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A Planar Wideband Inductively Coupled Feed Patch Antenna for UHF RFID Tag

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***Abstract*—A planar wideband patch antenna for ultra-high frequency (UHF) radio frequency identification (RFID) tag for metallic applications is presented in this research work. Three different shape patches are inductively coupled to a triangle loop to excite three resonances close to each other to form wide impedance bandwidth for universal application UHF (860-960 MHz) RFID. The structure of the proposed antenna exhibits planar profile to provide ease of fabrication for cost reduction well suited for mass production. The simulation of the antenna was carried out using Finite Element Method (FEM) based software, Ansoft HFSS v13. The performance of the design was verified by the simulation and measurement results which show good agreement. The simulated and measured impedance bandwidth of 113 MHz and 117 MHz (return loss ≥ 6 dB) was achieved to cover the entire UHF RFID operating frequency band worldwide.**

***Index Terms*—Complex impedance matching, metallic objects, patch antenna, radio frequency identification (RFID), ultra-high frequency (UHF).**

I. INTRODUCTION

Radio frequency identification (RFID) is a technology used for object identification based on radio communication. This technology has been adopted by various sectors such as supply chain automation, traffic management, security and access control, to name a few. Basic RFID system consists of a tag or multiple of tags and a reader where tags are attached to objects to be monitored while the reader reads the information carried by the tag. There are several operating frequency bands used in RFID which are low frequency (LF), high frequency (HF), ultra-high frequency (UHF) and microwave [1]. Owing to its longer read range, higher data transmission rate as well as larger storage capacity, UHF system are gaining more popularity compared to other systems. In passive UHF RFID system, tag is made of a microchip and an antenna without internal power source unlike active and semi-active tag where both types of tag are equipped with their own internal power source i.e. battery. As such, passive tags get its power from the incoming electromagnetic waves emitted by the reader.

In some applications, tag needs to be mounted on the surface of metallic objects such as steel plates or steel containers. However, when printed dipole like antenna are placed on the metallic surface, it suffers severe performance degradation due to shift in operating frequency, distorted radiation pattern and impedance mismatch which quickly reduce its read range or even cannot be read [2]. In order to mitigate this problem, several inverted-F antenna and microstrip patch antenna where they operate with a ground plane have been proposed [3-5]. Although have been proven to work, they have narrow bandwidth. It is known that operating frequencies of each country varies from one another in UHF RFID system. In Europe, the operating frequency is 866-868 MHz, in North America, the allocated frequency is 902-920 MHz while 952-956 MHz is used in Japan. Table 1 lists the operating frequency of several countries in the world.

TABLE 1
LIST OF OPERATING FREQUENCY OF SEVERAL MAJOR COUNTRIES IN THE WORLD

Region/ Country	Operating frequency, f_c (MHz)
North America	902-928
Europe	865-868
China	917-922
Japan	916-921 & 952-956
Australia	918-926
Hong Kong	865-868 & 920-925
Taiwan	922-928

Based on this situation, tag antenna with narrow bandwidth can only be operating at one particular country or region. As such, wideband patch antennas for worldwide operation have been presented in [6-8]. However, the impedance bandwidth of these tag were evaluated based on half power impedance bandwidth (return loss≥ 3 dB) that accounts for half of the power received by tag antenna is reflected at the antenna input impedance due to impedance mismatch. Moreover, the structure of the antenna required via hole, shorting plate or shorting wall which could increase the fabrication cost due to additional process of drilling and soldering. Several planar microstrip patch antennas without any electrical connection to the ground plane have been studied and proposed with the aim to reduce the cost of the tag antenna [9-11]. However, the narrow impedance bandwidth is the drawback of these antennas. Therefore, a simple wideband microstrip patch antenna design for metallic applications is desirable and worth developing.

