Effect of Cable Termination on EMI Measurement Results

M. Bittera, V. Smieško

Department of Measurement, Slovak University of Technology, Bratislava, Slovakia
Email: mikulas.bittera@stuba.sk

Abstract. *The paper deals with effect of terminations of interference cable of equipment under test to results of EMI measurements. It is evident that interference cables represent the potential sources of undesired radiation, which can be suppressed or emphasized by choice of termination load value. The behaviour of terminated two-wire cable is analysed in term of its input impedance. The radiation is also surveyed using numerical techniques based on models that are verified by analytical calculation and measurement.*

Keywords: EMI measurement, emissions measurement, cable termination, two-wire cable

1. Introduction

Especially due to many disturbing factors, electromagnetic interference (EMI) measurement is a very complex measurement. During the measurement we shall identify the maximal intensity of unwanted electromagnetic field radiated from the equipment under test (EUT), measure it and compare with limit values. Because of reproducibility, the measurement is performed strictly according to international standard [1]. Also EUT shall be in typical mode of operation and in a test arrangement that is representative of typical installation practice. It is because the influences of equipment, which are necessary for performing EMI measurement, and of test site arrangement, can be included into measurement correction or its uncertainty, but the effect of the EUT cannot [2].

The EUT cables and their arrangement are the most problematic part of EUT by emission measurement. Interference cables have to be connected to each interference port of EUT, while the type and length of cables have to be specified by equipment manufacturer. The cables should be no longer than 0.4 m. If it is necessary for normal operation of EUT the ends of interference cables that are not connected to other auxiliary equipment can be terminated by real impedance. In the paper, we concentrate on the role of termination of two-wire cable as prospective radiator of disturbance and its effect on EMI measurement reproducibility. We suppose that the cable is attached to electrically small tabletop EUT and the differential mode disturbance is applied on.

2. Problem analysis

In term of radiation, the behavior of the mentioned cable can be expressed using transmission line method. For a transmission line, it can be shown that the input impedance Z_{in} of a cable of length l and loaded by an impedance Z_L is

$$Z_{in} = Z_0 \frac{Z_L + Z_0 \tanh \gamma l}{Z_0 + Z_L \tanh \gamma l} \tag{1}$$

where γ is the propagation constant and Z_0 is the characteristic impedance of the transmission line. Having the distance D between the wires of the cable and the radius d of the conductors, the characteristic impedance of the two-wire cable in medium with permittivity ε is given

$$Z_0 = \frac{120}{\sqrt{\varepsilon}} \cosh^{-1}\left(\frac{D}{d}\right) \tag{2}$$

while propagation constant γ is also function of resistance R, conductivity G, inductance L and capacitance C of the cable, which are dependent on material parameters of the cable and its surrounding

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} \tag{3}$$

The using of transmission lines theory was verified also by the real measurement with network analyzer on chosen model of the two-wire line (see Figure 1). Using substitution (2) into (1) and the Ohm's law consequently, it is possible to calculate the current I through the transmission line.

The two-wire cable as antenna can be represented by rectangular loop antenna. In this case the magnitude of E-field component of electromagnetic field E in arbitrary point of the surrounding space specified in spherical coordinate system *(r, ϕ, θ)* is then given [3]:

$$E = \frac{8\eta I}{r} \frac{\sin\left(\frac{ka}{2}\sin\theta\cos\phi\right)\sin\left(\frac{kb}{2}\sin\theta\sin\phi\right)}{\sin\theta\sin 2\phi} \tag{4}$$

where I is feed current flowing through the loop antenna, η free space wave impedance, k phase constant; a and b represent the dimensions of the rectangle. In our case, it is evident that $a \gg b$, so the transmission wire can be compared with folded dipole. Hence, if the current is uniform along the antenna, the radiation is very weak for small b, since the radiation from the two long arms of the antenna nearly cancels. Of more interest would be the case when the current is not uniform (if $a \approx \lambda$), consequently the currents in the two long arms flow in the same direction. While the shorter side of the loop $b \ll \lambda$, the E-field radiated from the transmission line we get by simplification of equation (4):

$$E = \frac{\eta kbI}{r} \frac{\sin\left(\frac{ka}{2}\sin\theta\cos\phi\right)}{\sin\phi} \tag{5}$$

The equations (4) and (5) has two main disadvantages. They are suitable only for computing the E-field in far-field zone, which is not fulfilled in case of lower frequencies of our interest and they do not include other surrounding material as free space is. Therefore it is necessary to find other method. The [4] shows the advantage of numerical simulations that constitute powerful tool to analyze such structures as wire cables. To analyze the two-wire cable effect by numerical simulator, it is enough to build a proper model of such a cable.

