RANDOM ILLUMINATION BY A DIPOLE OF A TRANSMISSION LINE PLACED IN A ROOM. A PROBABILISTIC AND STATISTICAL APPROACH.

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ABSTRACT

Deterministic analysis of coupling between wireless communication systems and electronic devices connected by means of cables, is hardly achievable because of the large number of possible configurations. Then, a statistical approach seems more appropriate, and will be illustrated by the case of a simple transmission line placed inside a room, and illuminated by a randomly positioned and oriented dipole. The current induced in the load at one end of the line, is then a random variable characterized by means of its quantiles. The latters are functions of various factors of the line, their values are predicted using the kriging technique.

INTRODUCTION

Mobile phones, wireless laptops, walkie talkies and other wireless devices are used inside buildings, such as hospitals or offices where more and more sensitive and cabled electronic devices are encountered [1]. Their integrated circuits are more elaborate and powered by low voltages, and they thus need to be conveniently protected from the surrounding electromagnetic environment to avoid possible malfunctioning. That can be especially damaging with medical devices [2], for example. Although a deterministic study of the coupling is feasible, the variability and the multiplicity of possible configurations (due to the randomness of the position and the orientation of the emitter, the paths of cables which can differ from one configuration to another) makes it unreasonable. A probabilistic analysis appears to be more suitable in such a case [3], where all possible configurations are considered as the realizations of a random experiment. However, due to the required computational cost, only a sample of configurations can be studied. A statistical approach, based on an interpolation or estimation technique (like the Kriging one [4]), is then applied to predict the level of interferences induced in any other configuration from those of the sample.

In this paper, we apply the above mentioned scheme to the case of a randomly oriented and positioned dipole, emitting inside a room where a two wires transmission line is placed. The analysis follows the steps of the one previously introduced in the case of a single wire transmission line placed above an infinite ground plane [5].

THE COUPLING CONFIGURATION

A two wires transmission line of length L, with wires diameter d and separation distance h, is loaded by impedances Z_0= 50 Ω at one end and Z_L at the other end. The line is placed inside a 4m x 6mx 2.5m room, Fig. 1, the thicknesses of its walls, ceiling and floor are respectively 10 cm and 20 cm. They are made of a material of relative permittivity 4-j0.18. One side of the room is a bay-window 0.5 cm thick and of relative permittivity 1.5. The transmission line is illuminated by an elementary dipole, located inside the room, the position and orientation of which are random variables, emitting at a frequency of 1 GHz, a power of 2 W.

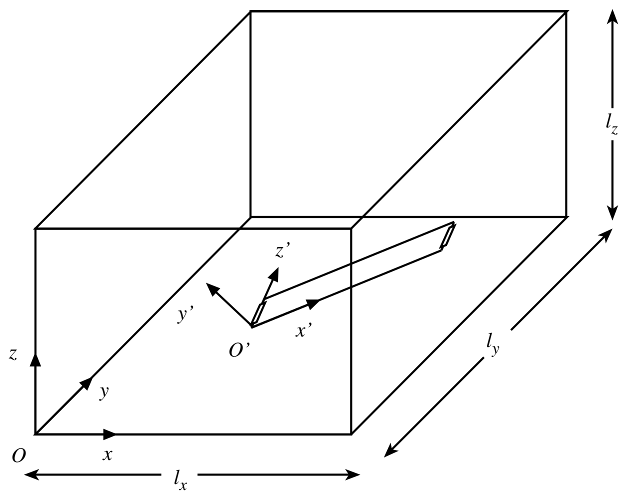

Fig. 1 Room and transmission line

Emitting dipole only inside the room

In a first step, the dipole is assumed to be alone inside the room. The radiated field at any point in the room is computed analytically for several random positions and orientations of the dipole. To carry out these calculations, the electric field is splitted into the direct LOS (Line of Sight) incident field and the fields reflected from the room walls. These reflected fields are computed using the images of the dipole with respect to the walls. Hard and soft polarization are considered, their related reflection coefficients can be found in [6], their weak values make it possible to take into account first order images only.

Transmission line and emitting dipole inside the room

In the second step, for each position and orientation of the dipole, the transmission line is illuminated by the fields computed in the first step. Assuming that the reaction of the line on the dipole and the room is negligible, the end-voltage of the line is computed using Taylor's model [7].

PROBABILISTIC AND STATISTICAL APPROACH

Let us first define the elements of the statistical vocabulary we are going to use in the analysis.

Observable: the parameter used to quantify the coupling of the illuminating wave to the transmission line. In our case, it is the modulus I of the current flowing in the terminal impedance Z_L or the quantile I_q which will be defined later on.

Factors: the observable is a function of a set of variables such as: the dimensions of the room, the length, wires separation and diameter and load impedances of the transmission line, the parameters of the illuminating wave. These variables are called factors and each one takes its values over some finite interval. We shall limit the analysis here to the wires separation h, the terminal impedance Z_L, the coordinates Xs, Ys, Zs of the center of the dipole, the angles θ and ϕ characterizing the orientation of the dipole. Thus, we have I = I(h, Z_L, Xs, Ys, Zs, θ, ϕ). We define the 2D and 5D vectors, respectively **f** = (h, Z_L) and **s** = (Xs, Ys, Zs, θ, ϕ).

Configuration: it is made of a loaded transmission line randomly illuminated by the dipole. Thus, for each configuration the components of **f** have fixed values, and **s** is a random vector the components of which are random variables uniformly distributed over their intervals of definition.

The probabilistic and statistical analysis makes use of two approaches, Monte Carlo and Kriging.