This letter proposes a planar wideband microstrip patch RFID tag antenna design for metallic applications. The wide impedance bandwidth is achieved by utilising three radiating element to excite three resonances close to each other. The complex impedance matching with the referenced microchip, Alien Higgs-3, with impedance value of $Z_{chip} = 31 - j212\ \Omega$ and sensitivity, P_{th}, of -18 dBm is realized by using inductively coupled triangle loop structure. The structure of the proposed antenna does not incorporate any via hole or shorting wall/plate which further simplify its fabrication process. The proposed antenna design concept and configuration will be explained in Section II. Section III demonstrates the simulation and measurement results while conclusions are drawn in Section IV.

II. ANTENNA DESIGN

One of the important aspects in tag antenna design is complex impedance matching technique for efficient power transfer between the microchip and the antenna. In this research, an inductively coupled triangle loop structure is used to transform the impedance of the patch antenna to match the referenced microchip's conjugate impedance value [12, 13]. Three resonating elements with slightly different resonance frequencies were employed to achieve wide impedance bandwidth as illustrated in Fig. 1. The shapes of the patches were derived from a typical rectangular patch. Two of the patches were meandered to reduce its overall length so as to realise a more compact antenna size. The input impedance at the antenna input terminal, Z_{in} is given by [14]

$$Z_{in} = Z_{loop} + \frac{(2\pi f M)^2}{Z_A} \tag{1}$$

where Z_{loop} is the input impedance of the feed loop, M is the mutual coupling between the loop and the radiating patches and Z_A is the impedance of the radiating patches. Based on equation 2, the input resistance depends on the mutual coupling between the feed loop and the radiating patches while the reactance value is contributed by the loop's inductance as given by (2) and (3)

$$R_{in}(f_0) = \frac{(2\pi f_0 M)^2}{R_A(f_0)} \tag{2}$$

$$X_{in}(f_0) = 2\pi f_0 L_{loop} \tag{3}$$

where the inductance of the triangle feed loop can be approximated using (4)

$$L_{loop} \approx N^2 \frac{\mu_0 \mu_r}{2\pi}\Big[2c\ln\left(\frac{2c}{0.5s}\right) + b\ln\left(\frac{2c}{0.5s}\right) - 2(b+c)\sinh^{-1}\left(\frac{b^2}{\sqrt{4b^2c^2-b^4}}\right) - 2c\sinh^{-1}\left(\frac{2c^2-b^2}{\sqrt{4b^2c^2-b^4}}\right) - (2c+b)\Big] \tag{4}$$

where b, c and s are the parameters of the loop. N, μ_0, and μ_r are the numbers of the loop's turns, permeability of free space and relative permeability of the substrate.

The substrate of the proposed patch antenna is FR-4 with relative permittivity, ε_r, of 4.4 and tangential loss, tan δ of 0.02 while the thickness of the substrate, *h* is 1.6 mm so as to make it low profile.

TABLE 1
OPTIMIZED DESIGN SPECIFICATION OF THE PROPOSED ANTENNA

Parameter	Value (mm)
$W1$	7
$L1_{p1}$	10
$L2_{p1}$	37
$L3_{p1}$	10
$L4_{p1}$	12
$W2$	5
$L1_{p2}$	15
$L2_{p2}$	37
$L3_{p2}$	14
$L4_{p2}$	14
$W3$	5
$L3$	86
c	29.4
b	34
s	2
$d1$	2
$d2$	1
$d3$	2
t	0.0358
h	1.6
Ground plane and substrate	130 x 63

The selection of this substrate permits reduction in antenna size as opposed to substrate with lower relative permittivity value. Moreover, it is one of the cheapest substrate available. However, a low antenna gain is expected due to lossy nature and the low thickness of the chosen substrate. Nevertheless, an acceptable gain performance is aimed throughout the entire UHF frequency band to ensure satisfactory read range.

