RFI/EMC SHIELDING IN CABLE CONNECTOR ASSEMBLIES

To employ shielded rooms and chambers in which to test EMI/RFI effects in systems, and then ignore adequate shielding of the connector assemblies which tie them together is counterproductive.

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NATIONAL AND INTERNATIONAL STANDARDS

International controls regulating the performance of systems when exposed to conducted and radiated interference have largely followed the lead of Part 15, Subpart J of FCC Regulations, which requires that computing devices meet defined limits of electromagnetic emission or reception.

Computing devices are defined by the FCC to include most electronic equipment used in computers, navigation controls, recording systems, and information storage or transfer devices. This broad definition encompasses data processing equipment, video games, digital meters, power supplies and a host of applications instantly recognizable by a wide sector of the general public. In addition, professional engineers have the responsibility of ensuring that their *equipment design* meets the requirements of specifications such as Subpart J regarding electromagnetic compatibility (EMC) or radio frequency interference (RFI).

Class A of FCC requirements apply to commercial, business or industrial devices, while Class B embraces devices used in residential or domestic environments (Table 1). Limits are placed on *conducted interference* from equipment operating between 0.45 MHz and 30 MHz, and on *radiated interference* from 30 MHz to 1000 MHz. Computing devices are defined by the FCC as any electronic equipment or components that use or generate frequencies above 10 kHz.

Test methods and equipment are specified in FCC document MP-4 for the U.S., and equivalent instructions are being prepared by CENELEC and the International Electrotechnical Commission, (IEC) for Europe and the rest of the electronics world, respectively.

In the U.K., current standards are BS 905 and BS 5627, but as yet they carry no legal status. Military authorities have also been very sensitive to the RFI/EMC problems for a long time, as exemplified by their adherence to MIL-STD-461 and DEF-STAN 59-41 in the U.K.

FUTURE LEGISLATION

The Treaty of Rome, charter of the European Economic Community (EEC), states that a free market shall be established in Europe by 1992, and all artificial trade barriers between member countries must be removed before that date. As a lack of EMC legislation can be construed as such a barrier, the European Commission has produced a general directive regarding electrical interference. This directive applies to electrical and electronic appliances, equipment and installations which contain components likely to cause electromagnetic disturbances, or the operation of which may be affected by such disturbances.

The EEC is expected to attach several European Norms (EN) to this directive, each EN applicable to different types of electrical equipment. One such EN is EN55 022 which applies to Information Technology Equipment, including telecommunication equipment. EN55 022 has been created from an International Recommendation, CISPR Publication 22. CISPR is the Committee Internationale Speciale des Perturbations Radioelectroniques.

A European Community (EEC) directive is to be issued shortly on the subject of electromagnetic interference. Within 18 months, all member states must comply with the directive, and it follows that BS 6527, the current U.K. standard, will be aligned to EN 55 022 and become the mandatory requirement, enforceable by the Department of Trade and Industry (DTI) before the middle of 1989. Any products which are offered for sale or hire in the U.K. after mid-1989 must therefore comply with BS 6527, compliance which should become part of any contract placed for such products. This will mean that shielding must be introduced in interconnecting cables and connectors, as well as in the system enclosure itself to ensure that undesirable signals are isolated from all areas where interference is at best a nuisance and at worst an electronic disaster. Protection has to be provided in cables and their terminating connectors both to keep unwanted emissions within a system and to prevent their entry into a system enclosure.

Radiation Limits Frequency (MHz)	Class A μV/m(30m)	Class B μV/m(3m)
30 to 88	30	100
88 to 216	50	150
216 to 1000	70	200
Conducted Limits		
0.45 to 1.6 MHz	1000	250
1.6 to 30	3000	250

Table 1. FCC Limits.

It is important to emphasize that compliance is likely to be attained economically only if EMC requirements are designed into equipment from product conception. Cable connector assemblies form part of the equipment requirements and must fall within the overall legislation. These too should be designed into the equipment with an eye toward EMC.

