connect annular capacitors in series with the cable screen are very costly, and very few are commercially available.

Where cables using capacitive screen termination can be long (say, longer than 30m), their capacitors will generally need protecting against the surge overvoltages caused by lightning channel currents within a couple of kilometres.

MOV surge arrestors have a high level of capacitance, so it might be possible to create the annular capacitor out of MOV material to get inherent surge protection.

Alternatively, routing the cable in a metal cable tray or duct (ideally, in a circular metal conduit) that is used as a PEC (see above), could provide sufficient shielding against the lightning induction.

e) Terminate one screen end with a discrete capacitor.

All the same comments apply as for the annular capacitor described above, except for the issue of the frequency range over which the termination method will allow the cable to achieve good shielding effectiveness.

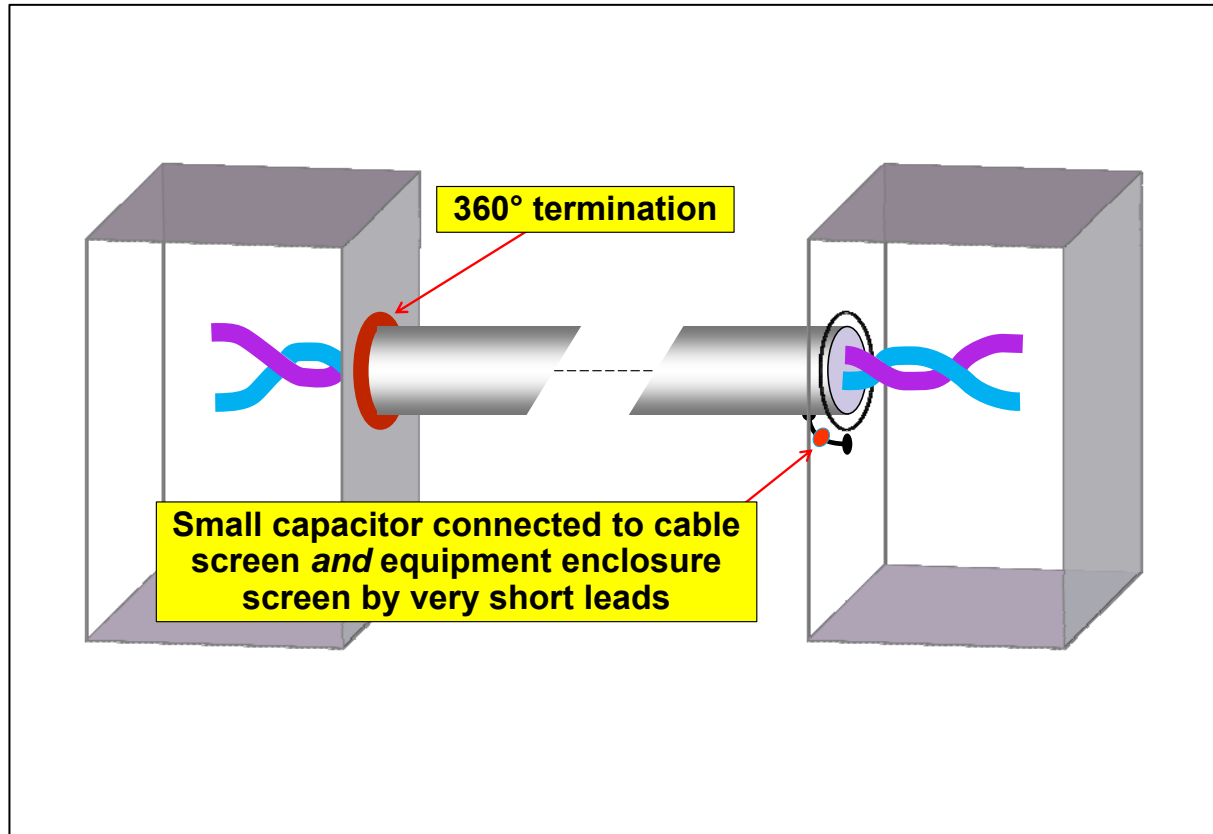


Figure 4 Hybrid termination with a two-terminal capacitor

Two-terminal capacitors, unlike annular types, unavoidably have a high level of series inductance in the capacitor and its connections. This inductance series-resonates with the capacitor ($f_{res} = 1/2\pi\sqrt{LC}$), making the screen's termination (and thus the shielding effectiveness of the cable) only effective over a limited frequency range.