Monte Carlo approach: This is a three steps method which provides an estimation of the probability density function (pdf) of the observable I for each configuration. First, we select at random Ns values of **s**, denoted $\mathbf{s_i}$, and for each one, we compute (or measure) the value of the observable Ii, i = 1,..., Ns. It is convenient to write Ii = I($\mathbf{s_i}$ / **f**). Here we have selected, at random, 7 values for each of the three coordinates of the center of the dipole, 5 values for each of the two angles (θ and ϕ) leading to Ns = 8575 illuminations for each value of the vector **f**. We then build the histogram from the values of Ii. In the last step, we fit the histogram with the pdf of a known probability distribution. In the following, we will deal mainly with the observable named the q^{th} quantile, computed either from the histogram (empirical quantile) or from the pdf (theoretical quantile), and defined as the values I_q such that Probability($I<I_q$) = q%.

Kriging: Let us now consider N_c values $\mathbf{f_j}$ of the vector **f**,. For each $\mathbf{f_j}$ compute the corresponding quantile q_j. For example, choosing 3 values for h and 3 for Z_L leads to N_c= 9. If the values of h and Z_L are regularly distributed over their intervals we say that we have built a complete experiment design. The techniques of experiment design are a well known approach to build an optimized, in some sense, data base for an observable [8]. The question now is, given a new configuration **f** which does not belong to the previously defined data base, how can we predict the related quantile value I_q ? This problem can be looked at as an interpolation one, and we shall provide an answer by means of an approach called Kriging where I_q is represented as the sum of two terms, a regression model and the realization of a random process of known covariance function. We seek a solution $I_q(\mathbf{f})$ as a linear combination of the $I_q(\mathbf{f_j})$, j= 1, N_c. In addition, the Kriging method provides for each predicted value $I_q(\mathbf{f})$ a standard deviation σ which is a measure of the degree of accuracy of the prediction. For a more complete presentation of Kriging, one may refer to [9]-[10]. The Kriging approach allows a fast prediction of a large number of values of an observable, from a small number of given values of this observable and is able to handle measurements errors.

RESULTS

When the dipole is alone in the room, we have shown that the magnitude of the emitted electrical field is a random variable which follows a Rice distribution. This result is to be expected since the dipole is not an isotropic source. Such a distribution has been proven to be adequate for describing the electric field magnitude distribution in lossy reverberating chambers [11], the room considered here can be looked at, in some way, as such a chamber.

When a transmission line of length 4.5 λ is placed inside the room, we have computed the histogram of the values of the electric field magnitude at the middle of the line, Fig.2. It appears that most of the values of the electric field are lower than 15 V/m, but a few data points exceed 30 V/m. The far end current values are mostly concentrated around the lower part of the data range with a very thin tail. The computed values are far lower than in the case where we have a single transmission line over an infinite ground plane [5] where the coupling occurs in the near-field region of the dipole and may be very strong as the dipole can be very close to the transmission line. Kriging of the q=95 quantile data (N_c=9) has been successfully achieved and validated, Fig.3. The quantile I_{95} has been computed for 3 values of Z_L : 0Ω, 100 Ω and 200 Ω. The red curve displays the interpolated values ofthe quantile obtained by means of Kriging. The dashed curves represents the interpolated values ± the standard deviation. The interpolation is validated using the test points which represents the exact values of the quantile computed for Z_L = 50Ω and 150Ω.

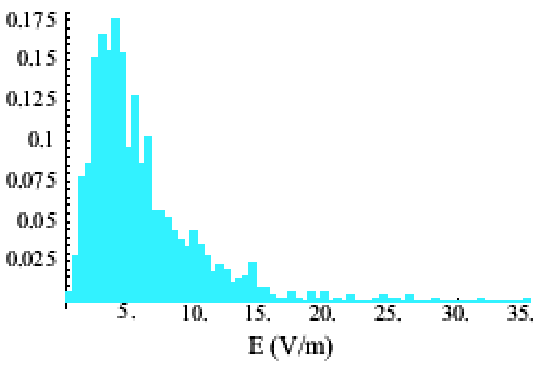

Fig.2. Histogram of the E field at the middle of the line

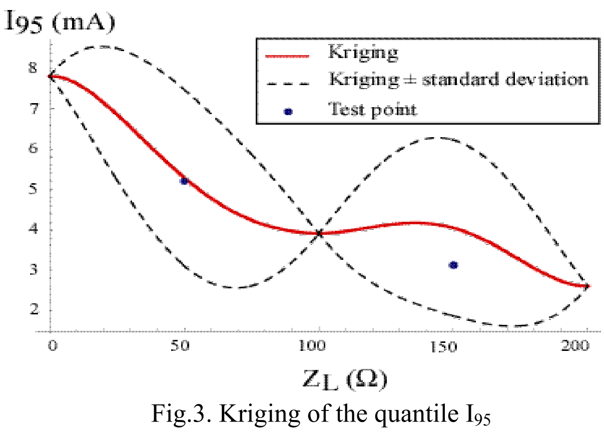

Fig.3. Kriging of the quantile I_{95}

CONCLUSION

This study has introduced and validated a statistical approach suitable for describing the coupling between a random dipole source and a transmission line placed in a room. The quantile of the far end current appears to be a well defined, relevant and stable observable. The kriging technique allows to perform a satisfactory interpolation of the computed or measured data in order to save time with reasonable uncertainties on the obtained results. Further work will deal with more complex models like multiconductor transmission lines placed in furnished rooms.

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