

## **SMALL PROXIMITY COUPLED CERAMIC PATCH ANTENNA FOR UHF RFID TAG MOUNTABLE ON METALLIC OBJECTS**

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**Abstract**—A very small patch type RFID tag antenna (UHF band) using ceramic material and proximity coupled feeding structure mountable on metallic objects is presented. The proposed tag size is  $25 \times 25 \times 3$  mm. Both of the radiating part and the feeding part of the proposed antenna is located in the same plate for easy implementation. The resistive and reactive components of the input impedance of the antenna can be easily matched to the tag chip impedance from the size of the feed loop and the distance between feed loop and radiating patch. The antenna satisfactorily operates on metal plates, so it is applicable in many applications. The proposed design is verified by simulation and measurements which show good agreement.

### **1. INTRODUCTION**

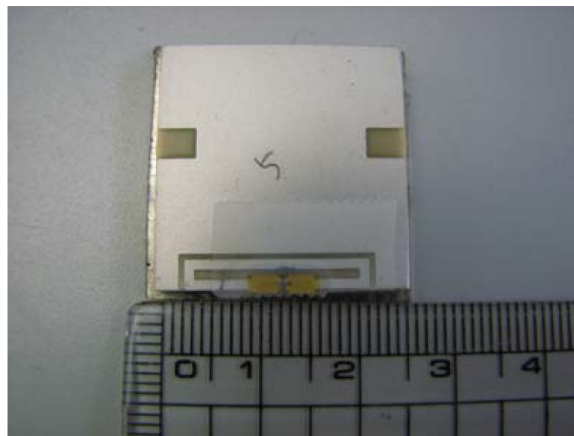
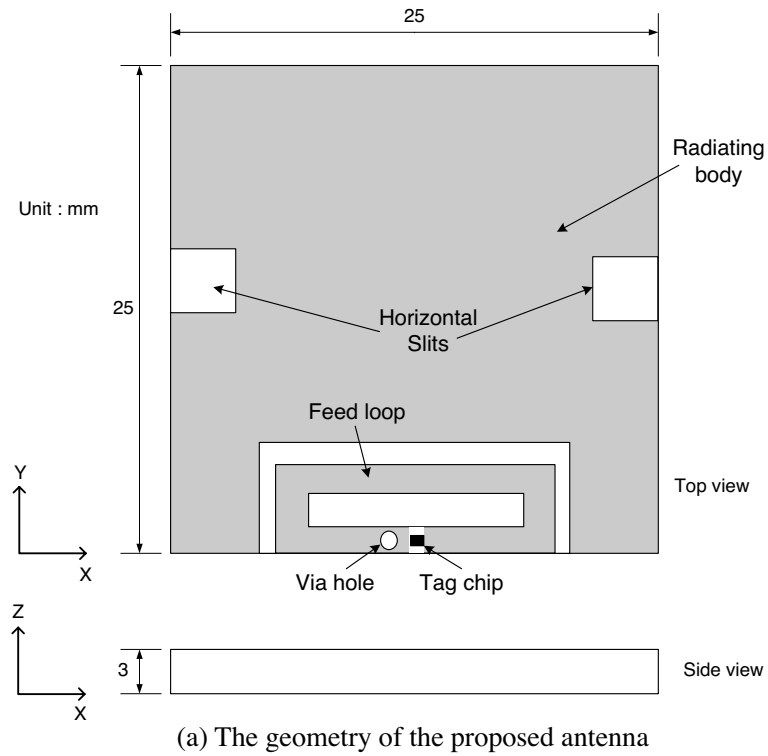
Radio frequency identification (RFID) is a rapidly developing technology which uses RF signals for automatic identification of object. Recently, RFID system in the UHF (Ultra High Frequency) band becomes more attractive for many industrial services because it is able to provide the high reading speed, capable multiple accesses, anti-collision, long reading distance compared to other frequency band RFID systems, so it has been widely used in many applications such as identifying objects in warehousing, supply chain, services industries, distribution logistics, and other automatic processes [1]. Recently, there have been many studies on RFID tag antennas in the UHF band, especially at 900 MHz. Because of the cost and fabrication requirement, tag antennas must be directly matched to the tag chip, which may have complex input impedance different from  $50 \Omega$ , and large capacitive reactance and small resistance are usually observed

