Problem of Bundled Two-Wire Cable of Tested Equipment in Emission Measurement

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Abstract. *Many factors that influence radiated emission measurement exist. Except of factors relative to measuring chain "test site – antenna – receiver" there are some factors caused by operating personnel like inappropriate configuration of tested equipment, etc. Tested equipments contain generally attached cables of different length; the longer ones shall be shortened by folding into a bundle. The aim of this paper is to analyze the behavior of such cables and its influence on results of radiated emission measurement.*

Keywords

Radiated emission measurement, bundled two-wire cable, method of moment.

1. Introduction

No doubt, that in electromagnetic compatibility (EMC) area emission measurements, especially radiated emission measurements represent the most difficult and also the most time-consuming measurements of tested equipment (EUT = equipment under test). The aim of this measurement is to identify the frequencies that have the highest disturbance level relative to the limit and consequently to measure the field strength on these frequencies using calibrated antenna placed in a known distance. The signal received by the antenna shall be transmitted to the test receiver. For frequencies of the highest disturbance in frequency range from 30 MHz to 1000 MHz the disturbance level shall be maximized by rotating the EUT and adjusting the antenna height from 1 m to 4 m. The measurement shall be carried out for both horizontal and vertical polarization of a receiving antenna.

According to relevant international standards [1], [2], the configuration of EUT shall respond to its configuration during normal operation. It means the measurement shall be performed whilst the EUT is in typical modes of operation and with cable position in a test arrangement that is representative of typical installation practice. Focusing just on tabletop devices, they should be placed upon a nonconductive table 0.8 m above the horizontal ground reference plane of the test site as it could be seen in Fig. 1 [2].

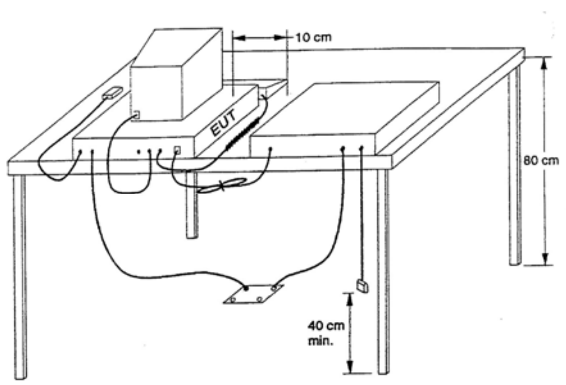

Fig. 1. Test place arrangement of a tabletop EUT for radiated emission measurement.

An interference cable shall be connected to each interference port on EUT, while its type and length shall be specified by an equipment manufacturer. All the cables (except power and communication cables) can hang no closer than 0.4 m from the horizontal ground plane. Longer cables shall be folded at the cable center into a bundle no longer than 0.4 m. The effect of varying position of each cable shall be investigated to find the configuration that maximizes each disturbance as constrained by its typical configuration in actual size.

In the paper, we concentrate on the role of two-wire cable attached to a small tabletop EUT as a prospective radiator of disturbance. It is because different lengths of these cables can influence the results of measurements [3]. Frequently longer cables are used as attached cables to different EUTs and therefore it is necessary to shorten them. Shortening of the cable using bundles also brings another problem with reproducibility of the measurement. In this paper, different approaches are used to analyze the behavior of such bundled cables.

2. Problem Analysis

The analysis of behavior of two-wire cable can be performed analytically, using numerical methods or the real measurement. Analytical methods help us to understand the physical problem, but they can solve only simple problems or problems with some simplifications. Hence, also in area of electromagnetism, recent numerical methods and codes are replacing the analytical solutions. Beyond these also measurement can be used. The results from the measurements reflect mostly the real behavior of the analyzed structure, but on the other hand they need too much time to be performed.

2.1 Analytical Approach

No doubt that analyzed two-wire cable can be considered to be a transmission line. According to [4], if a transmission line is not a lossless and perfect one, it behaves as an antenna. It means that a part of supplied energy is radiated into surroundings. Using transmission line method [5] we can compute the input impedance Z_{in} of such a cable:

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

where Z_0 is the characteristic impedance of the transmission line, Z_L is the load (termination) impedance, l is the length of the cable, and γ is the propagation constant, in general given by the expression

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} \tag{2}$$

where R, L, C and G are the cable parameters – resistance, inductance, capacitance or conductance per unit length.

