CHAMBER EXIT FILTERS FOR EMC TESTING

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ABSTRACT

Previous methods of taking cables through the walls of EMC test chambers have used filters designed for other purposes. After a review of the actual requirements for application to the emission and immunity testing in fully- or semi- anechoic chambers the unsatisfactory nature of these prior arrangements will be made clear. A principle by which filters may be designed to provide the required common-mode impedance and common-mode transmission loss will be described which embodies both series and shunt elements.
Examples of practical filters will be described that include a compact permanently-installed design and a temporary device appropriate for contract test work with varied cable types.
The novel shunt element and the improved series element offer other possibilities for improved networks useful for EMC testing.

BACKGROUND

Real-life installations of electronic equipment have “untidy” cable connections to the outside world. These are characterised by random - but not usually very tight - coupling to other cables and to conductive and dielectric structural elements. However, these cables almost never pass through a definite boundary surface as must be the case for product EMC testing. For example, CISPR22 (Ref 1) requires that the mains cables of table-top equipment drape to a junction box or artificial mains network bonded to the floor. Such an arrangement provides a near-zero common-mode impedance at this point - hereinafter called the “exit impedance” - much lower than is likely to be encountered in practical use.
This near-zero impedance has different effects according to the cable length expressed in terms of wavelength. At frequencies below that at which the combination of EUT and cable is quarter-wave resonant, the low exit impedance increases the interference current on the cable. This effect can be seen in Fig. 7 of the paper by Worm (Ref. 2), where it is noted that the use of a LISN with zero common-mode impedance in accordance with existing standards results in systematic *over-estimation* of emission in the range 30 to 80 MHz.
There will be many higher frequencies at which the cable will exhibit resonances which will be accentuated by reflection at the mismatch due to zero exit impedance. These resonances will be critically dependent on cable length and layout, and may mask or accentuate critical emmission or immunity problems. In summary, the use of a near-zero exit impedance according to the standards results in an overly severe test at low frequencies and poor reproduceability at high frequencies.

Recent work communicated within CISPR (Ref. 3, 4) has concentrated on the use of the MDS absorbing clamp as a device to reduce cable resonance. This has been shown to be helpful but far from perfect: The clamp has an excessively high common-mode impedance (recorded in ref. 2 Fig 8 as in excess of 1,000ohms at 30MHz) which leads to excessive reduction of low-frequency test sensitivity - though some reduction of sensitivity is desirable, as discussed above. The absorbing clamp also exhibits insufficient attenuation, which is manifest from the variation of its EUT-side input impedance as the AE-side load impedance varies. Furthermore it is bulky, and unlikely to be available off-the-shelf in sufficient numbers to cover the requirements for testing multi-cable EUTs.

So what is the ideal common-mode impedance for an exit filter?. Although 150 ohms has been widely adopted in standards (for example Ref. 5), there can be no analytically-satisfying rationale except to show that this figure is near to the geometric mean of the characteristic impedance that may be calculated for a variety of typical cable diameters positioned at typical distances from ground - which is indeed true.

Ref. 2 concludes that the Coupler-Decoupler Networks specified in Ref. 5 are technically suitable for use as exit filters in radiated field testing: the only snag is that, as is also pointed out in Ref. 4, they are intrusive to the cable, whilst the absorbing clamp is not.
It should also be noted that EMC testing in a fully anechoic room brings into question the concepts of test volume and cable exit point in a way which argues against use of a zero-impedance exit filter.

Accordingly we have investigated the design, construction, and performance of exit filters with a nominal characteristic impedance of 150 ohms. We have done so against the background of a target specification that seems appropriate for radiated emission and immunity testing: namely an exit impedance in accordance with Ref.5 of 150 ohms +60 -45 ohms over the frequency range 30 to 230MHz, and extended to +150 -75 ohms from 230 to 1000MHz, together with an attenuation of 20dB over the range 30-1000MHz when measured between 150 ohm terminations.