in passive RFID tag chips. So, the impedance matching technique using inductive coupling has been studied in relation to RFID tag antennas [2, 3]. The folded dipole or meandered dipole antennas with inductive coupling mechanism are widely used in many applications since they can be printed on a very thin film. However, in special RFID applications such as metallic components, the general label tags cannot operate in the surface of the conducting materials because of the degradation of tag antennas. Proper antenna design for RFID tag applications is becoming essential for the maximization of RFID system performance. In many applications, RFID tags need to be placed on metallic materials and to be very small. To meet this application requirement, the planar inverted-F antenna (PIFA) which can be used on metal has been proposed as a tag antenna [4]. To reduce the size of the patch antenna, two symmetric shorted microstrip patch antennas and a feed loop is studied [5]. To expand the bandwidth of the metal tag antenna, there have been studies which proposed using orthogonal proximity coupled patch antennas [6], and using T-matching network and double symmetrical radiating patches shorted to ground plane [7] in RFID tags.

Most of the metal tags consist of the complex geometry of more than two layers and they need to be implemented very carefully. Metal tags applied in specification fields have to be manufactured to a smaller size than the existing metal tags. In this paper we discuss a very small tag antenna, which uses a ceramic material, an inductively coupled feed and patch antenna suitable for the UHF band RFID tag which can be placed on the conducting materials and can be used in specified applications. Both of the feeding part and radiating part is located in the same plate, so the implementation process is very simple and then the cost can get lower. A rectangular tag with a height of 3 mm and an area of  $25 \times 25$  mm is proposed.

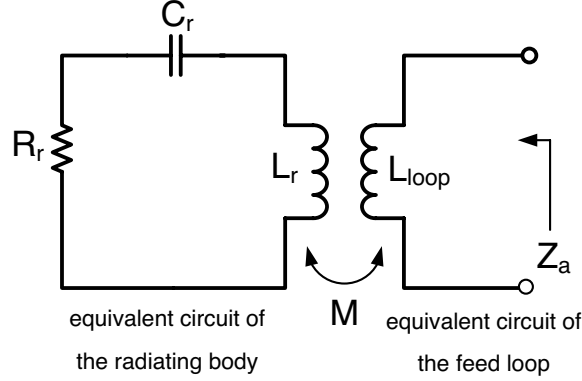
## 2. EQUIVALENT CIRCUIT OF THE TAG ANTENNA

The geometry of the proposed tag antenna and the photograph of the fabricated tag is presented in Figure 1. The antenna is composed of an inductively coupled rectangular feed loop and radiating body. The terminals of the feed loop are directly connected to the tag chip. The strength of the coupling is controlled by the distance between the feed loop and the radiating body as well as the shape of the feed loop [3]. Figure 2 shows the equivalent circuit of the proposed antenna. The inductive coupling is modeled by a transformer. The input impedance



(b) The photograph of the fabricated tag

**Figure 1.** Structure of the proposed antenna.



**Figure 2.** Equivalent circuit of the proposed antenna.

of the antenna  $Z_a$  is given by:

$$Z_a = R_a + jX_a = Z_{loop} + \frac{(2\pi f M)^2}{Z_r} \quad (1)$$

where  $Z_r$  and  $Z_{loop}$  are the individual impedances of the radiating body and the feed loop, respectively,  $M$  is the mutual inductance between them and  $f$  is the operating frequency.

