Design of Flexible RFID Tag and Rectifier Circuit using Low Cost Screen Printing Process

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Abstract

Flexible electronics is the future trend of the worldwide electronic industry. The RFID tag is one of the main applications in flexible electronics currently. This paper presents a flexible HF RFID tag which is manufactured by a low cost screen printing technique. The inductive coupling antenna is constructed by printing conductive silver paste on PET substrate to achieve good flexibility. The inductance and quality factor value of the antenna were designed using an EM simulator tool. Several design issues such as metal thickness, line width, and spacing between conductive coils related to the performance of inductive coupled antenna have also been analyzed carefully. The optimized antenna structure is properly chosen based on EM simulation results and measurements of several prototypes. A Philips I-CODE label IC was mounted on the inlay after being thinned. (The details of the manufacturing process flow will be examined in this paper later.) Finally, a half-wave rectifier circuit is proposed in this paper to demonstrate the potential of designing flexible circuitry using a screen printing process. In this design, one special High-DK material (with DK=20) which was developed by ITRI MCL was adopted to manufacture the capacitors in rectifier circuit. The experimental results shows that the rectifier which is powered by general RFID reader can be used to light up one typical SMD type LED successfully. The whole circuit size is about 16 cm^2.

I. Introduction

Flexible electronics is the future trend of worldwide electronic industry [1]. Figure.1 shows its applicable areas which include display, logic memory, sensors, OLED and printed RFID tags. Among these applications, the printed RFID tag is more mature than the others. The Radio Frequency Identification (RFID) technique is supported by Wal-Mart and is becoming one of the most popular wireless communication techniques in the world. RFID has several benefits relative to traditional bar-code technique such as non-contact reading, longer reading range, anti-pollution property, longer lifetime and larger carrying information capacity [2]. Table 1 shows various kinds of typical RFID systems. In general, RFID systems can be classified into three different types by operating methods which are passive, semi-active and active system. There are different operation frequency and standards in different countries. The common operation frequencies include 125 kHz in LF band, 13.56MHz in HF band, 915MHz in UHF band, 2.4GHz and 5.8GHz in microwave frequency. Of all of these standards, the passive 13.56MHz RFID system has been well developed and adopted in worldwide industry.

The main issue of spreading out RFID technology is how to lower the price of RFID tags in the process of manufacturing. Since flexible electronic technology has developed intensively all over the world in recent years, the printed RFID tag has become a possible solution to achieve the lowest cost. The developing research area of printed RFID tag covers all areas from material to process and component to system integration. These topics include organic semiconductor, organic logic memory and flexible printed antenna etc. In this paper, a printed RFID tag and rectifier circuit manufactured a using low-cost screen printing process is presented. The capacitors of rectifier circuit are made of flexible high dielectric constant (Hi-DK) substrate.

This paper proceeds as follows. In Section II the concept of the working mechanism of passive RFID system is examined in detail. Several design issues related to the performance of coil antenna are presented. The coil antenna design flow is presented. And some prototypes have been designed and manufactured to demonstrate the feasibility. In Section III the low-cost screen printing process is presented and examined intensively. In Section IV one rectifier was designed and manufactured by using low-cost screen printing process. Flexible high-DK material was adopted to design the capacitors in rectifier circuit. Finally, the conclusion is presented in Section V.

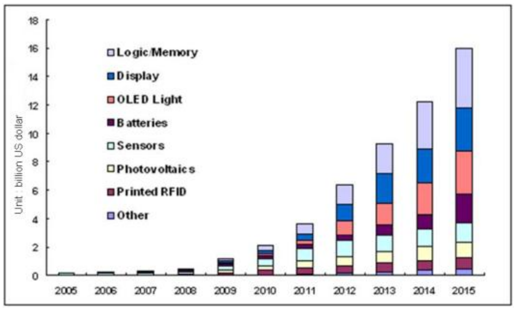


Figure 1 - Predication of future trend of flexible electronics (Source from IEK/ITRI)

Table 1 - RFID system category

	Near-field RFID		Far-field RFID	
	LF	HF	UHF	Microwave
Frequency	30-400kHz 125-134kHz	3-30MHz 13.56MHz	433MHz 865-965MHz	2.45GHz 5.8GHz
Reading Distance	Short	Higher	Long	Long
Data Rate	Very low	Low	Higher	Highest
Working Mechanism	Inductive Coupling	Inductive Coupling	Electromagnetic Radiation	Electromagnetic Radiation
Applications	Animal ID, Car, Access control	Smart labels, Contactless Card, Item-level tracking	Logistics tracking, Supply chain,	Moving vehicle toll, Asset tracking,