As a result, it is often necessary to choose a capacitor value that 'tunes' the resonance to provide the optimum benefit for the installation in question, at a particular time.

This is usually not too difficult if the RF threats are all around the same frequency, but 'tuning' the capacitive screen terminations is always time-consuming in practice.

Of course, it is possible that new RF sources might arise later on, making it necessary to try to retune all of the screen-terminating capacitors to achieve an adequate overall performance, which – if the frequency range is wide – might not be possible.

Perhaps the best discrete capacitors for this purpose are those embedded in silicone inserts, such as the EESeal™ supplied by Quell, Inc. These are very small, have very short connections, and are very quick and easy to assemble, even in multi-way connectors.

Figure 5 shows the insertion loss vs frequency for an EESeal capacitor connected between a connector's pin and its bodyshell. For a cable shielding effectiveness adequate for many general domestic, commercial and industrial applications, we would aim for a screen termination impedance of 1 ohm or less. Since Figure 5 was measured with a 50 ohm source impedance – a 1 ohm impedance corresponds to an insertion loss of 34dB.

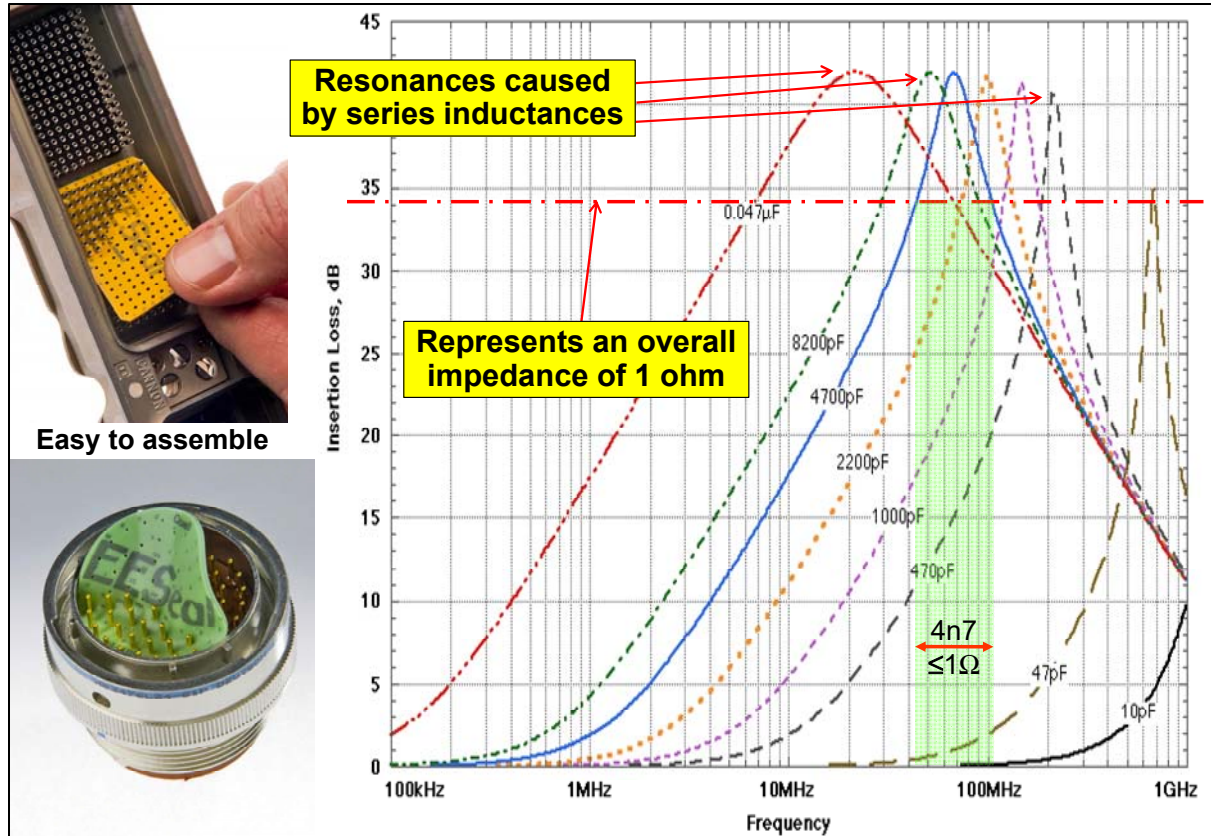


Figure 5 Insertion loss example for a discrete capacitor connected between pin and chassis (EESeal™ from Quell, Inc., www.eeseal.com)

The figure shows that for Quell's 4.7nF capacitors, we could only expect a screen-terminating impedance of 1 ohm or less, over the range 41 - 110MHz.

Very small multi-layer ceramic capacitors are, of course, readily available – but assembling them inside a connector or gland using very short leads is not at all easy or quick, and will almost certainly not exceed the performance of the EESeal™ types.

Hybrid screen termination using a discrete capacitor degrades the shielding effectiveness of the enclosure of the equipment at the capacitor-terminated end, although it can be recovered by connecting a suitably-specified filter (ideally a 'feedthrough' or 'through-bulkhead' type) to the wall of the enclosure at the point where the cable enters.

The performance of discrete capacitor shield termination can be significantly improved by using two or more capacitors in parallel. To make the best of this technique, they and their connections must be arranged symmetrically around the circumference of the connector or gland, as Figure 6 tries to show.