SHIELDING FEATURES

To employ fully shielded chambers or rooms ensuring that the environment is free from background radiation for the measurement of EMI/RFI effects in systems, then ignore adequate shielding of the connector cable assemblies which tie them together is counterproductive. For example, equipment can be manufactured, tested and found to be perfectly shielded. It is then connected perhaps to a printer which is equally well shielded, but if the cable shielding is inadequate at the frequency used, or the connectors at each end do not provide shielding continuity of the cable or, more importantly, have "holes" or discontinuities in metal shielding seams providing energy leakage paths, the shielding achievements of the equipment units so carefully designed and measured are rendered useless.

It is therefore vital to ensure that not only are the interconnecting cables and connectors equally well designed for shielding, at least to the adequate levels of the units at the frequency ranges to be used, but also that a consistent method of measuring their shielding effectiveness is used by the cable harness manufacturer.

Interconnection cables and connectors can radiate and receive interference very efficiently and constitute a major offending transmitter of RFI/EMI. Both shielding and grounding are therefore of prime importance in eliminating transmission and absorption of undesired signals or pulses.

The performance of a shielded connector should be closely related to the shielded cable to be terminated. Independent evaluation of each item has no practical value. A shielded cable and connector assembly ideally incorporates all attributes of good shielding and is an extension of the shielded equipment to be interconnected.

The majority of assemblies are, however, a compromise of practical considerations such as cost, size, flexibility, and ability to assemble; but the most important function of a shielded connector is to provide a low impedance path between cable shield and ground. Of course, it also shields the wires it contains.

To be truly effective, a shield must be properly grounded. If it is grounded only at one end, its usefulness is restricted to those frequencies for which the shield length is less than 1/6 the wave length, λ. At higher frequencies the shield must be grounded at both ends, and probably at some intermediate points to achieve desired shielding levels.

It is most important to ensure that there are no seams, slots or holes in the connector shield, since a length approaching $\lambda/4$ for such a slot will turn into a good energy radiator and the energy collected over the full length of the shield will then be pumped through the slot. Obviously, the smaller the slot or hole, down to zero, the higher the shielding effectiveness, to the limits set by material absorption and reflection.

Certain metal shields in connectors are closed by soldering along the joining lines of two separate halves, while others are a sliding fit. Although it is economical in manufacturing to spot-solder at intervals or to permit areas of overlap to be an imperfect fit, the final result could easily be to provide a series of slots leading to an inefficient shield with high interference levels for the interconnecting cable connector assembly.

SHIELDING DESIGN

The design of an adequate shielding system is a combination of the shielding and grounding of connector and cable shields, the material and thickness of the shielding medium, its permeability, μ, conductivity, σ, (relative to copper), and the frequency of the signal down the conductors, within the equipment, or of the external source against which shielding is required.

One of the real dangers, particularly at higher frequencies, is that the cable shield, or lead to ground, can easily equal or exceed a quarter wavelength and act as an efficient antenna or transmission line. What is acceptable at low frequencies can easily be useless as the frequency rises towards and beyond 1000 MHz.

It is therefore essential to provide multiple grounding points in the shield design to avoid such a transmission of unwanted energy. Thus, conventional grounding systems can often be quite inadequate even where the shielding design plus good cable shielding could have provided sufficient EMI/RFI protection.

Shielding requires the selection of a metallic material for the protective hood to surround the cable terminating connector. Selection criterion includes the thickness of the material. In order to reduce or attenuate a signal to 37 percent of its original amplitude, a thickness or skin depth of conductive material must be

