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Low-Cost Solution for RFID Tags in Terms of Design and Manufacture

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1. Introduction

Even invented and applied initially during the World War II, RFID (Radio Frequency IDentification) technologies [1] have attracted much attention recently. Precisely speaking, RFID technologies have been applied very widely in some proprietary or closed systems, for example, animal control [2], portal control (access badges), etc. in last decades. The main advantages of RFID application are, storing item data in an electronic way even for further update, data access by electromagnetic wave in a wireless manner, and allowing quick 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 [3]. By proposing a standard for the format of electronic data used for goods items, of which EPC (Electronic Product Code) [4] is an example, the products can be registered at once when they are shipped out from the factories in one country, and be released when they are checked out at the counter of a supermarket in the other country in the world. These products might have been transferred through Customs of many countries and carried by different traffic means. When being through these check points, the related data stored in the tags are updated. This is called "product tracking" and is to be carried out in an "Internet of Thing (IOT)" [5].

This Chapter is to have a review on the technology theme - how to provide low-cost RFID Tags, when RFID technology is to be applied into the logistics area where the RFID tags are supposed to be not re-usable and to be as "zero-cost" as possible. Generally speaking, there are three major parts composing a RFID Tag's total cost, namely, antenna, chip and assembly for them. The cost of antenna, in addition to the design phase, is mainly dependent on the manufacturing process. Therefore, manufacturing process should be focused if antenna's cost, then the tag, is concerned. This is the theme of this Chapter.

Not like the other antenna applications, for example, wireless LAN or mobile phone, in which antennas need to be compliant to the end products' appearance by following the market trend. In the tag antenna industry, on the contrary, it does not need to design or modify the tag antenna often. The tag antenna just needs to electrically match the chip used in the beginning of design. It is not necessary for tag providers to prepare a wide product spectrum in the market. Again, not like the mobile phone industry, RFID tag's players just

need few types of antenna to run their business. Therefore, they only need to pay their attention on the manufacture cost of tag antenna, because of the huge amount of worldwide supply.

For RFID tag chip, there is a key factor related to its cost-down, namely, reliability assurance. Since this kind of chip is very low-cost, possibly under sub-cent scale in the future, and is of huge amount in production, any means for total QC (Quality Control - checking any flaws in terms of chip's functions) in the manufacture procedure will raise their cost extremely. However, if not doing so, the risk of causing the chip silent or dead is very high, and under both of situation, the chip will not echo the reader's signal at all. Chip is always under high risk of being damaged from foundry to being packaged with antenna mentioned later. For example, electrostatics is one of killers, *i.e.* ESD (ElectroStatic Discharging) [6], in the whole procedure. Packaging the antenna and chip together is another potential bottleneck of the process of lowering the cost of a RFID tag, because that, both of production speed and reliable package is two important musts yet it seems a dilemma. Usually, this give hints that expensive and sophisticate machines are necessary, and that cost of each tag is raised again.

In this Chapter, focusing on the low-cost subject of RFID tags, the manufacture aspect of tag antennas is discussed. It has been believed that, applying the traditional printing technologies [7][8] 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 antennas by traditional printing methods including offset printing, screen printing and a hybrid one based on gravure printing and vacuum deposition technology, to demonstrate the possibilities of making low-cost tags in high-volume. Fig. 1 is a demonstration of high-speed production of RFID tags by offset printing technology. There are several tens of printed tag antennas on each paper sheet.



Fig. 1. Demonstration of high-speed production of RFID tags by offset printing technology

Tags working both for UHF band [9][10] and HF band [10] are explained from the design phase to the performance evaluation in this Chapter. The designed passive tags of UHF and HF bands are to be responsible for the EM wave of 915MHz and 13.56MHz, respectively, from the reader.

Conclusively, this Chapter contributes to thoroughly outline the related issues and technologies for producing low-cost RFID tags. From the method details in design to the manufacturing technologies involved are mentioned and discussed. Specially focusing on the various printing technologies, the author explains the associated advantages and disadvantages when applying them from the point of industrial view. Moreover, the characteristics of used material are fully investigated and explained as for the design and production of this kind of low-cost RFID tags. To an engineer, the present content does provide a technical guide for the purpose claimed by the Chapter title.

