Not for Reproduction CISPR/A/WG2ad-hoc-ferrite clamp(Mosshammer-Dunker)01-01
Original English January 2001

INTERNATIONAL ELECTROTECHNICAL COMMISSION

INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE (CISPR)

SUBCOMMITTEE A: RADIO INTERFERENCE MEASUREMENTS AND STATISTICAL METHODS

Project: **CISPR/A/WG2 ad-hoc Ferrite Clamp**

Subject: Radiated disturbance of equipment under test with connected cables, as a function of the termination impedance

Contents

1 Introduction

Liberalisation in the field of EMC testing and approval enables a free choice of certified laboratories. Hence, the reproducibility of EMC measurements independent of the laboratories needs to be increased, in order to guarantee the comparability of the tests made by the different laboratories.

Various standardised measurement methods will need to be improved in order to achieve this goal.

2 Measurement of the disturbance field strength

Increasing reproducibility is essential but also difficult in particular in the case of radiated disturbance measurements such as those in accordance with CISPR 16-2 and EN 55022, and especially in the case of complex radiating structures such as equipment under test (EUT) with connected cables. This is due to various factors, which will not be detailed here.

The complexity of such EUT depends on the unknown radiation properties that may vary greatly between test sites according to a number of factors, including the type, number, length and configuration of the connected cables, the size of the EUT relative to the length of the cables, the test configuration, and the various environmental conditions.

The main determining factors are without doubt the connected cables, which in certain cases act as the main source of radiation of electromagnetic energy, and their configuration.

The reproducibility of disturbance field strength measurements can be increased if the measurement uncertainties that are due to the connected cables and their configuration can be reduced. This should be achieved primarily by giving an exact description of the test configuration with only marginal scope for freedom.

2.1 Requirements for cables and their termination for fully anechoic rooms (FARs) and semi-anechoic rooms (SARs)

One known way of effectively increasing reproducibility in the frequency band below 150 MHz is to use an absorbing clamp that acts as a termination impedance for the connected cable.

Unfortunately, however, using an absorbing clamp also causes a sometimes significant reduction in the radiated disturbance and may therefore conflict with the aim of measuring the maximum radiated disturbance.

At the same time, the absorbing clamp serves to decouple the EUT from the network with a return loss from conducted disturbance from the network exceeding 20 dB.

3 Factors influencing the radiated disturbance

As already stated, and in particular in the frequency band from 30 MHz to 200 MHz, a large part of the disturbance energy is radiated by the cables connected to the EUT.

This radiation depends on the resonance properties of each cable itself. These are a function of frequency, and depend on the electrical length, complex termination impedance and excitation of the cable. The radiation from a cable can therefore be influenced by two factors:

a) changing the electrical length of the cable, and

b) changing the complex termination impedance of the cable.

The electrical length of the cable can be changed practically only by changing the physical length. Continuously changing the dielectricity surrounding the cable is practically impossible. (The physical length of the cable can be changed only by using external attachments such as ferrite rings. The cable itself cannot be changed.)

4 Influence of the cable length and termination impedance on the radiated disturbance

Various simulation calculations were made in order to study the influence of the two factors specified in section 3 on the radiation of an EUT with a connected cable in the frequency band from 30 MHz to 200 MHz in a semi-anechoic room (SAR).

A small item of IT equipment measuring 4 cm x 6 cm x 14 cm and located 80 cm above the ground was modelled on the basis of a real comb generator as the EUT, as illustrated in Figure 1. The equipment fed a cable terminated with different impedances to the ground.