Near the resonant frequency  $f_o$  of the radiating body, the resistance and reactance components of  $Z_a$  are given by [3]:

$$R_a = \frac{(2\pi f M)^2}{R_r} \frac{1}{1 + u^2} \quad (2a)$$

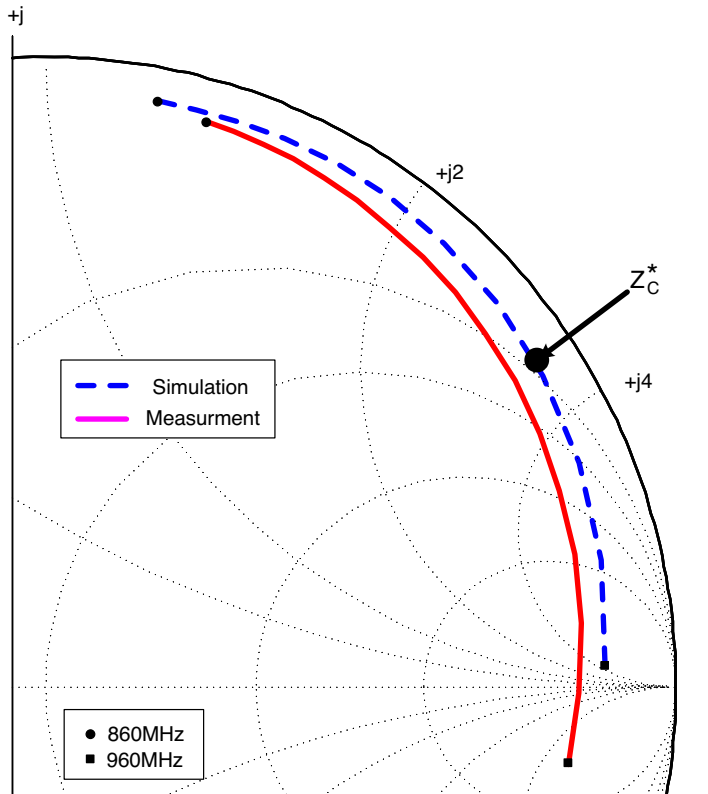
$$X_a = 2\pi f L_{loop} - \frac{(2\pi f M)^2}{R_r} \frac{u}{1 + u^2} \quad (2b)$$

where  $u = Q_r(f/f_o - f_o/f)$  and  $Q_r$  is the quality factor. When the operating frequency  $f$  equals to the resonant frequency  $f_o$  the components of the impedance becomes:

$$R_a(f = f_o) = \frac{(2\pi f_o M)^2}{R_{r, f_o}} \quad (3a)$$

$$X_a(f = f_o) = 2\pi f_o L_{loop} \quad (3b)$$

Equations (3a), (3b) show that  $R_a$  depends only on  $M$  while  $X_a$  depends only on  $L_{loop}$ . Therefore, the resistive and the reactive components of the input impedance can be adjusted independently.

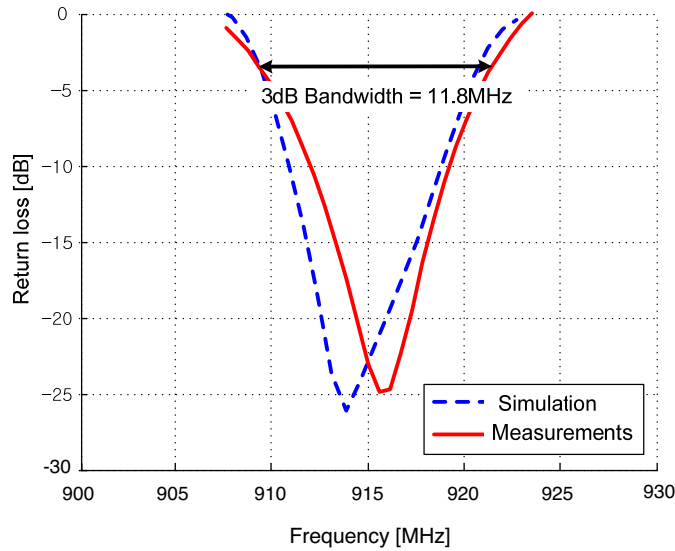


**Figure 3.** The input impedance characteristics.

### 3. TAG ANTENNA DESIGN

The geometry of the proposed tag antenna is presented in Figure 1. The proposed tag consists of a tag chip, a inductively coupled feed line, a radiating patch, the substrate filled with ceramic material and the ground plate. In the present antenna, the ground plate and the radiating plate are of the same size but when it operates being attached to a metallic surface, the entire surface must be considered as a ground. The radiating patch is a metal plate with the horizontal slits for adjusting radiation frequency and it is not connected to the ground plate unlike the other tag antennas. The loop type feed line is connected to the ground plate with via hole to minimize the feed length at resonant frequency. The tag chip is electrically connected to the feed line, which is located in the same plane of the radiating patch. In many applications, the resistance of the characteristic impedance