2. Design of antenna for RFID tag

Referring to Figure 2, RFID tag antenna is a kind of planar antennas [11], 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 [12] is used for the tags operating at frequency for UHF band and for higher bands. In designing such a kind of tags, 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. Usually, they are frequency-dependent, and practically, they should be given by real measurement in stead of consulting with literatures when the materials plus the used frequency are assigned. Measurement techniques for these two parameters are to be discussed later.

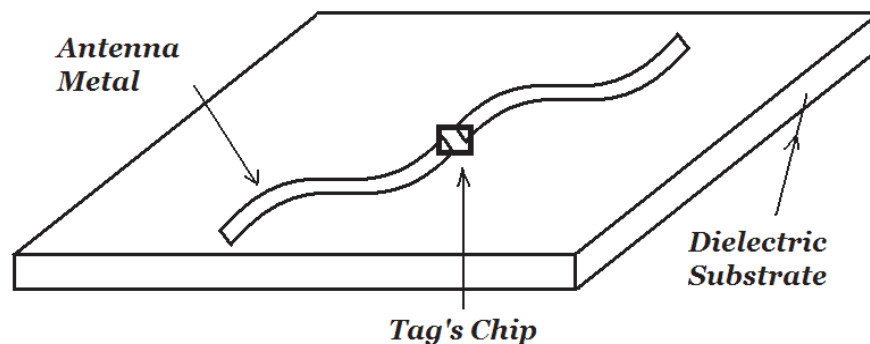


Fig. 2. The physical structure of a RFID tag.

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. For passive tags, the chip specially makes use the incoming wave as the DC bias energy for itself in addition to interpreting the commands inside the wave from reader. As depicted in Figure 2, 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, 50Ω or 75Ω , to have impedance match with transceivers or the 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 [12] 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 3. 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 at the operating frequency. The present tag antennas are developed based on this fundamental theory.

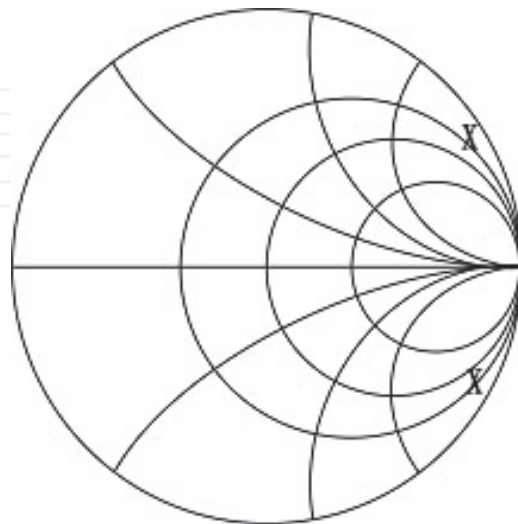
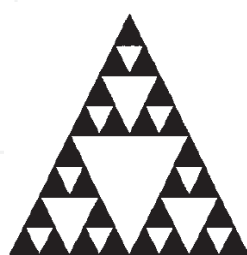


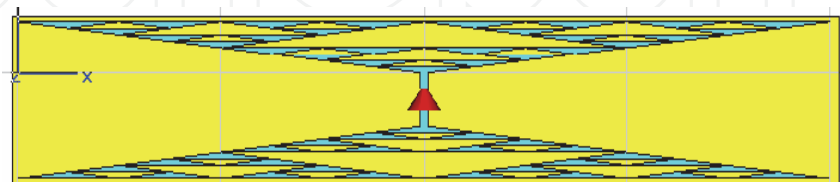
Fig. 3. Situation of complex conjugated impedance matching on the Smith Chart [12]

As an Electromagnetic design tool, CST [13] is employed to help design antenna prototype in this work. As mentioned above, dipole antenna is a good reference for designing RFID tag antennas, however, varied constraints may be usually applied for the commercial tags, for example, wider bandwidth, limited antenna size or different used materials, etc. Consequently, an antenna engineer actually has not many directions to design out a tag antenna, if he or she is not so experienced, even an expensive EM simulation package, say, CST, is available. Try-and-error approach is practical, but only for well-educated and experienced engineers, because he or she knows the antenna insight well. Under such a situation being lacking in much design experience, a systematic design methodology is probably useful.



