RFID Tag Antennas Designed by Fractal Features and Manufactured by Printing Technology

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Abstract. Based on the fractal features, this work is to design RFID Tag antennas with minimum area needed as a tag. The designed passive tag is to be responsible for the EM wave of 915MHz from the reader. The concept of complex conjugated matching is used in designing the antenna. Electromagnetic Simulation tool is also used to help this design as well. The techniques of measuring the material parameters necessary in the design procedure are also mentioned in this paper. Offset printing technology is employed to manufacture these tag antennas which is assumed as a kind of low-cost tags. Real performance of these tags is also shown in this work.

1 Introduction

Even invented and applied initially during the World War II, RFID (Radio Frequency Identifi-cation) [1] has attracted much attention recently. Precisely speaking, RFID has been applied very widely in some proprietary or closed systems, for example, animal control, portal control (access badges), etc. in last decades. The main advantages of RFID application are, storing item data in an electronic way, data access by electromagnetic wave, and allowing multiple accesses to RFID tags. Based on the diverse applications, different spectrum bands are allocated, for example, LF (125 - 134.2 kHz and 140 - 148.5 kHz) for animal control, HF (13.56MHz) for electronic ticket, and UHF (868 MHz-928 MHz) for logistics, etc. Most of the frequencies are located in the ISM (Industrial, Scientific and Medical) bands [1].

However, RFID was emphasized again mainly because of the need of supply chain [2]. By proposing a standard for the format of electronic data used for goods items, of which EPC (Electronic Product Code) [3] is an example, the products can be registered at once when they are shipped out from the factories, and be released when they are checked out at the counter of a supermarket. This is called “product tracking” and is to be carried out in an “Internet of Thing”.

When the RFID tags are used in the logistics, they are not supposed to be recycled after being used. Therefore, the cost of tag will be a key factor to determine if this technology can be widely applied or not. There are three parts composing the tag

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cost, namely, antenna, chip and assembly for them. It has been believed that, applying the traditional printing technologies [4] to produce the antennas will lower the cost of the antenna part. One of the major efforts of this present work is to produce the tag antenna by traditional offset printing method to demonstrate the possibilities of making low-cost tags in high-volume.

Based on the fractal features [5], this work is to design RFID Tag antenna with minimum area used as a tag. Usually the fractal antennas own the characteristic features of minimization, wideband and multi-band. As a matter of fact, design by fractals is also able to give an engineering path to follow in the simulation procedure when searching for the target. As a RFID application in UHF band [6], the designed passive tag is to be responsible for the EM wave of 915MHz from the reader.

Referring to Figure 1, RFID tag antenna is a kind of planar antenna, in which the antenna metal layer is laminated on a dielectric substrate. Usually, even they look diverse in shape in RFID Tag industry; the type of dipole antenna is used for the tags operating at frequency for UHF band and for higher bands. In designing such a kind of tag, the material parameters, for example, the conductivity σ of the antenna metal and the dielectric constant ε_r, are necessary to be given in the simulation phase. In this work, the measurement techniques of material parameters are also mentioned. Performance evaluation both by simulation and measurement are shown in this paper.

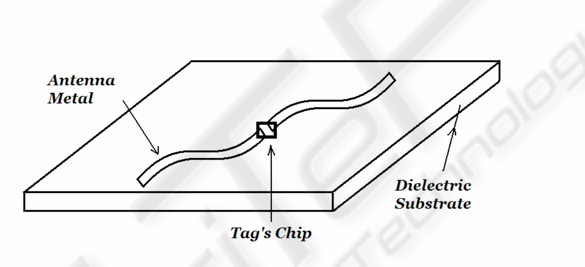

Fig. 1. The physical structure of a RFID tag.

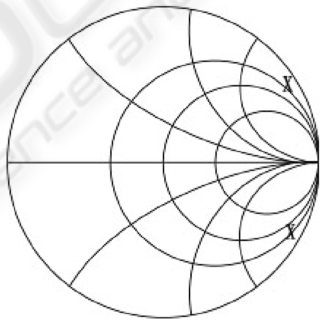

Fig. 2. Situation of complex conjugated impedance matching on the Smith Chart.