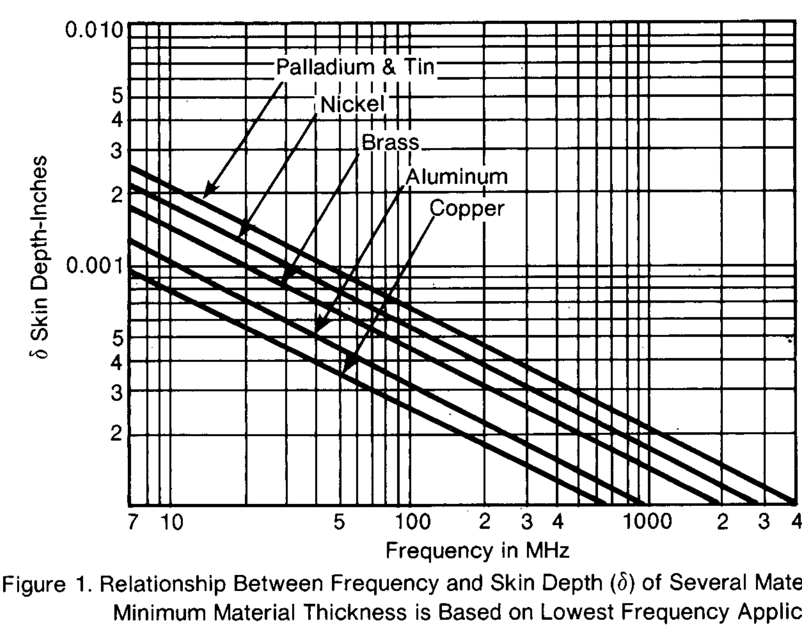

Figure 1. Relationship Between Frequency and Skin Depth (δ) of Several Materials. Minimum Material Thickness is Based on Lowest Frequency Applicable.

present in the path of the wave in accordance with the following formula:

Skin Depth, $\delta = 2.6 \text{ in} / (f\sigma\mu)^{1/2}$ or

$66.04 \text{ mm} / (f\sigma\mu)^{1/2}$

where

f = Frequency

μ = Permeability

σ = Relative conductivity

A shield skin depth of 3δ must be provided to adequately attenuate radiated emissions.

Figure 1 shows skin depth versus frequency (MHz) for various materials, and Table 2 gives relative values of μ and σ, including those for steel, the most commonly used shielding material.

Reflection losses also must be considered when evaluating shielding effectivenss. These are analogous to losses due to refraction and reflection of light since they are dependent on changes of impedance in the media through which the waves travel. However, the thickness of the shielding is of less importance to reflected energy since the major part of the loss occurs at the surface of the conductive shell, almost regardless of thickness.

One method of ensuring shielding continuity of the cable braiding or foil involves a ferrule slid over the shield, tightly crimped, and a fully seamed steel cover, bright tin-plated, and continuously soldered to the connector mounting flange at one end. The rear cylindrical neck of the metal cover is also machine crimped over the ferrule to ensure full continuity of shielding to ground via the metal shells of the connectors. The shielded connector with conductor joined to the contacts in the normal manner, i.e., crimped or soldered, is then overmolded to provide an insulated and appealing finish overall.

It is important to realize that shielding to a greater level than appropriate to the particular equipment, its environment or frequency range, is unnecessary and unduly expensive to the manufacturers of both the cable connector system and the equipment, and thus to the end user. It is occasionally found that a specified level of shielding has been requested by an OEM as an insurance policy, rather than as a necessity, resulting in a correspondingly high premium. Rather, the supplier should be advised of the worst conditions to be met in the field and the frequencies used or likely to be encountered. Typical cable screenings follow this general pattern:

Material	σ	μ
Copper	1.00	1
Aluminum	0.61	1
Brass	0.26	1
Nickel	0.19	1
Tin	0.15	1
Steel CS50	0.10	1000

Table 2. Relative Values of Conductivity and Permeability for Six Metals.

Single-braided Cable. Offers protection from low impedance sources such as motor control circuits, magnetic coils, process control equipment and general domestic applications.

Double-braided Cable. Offers protection from higher frequencies, such as in computers, CAD/CAM and local area network (LAN) systems.