Based on the initial calculated value of the antenna parameter, the antenna was simulated using electromagnetic simulator Ansoft HFSS v13. Afterwards, parametric optimization was conducted to find the optimal design parameter value. To further demonstrate the characteristic of the proposed metal tag antenna, a prototype has been fabricated as shown in Figure 2. The optimal antenna parameter value is tabulated in Table 2.

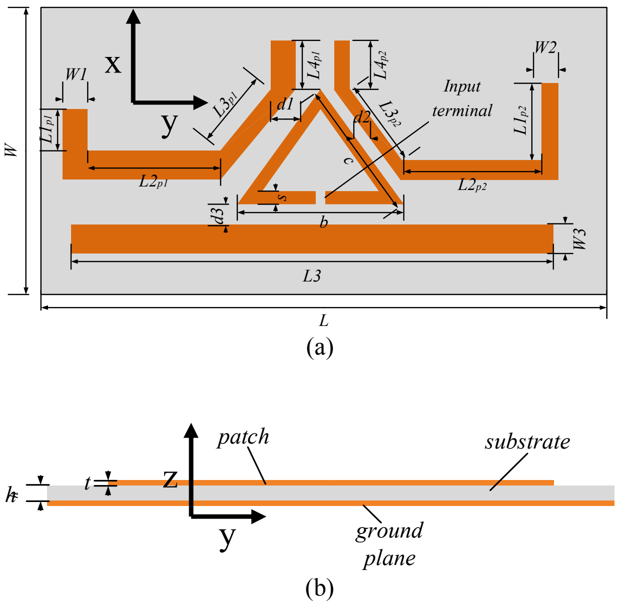


Fig.1 The geometry of the antenna. (a) Top view and (b) side view.

Fig. 3 Prototype of the proposed wideband antenna.

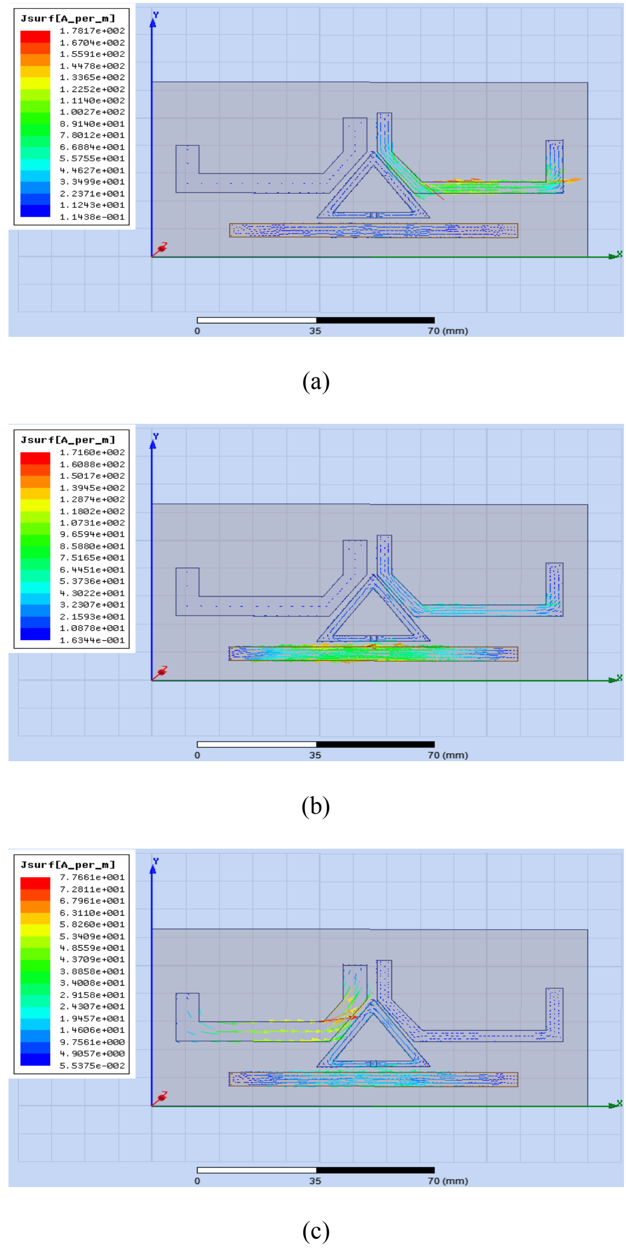
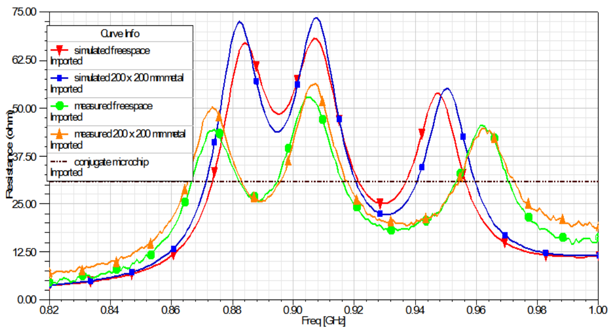