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 a medium with the permittivity ε is given by

$$Z_0 = \frac{120}{\sqrt{\varepsilon}} \cosh^{-1}\left(\frac{D}{d}\right). \tag{3}$$

Using substitution (3) into (1) it is possible to compute the current I through the transmission line using Ohm's law.

The method of computation of E-field and H-field components of an arbitrary shape antenna can be found e.g. in [6]. In far-field region, the E-field component $\boldsymbol{E}$ is given:

$$\mathbf{E} = -j\omega \mathbf{A} \tag{4}$$

where $\boldsymbol{A}$ represents magnetic vector potential:

$$\mathbf{A} = \frac{\mu}{4\pi} \iiint_V \mathbf{J} \frac{e^{-jkr}}{r} dV \tag{5}$$

where $\boldsymbol{J}$ is electric current source, V the analyzed volume and r the distance from the source to the observation point.

The two-wire cable as an antenna can be represented by a loop antenna with a rectangular shape. In this case, $\boldsymbol{J}$ represents the volume current density and (5) is reduced to a simpler integral over the surface S. Then, the magnitude of E-field component of electromagnetic field $\boldsymbol{E}$ in an arbitrary point of the volume V specified in spherical coordinate system (r, ϕ, θ) is then given [6]:

$$E = \frac{8\eta I}{r} \frac{\sin\left(\frac{ka}{2}\sin\theta\cos\phi\right)\sin\left(\frac{kb}{2}\sin\theta\sin\phi\right)}{\sin\theta\sin 2\phi} \tag{6}$$

where I is the 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 $a \gg b$, the transmission wire can be compared with a folded dipole. Hence, if the current is uniform around 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 $a \approx \lambda$), such that the currents in the two long arms flow in the same direction. For this, such antenna must be considered as a kind of a resonant cavity that is excited in a desirable mode [7].

While the shorter side of the loop $b \ll \lambda$, we get the E-field of the transmission line by simplification of (6):

$$E = \frac{\eta k b I}{r} \frac{\sin\left(\frac{ka}{2}\sin\theta\cos\phi\right)}{\sin\phi}. \tag{7}$$

Equation (7) can be used just for E-field computation of the simple and straight two-wire cable without any complexity. Hence it cannot be used for analysis of radiation from more complex systems.

2.2 Numerical Approach

Nowadays, there are many electromagnetic field simulators used to solve electromagnetic problems. They are very useful especially when a solved problem has no analytical solution. In our case of analysis of radiation of antennas and other wire structures, the most popular simulators are based on method of moments.

Method of moments (MoM) solves Maxwell's equations in their integral form and in frequency domain [8]. Principle of MoM is based on discretizing the solution domain, on dividing the analyzed structures to the smaller parts, called segments. Then the integral equation could be transformed to a system of linear equations, so the matrix is build, then it is inverted or the iteration is used to find the solution. The matrix building and its solution must be repeated for each frequency. In general, if the structure has more segments it means that one needs more time for calculation, but has more accurate results. So, it is necessary to strike a balance between the number of segments and the calculation accuracy [9].

For our analysis the electromagnetic field simulator FEKO was used [10]. This simulator allows computing field distribution for different wire, surface and volume metallic structures. For getting appropriate results using the simulator it is important to choose the proper model of the analyzed structure. In our case of two-wire cable, the simplest model is represented by a loop antenna with a rectangular shape, as it was mentioned above; it consists of two parallel wires with signal source and termination. Also, more complex system could be solved, so the numerical approach is used to survey the behavior of cables with bundles.

2.3 Measurement

The analysis performed by measurement represents the most accurate analysis in spite of fact that its results are loaded with errors of measurement. But these errors are generally the same ones that influence the measurement of radiated emission [11] and therefore in this case their effect can be neglected.