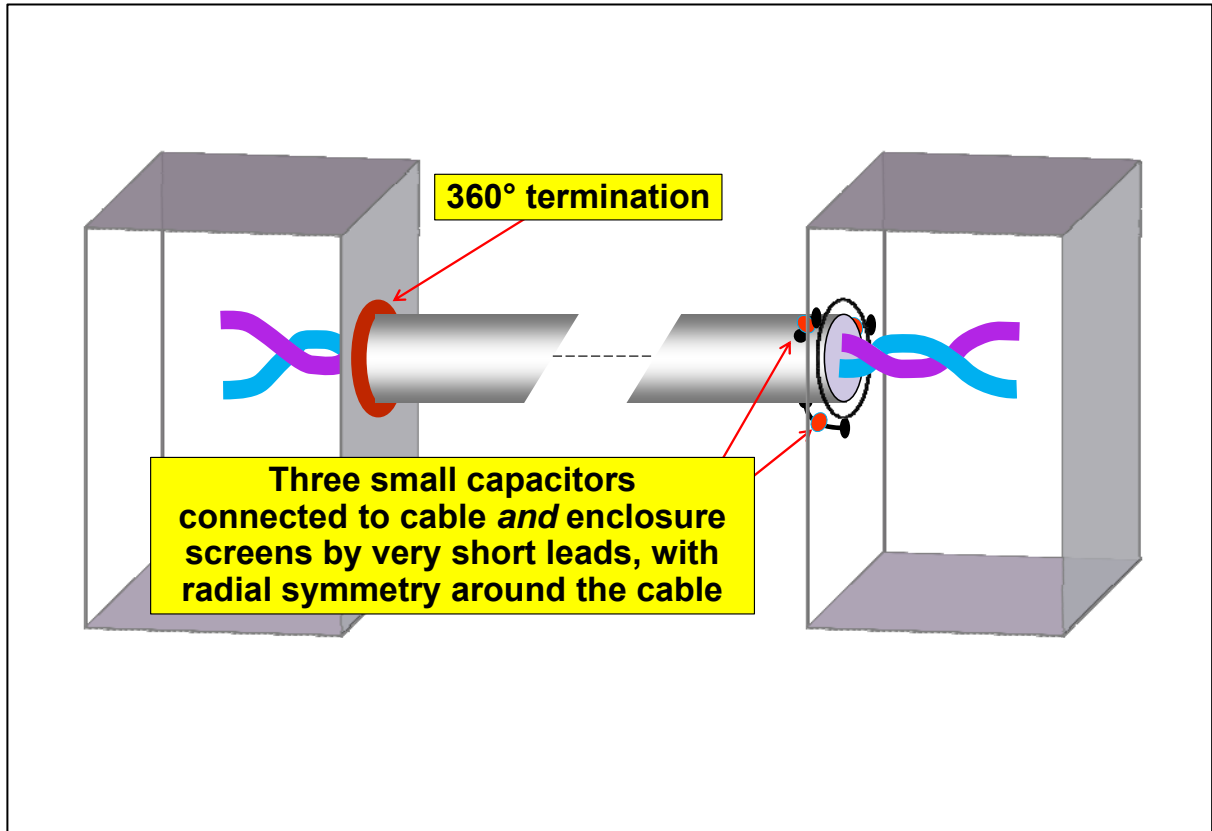


Figure 6 Hybrid termination with three two-terminal capacitors

f) Terminate the screen at one end only (OEO)

Unless the length of the cable is less than one-sixth of a wavelength at the highest threat frequency (e.g. under 5MHz for a 10 metre cable) – this is really only an appropriate technique when all else has been tried and desperation sets in. See Figure 7.

