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The Effect of Cable Terminations on EMI Measurements

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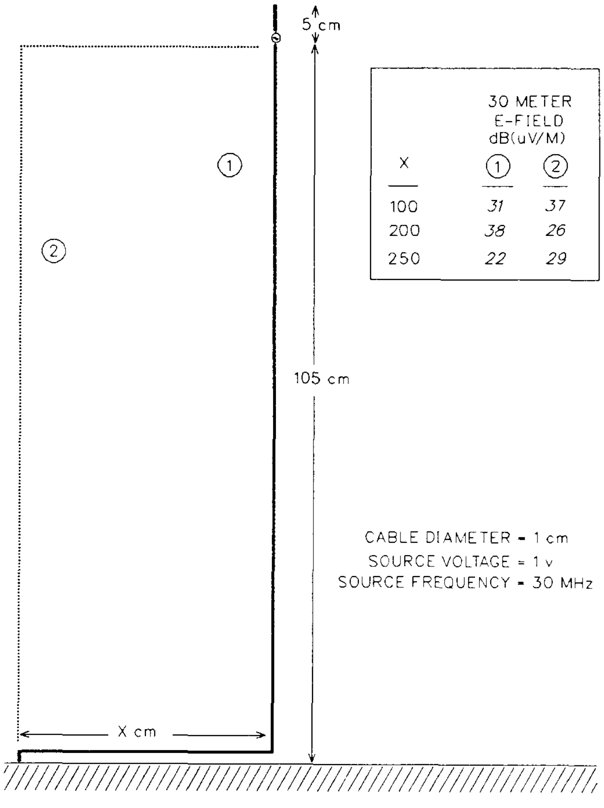
Abstract

Test procedures for measuring radiated electromagnetic interference (EMI) do not generally define a specific method for terminating power and signal cables. Yet, common-mode currents on these cables are often a significant radiation source. This paper investigates the effects of using uncontrolled or undefined cable terminations during EMI measurements. Models and measurements are used to illustrate how specific terminations can be used to achieve particular measurement goals.



	30 METER E-FIELD dB(uV/M)	
X	①	②
100	31	37
200	38	26
250	22	29

Figure 1. E-Field from End-Driven Wire Model with Different Cable Lengths

Introduction

The FCC's EMI test procedure (MP-4) [1] is designed to *maximize* emissions for a *typical* configuration. Specific methods for terminating power and signal cables are not specified for radiated EMI measurements. Instead, it is left up to the test engineer to find the configuration that "is likely to produce maximum emissions."

Unfortunately, common-mode[1] currents induced on the power and signal cables are often a significant source of radiated EMI. The amplitude of these currents is generally a function of frequency, cable termination, cable length and cable position. Finding a specific combination of these factors that truly maximizes emissions is often impractical. Therefore, when equipment is measured at different test sites or by different test engineers, unique test configurations may be defined and the measurements can disagree significantly.

Examples

In order to illustrate the effect that cable placement and termination can have, consider the configuration in Figure 1. The equipment-under-test is modeled with a wire driven by a voltage source near one end [2]. The wire drops to within 2 cm of the ground plane and runs horizontally for an additional 100, 200, or 250 cm. A short vertical segment terminates the wire at the ground plane.

A moment-method algorithm, NEC2 [3], was used to analyze this configuration. The calculated electric field strengths for three cable lengths and two cable orientations are listed in the figure. The amount of common-mode current induced on the cable and the radiated electric field are very dependent on the effective cable length. There is a 16 dB difference

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[1] Common-mode, in this case, refers to the net current passing through a plane perpendicular to the cable (i.e. the component of the current that does not return to the source by any of the conductors in the cable).

between the 200 and 250 cm extensions with the cable in position 1. With the cable in position 2, there is still a significant dependence on the overall cable length. However, in this case it is the shorter length that results in the maximum emissions.

Typically, cables are run a considerable distance before being terminated. When this happens, the actual impedance seen by the source is not well defined and the amount of current induced on the cable can change significantly with minor changes in cable position. To illustrate this effect, a stable battery-powered EMI source was positioned on a table one meter above a raised metal floor (Figure 2). The case of the EMI source was connected to the shield of a coaxial cable that dropped to the floor. Two meters of cable were coiled on top of the raised metal floor and the rest of the cable was fed through a hole in the floor. The section of floor upon which the configuration was located was mounted on a turntable.

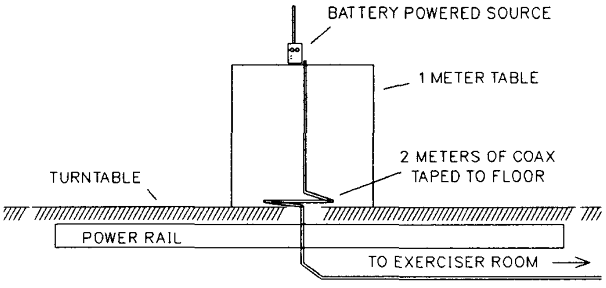

Figure 2. Configuration Used to Study Effect of Signal Cable Termination

The turntable is designed to rotate equipment-under-test during an EMI measurement. As the turntable is rotated, the orientation of cables under the floor changes with respect to the ground plane and other cables. As a result, the cable's common-mode termination impedance is not only undefined, but it changes as the turntable rotates.