On the other hand, it is not possible to survey very simple structures due to impossibility of their realization. In our case, it is not possible to realize point source of voltage. Hence, another model is created, the metallic box with dimensions 10×10×10 cm and connected with a two-wire cable. All the measurements were performed in a semi-anechoic chamber of STU FEI to avoid a disturbance from surroundings. These results are also influenced by a reflection from the reference ground plane, which is in the chamber with and by a receiving antenna.

3. Results

In term of electromagnetic compatibility and especially radiated emission, for the purpose of analysis it is important to know values of E field in some distance of the disturbing structure. Because we own 3 m test site, all results of field are obtained in 3 m distance.

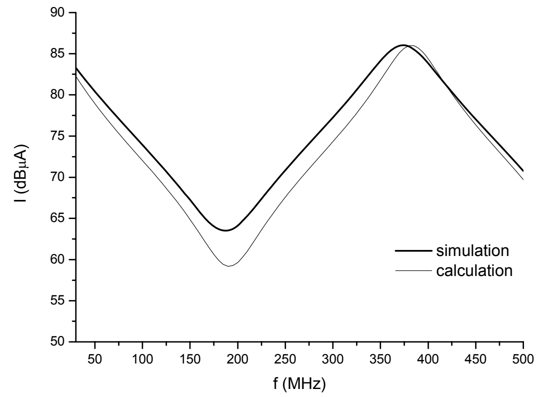

Fig. 2. Frequency dependence of supply current of 40 cm two-wire cable.

At first we assume a very simple model of two-wire cable, which consists of two parallel wires with 50 Ω termination on one end and with point source of voltage on the other one. The model of the cable has parameters of a conventional two-wire cable; the diameter of a wire is 0.4 mm and the distance between wires 1.8 mm. Following standards [1], [2], we assume the 40 cm long cable. The signal voltage has the constant level of 10mV in the whole frequency range from 30 MHz to 300MHz (or 500 MHz). The behavior of such a model is surveyed using analytical or numerical approach. The results of analytical calculation and simulation using FEKO solver respectively, are shown in Fig. 2 and 3.

The computed supply current of the two-wire cable is very similar to the simulated one, as it could be seen in Fig. 2. Their frequency dependences have the same tendencies; only the frequency of the maximum calculated current is slightly moved to higher values of frequencies. Fig. 3 shows the frequency dependence of calculated and simulated values of E-field in distance 3 m from the analyzed cable. Some differences are evident there, especially at lower frequencies. It is because in equation (7) only far-field components of E-field are considered. In case of this model of two-wire cable there is no difference between the frequency of the maximal current and the radiated E-field [3] due to no presence of a reference ground plane. The analytical solution shows some imperfections also in such a simple model so in the next analysis the analytical calculation is avoided.

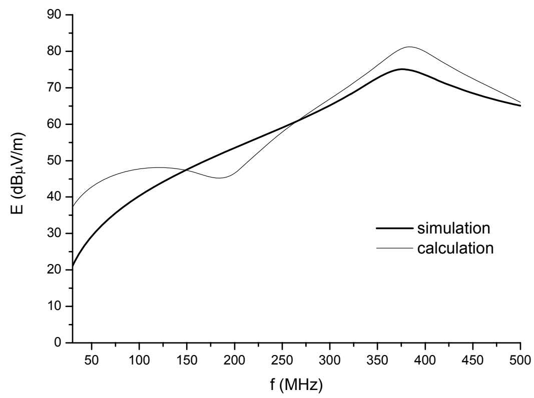

Fig. 3. Frequency dependence of radiated E-field from 40 cm two-wire cable in 3 m distance.

In the next analysis, another more complicated model, consisting of a metallic box and an attached wire, is used. The behavior of 1 m long two-wire cable folded at the cable center into a bundle is surveyed. There are some degrees of freedom, which can be changed to arrange the longer cables to ones no longer than 0.4 m. It is considered that the bundle is created as meanders (not loops) and joined in its center. So it creates figure in shape of eight due to the character of the cable (see Fig. 4). The cable bundle is then characterized by:

- The length of the cable bundle – the parameter α;
- The diameter of the cable bending – the parameter ρ;
- The number of meanders in the bundle – n.