Fig. 3 Surface current distribution of the antenna at three resonant frequency. (a) 882 MHz, (b) 908 MHz and (c) 949 MHz.

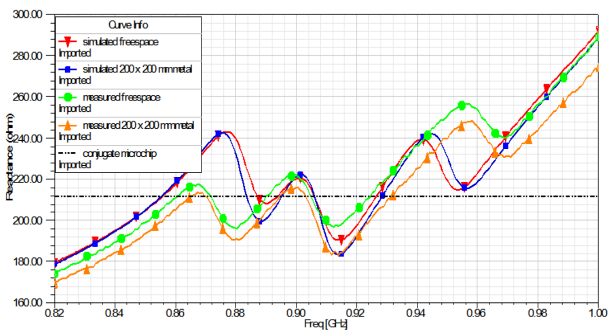
III. RESULTS AND DISCUSSION

The antenna design was modelled and simulated using commercial electromagnetic simulator, Ansoft HFSS v13. To prove that the proposed antenna resonates at three slightly different operating frequencies, the surface electric current density was obtained from the simulation as shown in Figure 3. It is observed that the antenna exhibit three resonances at 882 MHz , 908 MHz and 949 MHz due to self-resonance of the patches.

In order to access the performance of the antenna on metallic surface, a metal sheet of size 200 x 200 mm^2 is created in the simulation model where the proposed tag antenna is being mounted on it. Because of the antenna is to be fed by differential signal from the microchip, impedance measurement technique proposed in [15] is used. The simulation and measurement results of the antenna input impedance are shown in Fig. 4. It is observed that there is only slight shift in frequency between the free space scenario and when mounted on metal sheet in the simulation while measurement results show hardly any shift between the two scenarios. The difference between simulated and measured impedance might be due to fabrication inaccuracy and environment effect during the antenna measurement. Nevertheless, it can be safely concluded that the impedance of the proposed antenna is barely affected when being attached on metallic objects hence giving clear indication it is able to be implemented for metallic applications as opposed to typical label typed dipole antenna tag.



(a)



(b)

Fig. 4 Simulated and measured impedance of the antenna and the microchip conjugate impedance value against frequency. (a) Resistance and (b) reactance value against frequency.

The impedance bandwidth of the proposed antenna is then evaluated based on 6-dB return loss which is calculated based on (5) [16].