2 Design of Tag Antenna Using Fractal Features

The operation in a tag is that, the antenna receives the incoming EM energy and transfers into the chip; and chip sends back the data-modulated EM wave to the RFID reader. As depicted in Figure 1, to ensure the efficiency of energy transfer in between chip and antenna, they should be in a "match" condition. In ordinary antenna industry, the antenna is designed with a standard input impedance, for instance, $\mathbf{50\,\Omega}$ or $\mathbf{75\,\Omega}$, to have impedance match with transceivers or other RF devices. However, in the RFID Tag industry, for the purpose of cost-down, usually the match network inside the chip is not offered. Consequently, it needs a complex conjugated matching to ensure highest power transfer in between the chip and antenna, namely, to maximize the tag performance. Those two "X" marks show the input impedance positions of the chip and antenna on the Smith Chart in Figure 2. Most of the cases, chip's is the lower "X", and antenna's is the other one. That means, usually the chip is capacitive; and the antenna for being designed should be inductive. The present tag antenna is developed based on this theory.

As an EM design tool, CST [7] is employed to help design antenna prototype. Since there two kinds of material are involved in the tag, and since this tag antenna is to be printed on paper by offset printing technology, before beginning the design, the conductivity $\boldsymbol{\sigma}$ of the conductive ink, the paper's dielectric constant $\boldsymbol{\varepsilon_r}$ and its associated loss tangent $\mathbf{tan}\,\boldsymbol{\delta}$ should be given. The lithographic conductive ink used in this work is CLO-101A purchased from Precisia LLC [8], and its corresponding conductivity $\boldsymbol{\sigma}$ was measured based on the technique described in the literature [9][10]. The metal cylindrical cavity shown in the Figure 3 is used to measure the ink's conductivity according to that theory. The ink is coated on the inner side of the right and left planar walls of this cavity. The measured conductivity is $\mathbf{3.85\times10^{6}}\ \boldsymbol{S/m}$, which is only 6.6% or so of the copper's $\mathbf{5.8\times10^{7}}\ \boldsymbol{S/m}$. As what expected, such a kind of ink is not as good as ordinary conductors to be antenna radiating material. This should be seriously taken into account when the tag performance is emphasized and they are produced by printing technologies.

Fig. 3. Metal cylindrical cavity for measuring the ink's conductivity.

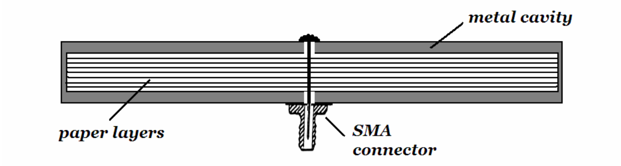

Fig. 4. Rectangular cavity for measuring the dielectric constant of coated paper.

On the other hand, the dielectric constant ε_r of the coated paper, which is used as the substrate of the tag, can be obtained by applying the technique of cavity resonator [11][12]. By this method, referring to Figure 4, the frequency response is measured two times at least for this rectangular cavity with different height. The paper layers are contained in this cavity in measurement. The resultant dielectric constant ε_r of paper used is 2.83 and its $\tan\delta$ is 0.046 around the frequency 915MHz. This shows that the paper is of a little loss and should be carefully considered.

To have a path to follow for designing the antenna shape that is of complex conjugate matching with the chip, the fractal is used to generate it. Among the fractal geometries, the Sierpinski gasket fractal is adopted to develop, see Figure 5.

The chip used in this project is the XRA00 of Alien Technology [13], which has an input impedance $6.7 - j197.4\Omega$. Hence, the target impedance for the antenna is $6.7 + j197.4\Omega$ in theory. Fig. 6 is the simulation model established in the CST package for a tag antenna. It is based on the Sierpinski gasket fractals. In addition to generating fractals through different stages, the rectangular dimension of this tag is also under adjustment to search for the target input impedance of the antenna. Table 1 shows the simulated input impedance of this fractal antenna due to different dimension. Some of the candidates in this table are to be printed and analyzed later.

