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Statistical Analysis of Matching Properties of Randomly Distributed Thin and Thick Dipoles

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Abstract

A statistical analysis of the matching properties of a dipole surrounded by thin and thick randomly distributed loaded dipoles is presented. The input impedance and input reflection coefficient of the driven dipole is obtained by using the IEMF method and validated by NEC and measurements. The cumulative distributed functions are presented for different dipole densities and the mismatch of a surrounded thin or thick dipole is studied for different surrounding loads.

1. Introduction

UHF RFID (Radio Frequency Identification) technologies are used for tracking and identification of objects and persons. In some applications, such as tracking in laundry, the density of RFID tags is high and this may give rise to an important electromagnetic coupling between tag antennas which modifies antenna's parameters, i.e. matching properties and radiation pattern. These electromagnetic modifications can alter and degrade the communication links between devices. Despite an initial description of the mutual coupling between RFID tags [1], the statistical modelling of the impact of the mutual coupling for high densities of RFID tags is still a new topic.

Following a series of previous publications [2] and [3], we model a set of randomly distributed tags by dipole-like antennas and we extract a statistical estimation of the behaviour of the straight dipoles in a randomly distributed set. In this paper, we will compare the statistical behaviour of thin and thick dipoles according to their mismatch properties. The electromagnetic coupling between thin dipoles can be easily modelled by IEMF method (Induced ElectroMotive Force) while a rigorous numerical simulation or measurement is time consuming for thick dipoles. The idea is to show that the rate of mismatch of realistic dipoles in a random set with a given density, can be estimated by the thin dipoles in the same set.

2. Simulation and measurement

The advantage of IEMF method [4] is its simplicity and reduced calculation time, the drawback is that this method gives accurate results only for thin dipoles (diameter less than $10^{-3}\lambda$). As the aim of this paper is to make a statistical

assessment of the mismatch behaviour of dipoles, the IEMF method is a good candidate to produce a rich database. If the statistical behaviour of thick dipoles are similar to that of the thin dipoles, then IEMF applied to thin dipoles would become the reference method. In order to prove this concept, some extra steps are necessary. Due to limited precision of IEMF for thick dipoles, we use NEC which is a numerical electromagnetic simulator based on MoM. The IEMF results are thus compared with NEC results for thin dipoles and NEC results are compared to measurements for thick dipoles.

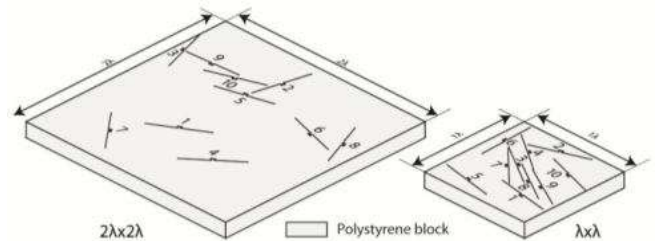


Figure 1: Set of randomly distributed dipoles on a polystyrene block of $2\lambda \times 2\lambda$ and $\lambda \times \lambda$.

First the input impedance of an isolated thick dipole is measured. Then in a given set of randomly distributed dipoles, the input impedance of a driven dipole is measured while others are short-circuited. The thick dipoles are made of copper wires of length 17 cm ($\approx 0.5\lambda$) and diameter 1 mm ($\approx 3 \times 10^{-3}\lambda$). The set of dipoles are fixed in a block of polystyrene (Figure 1). The driven dipole is fed with a differential probe using a 2-port VNA.

Figure 2 presents the real and imaginary parts of the input impedance of an isolated dipole as a function of the frequency. NEC results for both thin and thick dipoles are in excellent agreement with IEMF and measurements, respectively. Figure 3 shows the input impedance of dipole no.1 in the highest distribution density $\lambda \times \lambda$. The input impedance of surrounded dipoles deviates from that of an isolated dipole and the perturbation is globally more important in the highest density configuration but highly depends on the position of the driven antenna with respect to the others. As these given configurations are two examples among an infinite number of distribution possibilities, the mismatch of a surrounded dipole should be quantified statistically by taking into account an important

number of distribution profiles. Given the important number of samples, the results are only based on simulations.