$$RL(dB) = -20\ \log_{10}|\Gamma| \qquad (5)$$

where Γ is the reflection coefficient at the antenna input terminal given by

$$\Gamma = \frac{Z_{chip} - Z_{in}^*}{Z_{chip} + Z_{in}^*} \qquad (6)$$

The simulated and measured return losses of the antenna are 113 MHz and 117 MHz respectively both above the required 100 MHz for universal operation as depicted in Fig. 6. To further investigate the performance of the antenna, the simulated radiation patterns for both scenarios were carried out. Since the main aim of this research is to design a wideband antenna, radiation patterns at three different operating frequencies allocated for Europe, North America and Japan were obtained. These frequencies were chosen since they occupy the lowest, middle and highest operating frequencies within the UHF band. From Fig. 7, Fig. 8 and Fig. 9, it is seen that at all three frequencies, the back lobe radiations are higher in free space than when mounted on metallic objects. This is due to the reflection of the backside radiation lobe because of the large metal sheet. As a result, the antenna gain increased when being mounted on large metal plate. The simulated peak gain is shown in Fig. 10. The read range of the antenna can be theoretically calculated using Friss free space equation as expressed in (7) [5]

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_r \tau}{P_{th}}} \qquad (7)$$

where λ is the free space wavelength, P_t is the power transmitted by the reader, G_r is the reader antenna gain, G_t is the gain of the tag antenna, P_{th} is the threshold power of the microchip and τ is the power transmission coefficient which is determined by the impedance matching of the microchip and the antenna. The power transmission coefficient, τ, can be expressed as

$$\tau = 1 - |\Gamma^2|, 0 \le \tau \le 1 \qquad (8)$$

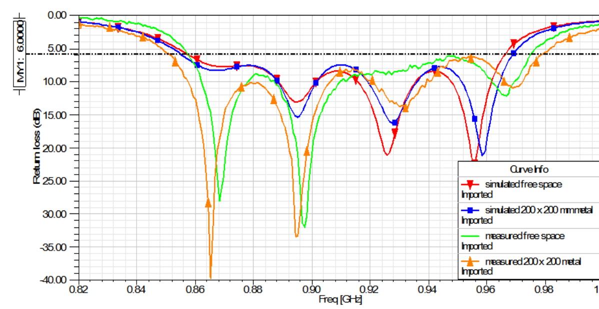


Fig. 6 Return loss (dB) of the proposed antenna.

Since the antenna possess at least a minimum impedance performance of 6 dB return loss, the power transmission coefficient of at least 0.75 is guaranteed for the entire UHF RFID band. Table 3 shows the theoretical read range at three operating frequency for Europe, North America and Japan. A minimum calculated read range of 2.68 meter is achieved by the proposed antenna.

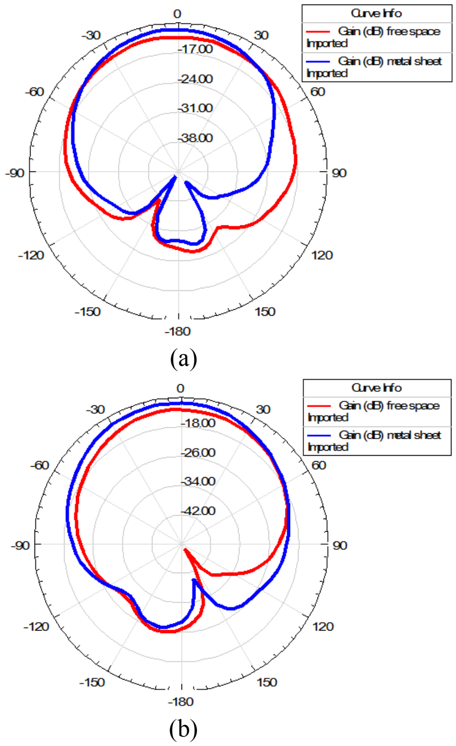


Fig. 7 Simulated radiation pattern at 866 MHz. (a) E-plane and (b) H-plane field pattern.