Stage 3

(a)



(b)

Fig. 4. (a) Sierpinski gasket fractal, (b) Simulation model of a tag antenna in the EM package CST

Antenna design based on fractals [7][14], see Fig. 4(a), has attracted attention recently in antenna industry or academics since it is quite easy to follow. Fig. 4(b) shows a simulation

model of a tag antenna based on 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. A single RFID tag of UHF band designed by fractal methodology and made by offset printing technology is shown in Fig. 5. This tag antenna has also been printed by screen printing approach on PET (Polyethylene terephthalate). Usually, screen printing is able to offer thicker film and better performance, yet suffering with slower production speed.



Fig. 5. A single RFID tag of UHF band made by offset printing technology

3. Review and application of the printing technologies for RFID tags

In the report [8], there have been many kinds of traditional printing technologies mentioned and discussed. For example, offset printing (lithography), flexography, gravure process, screen printing, etc. Each one has its unique advantages and associated drawbacks in terms of the combined factors of engineering and cost. For example, offset printing is fast, yet only provides thin printed layer not mentioning its expensive equipment investment. Fig. 6(a) shows an offset printing machine in a shop. Screen printing is usually considered to be capable of providing thicker layer, yet speed is not so competitive in production. In theory, the tag antenna should be full of metallic material to have highest receiving and radiating efficiency. However, constrained by the printing process, usually the ink used is with low conductivity (discussed below) because that the other non-conducting materials are added into ink. Fig. 6(b) shows its printing process [8].

Another issue is that, the printed layer provided by offset printing usually is of the order $1\sim 2\ \mu\text{m}$ which is not enough to be a good radiating metal for antenna considering the sufficient skin depth [12]. Fortunately, one can use the multi-stage of plate cylinders, see Fig. 6(b), and multiple printing procedure to increase the necessary thickness before the ink is not attachable. That means, there are three cylinders (three stages) at least in charge of three color inks in sequence in a normal printing machine, then the thickness increase can be achieved by putting the same conducting inks on the cylinders in different stages. If the thickness is still not satisfied after a printing running on the machine shown in the Fig. 6(a), feeding the printed sheets into machine from beginning again for multiple printing can be considered. Fig. 1 shows the resultant sheets by such an engineering approach.

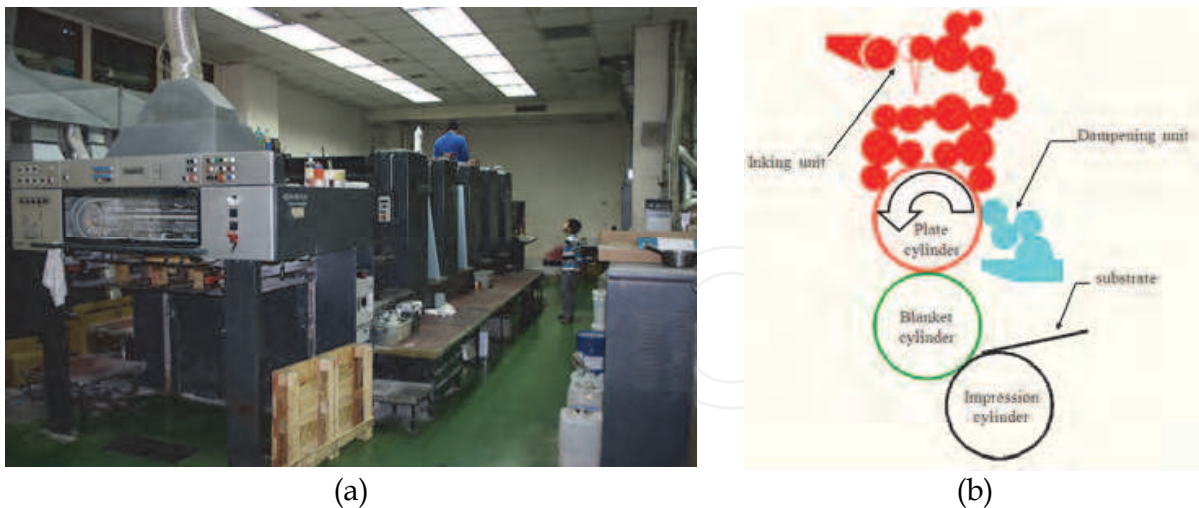


Fig. 6. (a) A high-speed offset printing machine; (b) the offset process [8]