SHUNT ELEMENTS IN EXIT FILTERS

It is evident from the above discussion that the high impedance and limited attenuation of the absorbing clamp - which was designed for a quite different application - arise from the lack of any intentional shunt element.
Since it is desirable that that an exit filter be non-intrusive to the cable, such a shunt element must involve a capacitive coupling to the outside of the cable. This may be achieved by bringing earthed material into close contact with the cable outer. An appreciable length of cable needs to be contacted to provide a useful capacitance, but this treatment will form a transmission line whose resonance may disturb the filter characteristics if it falls within the operating frequency range. Accordingly we have made multi-section filters comprising several sections each using a ferrite sleeve as series element working with a capacitive section whose length is optimised to cover just part of the frequency range. With an impedance goal of 150 ohms over the whole frequency range it is also necessary to adjust the impedance of each ferrite sleeve by means of inductively-coupled loading networks. The common-mode equivalent circuit of a single section is shown in Figure 1, and Figure 2 shows how the impedance of a ferrite sleeve may be modified to achieve the necessary precision of impedance and bandwidth. This technique could also be used to produce filters for other values of characteristic impedance.
As an example of what has been achieved to date, Figure 3 shows the common-mode impedance measured 100mm from the EUT end of a compact high-performance filter comprising 8 ferrite sleeves and 2.2 metres of cable wrapped tightly with knitted monel-metal mesh. This impedance is well within the target specification: In fact it conforms down to 10MHz irrespective of AE-side impedance, which indicates a degree of overkill in the design. As may be seen from Figure 4 the transmission loss also betters the target. This filter is built into a metal box 160 x 100 x 50mm and is intended for bolting onto the test chamber filter plate. It is *electrically* non-intrusive, but since the target cable is embedded in it during manufacture this design is most suitable for commonly-used circuit formats such as mains power and LAN connections. The actual device characterised here was constructed with Cat. 5 data cable, and is useable with other telecommunication cable formats by patching interface connectors in the same way as is Richard Marshall Limited's Versatile CDN x46ST8 (Ref 6).

CLAMP CONSTRUCTION OF EXIT FILTERS

For complete flexibilty in application - and the ability to avoid any bundling of cables within the test volume with its consequent reduction in test repeatability - a clamp-type construction that can be applied to the EUT cable *in situ* is required. Split ferrite sleeves with plastic retaining clips are readily available, and it has proved possible to use conductive fabric supported on soft plastic foam to form a clip-around shunt capacitor. This results in a practical, but relatively bulky assembly. However its bulk may be concealed in a cable duct which also allows the construction of economical multiple cable assemblies to support the testing of telecommunications and other EUTs with several cables to the outside world. Figure 5 shows how a 4-cable shunt capacitor may be arranged for easy assembly into a 100mm wide duct. This particular width is chosen for compatibility with the standard 100mm ferrite tile.
The performance of a 5-section clamp filter using this construction is shown in Figures 6 and 7. The 560mm length of ducting used was chosen as the minimum that would provide the desired characteristics - which it does, almost. With a longer duct length the specification can easily be bettered.

CONCLUSION

The introduction of shunt capacitance to common-mode filters and impedance networks, together with the modification of ferrite sleeve impedance by added passive elements, gives substantially increased design freedom and should lead to more reproduceable test methods that are more representative of the real world. The same techniques offer the possibility of making transformer-coupled CDNs for conducted EMC measurements.

ACKNOWLEDGEMENTS

Thanks are due to Martin Alexander of NPL who has provided information about CISPR work in this field.

Some of the arrangements described in this paper are the subject of patent applications. Licenses are available on a reasonable and non-discriminatory basis in accordance with the ECMA code of conduct in patent matters.

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2) S B Worm, On the relation between radiated and conducted RF emission tests, Philips Research, *13th International Zurich Symposium & Technical Exhibition on EMC, February 16-18, 1999, pp515-520.*

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5) "Electromagnetic Compatibility (EMC) Part 4: Testing and measurement techniques. Section 6: Immunity to conducted disturbances induced by radio-frequency fields" *European Standard EN61000-4-6:1996.*

6) "RML series 46 Versatile Coupling/Decoupling Networks" *Richard Marshall Limited, 30 Ox Lane, Harpenden, AL5 4HE, UK*