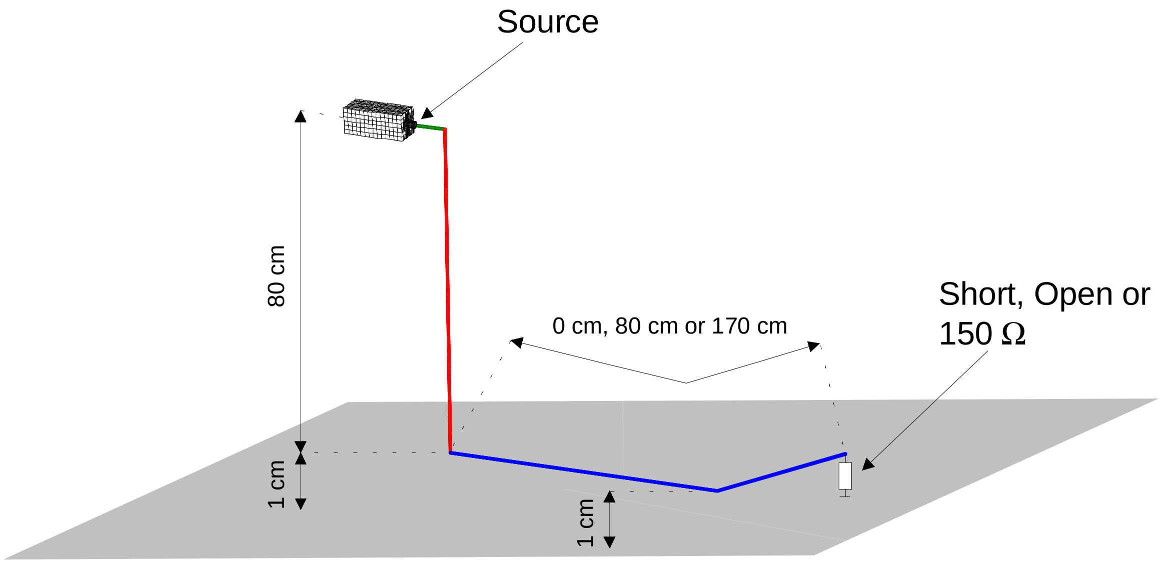


Figure 1: **Schematic diagram of the simulated IT equipment, 80 cm above the ground, with cables of different lengths and with different termination impedances**

The total power radiated by the structure was assessed, taking into account the different cable lengths and configurations and different termination impedances.

The fact stands that each cable is at resonance, and maximum radiation occurs, at a multiple of the quarter wavelength for a short circuit and of the half wavelength for an open circuit.

Two conclusions can be drawn from this: **first**, a cable length of at least 250 cm is required to measure the maximum radiated disturbance at 30 MHz; **second**, the termination impedance decisively influences the first possible resonant frequency and the height of the resonance through its non-reactive part.

4.1 Cable length and type, and location of the termination

Figure 2 illustrates the two conclusions drawn in subsection 4.1:

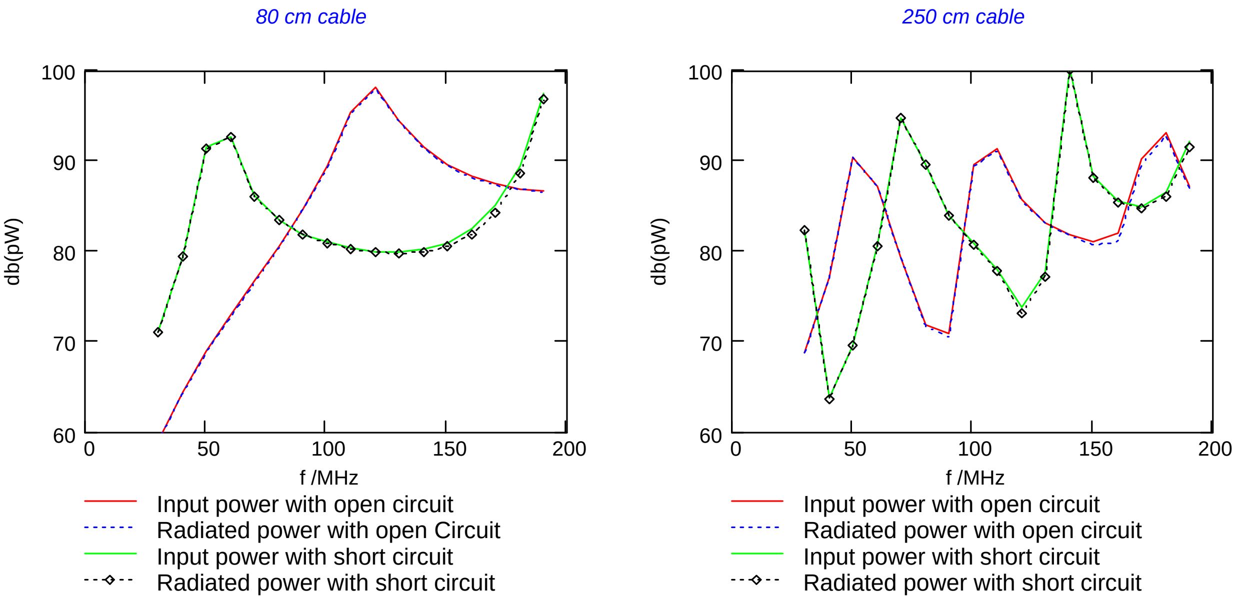


Figure 2: **Resonance of a cable with a length of 80 cm and 250 cm for a short circuit and an open circuit**

The diagrams show clearly that the resonant frequency of the cable varies according to the cable termination. Resonance is caused at either the quarter or the half wavelength frequency, irrespective of the cable length.