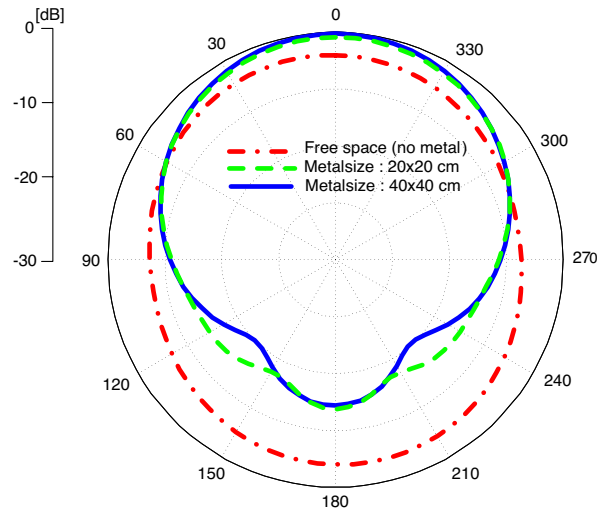
of the tag chip is found to be in the range of 3 to 150  $\Omega$ , and the reactance is in the range of  $-200$  to  $-50 \Omega$  (capacitive). In this paper, the antenna is designed for a tag chip (commercial RFID tag chip: Alien Higgs chip) with an input impedance of  $Z_c = (12 - j140) \Omega$  at a resonant frequency of 910 MHz. The conjugate match is achieved between the input impedance of the proposed antenna and the tag chip by adjusting radiating patch and the feed line. By varying the distance between the radiating patch and the feed line, the resistive component of the input impedance can be adjusted and the reactive component of the input impedance can be adjusted by varying the length of the feed loop. The operating frequency is slightly adjusted by varying the horizontal slit length of the radiating patch, while the input impedance of the antenna is almost unaffected.



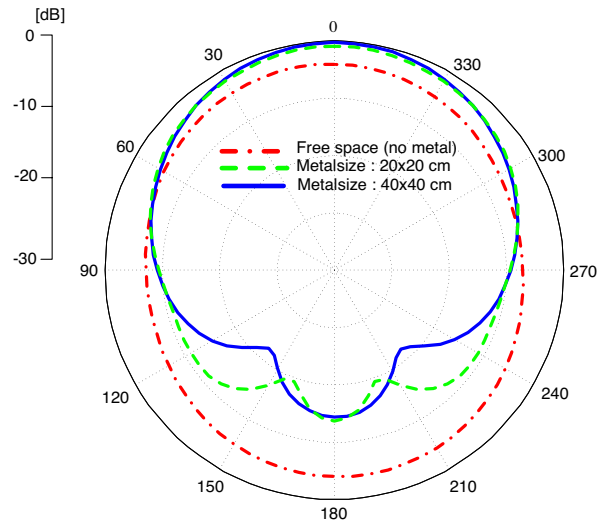
**Figure 4.** The return loss of the proposed antenna.

#### 4. SIMULATION AND MEASUREMENT

A prototype antenna has been designed and implemented for a tag chip with an complex conjugate impedance of  $Z_c^* = (12 + j140) \Omega$ . This impedance is a measured data when the power of  $-10$  dBm is applied to the tag chip. The overall size of the antenna is only  $25 \times 25 \times 3$  mm and the operating frequency is 910 MHz and the relative dielectric constant of the ceramic substrate is 48.