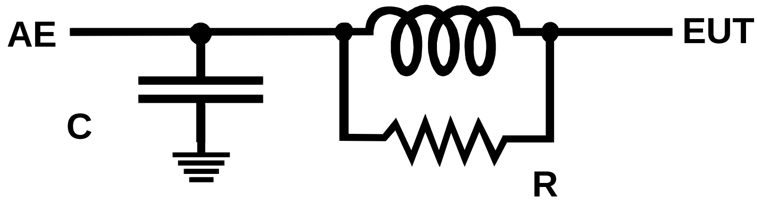

Figure 1. Single section common-mode equivalent circuit

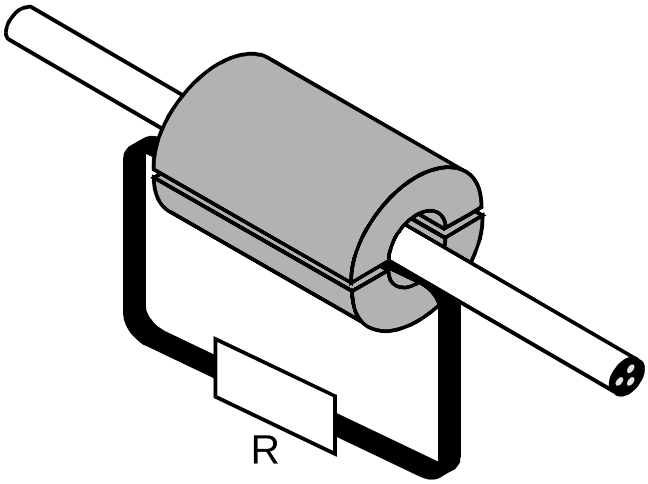

Figure 2 Principle of series-impedance compensation

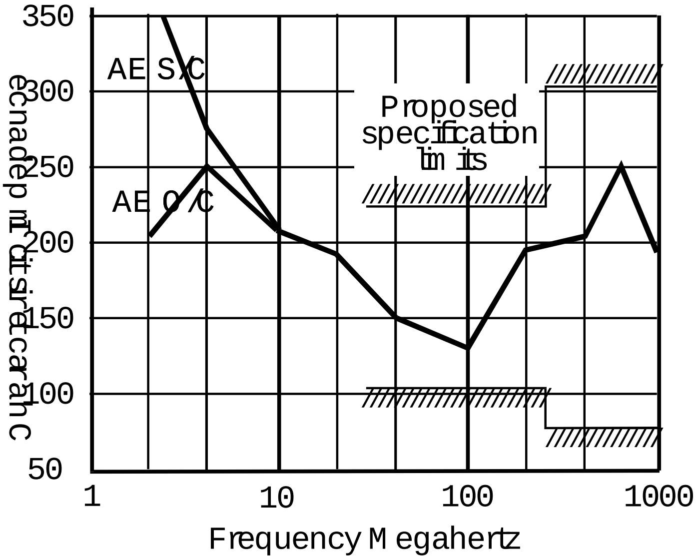

Figure 3 C/M Characteristic Impedance of boxed filter

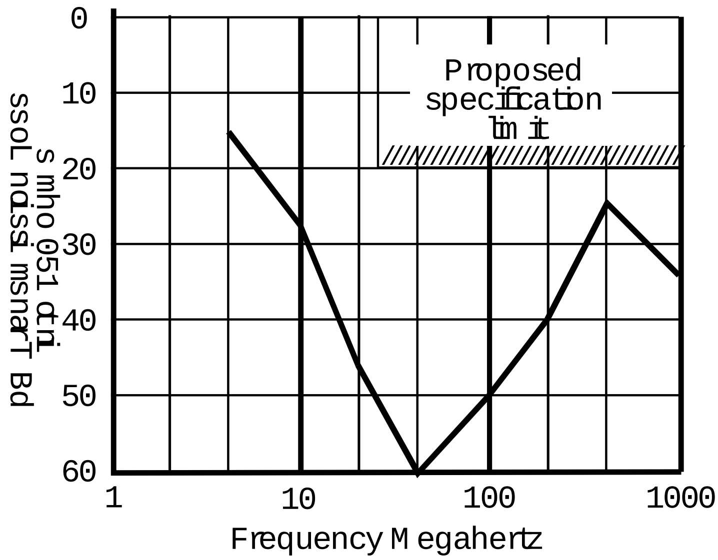