Fig. 7. A hybrid method with gravure printing and vacuum deposition technology

Traditionally, gravure printing is thought as a factory process for mass production of printing subjects on diverse substrates, for example, papers, plastics and metal films, etc. Furthermore, it is usually adopted to produce the goods bag; consequently, it seems a good idea that one can print the RFID tag on the bag with the same printing process to form a “smart bag”. This is another thought of using traditional printing technology to promote RFID technology into the logistics, not mentioning the advantage of cost-down. A hybrid method with gravure printing and vacuum deposition technology has been proposed [10], in which the former is mainly to produce the printing mask and the latter functions to deposit metal film on the substrate. Such a method is implemented in a factory scale for mass production either producing tags only, see Fig. 7, or producing “smart bag” mentioned above.

Fig. 8 is a HF tag operating at 13.56MHz and is used to be embedded inside an ID card of students in Taiwan. It is made by such a hybrid process. Usually, the planar coil is used as the antenna structure for this band.

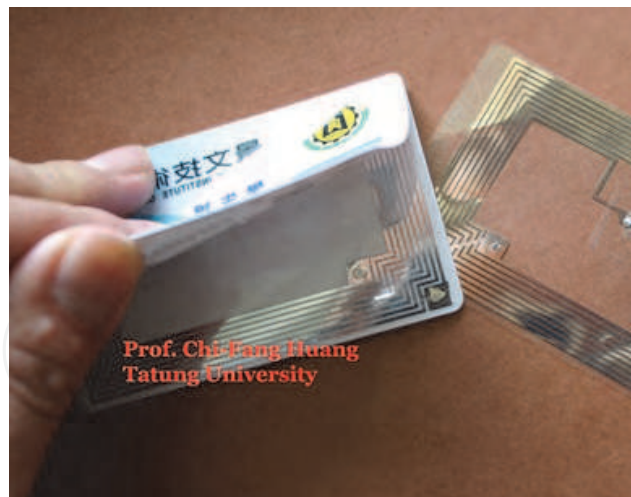


Fig. 8. A HF tag

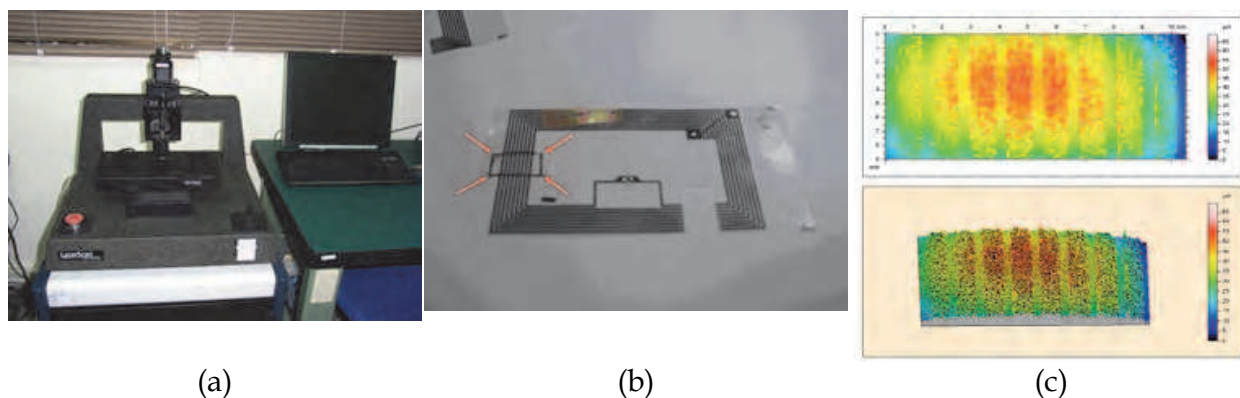


Fig. 9. (a) A confocal laser scanning microscope (b) Antenna film under measurement (c) measured thickness distribution

Unfortunately, this hybrid method is not able to offer thicker metal film as well, actually, what deposited is thinner, usually is about lower than half μm , even the layer is complete metal material. In industry, the thickness due to this process or by the other printing techniques all should be well monitored in terms of quality control. A confocal laser scanning microscope [15] has been suggested to measure the thickness of the RFID tag antenna made by this hybrid method as shown in Fig. 9(a). Fig. 9(b) is the antenna film under measurement and Fig. (c) shows the measured thickness distribution. It is indeed observed from Fig. 9(c) that requiring the uniformity of metal film is a main issue in this kind of production.