II. Coil Antenna Design

In general, RFID systems are composed of two parts, interrogator (reader) and transponder (tag) [2]. The reader is constructed of hardware circuits and coil antenna. The tag system is constructed of tag chip and coil antenna. The passive type 13.56MHz RFID system is called "passive" because there's no battery in the tag system. Since there's no power source on tag itself, it must be turned on by an external power source. Figure 2 shows the power transfer mechanism in a 13.56MHz RFID system. The left side of Figure 2 is the RFID reader, Ri represents the source resistance and Cr represents the resonant capacitor inside RFID reader. And the right side of Figure 2 is the tag system, Cr represents the resonant capacitor inside tag chip and Cp represents parasitic capacitor of the tag coil antenna. The main power transfer mechanism between reader and tag relies on inductive coupling. As you can see in Figure 2, the reader transmits power in the form of magnetic field. And when the magnetic field produced by coil antenna of reader passes through the coil antenna of tag, it induces a potential voltage between two connection points of the tag coil antenna. This induced potential voltage can be used to turn on the tag chip after being rectified by the internal rectifier circuit of the tag chip. As shown in Figure 2, the coil antenna and the internal capacitor of the tag chip Cr constitute a parallel resonant circuit. This resonant circuit resonates at 13.56MHz which is the operating frequency of RFID system. Therefore the tag chip can get maximum input voltage through this parallel resonant circuit. According to equation (2.1), the resonant frequency of this parallel resonant circuit can be decided by the inductance of tag coil antenna and the capacitance of capacitor Cr inside of the tag. Then formula (2.1) can be transformed into equation (2.2). Therefore the inductance of coil antenna can be calculated easily.