The diagrams also show that, as expected, the 250 cm cable achieves its first quarter wavelength resonance at 30 MHz. As a result, the power radiated by the cable at this frequency is more than 10 dB higher than that radiated by the shorter cable.

The power radiated by each cable is almost equal to the input power. The input impedance and the termination impedance comprise practically no resistance that can consume the input power. Hence, an almost perfect standing wave can be formed on the cables, and almost all the input power can therefore be radiated.

If the cables are terminated with a non-reactive impedance, a more or less progressive wave can be formed, depending on the impedance matching, and transform some of the input power into heat in the termination impedance.

The resonance maxima and minima as shown above will more or less disappear, depending on the factor of quality of the whole structure, as illustrated in Figure 3.

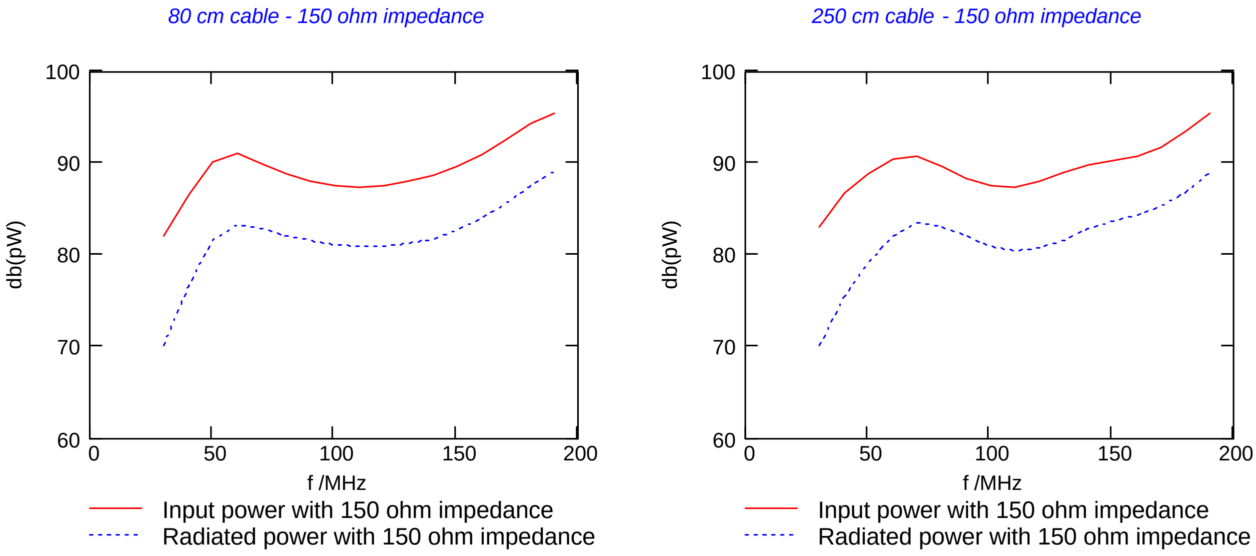


Figure 3 **Radiation from the cables with a non-reactive termination impedance**

The diagrams show clearly that the two cables radiate almost identically. The amplitude of the radiated power is basically the same. The only difference is the frequency of the maximum in the lower frequency band. This shows that the 250 cm cable radiates in the same way as the 80 cm cable.

This phenomenon can be explained as follows: as illustrated in Figure 1, an 80 cm section of the 250 cm cable runs vertically down to a height of 1 cm above the ground, and the rest (170 cm) runs horizontally at a height of 1 cm above the ground; the end of the cable is connected to the ground with a termination impedance.

In this configuration, the section of the cable that runs horizontally can be seen as a separate "single-wire cable over a conductive environment" with an input impedance (characteristic impedance of the vertical section of the cable), a characteristic impedance (approximately 180 Ω in this example), and a termination impedance. This section of the cable, like any cable, has transformation properties and will therefore transform, at its input where it meets the vertical section of the cable, the 150 Ω termination impedance as a function of frequency. This produces an 80 cm vertical section of cable with a specific termination impedance; in this case the impedance is not 150 Ω, but varies according to the electrical length of the transforming (horizontal) section of cable and the frequency.