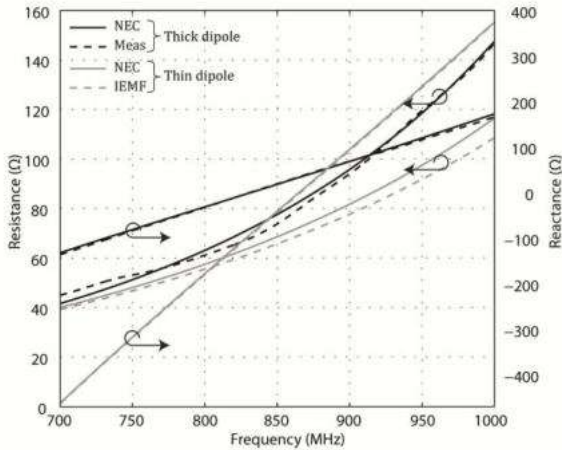


Figure 2: Input impedance of an isolated thin and thick dipole.

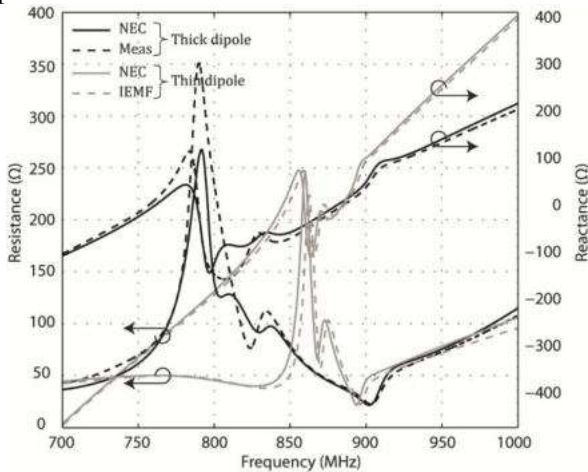


Figure 3: Input impedance of dipole no.1 in $\lambda \times \lambda$ distribution area.

3. Statistical analysis

In order to statistically assess the mismatch of a surrounded dipole in different random configurations, the reflection coefficient for the i^{th} surrounded dipole is defined by: $\Gamma_{in_i} = (Z_{in_i} - Z_{ref}^*) / (Z_{in_i} + Z_{ref})$ where the reference impedance Z_{ref} is the complex conjugate of the self-impedance of an isolated dipole at the working frequency (892 MHz). The experimental data include 200 random configurations of 10 dipoles. The input reflection coefficient (Γ_{in}) for each dipole has been calculated when all others are either short-circuited or matched. The cumulative distribution functions (CDF) for the magnitude of the input reflection coefficient in dB are presented in Figure 4. For the two different loads, there is an excellent agreement between the CDF obtained by IEMF and NEC for thin and thick dipoles. This happens while the self or input impedance of an isolated or surrounded thin and thick dipole is different. Still the statistical behaviours of the two dipoles are very similar to each other and thus the amount of mismatch of thick dipoles for a given distribution density can be estimated by thin

dipoles. By fixing a threshold for $|\Gamma_{in}|$, the percentage of dipoles having a smaller reflection coefficient can be estimated for both densities and terminating loads. Table 1 summarizes these results.

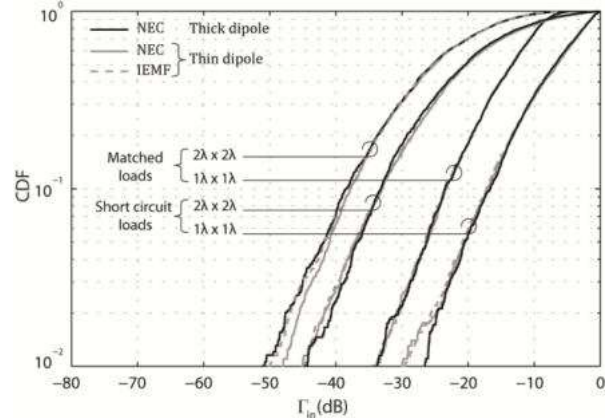


Figure 4: CDF of $|\Gamma_{in,i}|$ of a dipole, surrounded by short-circuited or matched dipoles

Table 1: Percentage of matched dipoles.

Threshold	$ \Gamma_{in} = -10$ dB		$ \Gamma_{in} = -15$ dB	
Load	Short	Matched	Short	Matched
$2\lambda \times 2\lambda$	85%	96%	70%	87%
$\lambda \times \lambda$	33%	77%	14%	40%

4. Conclusions

The behaviour of thin and thick dipoles, according to their matching properties, in a randomly distributed set is estimated and compared to each other. The results show that the realistic thick dipoles can be faithfully represented by thin dipoles when the goal is to have a global estimation of their behaviour and not the mismatch of one dipole in a particular configuration. In on-going works, our approach is extended to statistically assess the radiation pattern distortions of surrounded dipoles.

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