On the other hand, confocal laser scanning microscope is a kind of expensive equipment, on the contrary, economic ones for quick testing in manufacture lines are crucially necessary. A method of using the concept of eddy current [12] is also proposed [16]. Referring to the Fig. 10, a coil probe is designed to test the film sample which will affect the coil inductance because of the generation of eddy current on the circular conducting film. Such a deviation of inductance will be converted into a voltage reading by an electronic circuit to show the related thickness of printed film. This equipment and technique are very convenient for engineers to monitor the production line as for the film thickness from time to time.

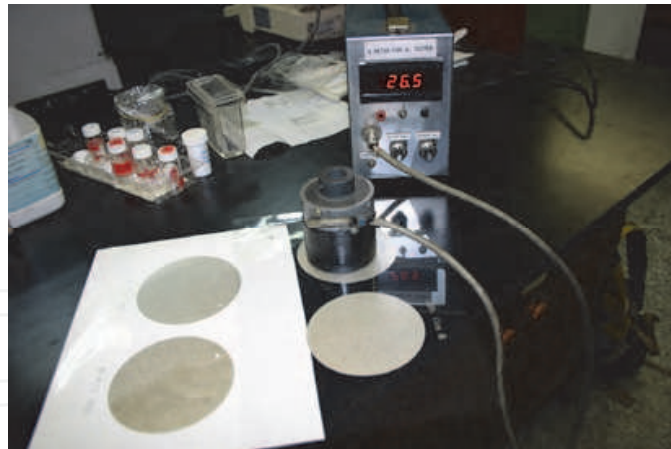


Fig. 10. An economic method to measure the conducting film's thickness

Material factors are very important in antenna design and should be studied thoroughly. Since there are two kinds of material being involved in the tag, and since this tag antenna is to be printed on a substrate, for example, the paper when using offset printing technology, before beginning the design, the conductivity σ of the conductive ink, the paper's dielectric constant ϵ_r , and its associated loss tangent $\tan \delta$ should be given. The lithographic conductive ink used in this series of study of offset printing is CLO-101A purchased from Precisia LLC [17], and its corresponding conductivity σ was measured based on the techniques described in the literatures [18][19]. The measured conductivity is $3.85 \times 10^6 \text{ S/m}$, which is only 6.6% or so of the copper's $5.8 \times 10^7 \text{ S/m}$. 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.

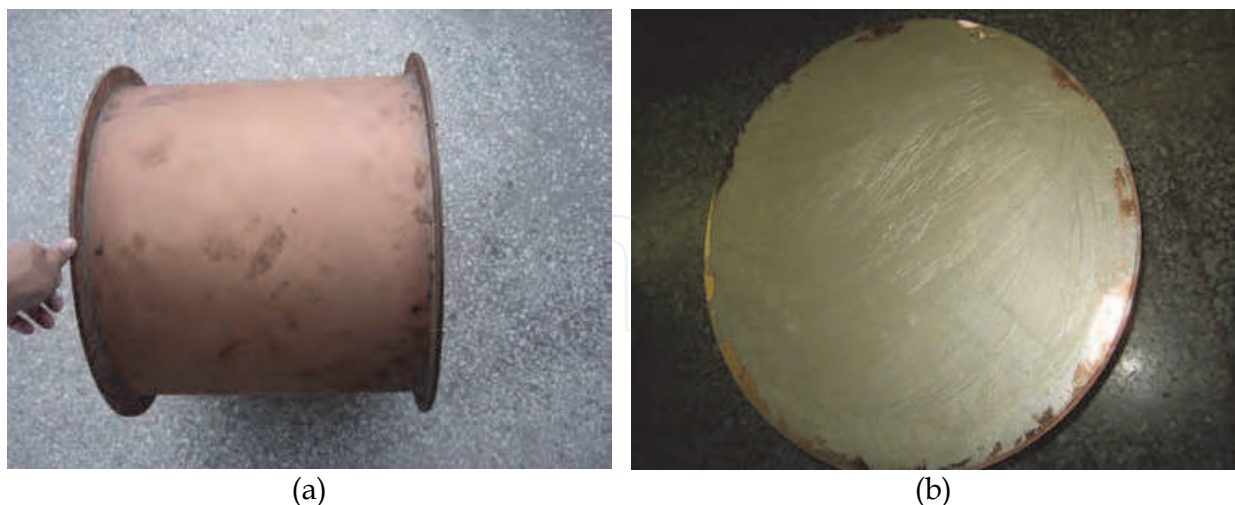


Fig. 11. (a) A resonating metal cavity following the theory in [19], (b) conducting ink on the wall