This means that, in this configuration, the length of the section of cable that contributes to the radiation is only 80 cm.

In order to support this phenomenon, the test configuration was modified as illustrated in Figure 4 so that the cable first runs horizontally at a height of 80 cm above the ground and then runs vertically down to the ground.

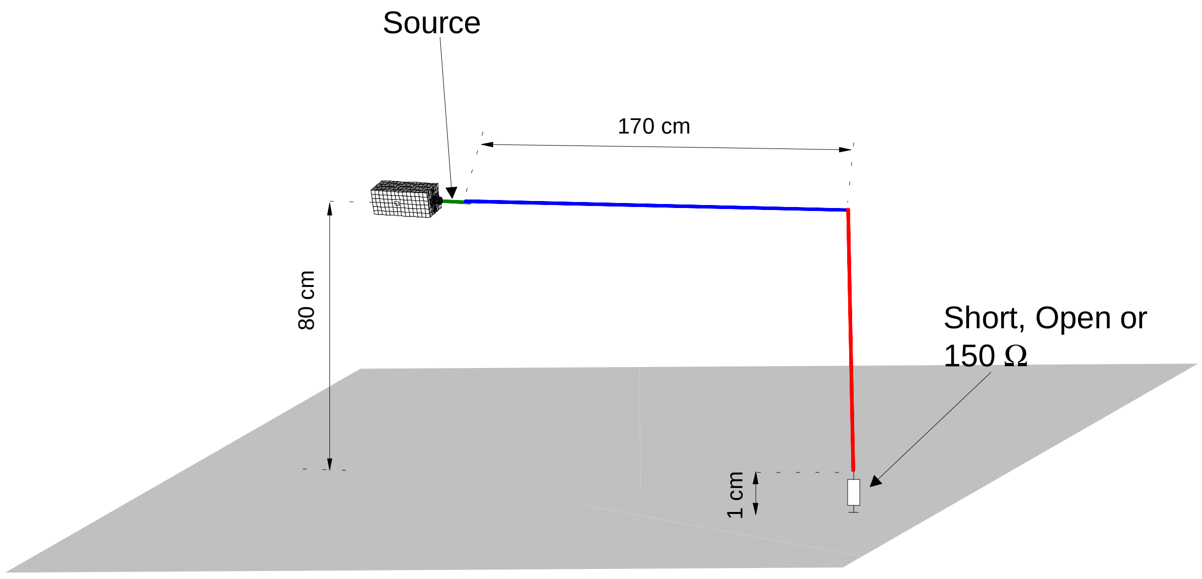
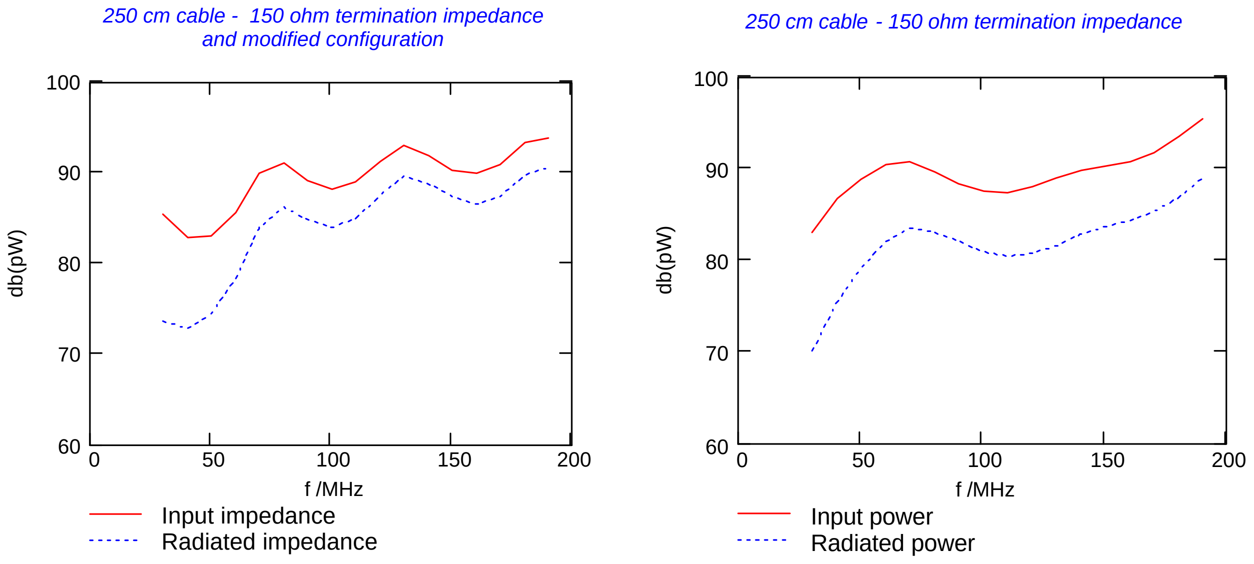


