Design and Modeling of Embedded 13.56 MHz RFID Antennas

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I. INTRODUCTION

Radio Frequency IDentification (RFID) Tags have become quite widespread in many services in the industry such as access control, parcel and document tracking, distribution logistics, automotive systems, and livestock or pet tracking. In these applications data are contact-free transferred to a local querying system (reader or interrogator) from a remote transponder (tag) including an antenna and a microchip transmitter. A suitable antenna for these tags must have low cost, low profile and especially small size whereas the bandwidth requirement (few kilohertz) is less critical.

A lot of interest has grown into the 13.56 MHz frequency in the last decade more than the VLF, LF and UHF bands .The use of 13.56 MHz frequency is proven to be very advantageous over these other bands [1], [2]:

- Frequency band available worldwide as an ISM frequency
- Excellent Immunity to environmental noise and electrical interference
- Minimal shielding effects from adjacent objects and the human body
- Freedom from environmental reflections that can plague UHF systems
- Good data transfer rate
- On-chip capacitors for tuning transponder coil can be easily realized
- Cheap ICs, disposable tags
- Cost effective antenna coil manufacturing
- Low RF power transmission so EM regulation compliance cause no problems

Most of the 13.56 MHz HF RFID systems employ the near field inductive coupling of the transponder tag with the reactive energy circulating around the reader antenna [1]. Since these tags are passive which means no internal power supply is needed, the necessary power required to energize and activate the tag's microchip or low-power CMOS Integrated Circuit (IC) is drawn from the localized oscillatory magnetic field created by the reader unit's antenna. [1] In order to charge up the IC with inductive coupling, the IC should be capacitive which requires the impedance of the radiating element (antenna) to be conjugately matched with respect to the IC's input impedance. For this reason highly inductive printed spiral coils are used for 13.56 MHz RFID applications as antennas.

In this paper, design and modeling of a single-layer 13.56 MHz RFID tag is presented with the development of the double-layer design to reduce size with the aid of IE3D software, which is based on method of moments (MoM).The antenna challenges which include port matching, efficiency, and size at 13.56 MHz as well as the performance advantages over the UHF band are also addressed in this paper.

II. ANTENNA DESIGN AND MODELING

The single-layer tag is shown in Figure 1.The inductor coil tag antenna is 4.7cm by 7.9cm with aluminum metal pattern printed on top of low-cost and easily manufacturable PET (polyethylene terephalate, ε_r =3.2, tanδ=0.017), and adhesive

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dielectric layers as shown in Figure 1. The IC is placed in the center where the two extended ports are. Figure 2 presents the lumped element model for the single-layer tag. This model is a modified version of previous RF inductor models [3, 4]. Since one-port measurement was conducted, the second port was shorted as seen in the model. This model was run through ADS simulation software's optimization process to obtain the freq-independent resistance (R), inductance (L), and capacitance (C) values using the input impedance results of the one-port measurement.

In Figure 1 the geometry for the double-layer tag is also shown. The inductor coil tag antenna is 4.0cm by 2.72 cm (economy in area by a factor of 3) with double-sided aluminum metal pattern (top+bottom) printed on PET and adhesive dielectric layers also displayed in figure 1. The single-layer model as described above was used to retrieve the R, L, and C of the circuit model given that the double-layer tag is merely two single-layer tags in series because of the way the two inductor coils are connected to each other.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The R, L, and C values from the single and double-layer lumped element models are presented in Table 1. The one-port measurement of the reflection coefficient (S11) gives the input impedance of the tag for both cases as shown in Figure 3. The lumped element model was optimized so that the measured input impedance data and the model data align perfectly. The IC was placed and the return loss was also measured as shown in Figure 3 again for both cases. The IC's parallel load capacitance and resistance (23.5 pF and 28 kOhm) with the input impedance of the tag create the resonant circuit centered at 13.67 MHz (single-layer) and 13.94 MHz (double-layer).

	Cp (pF)	Rp (Ohm)	Cadh (fF)	Ls (uH)	Rs (Ohm)	Csub (fF)	Rsub (Ohm)
Single-layer	8.71	55.87	346.36	4.16	5.46	576.44	599.48
Double-layer	30.03	9.76	796.18	2.40	4.19	1545.67	757.92

Table 1. Single and Double-layer lumped component model R, L, C values

The double-sided metal tracing creates more parasitic capacitance as seen from the *Cp*, *Csub*, and *Cadh* in Table 1. The substrate resistance, *Rsub*, is also quite high for both cases indicating how lossy the material is. The series inductance, *Ls*, and resistance, *Rs*, characterizes the inductor coil. The *Ls* depends on the overall length of the metal inductor coil; meanwhile, the *Rs* is mainly controlled by the width of inductor coil. The *Rp* is the result of pad capacitance which dominates in the single-layer case due to the use of bridge structure to connect one end of the inductor to the other.

The performance of the coil antenna as the radiating element depends on the efficiency which defines the read range of the tag. The fabricated tags yield operational distances of 37 cm (single-layer) and 22 cm (double-layer). The inductance of the coil plays a major role in the near-field coupling. The magnetic flux created inside the coil due to the inductive coupling between the reader and the tag is a function of the size and the number of turns of the coil. Another factor that limits the efficiency of the coil antenna is the PET dielectric loss (tanδ=0.017). As seen from Table 1, the double-layer *Rsub* is almost 3 times more resistive than the single-layer which indicates the presence of power leakage into the substrate. This also contributes to lower the efficiency as well as the read range. The plots in Figure 3 display the relationship between read range and return loss. The amount of power that is radiated by the double-layer tag is about 5 dB less than the single-layer. This explains why the read range of the double-layer tag drops to almost half of the single-layer. Differing from UHF (i.e. 915 MHz applications) systems, the RF field at 13.56 MHz is not absorbed by water or human tissue, which allows operation through water or human beings with the trade-off of having a larger physical size. The influence of the air moisture on the performance and efficiency is also negligible [2].As a result of the near-field operation of 13.56 MHz RFIDs (power decreases with 6th order of distance), the disturbing influence of adjacent systems or external noise is much lower compared to UHF systems (power level decreases as the square of the distance) [2], something important in RFIDs for tire/pallet inventories.