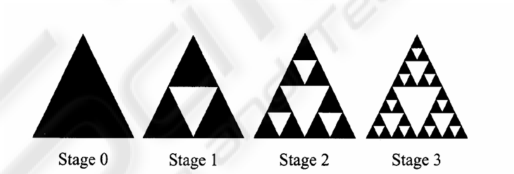

Fig. 5. Sierpinski gasket fractals.

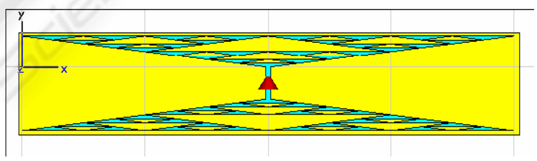

Fig. 6. Simulation model of a tag antenna in the EM package CST

Table 1. Simulated input impedance of the tag antenna.

Tag dimension mm x mm	R (Ω)	jX (Ω)
10 x 120	9.211	31.86j
10 x 130	9.614	51.86j
10 x 140	10.32	75.71j
10 x 150	10.08	91.83j
10 x 160	9.728	119.4j
10 x 170	12.95	145.6j
10 x 180	15.04	178.5j
10 x 190	18.31	221.8j
10 x 200	20.15	281.3j

3 Printing Tag Antenna and Performance Analysis

Figure 7 shows a demonstration of the printed paper sheets on which many tag antennas had been printed by offset printing technology. This antenna is based on the simulation results mentioned above and operating in UHF band.

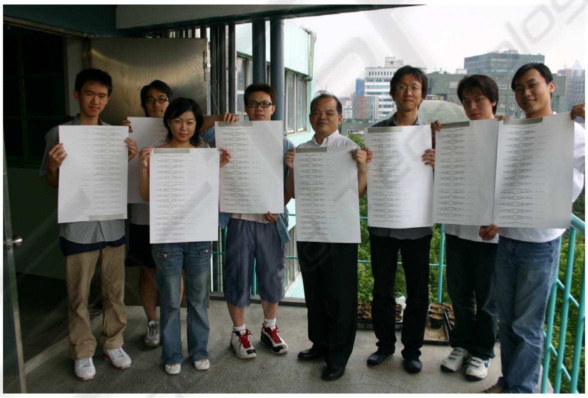

Fig. 7. Demonstration of high-speed production of RFID tag by offset printing technology.

Figure 8 shows the details of this printed tag antenna with a dimension 10mm x 180mm. In an antenna anechoic chamber, by using a UHF reader in measurement, this tag's responsible distance is about 1m. For the purpose of comparison, around the same dimension, this antenna shape have also been made by screen printing and by ordinary PCB process, the former can reach to 1.5 m and the latter can reach up to 3.4m. These antennas are supposed not perfectly matched with the chip. The farther distance they can make is because the screen printing can print thicker film than offset printing does; and the PCB process is to provide 0.018mm thick metal layer of copper. Less conductive ink, thinner printed ink's layer and substrate with higher loss (coated paper) indeed make the tag antennas produced by offset printing technology less efficiency. Anyway, its unique advantage is to able produce tags in high-speed and in high volume, yet being low-cost.

Fig. 8. A single RFID tag of UHF band made by offset printing technology.

4 Conclusion

This paper has outlined and demonstrated a complete procedure by which the offset printing technology is applied to produce high volume and low-cost RFID tags. Based on the concept of complex conjugated matching, the design for tag antenna is carried out firstly by the help of the EM simulation package. To precisely design the antenna by computer simulation, the techniques of measuring material parameters given in literatures are also applied to obtain those parameters of conductive ink and paper. By the up-to-date offset printing machine, the tag antenna had been printed out by a high-speed manner to demonstrate its possibility to be a low-cost product.

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