Figure 4: **Modified test configuration**

The following two diagrams show convincingly how the configuration of the cable affects the way in which it radiates. The left-hand diagram shows that the radiation from the cable is similar to that of the 250 cm cable as illustrated in Figure 2, with, of course, the influence of a non-reactive termination impedance that consumes some of the input power and greatly reduces the excessive resonances.


250 cm cable - 150 ohm termination impedance and modified configuration

250 cm cable - 150 ohm termination impedance

Figure 5: **Radiation from the 250 cm cable in different configurations**

5 Conclusions and proposals

The following conclusions can be drawn from the simulation calculations:

The power radiated by the cables as a function of frequency depends on the electrical length and termination impedance of the cables.

Short and open circuits at the end of a cable produce the best resonance conditions and hence clear radiation maxima and minima.

Non-reactive terminations can produce a considerable reduction in maximum radiation, but also prevent minimum radiation.

The cable configuration in an SAR has an effect that is not to be underestimated on the electrical length of the section of cable that contributes to the radiation and therefore also on the power radiated as a function of frequency.

The following can be said in respect of the requirements as specified in subsection 2.1 – increasing the reproducibility of radiated disturbance measurements, measuring the maximum radiation of the EUT, and decoupling the EUT from the subsequent network:

If a non-reactive termination impedance is used that is more or less matched to the wave impedance of the cable and transformed accordingly on the cable after the 80 cm vertical section, resonances can be reduced and hence measurement reproducibility increased. However, for the reasons given above, the maximum radiation cannot be measured. This must be taken into account.

It can be argued that under practical operating conditions an EUT will be connected via its cables to the network, and the network impedance will therefore always act as the termination impedance, and hence that the excessive resonance that occurs in short and open circuits is not to be expected. The test configuration should provide real operating conditions in order to correctly assess the disturbance potential of the EUT. In practice, however, the network impedance is not stable, hence the question arises as to whether or not the 150 Ω impedance as specified in the standard is to be viewed as correct.

In principle, this is of course a rational approach. However, as illustrated in Figure 5, resonances occur in a cable configuration as shown in Figure 4 even with a non-reactive termination impedance. These resonances would not be noticeable in the configuration as shown in Figure 3, in particular in the lower frequency band, because the cable would be too short. Here again, however, it can be argued that under practical operating conditions there is rarely an ideal ground plane 80 cm below the EUT and that most of the cables run along the ground. The results achieved using the modified cable configuration are therefore to be viewed as more realistic. This means that the standardised configuration for cables up to their termination impedance in disturbance field strength measurements needs to be redefined.

One alternative is to use a decoupling network, which, although costly, provides not only a frequency-independent network impedance but also good decoupling from the network. This option is not, however, feasible in an FAR and also in general, because of the numerous different interface adapters required.

An absorbing clamp also provides relatively good decoupling from the network, but has the added advantage that it acts as a termination impedance that is independent of the ground connection and auxiliary equipment. The disadvantage, however, is that the absorbing clamps currently available do not provide a stable termination impedance: the input impedance decreases exponentially from approximately 1200 Ω at 30 MHz to approximately 150 Ω at 100 MHz. This means that radiation maxima and minima still occur in this frequency band, which has a negative influence on measurement reproducibility.

Another solution is to transform after an 80 cm section of the cable a non-reactive impedance that can be switched between average and very low. Measurements can therefore be made with each of the two different cable terminations, and the highest of the two field strengths measured on each frequency is to be taken as the result. Connecting an absorbing clamp behind a switchable impedance could offset the clamp's disadvantage – the high input impedance at low frequencies – while securing its advantage – good decoupling from the network independent of the ground connection.

Finally, it should be noted that all the proposed solutions involve shortening the electrical length of the section of cable that acts as the main source of radiation. It therefore remains unclear how to deal with the considerable reduction in radiation in the lower frequency band. It must be made clear that these solutions without doubt conflict with measuring the maximum radiation as required in CISPR 16-2.