Effect of Bundled Power Cable on Radiated Emission Measurement

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Abstract. *The paper deals with effect of different types and different arrangements of power cables of equipment under test to results of EMI measurements. It is because the cables attached to tested equipment represent the potential sources of undesired radiation. The influence of two- and three-wire power cables is surveyed using numerical techniques based on models that are verified by analytical calculation and measurement.*

Keywords: EMI measurement, power cable, numerical simulation

1. Introduction

The main task of electromagnetic interference (EMI) measurement is to identify and measure the maximums of unwanted radiation from equipment under test (EUT). According to international standard [1] the EMI measurement shall be performed whilst operating the EUT is in typical mode of operation and with cables position in a test arrangement that is representative of typical installation practice. The effect of varying position of each cable shall be investigated to find the configuration that maximizes disturbance as constrained by its typical configuration in actual size.

In the paper, we concentrate on influence of power cable of typical tabletop EUT as prospective radiator of disturbance when differential mode disturbance is applied on it. It is because different arrangements of these cables can influence the results of measurements. Also the comparison of two-wire and three-wire cable effect to EMI measurement is surveyed.

2. Subject and Methods

The analysis of behaviour of cable structures can be performed analytically, using numerical methods, or by the real measurement. The [2] shows the advantage of numerical simulations that constitute powerful tool to analyse such structures. To analyse the two-wire cable effect, we had to build a proper model of such a cable with similar behaviour. At first a model of simple 40 cm long two-wire cable was chosen, which consists of two parallel wires with 50 Ω termination at one end and with point voltage source on the other one. The diameter of these wires is 0.4 mm and the distance between them 1.8 mm. Such a loss and non-perfect cable can be considered to be a transmission line that behaves as radiator. Using transmission line method [3] we can compute the input impedance Z_{in} of such a cable:

$$Z_{in} = Z_0 \frac{Z_L + Z_0 \tanh \gamma l}{Z_0 + Z_L \tanh \gamma l} \qquad (1)$$

where l is length of the cable, γ is the propagation constant, Z_L is the terminating impedance 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 permitivity ε is given:

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

Using substitution Eq. 1 into Eq. 2 it is possible to compute the current I through the transmission line using Ohm's law.

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 volume V specified in spherical coordinate system (r, ϕ, θ) is then given [4]:

$$E = \frac{8\eta I}{r} \frac{\sin\left(\frac{ka}{2}\sin\theta\cos\phi\right)\sin\left(\frac{kb}{2}\sin\theta\sin\phi\right)}{\sin\theta\sin 2\phi} \tag{3}$$

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 very 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 $b \ll \lambda$, we get radiated E-field of the transmission line by simplification of Eq. 3:

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

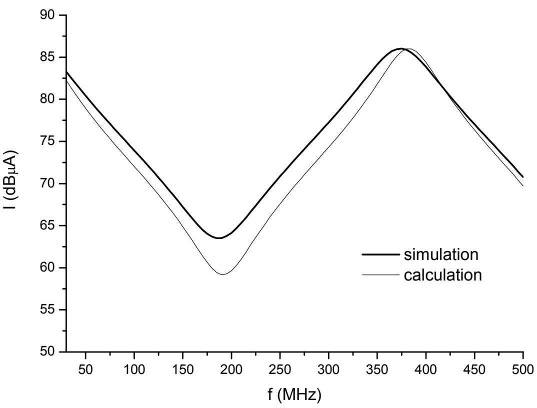

Fig. 1. Frequency dependence of supply current of 40 cm two-wire cable.

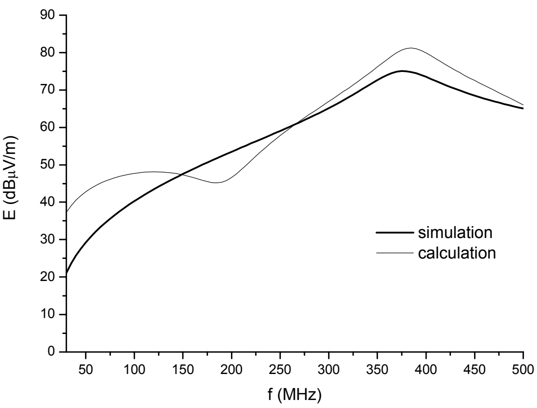

Fig. 2. Frequency dependence of radiated field from of 40 cm two-wire cable in 3 m distance.

Values of supply current I and electric field E in frequency range 30 ÷ 300 MHz obtained by theoretical computation using Eq. 1 and Eq. 4 and numerical simulation using method of moments, which assumes the model with same parameters, are shown in Fig. 1 and 2. We assume that signal voltage has the constant level of 10 mV 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 there some differences of E-field values in measuring distance 3 m are evident especially at lower frequencies. It is because in Eq. 4 we consider only far-field components of E-field. The validation of this model using real measurement can be found in [3]. Another more complicated two-wire model is 1 m long cable folded at the cable centre into a bundle to get cable no longer than 0.4 m. It is considered that the bundle is created as meanders and joined in the centre. Because the model of such an arrangement cannot be surveyed using simple analytical equations, real measurements were performed to validate it. In measurement the metal plate of 10×10 cm, which shall be considered also in numerical simulations, was used to avoid the influence of real voltage source. There are small differences between measured and simulated values of E-field in test site at point of receiving antenna (see Fig. 3). But it is important to notice that frequencies of maximal E-field values are the same. The difference at frequencies lower than 100 MHz is caused by high noise level of measuring receiver and additional equipment present during the measurement. Based on this similarity in next it is possible to replace time-consuming measurements or inaccurate analytical calculation by numerical simulations to survey the behaviour of two-wire cables of arbitrary shape.