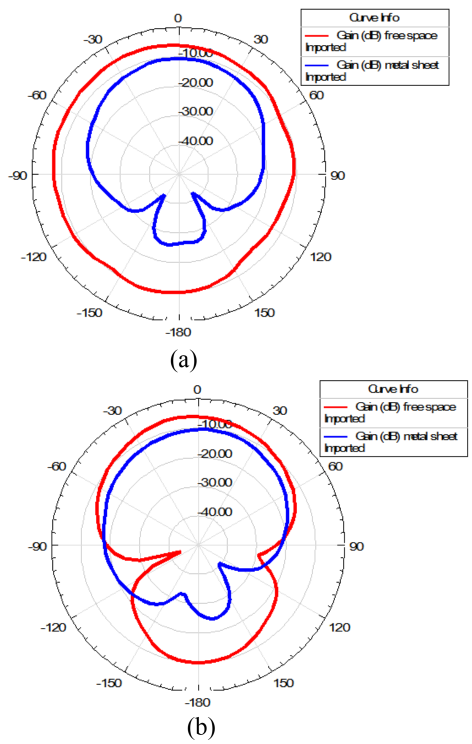


Fig. 8 Simulated radiation pattern at 915 MHz. (a) E-plane and (b) H-plane field pattern.

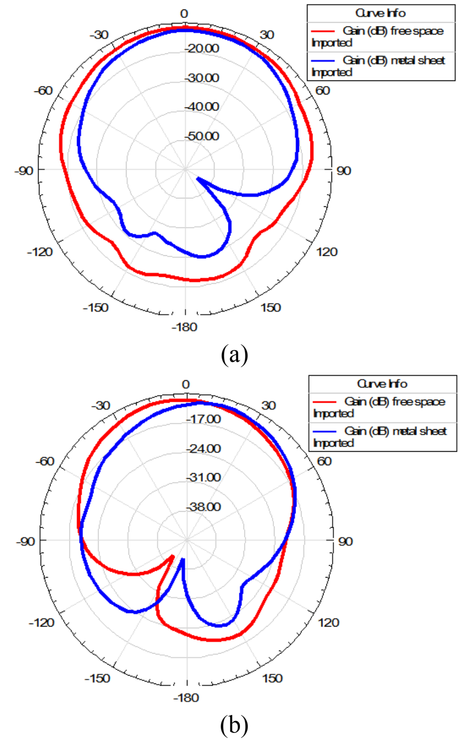


Fig. 9 Simulated radiation pattern at 954 MHz. (a) E-plane and (b) H-plane field pattern.

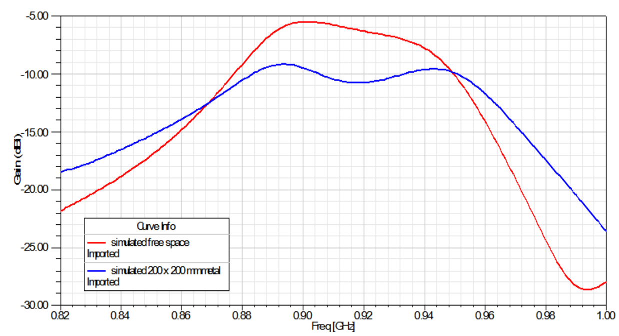


Fig. 10 Simulated peak antenna gain of the proposed antenna.

TABLE III
THEORETICAL CALCULATED READ RANGE OF THE PROPOSED ANTENNA

Country/ Region	Center freq., f_c (MHz)	EIRP (W)	Simulated peak gain (dBi)		Calculated read range (m)	
			Free space	200 x 200 mm^2 metal sheet	Free space	200 x 200 mm^2 metal sheet
Europe	886	3.3	-13.28	-11.50	2.68	3.33
North America	915	4	-6.05	-10.56	6.18	3.61
Japan	954	4	-11.54	-12.06	2.99	2.80

IV. Conclusions

A new wideband microstrip antenna for tagging metallic objects is presented in this paper. The designed tag antenna demonstrates simulated and measured impedance bandwidth of 113 MHz and 117 MHz based on 6 dB return loss. Moreover, the antenna exhibits planar configuration without any multi or cross-layered configuration which significantly reduces the fabrication cost especially for mass production. For future work, radiation pattern measurement will be conducted to verify the simulation results.

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