$$f = \frac{1}{2\pi\sqrt{L \cdot C}} \tag{2.1}$$

$$L = \frac{1}{(2\pi f)^2 C} \tag{2.2}$$

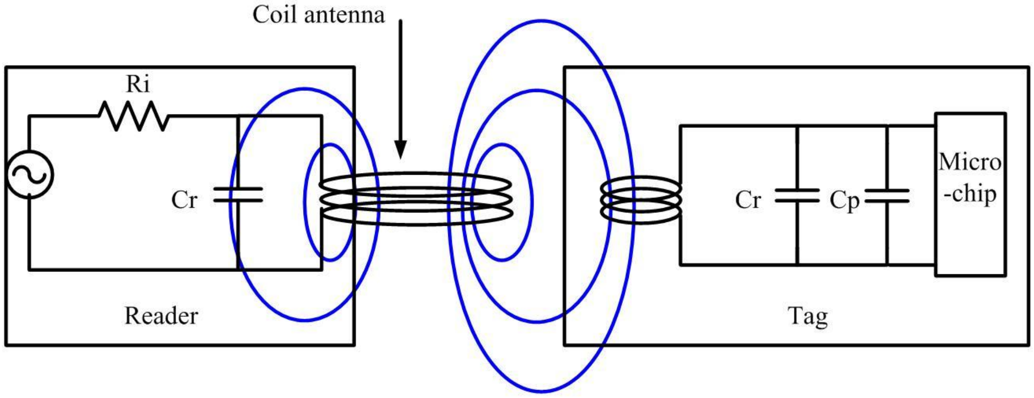


Figure 2 - 13.56MHz RFID system working mechanism

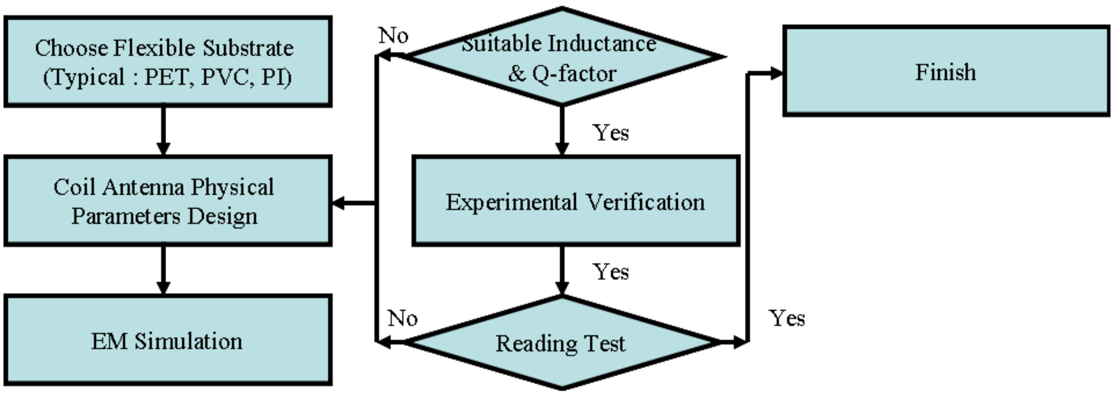


Figure 3 - Coil Antenna Design Flow

According to the previous description, the coil antenna design flow can be described by Figure 3. In the beginning, a flexible substrate has to be chosen. There are three common types of flexible substrates PET (polyethylene terephthalate), PVC (polyvinyl chloride) and PI (polyamide). Then the initial physical parameters of coil antenna have to be defined according to the process design rules and specifications. The physical parameters of coil antenna include width of conductor, gap between conductors, thickness of conductor, numbers of turn and the occupied area of coil antenna. After choosing these, the physical embodiment of coil antenna can be constructed in an EM simulation environment. Then the inductance and quality factor of coil antenna can be extracted using the EM simulator. If the simulation results conform to specifications, the coil antenna can be manufactured for experimental verification. Otherwise, the coil antenna has to be redesigned to meet the specifications.

For example, an I-CODE Label IC is used in this research. The typical value of internal capacitor Cr is about 23.5pF. Therefore according to equation (2.2), the inductance of coil antenna is about 5.86uH. A series of coil antennas with different physical parameters were designed as testing samples according to the coil antenna design flow shown in Figure 3. These test samples of coil antennas cover several different physical parameters such as line width/gap of 800um/200um, 800um/300um, 600um/200um, and 600um/300um and occupied areas of 4cm*4cm and 5cm*5cm. Table II shows the measured results of these test samples. From these measured results, the coil antennas with wider line width or bigger occupied area have higher quality factors. Besides, the coil antennas with narrower line gap have better quality factor under the same conditions of line width and occupied area. In general, printed silver paste has poorer conductivity than copper. From equation (2.3), the resistance of conductor is inversely proportional to the cross section area of conductor. Furthermore, from equation (2.4), the quality factor of coil antenna is inversely proportional to the resistance of conductor. And the cross section area of conductor is equal to line width multiplied by the thickness of the conductor. Therefore the coil antenna with thicker conductors has a better quality factor than others. In practical application, coil antennas of RFID tag with better quality factors have longer reading ranges. However, this is a trade-off between cost and performance of the RFID tags.

$$R = \rho \frac{L}{A} \tag{2.3}$$

$$Q = \frac{2\pi fL}{R} \tag{2.4}$$

Table 2 - Measured Results of Coil Antennas

	Line Width(um)	Gap (um)	Area (cm^2)	Numbers of turn	Resistance	Inductance(nH) @ 13.56MHz	Q @ 13.56MHz
1	800	200	5*5	8	15.4	5449.875	20.263
2	800	300	5*5	9	15.5	6065.327	18.663
3	800	200	4*4	12	13.9	5899.547	18.050
4	600	200	4*4	10	18.9	5525.497	16.945
5	600	300	4*4	11	19.5	5898.656	15.399
6	800	300	5*5	9	17.8	6121.765	19.407
7	800	300	4*4	14	16.4	5651.096	18.434
8	800	300	4*4	13	15.9	5562.132	19.649
9	800	300	4*4	12	16	5469.528	19.511

III. Screen Printing Process Flow

In this paper, low-cost screen printing process was adopted to manufacture printed RFID tags. Figure 4 shows the details of the process flow. As in our previous description, the flexible substrate has to be chosen first. Then the trace of coil antenna called the "1st conductor" is printed and cured. After that, a special procedure called "heat and press" is done to get better electrical properties of the coil antenna. The reason for this procedure is to reduce the resistance of the conductors by increasing the density of the silver paste. Then solder-mask is printed and cured for manufacturing the underpass of the coil antenna. Afterwards, the second layer conductor called the "2nd conductor" is printed and cured to form the connection of the underpass part. The completed coil antennas are shown in Figure 5(a). Finally, ACF (anisotropic conductive film) lamination has to be done for bonding the tag chip. The fabricated flexible printed RFID tag is shown in Figure 5(b). Figure 6 shows the test environment of the flexible printed RFID tag. The flexible printed RFID tag can be read successfully by reader with a reading range greater than 10cm.