3. Results

As the model of the interference cable simple 40 cm long two-wire cable was chosen, which consists of two parallel wires, with 50 Ω termination on one end and with point voltage source on the other one. The load impedance is chosen not equal to characteristic impedance to survey its radiation behavior. The diameter of these wires is 0.4 mm and the distance between them 1.8 mm. The long two wire cables are coated by plastic insulation. The input impedance Z_{in} of this model was obtained using all the mentioned methods. In Fig. 1 one can see the conformity of the results. Even though the first impedance maximum is expected at first resonance frequency about 187 MHz, the permittivity of the isolating material, which is higher than permittivity of free space, causes the shift of resonance frequency to the lower values (about 110 MHz). Also values of supply current I and electric field E in frequency range 30 ÷ 500 MHz obtained by theoretical computation using (1) and (4) and numerical simulation of chosen model, but without isolation, are shown in Fig. 2. We assume that signal voltage has the constant level of 1 V in whole frequency range. In case of current comparison their frequency dependences have the same tendencies; only frequency of maximum calculated current is slightly moved to higher values of frequencies. On the other hand some differences of E-field values in distance 3 m are evident especially at lower frequencies. It is because equation (5) is suitable only for computation of E-field in far-field. The validation of this model using real measurement can be found in [3].

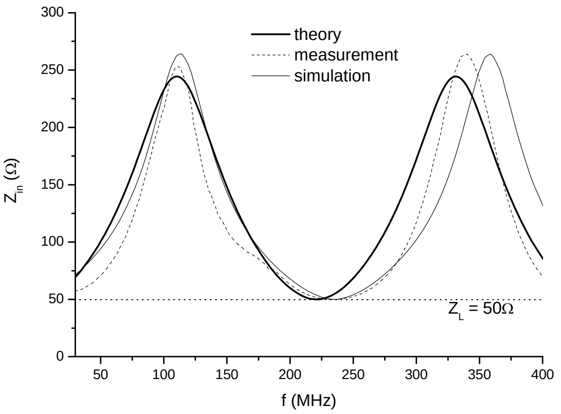

Fig. 1. Frequency dependence of input impedance of 40 cm two-wire cable for 50Ω load.

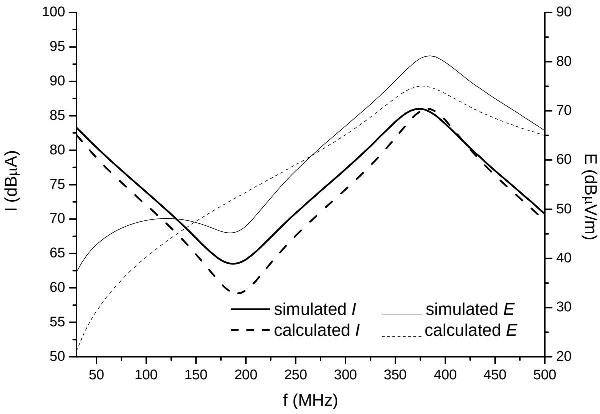

Fig. 2. Frequency dependence of supply current of 40 cm two-wire cable and radiated field in 3 m distance.

It is expected that cable terminated by load impedance Z_L, which is equal to characteristic impedance Z_0, has the lowest unwanted radiation. In most cases unfortunately we do not know the impedance Z_0. Then the determining parameter is input impedance Z_{in} of the analyzed cable. It can be obtained simply by measurement using network analyzer (see Fig. 3). The input impedance Z_{in} determines the behavior of such cables; we expect usually the maximum of radiation if the Z_{in} is in its minimum and vice-versa.

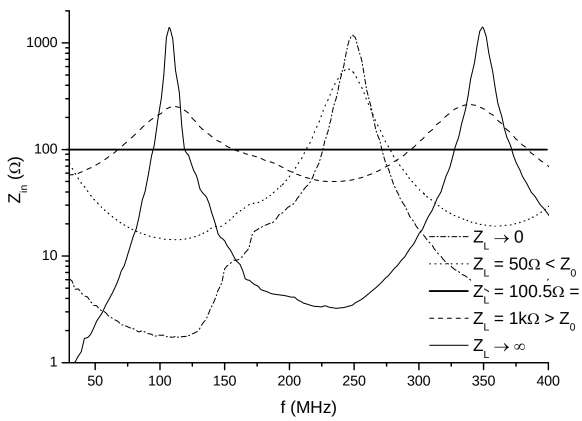

Fig. 3. Measured values of input impedance Z_{in} of 40 cm two-wire cable for different terminations Z_L.