On the other hand, when applying the hybrid method of gravure printing and vacuum deposition technology, the different considerations are encountered. Firstly, PET (Polyethylene terephthalate) is always used as the antenna substrate for this method. Using

the method mentioned in [20][21], Fig. 12 shows a closed metallic cavity, inside which the dielectric material under test is enclosed, for measuring layered PET's dielectric constant and loss tangent. The results are $\epsilon_r = 3.733$ and $\delta = 0.0158$, respectively. On the other hand, the measured dielectric constant ϵ_r of paper used for offset and screen printing is 2.83, and $\tan \delta$ is 0.046 around the frequency 915MHz. This shows that the paper is with more loss than PET and should be carefully considered. That means PET is better than coated paper as the substrate of the tag antenna. Anyway, PET has an environmental pollution issue, if the printed tags are to be used for logistics. Also, even the vacuum deposition technology is usually not able to provide enough thickness of conducting film as the radiator of tag antenna, $1 \mu m$ or so in our realization shown in Fig. 7 and Fig. 8, but it has equal conductivity as what the aluminum has. It has been found that, the performance made by it is quite better than that of offset printing on papers.

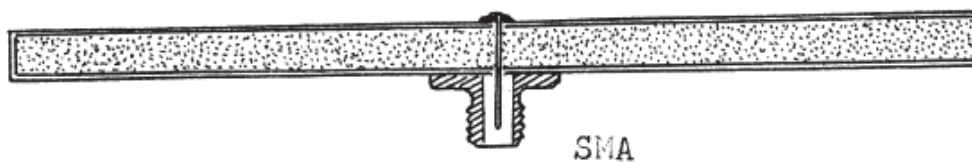


Fig. 12. Cavity method for measuring the PET's dielectric constant and loss tangent



Fig. 13. A tag using the company brand being antenna's arm

As for further application, usually text or company logo may be designed into the antenna shape. Following the idea published in [22], a tag antenna using the brand name of TATUNG COMPANY [23] is shown in Fig. 13, which is made by offset printing. Such a kind of design benefits the advantage without applying patent for the tag. However, because of the physical nature of antenna, for instance, its current distribution, normal computer fonts are not necessary to fit to the working shape of antenna.

Another example is shown in Fig. 14, where the logo of Taiwan Lamination Industries, Inc. [24], who is a gravure printing company, is to form one arm of the dipole antenna. This tag is made by the hybrid method of gravure printing and vacuum deposition technology, and produced by Taiwan Lamination Industries, Inc. TI's RFID chip [25] is used for this UHF tag shown in Fig. 14, which has input impedance $380 - j62.12\Omega$. Hence, the target impedance for the antenna is $380 + j62.12\Omega$ for a complex conjugated matching condition in theory. The simulation model established in the CST package for this tag antenna is shown in Fig. 15.