The basic considered configuration is chosen like 1 m long two-wire cable folded in center into 14 cm long bundle with two meanders and 3 cm diameter of bending. Then the maximal length of such a cable is 40 cm exactly. All the analysis is performed for vertically polarized waves, where higher radiation is supposed.

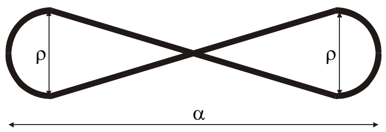

Fig. 4. Model of the cable bundle and its parameters.

At first the radiated emission measurement of such a model was performed. The results of measurements are influenced by all the equipment present in the test place during the measurement as well as they are loaded by uncertainty of the entire measuring chain. But these results represent the reference for other measurements that will be affected similarly and also for the analysis using simulations. Also simulation based on this real model was performed (see Fig. 5). Also the reference ground and the receiving antenna, in height 1 m over the ground and in 3 m distance from the cable, were included into the simulation model to get the most realistic results of analysis.

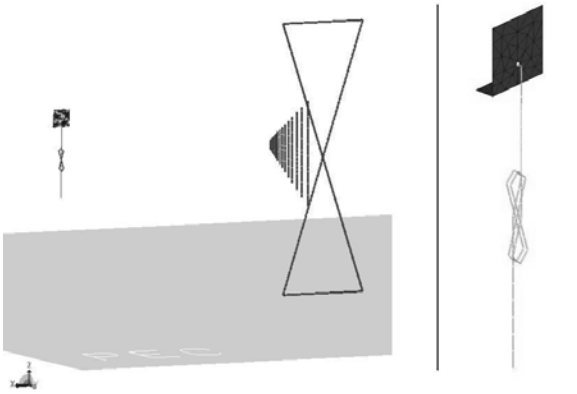

Fig. 5. The model of the real measurement configuration for FEKO and the detail of a simplified box with a bundled wire.

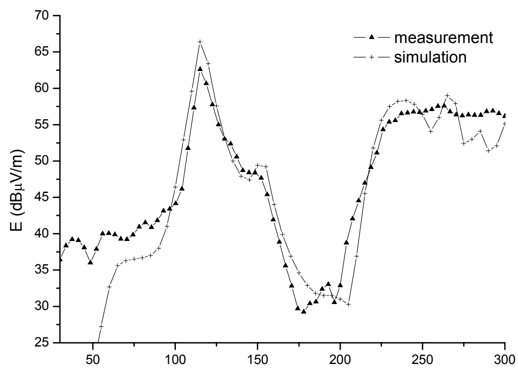

Fig. 6. Frequency dependence of radiated E-field from the bundled two-wire cable in 3 m distance.

As it can be seen in Fig. 6 there are small differences between measured and simulated values of E-field in the test site at the point of the receiving antenna. It is important to notice that the frequencies of the maximal E-field values are the same. The difference at frequencies lower than 100 MHz is caused just by a high noise level of the measuring equipment. This similarity means that next it is possible to replace time-consuming measurements by simulations and then all the further analysis is performed using numerical simulation using FEKO.

As it was noticed three parameters of the bundle can influence the E-field frequency spectrum. During the entire analysis we consider 1 m long cable. If it is necessary its length can be shorter or longer than 0.4 m. At first we examined the influence of the length of bundle α. Its effect can be seen in Fig. 7. With its increasing length the frequency of maximum also slightly increases, approximately 10 MHz change in the frequency of maximum belongs to 2 cm change in length. At that, level of E-field changes too, but this change is marginal.

Another parameter, which changes can influence the radiation behavior from the bundled cable, is the diameter of the cable bending ρ. The analysis was performed for the change of the diameter ± 2 cm. The influence of the varied parameter ρ is more evident than in the previous case (see Fig. 8). By decreasing ρ not only the frequency of the maximal radiation from the cable is increased but also the level of this radiation. This jump is almost 10 dB for the decrease of the diameter of 2 cm (in this case the frequency shift is approximately 20 MHz). The raising values of radiation are then caused not by increased but by decreased area of so created bundle loops. This fact was also observed by some measurements. It is necessary to note that the area of the radiation (the area between the two wires of the cable) is the same during the whole analysis, just the geometry of the bundle is changed.