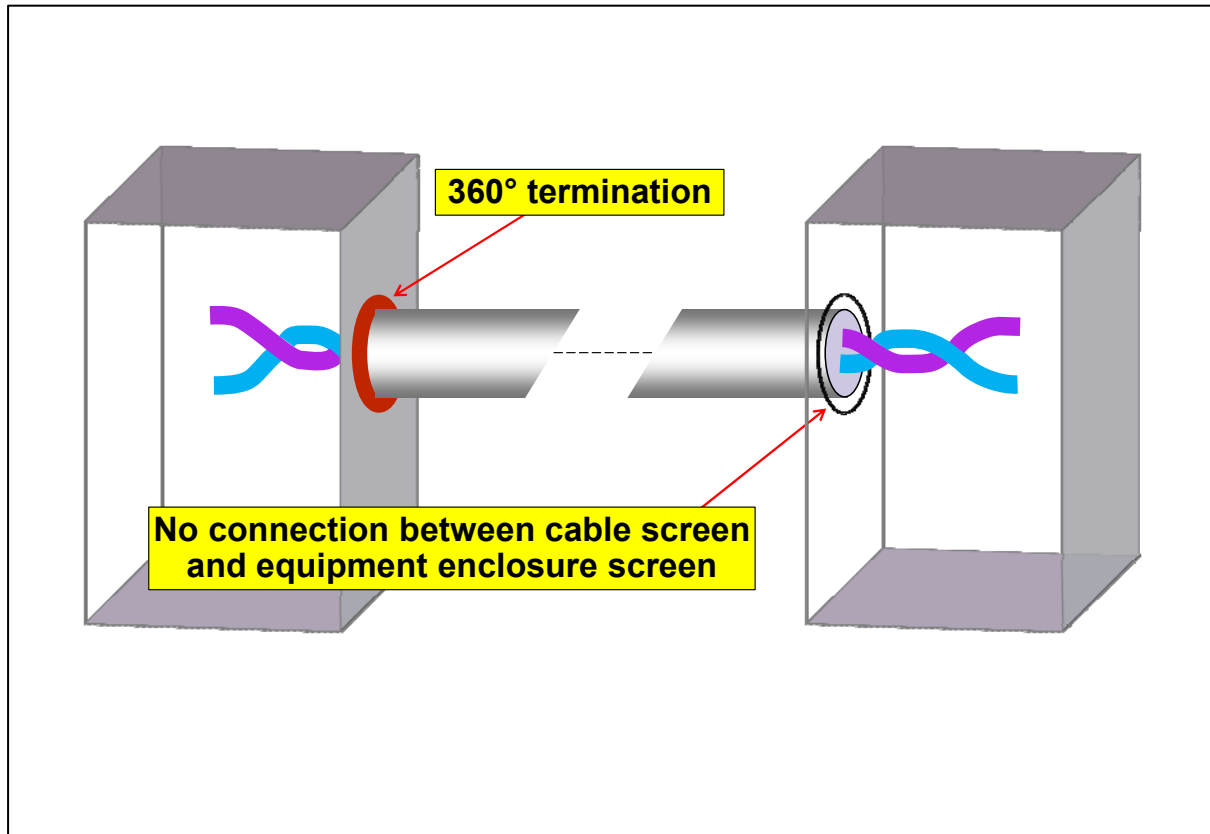


Figure 7 One-ended screen termination

Someone talking on a cellphone, and getting within a couple of metres of the cable, could quickly reveal its total lack of shielding effectiveness at higher frequencies.

Nevertheless, in situations where the RF environment is relatively quiet, other cables and equipment in the system and installation are also quiet at RF frequencies; and cellphones and the like will not be used nearby, OEO screen termination might be acceptable.

Such situations were common worldwide 50 or more years ago, making OEO screen termination a perfectly good way of protecting analogue signals (they were nearly all analogue) from the electrostatic (stray capacitance) coupling from mains distribution networks. Only cables used near radio transmitters, which were few and far between in those days, needed to use 'proper' RF termination (360° termination at both ends).

This is why EMC textbooks first written many years ago distinguish between "low frequency" and "high frequency" cables, based on the signals they are intended to carry, and recommend different screen termination techniques for each type.

These days, when every product contains *at least* one digital processor with significant levels of continuous common-mode noise emissions to *at least* 300MHz (increasing with every new generation of ICs), and the environment is increasingly polluted with RF communications and industrial/scientific/medical RF noise from 150kHz to at least 2.45GHz – *all* cables must be treated as "high frequency" types, regardless of the actual differential-mode signals they are intended to carry.

Of course, even if OEO termination achieves adequate overall performance at that time, future changes to the system, to nearby systems, or to the electromagnetic environment, could well mean that the cable's shielding effectiveness becomes inadequate, possibly causing very costly downtime.

It is important to be aware that OEO screen termination effectively ruins the shielding effectiveness of the enclosure of the equipment at the non-terminated end. This can be recovered by connecting a suitably-specified filter (ideally a 'feedthrough' or 'through-bulkhead' type) to the wall of the enclosure at the point where the cable enters it.

When the equipment manufacturer species OEO screen termination

Quite often, such a specification in an Installation Manual is an indication that the product's designers don't understand how to design products so that they can easily be installed and used in real life (never mind comply with the EMC Directive).

This is not theoretical posturing – I write this from personal experience over decade: before 1990 I was just such a designer.

Figure 8 shows one way of using such an item of equipment, without compromising the shielding effectiveness of the cabinets in which the equipment is housed.