To confirm our expectation we used numerical simulation with chosen model - simply hanging 40 cm long two-wire cable with given parameters. Two different simulations were performed – to obtain E field in 3 m distance from the cable in free space and in presence of ground plane (1 m over the plane as it is given for standard EMI measurement). The results of simulations are shown in Figures 4 and 5. As we can see from these dependences, the E field from cable terminated by Z_0 is not constant but without evident or sharp extremes. Using terminators with lower values of Z_L the cable behaves as folded dipole and for higher values of Z_L as classic half wave dipole, but with half value of maximal radiation frequency. The level of radiated E field depends on difference between values of terminating impedance Z_L and characteristic impedance Z_0 of the cable. It means that the worst situation of EMI measurement is when we used the interference cable with open or short circuit. Note in Fig. 4 that for lower values of Z_L there are no minimums in the E field frequency dependence, they appear just in case of ground plane (Fig. 5). Otherwise, the ground plane presence does not influence the frequency dependences of E field very evidently. Results shown in Fig. 5 can help us to find the frequency with maximal radiation.

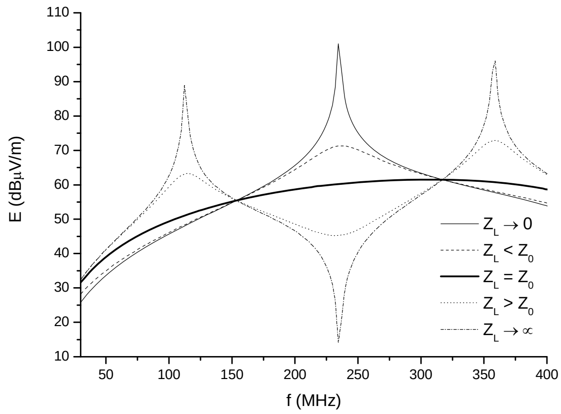

Fig. 4. Frequency dependence of radiated E-field from 40 cm two-wire cable as a function of terminator value Z_L in free space

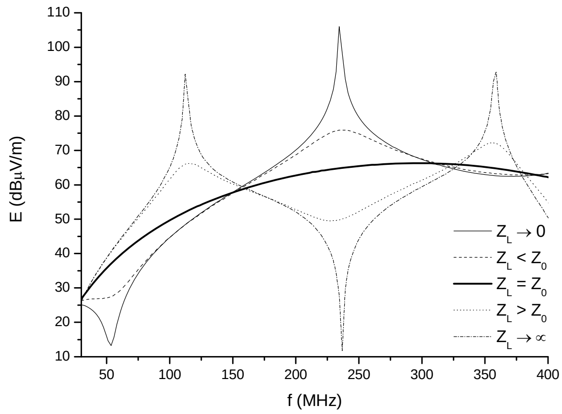

Fig. 5. Frequency dependence of radiated E-field from 40 cm two-wire cable as a function of terminator value Z_L with ground plane

4. Discussion

The models of two-wire interference cable were presented, verified and analyzed to survey the properties and behavior in term of potential radiation due to differential mode disturbance. In general, the character of cable radiation is given by properties of the cable. The wrong termination can cause additional maximums of radiation and the fail of the EMI measurement test consequently. To get the frequencies of potential radiation maximums quickly one can use mentioned method – measurement of input impedance of the cable. Hence to minimize the radiation from the cables of EUT, it is recommended to terminate them by impedance with value close to characteristic impedance (it is necessary to get as straight frequency dependence of impedance as possible).

Acknowledgements

This research was financially supported by the project VEGA VG 1/0551/09 and by the Ministry of Education of the Slovak Republic under grant 2003SP200280202.

References

[1] CISPR 22 Information technique equipment – Radio disturbance characteristics – Limit and methods of measurement. 5th edition, IEC, 2005.

[2] Bittera, M., Smieško, V., Kováč, K. Problem of bundled two-wire cable of tested equipment in emission measurement, *Radioengineering*, 15(4): 22-26, 2006

[3] Bittera, M., Smieško, V., Kováč, K. Interference cable effect to EMI measurement results. In proceedins of the Meditarreanen Microwave Symposium MMS, 2007, 159-162.

[4] Hallon, J., Kováč, K., Szolik, I. Geometrical configuration of cabling as factor influencing the reproducibility of EMC imunity tests. *Radioengineering*, 15(4), 27-33, 2006