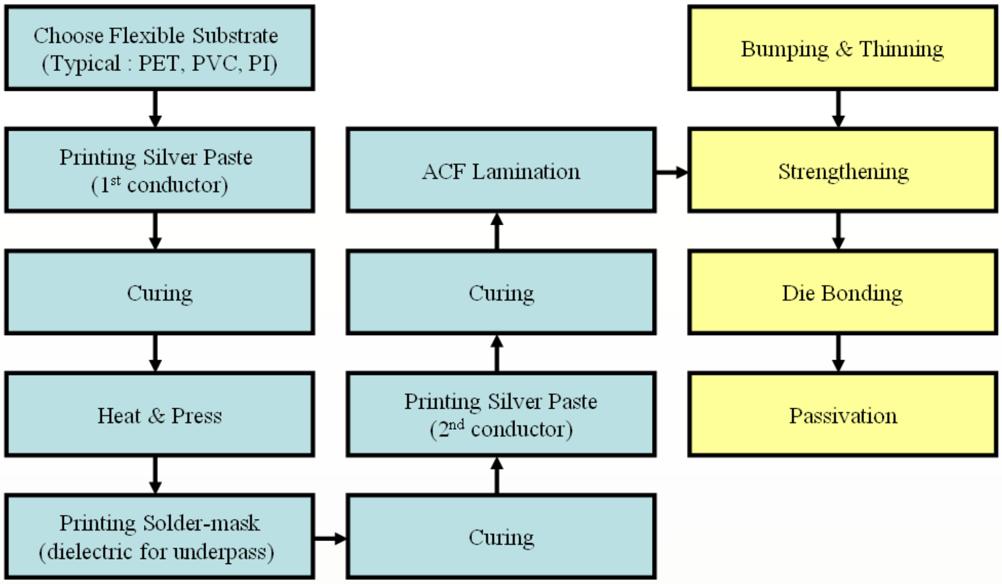
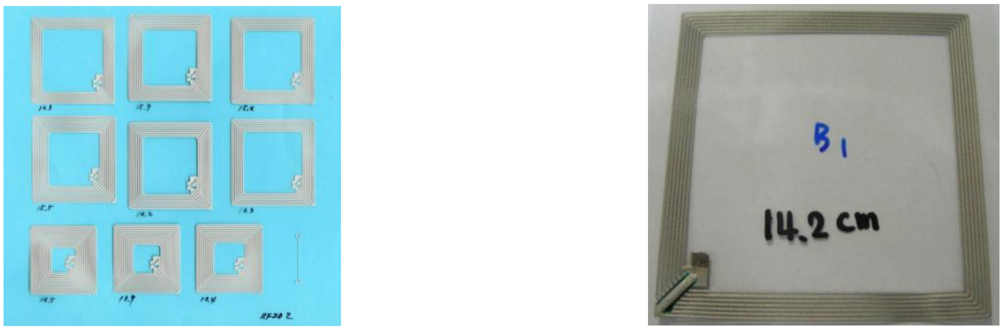


Figure 4 - Manufacturing Process Flow of Flexible Printed RFID Tag



(a) **(b)**

Figure 5 - Photos of Embodiments (a).Coil Antenna (b).Flexible RFID Tag

Figure 6 - RFID Tag Testing Scenario

IV. Rectifier Circuit Design

Since 1899 when Tesla tried to use a coil conductor to transmit high power energy, wireless power transmission has been a popular research topic [3]. In this section, a flexible half-wave rectifier circuit is presented. The flexible half-wave rectifier circuit was fabricated by using the previously described screen printing process. A special High-DK material developed by MCL, ITRI [4], is introduced into this process for manufacturing the flexible capacitors in the rectifier circuit. Figure 7 shows the half-wave rectifier circuit structure [5]. The whole circuit includes one coil antenna, two capacitors, one Schottky diode and one SMD type LED. The purpose of the coil antenna is to transfer power from the reader described in Section II. One of the capacitors is the resonant capacitor and the other one is the filtering capacitor. An HSMS-2852 zero bias Schottky diode [6] from Avago Technology was used in this design. This Schottky diode is suitable for small signal operation (<20dBm) and can be used under 1.5GHz.

The flexible Hi-DK material was adapted to fabricate the resonant capacitor and filtering capacitor in the rectifier circuit. The dielectric constant of the flexible Hi-DK material was measured as 20 at 1MHz by an HP 4275A LCR meter. And the variation of the dielectric constant at high frequency was also measured by HP 8510C. Figure 8 (a) shows the measured results. And Figure 8 (b) shows the flexibility of Hi-DK substrate. The thickness of the Hi-DK substrate is about 50um. The capacitance of resonant capacitor is about 23.5pF. And the capacitance of filtering capacitor is about 200pF. Figure 8 (c) shows the rectifier circuit layout. The whole circuit size is about 16cm^2. The test circuit is shown in Figure 8 (d). The LED on the flexible rectifier circuit can be lit up successfully by the 13.56MHz RFID reader. The maximum lightening distance is about 11cm. Figure 9 shows the details of the measured results for the rectifier circuit. When the rectifier circuit is placed 11cm distance from the RFID reader, the output voltage of rectifier circuit is about 1.8V and the output current is about 0.3mA.