Fig. 14. A tag antenna using a company logo

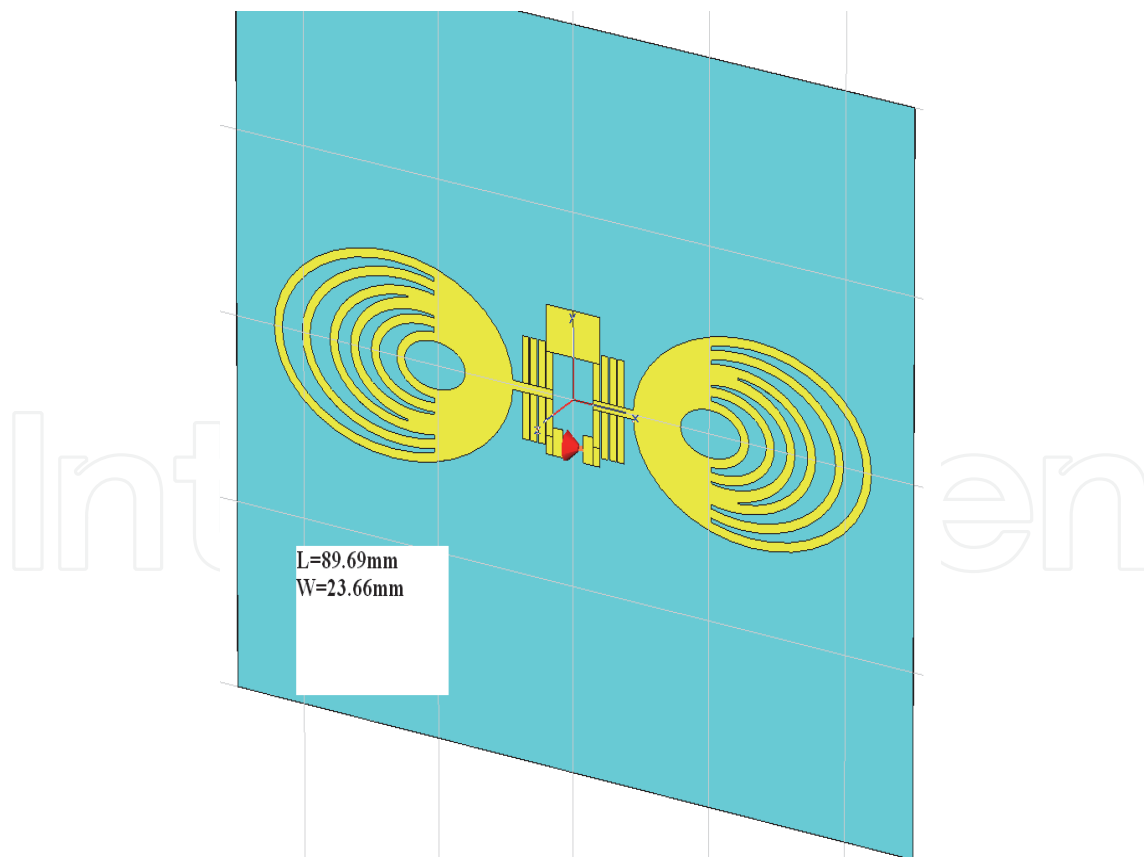


Fig. 15. Simulation Model of a UHF tag antenna

4. Performance analysis

As an example, back to the tag shown in Fig. 14 which is made by the hybrid method of gravure printing and vacuum deposition technology and has a size $85.8\text{mm} \times 23\text{mm}$, it can have a reading distance about 5 m when the measurement is carried in an antenna anechoic chamber in Tatung University. The tag shown in Fig. 5 has a dimension $10\text{mm} \times 180\text{mm}$. The reading distance of tags made by offset printing is always less than 2m. Less conductivity σ of conductive ink, thinner printed ink's layer and higher loss in substrate (coated paper) indeed make the tags produced by offset printing technology less efficiency. Anyway, both of these two different approaches have unique advantage of being able to produce tags in high-speed and in high volume, yet being low-cost. Anyway, sometimes the reading distance is not the absolute criterion to judge the tag performance. If the application focuses on the aspect of cost than the reading distance, the tags produced by the offset or screen printing on paper are more preferred.

5. Value-added application for RFID tags

As mentioned above, gravure printing is usually employed in making plastic bags, see Fig. 16. The concept of "smart bag" may be presented if the production both of bag and RFID tag can be combined together. Fig. 17 shows a new concept of embedding a RFID tag into the layer of a bag to form a "smart bag". In such a value-added application, however, some limitations should be considered. For example, thin metal foil and lossy paper (say, lossy Kraft paper) are not proper as the cover layers of the bag, because of their influence on the UHF wave transmission.