IV. CONCLUSIONS

Designing an inductor-coil embedded antenna for 13.56 MHz RFIDs present various challenges such as the parasitic capacitance and dielectric material (i.e. PET) limitations. The parasitic capacitance shifts the resonant frequency, so capacitance compensation should be considered such as adding series pad capacitance to reduce the effect. The dielectric materials used for these applications are generally very cheap yet lossy. This weakens the read range performance of the tag. Better performing 13.56 MHz RFID tags could be achieved by using less lossy dielectric materials and diminishing the ill-effect of parasitic capacitance by introducing series pad capacitance. In addition to this, the growth of the 13.56 MHz RFID market has benefited from the better performance of 13.56 MHz RFIDs compared to UHF RFIDs in complicated environments that get affected by factors such as air humidity or presence of human beings and water.

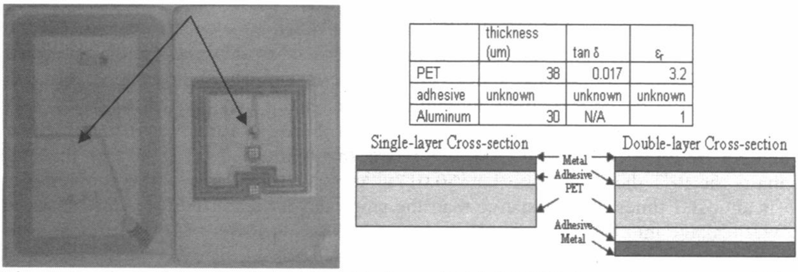
V. REFERENCES

1. UPM Rafsec 2002-2004, Tutorial Overview of Inductively Coupled RFID Systems, May 2003

2. AIM Frequency Forums, AIM FF 2000:001 Ver 1.0, Draft Paper on the Characteristics of RFID-Systems, July 2000

3. Joonho Gil and Hyungcheol Shin, "A simple wide-band on-chip inductor model for silicon-based RF ICs," *IEEE Transactions on Microwave Theory and Techniques,* vol. 51, No. 9, pp. 2023-2028, September 2003

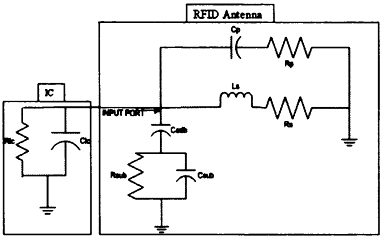
4. Jose R. Sendra, Javier del Pino, Antonio Hernandez, Javier Hernandez, Jaime Aguilera, Andres Garcia-Alonso, and Antonio Nunez, "Integrated inductors modeling and tools for automatic selection and layout generation, " *IEEE Proceedings of the International Symposium on Quality Electronic Design (ISQED'02)*



	thickness (um)	tan δ	ε_r
PET	38	0.017	3.2
adhesive	unknown	unknown	unknown
Aluminum	30	N/A	1

Figure 1. Single-layer (Left) and Double-layer (Right) RFID Tags. Metal trace widths are 0.8 (single-layer) and 1.4 mm (double-layer) and line spacing for both tags are 0.4

mm, # of turns: 7 (single-layer), 3+4 (double-layer), and arrows indicate where the IC is placed.



Ls: the series inductance of the square spiral
Rs: the ohmic losses in the metal traces of the spiral
Cp: capacitive coupling due to the electrical field between the spiral tracks and the pad capacitance
Rp: resistance in series with Cp
Cadh: the adhesive material capacitance between the coil and the PET substrate
Csub: the PET substrate capacitance
Rsub: the resistive loss in the PET substrate
Ric: IC resistance
Cic: IC capacitance

Figure 2. Lumped element model for Single-layer and Double-layer RFID Tags.

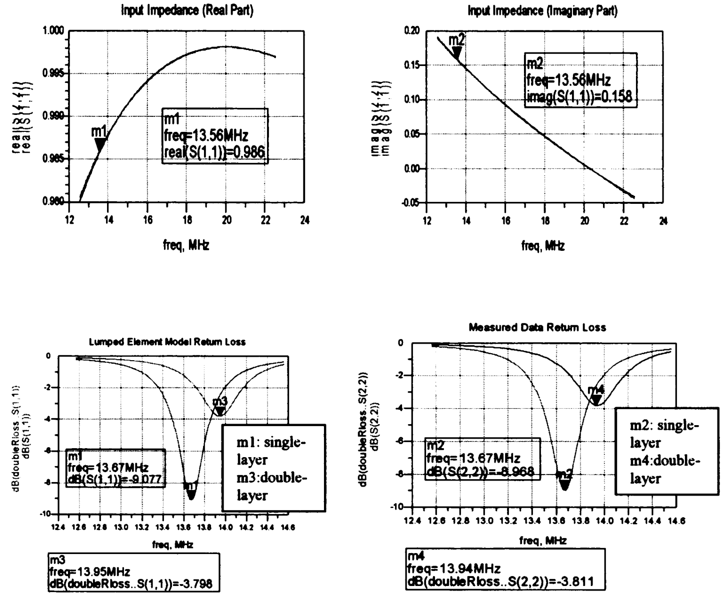


Figure 3. The single-layer and double-layer input impedance and return loss results. (**S22 is the S11 for the measured data, S22 just indicates the second set of data)