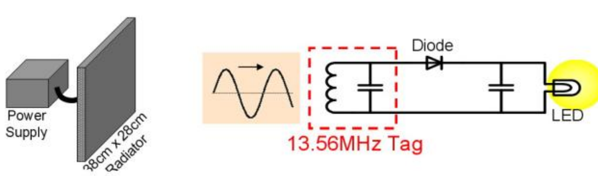
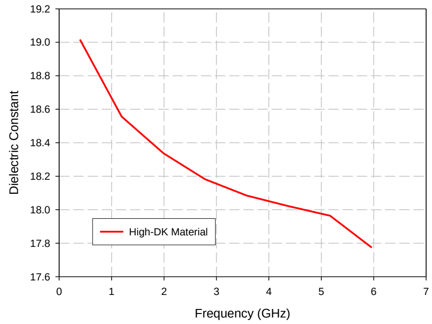
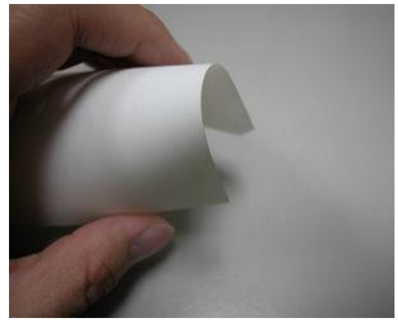


Figure 7 - Half-wave Rectifier Circuit Structure



(a)



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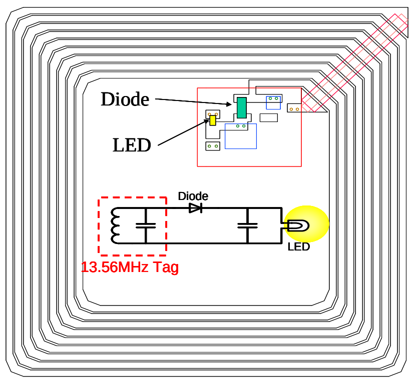
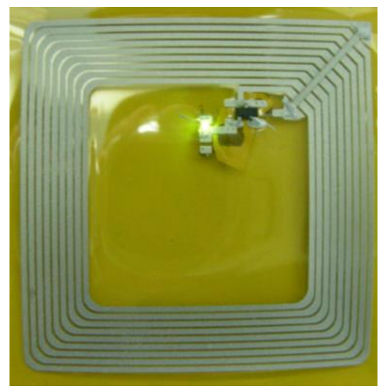


(c)



(d)

Figure 8 - (a).Measurement of Hi-DK material (b).Photo of flexible Hi-DK material (c).Layout of rectifier circuit (d).Photo of rectifier circuit

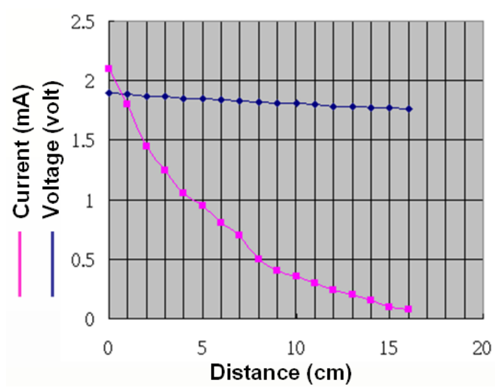


Figure 9 - Measured Result of Rectifier Circuit

V. Conclusion

In this paper, the design flow of coil antenna and the flow of a low-cost screen printing process have been examined in detail. Several design issues related to performance of coil antenna have been analyzed. And according to these analytical and experimental results, printed RFID tags have been designed and fabricated successfully. The measured result shows that the readable range is greater than 10cm. Finally, special Hi-DK material was integrated into the low-cost screen printing process. One flexible rectifier circuit system has been designed and manufactured successfully. The rectifier circuit can be used to light up one typical SMD LED within 11cm of the 13.56MHz RFID reader. This rectifier circuit demonstrates the potential of designing flexible circuitry using screen printing process. In the future, organic semiconductor device will be integrated into this process to achieve the all printed circuitry.

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