(a) x-z plane



(b) y-z plane

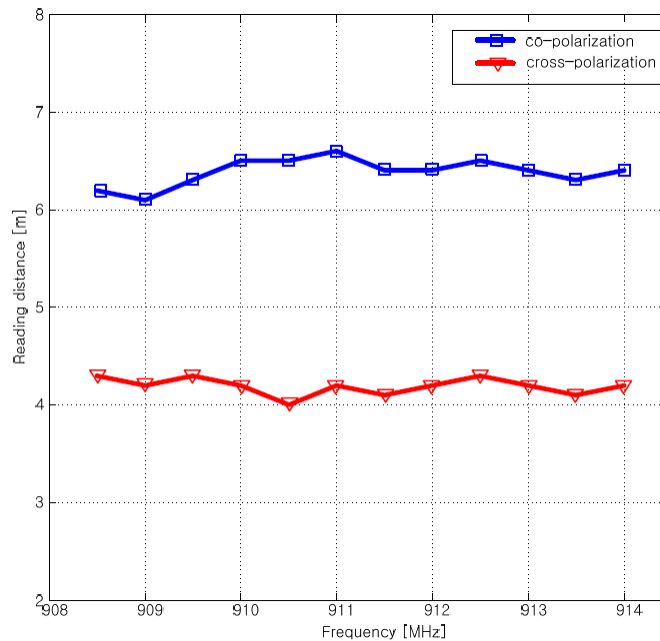
**Figure 5.** Calculated radiation pattern by CST microwave studio at 910 MHz.

Figure 3 shows the simulated and measured data for the input impedance of the antenna when it is attached to a metal plate. The simulation is performed using CST Microwave Studio. The measured

data agreed well with the simulated data.

Figure 4 shows the simulated and measured return loss of the proposed antenna with respect to the conjugate of the input impedance of the tag chip  $Z_c^*$  when it is attached to a metal plate. The 3 dB return loss bandwidth is 11.8 MHz which fully covers the bandwidth of the Korean RFID frequency band (908.5~914 MHz).

To study the effect of the size of metallic objects for the prototype antenna, the radiation pattern is simulated with different size of metal plates (mounted on free space,  $20 \times 20$  cm,  $40 \times 40$  cm) in Figure 5. Figure 5 shows that the main beam direction is not steered by the metallic plates, and the proposed antenna has an omni-directional radiation pattern. The half power beamwidths are about  $100^\circ$  in both  $E$ - and  $H$ -planes. The simulated directivity of proposed antenna with metal plate is about 5.21 dBi and the simulated radiation efficiency is about 35% at resonant frequency of 910 MHz because of the small antenna size and high dielectric constant of the substrate.



**Figure 6.** Maximum reading distances of tag mounted on metal plate via Korean RFID frequency.

Figure 6 represents the measured maximum reading distances of tag for various frequencies in Korean RFID band with co polarization and cross polarization when using the RFID reader made by ETRI



(EPR-630) which authenticated in the EPC global and the patch type reader antenna with linear polarization. The measurement was carried out with the antenna placed at the center of a  $40 \times 40$  cm metal plate. The reading distance is over 6 m for all frequencies in Korean RFID band, so it shows that the bandwidth of this proposed antenna fully covers the Korean RFID band.

Table 1 shows the maximum reading distances of tag for metal plates of different sizes. It is clear that the antenna operates satisfactorily on various size of metal plates, so the tag can be used on metal plates for the best performance in specific applications such as automobile components.

**Table 1.** Measured maximum reading distances of tag mounted on various sizes of metal plate.

Metal plate size	Maximum reading distance [m]
Free space (no metal )	4.2
$20 \times 20$ cm	6.4
$40 \times 40$ cm	6.6

## 5. CONCLUSIONS

A design for very small tag antenna ( $25 \times 25 \times 3$  mm) using ceramic material at UHF band mountable on metallic objects was implemented. The antenna can be directly matched to the arbitrary complex impedance of a tag chip. It is verified that the proposed tag has good performance by measuring the reading distance over 6 m on metallic plates. The proposed tag is very small, so it may be used with a conducting plate to facilitate mounting it on curved surfaces as cans if necessary.

## ACKNOWLEDGMENT

This research was supported by the IT R&D program of MKE/IITA [2008-S-023-1, Development of Next Generation RFID Technology for Item Level Applications].

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