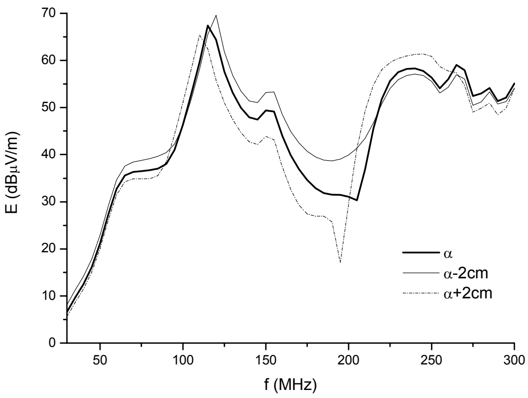

Fig. 7. Frequency dependence of the radiated E-field from the bundled two-wire cable in 3 m distance for different α.

In the analysis of the number of meanders n in the bundle of the cable we consider the cable with the fix length of 1m while the parameters of a bundle are changed in ratio $\alpha : \rho = 14 : 3$, as it is in the basic configuration of the cable of two meander bundle. Also the length of the shortened cable is considered to be fixed 0.4 m, so just the rest 0.6 m of the cable is arranged to the bundle. As it can be seen in Fig. 9 the worst situation is in the case of just one meander in the bundle. Then the problem of the second maximum is more important; it has higher level of radiation than the first one, as it is in all other cases. If we have 2 or more meanders in the bundle the level of radiation remains the same, there is just the frequency shift of about 10 MHz.

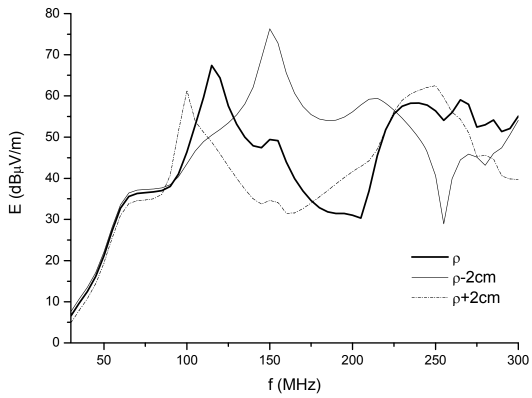

Fig. 8. Frequency dependence of the radiated E-field from the bundled two-wire cable in 3 m distance for different ρ.

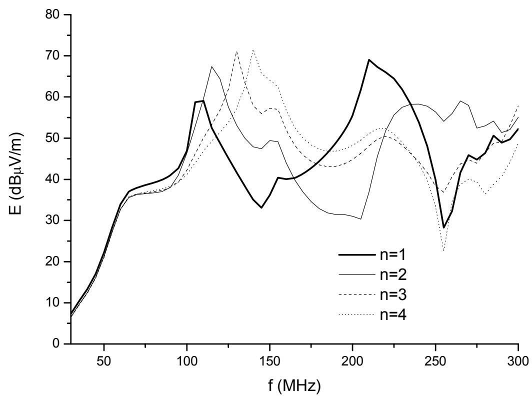

Fig. 9. Frequency dependence of the radiated E-field from the bundled two-wire cable in 3 m distance for different *n*.

4. Conclusion

The analysis of the bundled two-wire cable to the emission measurement is provided by this paper. Because of impossibility of using classical analytical methods, the numerical method using the electromagnetic field simulator FEKO was used to perform this analysis. The reliability of simulation results was also confirmed by the theoretical calculation for the simple two-wire cable as well as by measurement for the more complicated model of the bundled two-wire cable. From three mentioned and analyzed parameters of the cable bundle, the diameter of the cable bending influences the results of radiated emission mostly. The length of the bundle and the number of meanders in the bundle cause just slight shift of the frequency of the radiation maximum, the level of radiation keeps almost the same. Hence, this is very important for EMC operators to keep minimized areas of possible loops by creating bundles during the test.

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