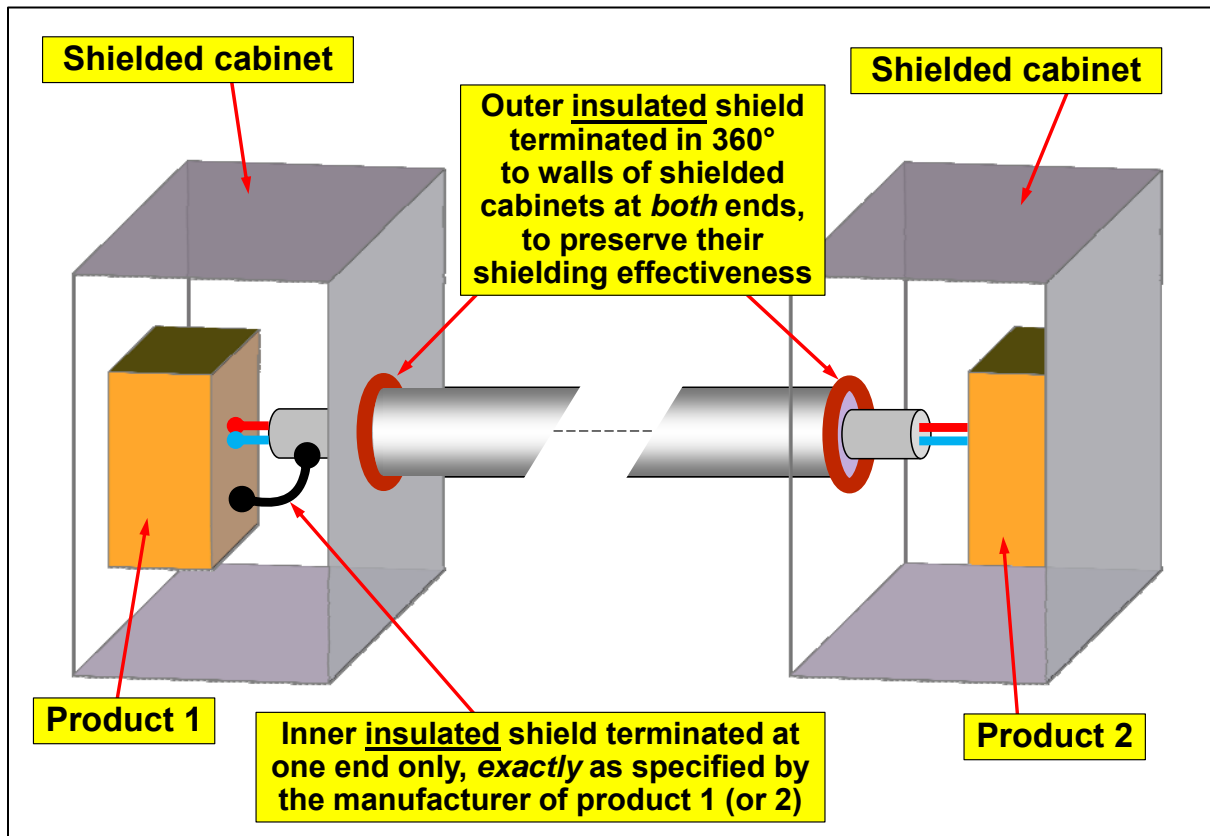


Figure 8 When termination a cable shield at both ends would contradict manufacturer's installation instructions

Passing *any* conductor through the wall of a shielded enclosure, without either –

- directly termination it to the wall at that point
- 360° termination its cable shield to the wall at that point
- filtering the conductors using filters that are connected to the wall at that point

– would completely ruin the shielding effectiveness of the cabinet (see 4.3.17 of [7]; 3.10-1 – 3.10.3 of [3], and pages 148, 153, 154 of [4]). Figure 8 shows how b) above can be implemented whilst still complying with the manufacturers installation specifications.

The cable used between the shielded enclosures must be a double-insulated-screen type. This is *not* the same as an ordinary double-screened cable, in which two shielding layers are laid one on top of the other, in contact.

The outer of the two insulated screens need not be part of the cable, it could be a shielding conduit applied over the top of one or more screened cables.

If I were you, I wouldn't start from here (cost-effectiveness in the real world)

If a product, system or installation is designed with the intention of terminating cable screens at only one end, and interference problems are experienced during commissioning, the connector types that have been used often make it difficult and costly to modify so as to achieve hybrid or 360° termination at both ends.

Even a few days delay in commissioning a system can cost a great deal more than it would have done to construct the system with hybrid or 360° screen termination at both ends in the first place.

But if one starts with a system constructed using 360° cable screen termination at both ends, it is easy and quick to modify it to use one of the other methods.