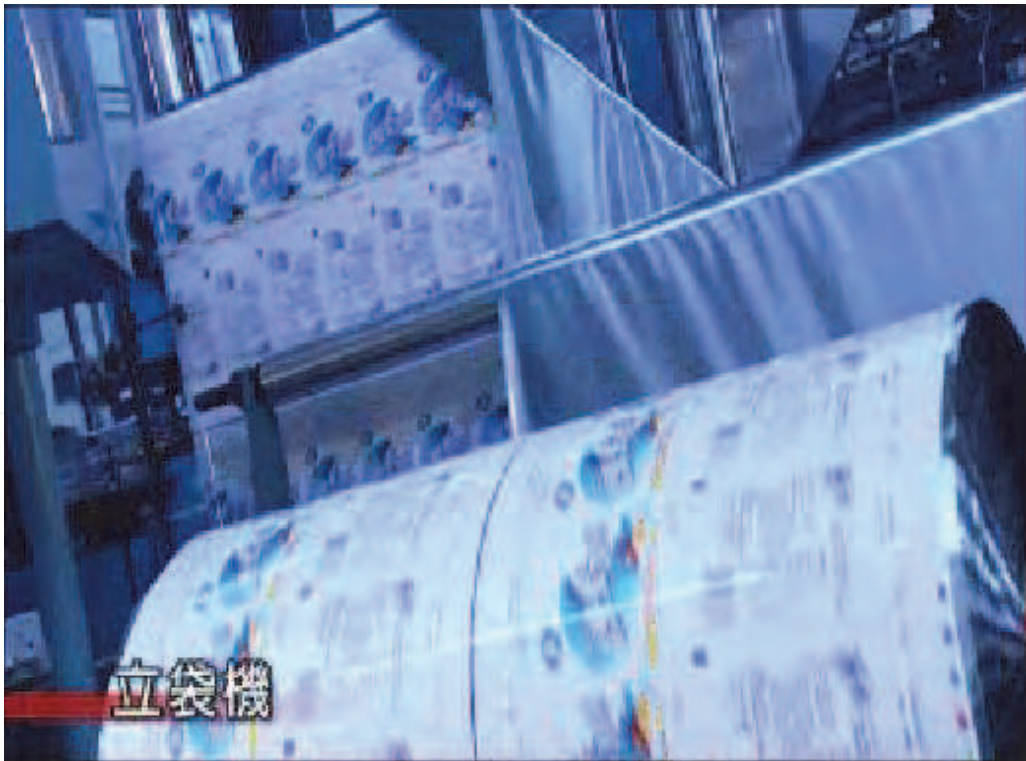


Fig. 16. Process of bag production in a gravure printing factory



Fig. 17. "Smart bag" – embedding a RFID tag into a plastic bag

6. Conclusion

This Chapter has outlined and demonstrated a complete procedure by which the offset printing technology or the hybrid method of gravure printing and vacuum deposition 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 by the help of the EM simulation package is explained firstly. To precisely design the antenna by computer simulation, the techniques of measuring material parameters are also applied to obtain those parameters of conductive ink, paper and PET substrates. By the up-to-date offset printing and gravure printing and vacuum deposition machines, the tag antennas had been printed out by a high-speed manner to demonstrate its possibility to be a low-cost product.

7. Acknowledgements

This series of RFID tag project was initially granted by Tatung Company [23], Taipei, TAIWAN, who plays the main role offering long-term support for the academic-industrial projects being carried on in Tatung University, and then Taiwan Lamination Industries, Inc. [24], who is a gravure printing company and is involved now in the development of PET-based printed tags and "smart bags" mentioned above. The interactive experience between the authors and managers of this company has generated much new knowledge of the hybrid method of gravure printing and vacuum deposition technology. Both of these two companies are appreciated. Sun Sui Print Co., Ltd [26], Taipei, TAIWAN, is appreciated for their kind support to provide the offset machines in printing the RFID tags designed in the present work. Moreover, we want to specially thank Mr. Wen-Ho Wu, the factory manager of this company. Without his professional guide in the offset printing procedure, this present work would not be done completely.

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With the increased adoption of RFID (Radio Frequency Identification) across multiple industries, new research opportunities have arisen among many academic and engineering communities who are currently interested in maximizing the practice potential of this technology and in minimizing all its potential risks. Aiming at providing an outstanding survey of recent advances in RFID technology, this book brings together interesting research results and innovative ideas from scholars and researchers worldwide. *Current Trends and Challenges in RFID* offers important insights into: RF/RFID Background, RFID Tag/Antennas, RFID Readers, RFID Protocols and Algorithms, RFID Applications and Solutions. Comprehensive enough, the present book is invaluable to engineers, scholars, graduate students, industrial and technology insiders, as well as engineering and technology aficionados.

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