Combined Braided and Foil Wrapped Cable. Offers protection at frequencies approaching 1 GHz or where total shielding is required. Such applications include military telecoms and high security fields. Conductors can be individually screened to eliminate cross-talk between conductors at a higher cost.

MEASUREMENT OF SHIELDING EFFECTIVENESS

When considering the in-house measurement of shielding effectiveness, it should be realized that FCC regulations require measurement of the shielding of the actual "black box," complete with interconnection cable connectors and a shielded room free from background radiation. The manufacturer of cable connector systems must show that the addition of shielded connectors has not changed the original shielding provided by the selected cable. This can be ensured consistently by using relatively simple and available equipment.

Using a metal sheet as a ground plane, a signal is supplied to the connector with a sweep generator as signal source. A spectrum analyzer with digital memory is used for recording all measurements. The process offers a comparison of the "free air" signal levels from the cable to be used, against the signal level from the same cable with shielded connectors fitted. The shielding effectiveness of the complete assembly is thus recorded as a measure of the efficiency of the connectors in maintaining the cable shielding over the required frequency range. The general range for measurement is 100 kHz to 1 GHz.

In practice, a signal supplied by a tracking generator is applied to adjacent connector pins at the "send" end of the cable assembly under test, and the "receive" end is terminated by a 50-ohm resistance. The "return" conductor is grounded at the "send" end. The signal is swept over the range 100 kHz to 1000 MHz, emanating energy received by antennae appropriate to the frequency. The terminating boxes are bonded to a suitable metal ground place.

A spectrum analyzer connected to the antenna stores the results in memory (Figure 2). The exercise is repeated using a control cable, as in the harness under test, but without the shielded connectors. The results are stored in a second memory and include the effects of the electromagnetic ambient.

By subtracting the two memories, the total shielding efficiency of the cable/connector assembly is measured and can be recorded on an associated plotter or printer for reference.

In Figure 3, the lower curve shows the energy levels emanating from an unterminated but shielded control cable using both braid and foil with the input signal swept over the fre-

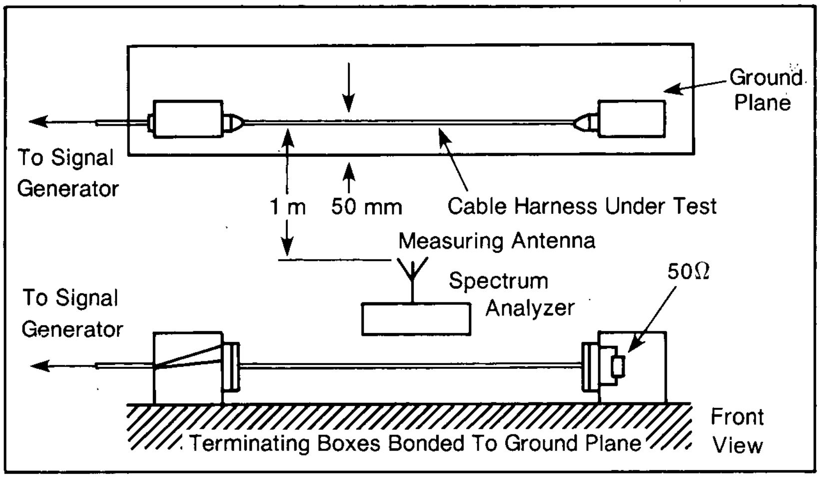

Figure 2. Test Configuration.

quency range of 150 kHz to 1 GHz. The upper curve shows the zero or minimal degradation of the cable shielding efficiency when terminated by connectors using shielding hoods and a continuous soldering process. They amply illustrate the rewarding effect of careful attention to every detail of full continuity, absence of holes, seams or slots and low impedance interconnections.

CONCLUSIONS

The following guidelines apply to all professional cable connector designs and casual attention to any of them can result in an unworthy interconnecting means which can seriously affect the integrity of the sophisticated high quality enclosures. A good cable connector design system will feature the following:

- Low impedance between shields of mating connectors.
- Low impedance interconnection between cable and connector shield.