Although the configuration above the floor in Figure 2 was shown to be a stable and omnidirectional radiation source, changes in the cable position below the ground plane caused the level of common-mode current on the cable to change as the turntable rotated. This caused the radiated EMI to vary unpredictably. Figure 3 shows how the measured field strength at three frequencies varied as a function of turntable position.

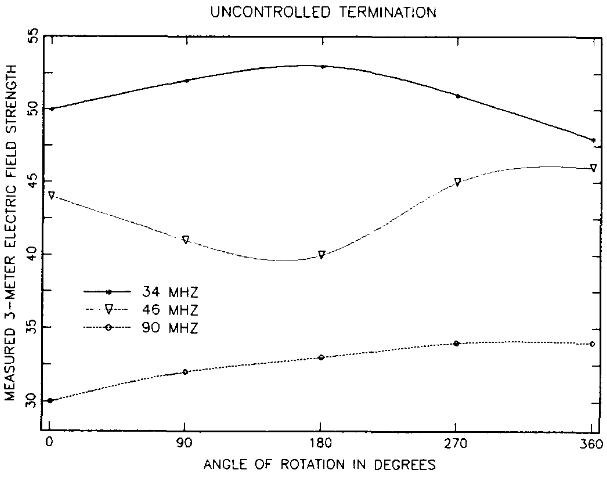

Figure 3. Measured Electric Field as a Function of Turntable Position

Bonding the cable shield to the ground plane above the floor essentially eliminated this problem by providing a well defined common-mode termination to the ground plane that was independent of turntable position. Note that it is not necessary to terminate the individual signal wires in a well shielded cable in order to provide a good common-mode termination. The net common-mode current is equivalent to the current on the external surface of the cable shield so a 360 degree connection between the shield and the ground plane is sufficient.

Another stable termination was achieved by cutting the cable at a point above the ground plane. This is perhaps the easiest and most repeatable common-mode cable termination, however it is not

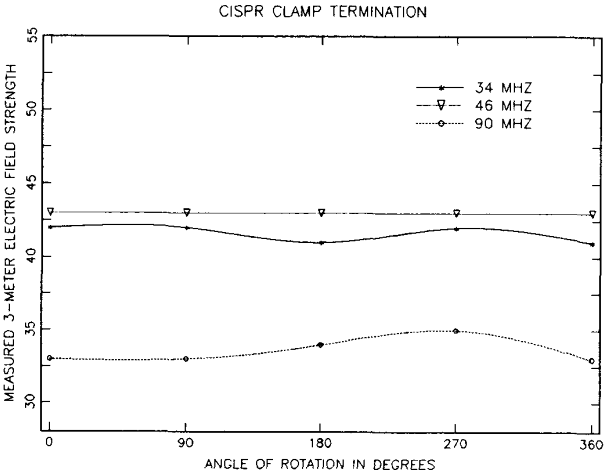

Figure 4. Measured Electric Field as a Function of Turntable Position

practical in most cases because it precludes normal operation of the EUT.

Placing an absorbing clamp [4] on the cable just before it went below the floor reduced the measurement's dependence on turntable position significantly as shown in Figure 4. The absorbing clamp provides a reasonably stable, common-mode termination for shielded or unshielded cables and it does not interfere with the operation of the EUT.

An envelope of the radiated EMI for the configuration in Figure 2 with three different terminations is plotted in Figure 5. Note that each termination tends to maximize the radiation at different frequencies. It could be argued that the absorbing clamp termination provides the best indication of the cable's potential to radiate independent of the cable length and frequency. However, lossy terminations damp out resonances, and do not "tend to maximize" radiated emissions. For this reason they are generally unsuitable for FCC EMI tests. Low-loss terminations, such as shorting the cable shield to the ground plane, will maximize emissions at certain frequencies but they may mask potential radiation problems at other frequencies.

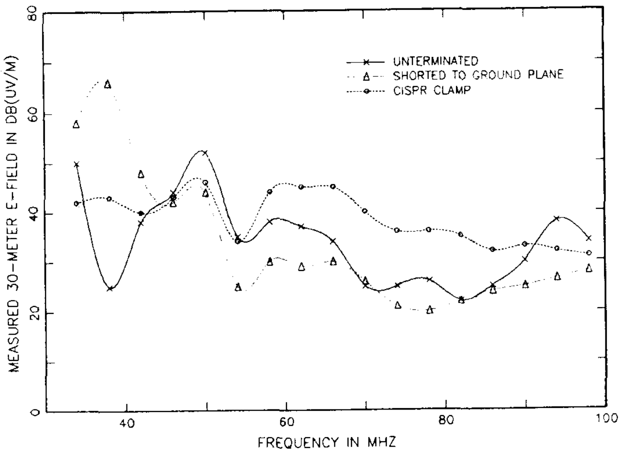

Figure 5. Measured Electric Field Using Three Different Cable Terminations

Conclusion

Any EMI test procedure has to make a trade-off between being practical, being repeatable, being typical, and maximizing emissions. The existing FCC procedure favors "typical" configurations with undefined common-mode cable terminations. Unfortunately, this can be a significant source of site correlation problems. The obvious solution is to introduce a well-defined method of terminating power and signal cables (e.g. shorting the cable shield to the ground plane or using a CISPR clamp). In the meantime, the best the EMI test engineer can do is to be aware of the significance of common-mode terminations and try to avoid situations where the common-mode termination impedance is completely undefined or not repeatable.

References

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