3. Results

Following previous analysis all the results were obtained using numerical simulation - moments method - based on mentioned cable models. The radiations of two basic types of power cables -two-wire and three-wire (with protective earth wire) cables are compared. Power cable shall fall down straight to the reference ground and then lead to electrical socket. The dominant component of the radiated E-field from such a cable is perpendicular to the reference ground, so it shall be measured with vertically polarized antenna. As it is seen in Fig. 4 the frequency dependence of radiation from the three-wire cable in distance of 3 m has the same tendency as two-wire cable, but it is approximately 3.5 dB lower than in case without protective earth wire. It is because the earth-wire shields the radiation caused by other differential disturbing current flowing through the other two wires.

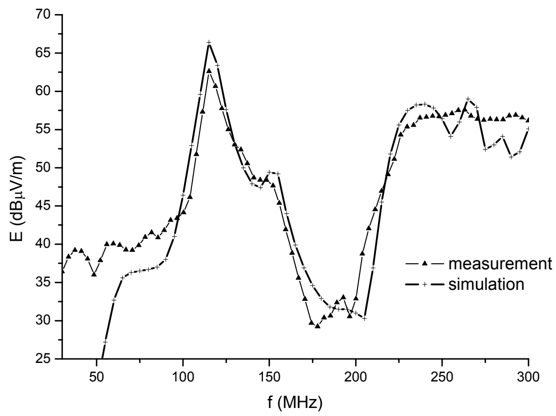

Fig. 3. Frequency dependence of radiated E-field from 1 m long bundled two-wire cable in 3 m distance.

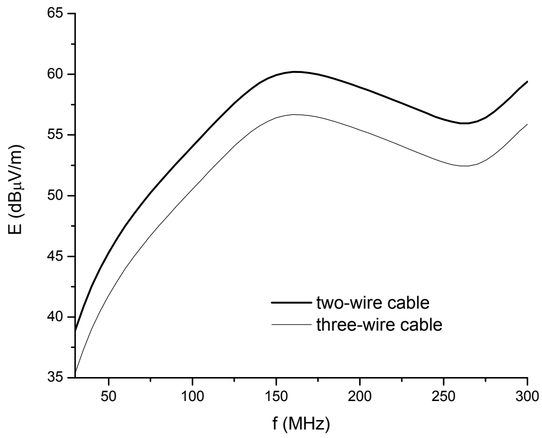

Fig. 4. Frequency dependence of radiated E-field from different 1 m power cables.

In case of longer power cable it is possible to fold it into a bundle using meander technique. To survey the behaviour of such cables we used the verified model of bundled cable. The analysis was performed for dominant vertically polarised component of E-field of 1.5 m long power cable. As one can see in Fig. 5 and 6, another peaks of radiation in analysed frequency spectrum appeared, but the radiation of analysed cables is similar. Due to additional meanders in the bundle, which cause reduction of bundle dimensions, there are minimal differences of radiation level; one can notice only frequency shifts of the radiation peaks. Comparing radiation level of three-wire power cable it is lower than of two-wire cable similarly to previous case and the frequency shifts are more evident.

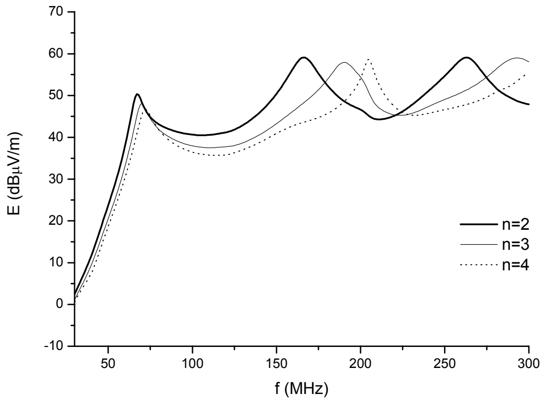

Fig. 5. Frequency dependence of radiated E-field from bundled two-wire power cable as a function of number of meanders n in bundle.

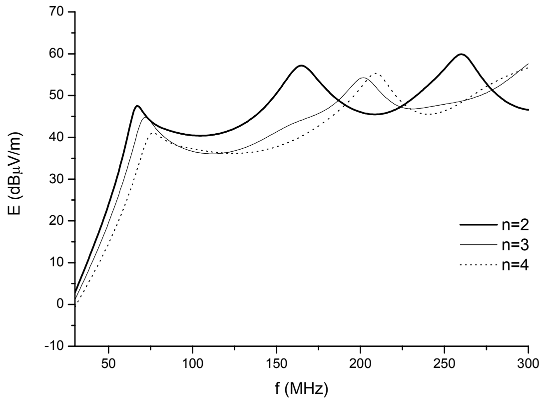

Fig. 6. Frequency dependence of radiated E-field from bundled three-wire power cable as a function of number of meanders n in bundle.

4. Conclusion

Two models of power cable were analysed to survey the properties and behaviour in term of potential radiation due to differential mode disturbance. Dominant radiation that we got from hanging cables is vertically polarized so the analysis is performed for vertically polarized antenna. In general, three-wire cable has less level of radiation due to wire joined with reference ground that represents protective earth. This fact is valid also for cables arranged into bundles. Because another maximums of undesired radiation are generated, it is preferable to avoid creating cable bundles over the reference ground to minimize the radiation of such a cable.

Acknowledgements

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