Figure 4 C/M transmission loss of boxed filter

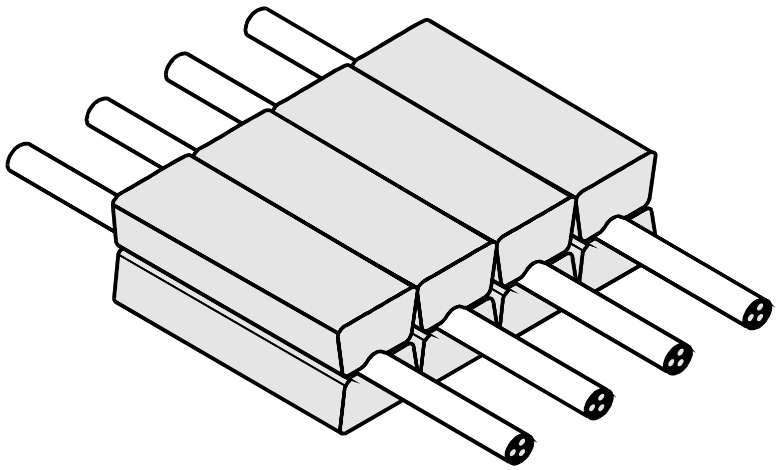

Figure 5 Shunt loading of cables in a duct

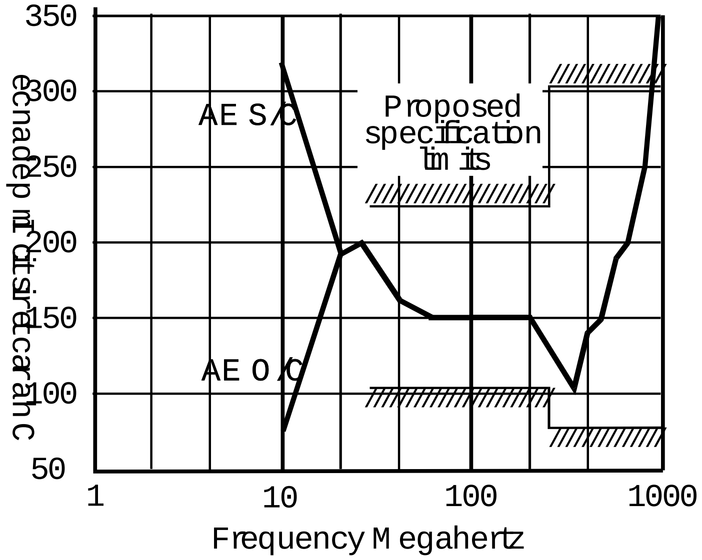

Figure 6 C/M Characteristic Impedance of clamp filter

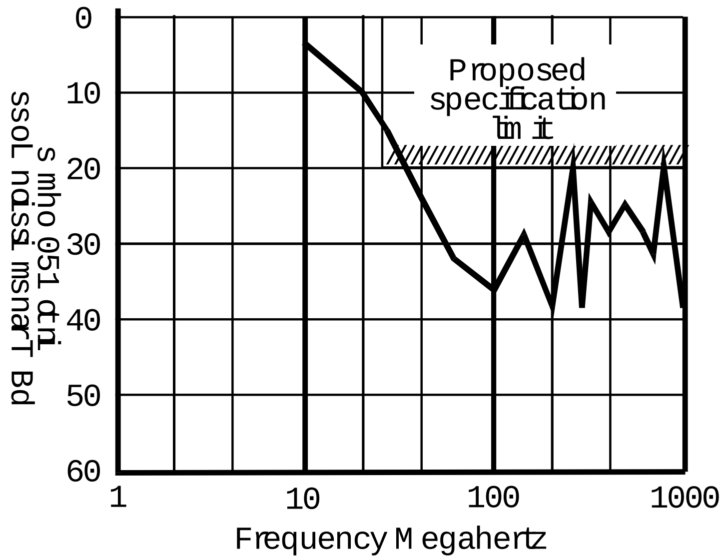

Figure 7 C/M transmission loss of clamp filter