This is why Bob Plowman, then EMC expert for Rolls Royce Marine Ltd. and very experienced indeed with all manner of installations, gave me the following advice during a break in an EMC seminar in the early 90s:

“It is generally much more cost-effective overall to design using 360° termination at both ends, and connect all cable armour to use it as a PEC. Then degrade the cable shielding effectiveness as necessary on a case-by-case basis during installation and commissioning, using hybrid or even one-end-only termination.”

Safety and criticality considerations

Of course, this brief article does not consider anything that could have an impact on safety or financial risks.

Where such risks exist, degrading the designed shielding effectiveness of the cables because of installation difficulties on the site, would require rather more serious thought than simply allowing a contractor to gaily work his way down the a) to f) list of screen termination options above, as he feels is best!

Official guides

There are many official guides on how to install electronic equipment, and some of them are not up-to-date. Even when they do describe current good practices, many installers still seem to do what they learned 30 years ago as an apprentice, disregarding all official guides and manufacturers' installation manuals.

For instance, DEF STAN 59-41 Part 7: 1995 (since superseded by DEF STAN 59-411, Part 5: 2007), gives guidance on good installation practices for EMC in HM Ships. In 1999 I was training a bunch of atomic submarine designers on that topic, and when I said cable screens must be terminated 360° at both ends, they all looked horrified! Oh no, (they all said, quite loudly) cable screens must only be terminated at one end, to prevent ground loops. Surely I knew that?

But having met this reaction before, I had come prepared! Yes, they all agreed, DEF STAN 59-41 Part 7:1995 was their installation 'Bible' – so I showed them its Clause 10.26, on page 70,

which very clearly states that to provide RF protection a cable's screen must be peripherally (i.e. 360°) bonded to the equipment *at both of its ends*. They were all quite obviously shocked, then went quiet and looked rather thoughtful for a while.

In 2008 I saw an article in "The Industrial Ethernet Handbook", that insisted that screened Ethernet cables must only be terminated at one end, "to prevent ground loops".

Unfortunately, the requirements of BS EN 50174-2 – that Ethernet installers are supposed to follow, requires 360° screen termination at *both ends* (see Clause 6.3.2, pages 15-16 of its 2001 Edition).

Some industry guides and standards are very good, but unfortunately some are sadly in need of revision as regards the EMC installation techniques required these days. So when following an industry guide on screened cable installation, it is best to be aware of current good installation practice, and not follow *any* guides uncritically.

I hope you have found this short article interesting and useful. Unless a better idea presents itself, in the next one in this series I intend to cover how to design I/Os so they will not suffer from so-called 'ground loop' problems due to shield currents.

References

- [1] Keith Armstrong, "*Design Techniques for EMC, Part 2 – Cables and Connectors*", at <http://www.compliance-club.com/KeithArmstrong.aspx>. You will have to register, but it only takes a few seconds and access is immediate.
- [2] Tim Williams, "*EMC for Product Designers, Edition 4*" Newnes, 2007, ISBN: 0-7506-8170-5
- [3] Keith Armstrong, "*EMC for Systems and Installations*", at <http://www.compliance-club.com/KeithArmstrong.aspx>. You will have to register, but it only takes a few seconds and access is immediate.
- [4] Tim Williams and Keith Armstrong, "*EMC for Systems and Installations*", Newnes, 2000, ISBN: 0-7506-4167-3, RS Components Part No. 377-6463
- [5] John R Barnes, "*Robust Electronic Design Reference Book, Volume 1*", Kluwer Academic Publishers, 2004, ISBN 1-4020-7737-8
- [6] BS IEC 61000-5-2:1997, "*Electromagnetic Compatibility (EMC) – Part 5: Installation and Mitigation Guidelines - Section 2: Earthing and cabling*"
- [7] Keith Armstrong, "*Design Techniques for EMC, Part 4 – Shielding (screening)*", at <http://www.compliance-club.com/KeithArmstrong.aspx>. You will have to register, but it only takes a few seconds and access is immediate.