A Novel Design of UHF RFID Passive Tag Antenna Targeting Smart Cards Limited Area

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***Abstract*—The aim of this paper is to design an Ultra High Frequency (UHF) Radio Frequency Identification (RFID) passive tag antenna to fit in the limited space of smart cards, such as bankcards, along with contactless payment facility and Europay, MasterCard and Visa (EMV) chip. In this paper, UHF tag antenna is designed using Monza R6 chip specifications from Impinj manufacturers while focusing on high performance and read ranges of upto 12 meters with very small sized antenna dimensions of $17.9 \times \ 47.30 \ \mathrm{mm}^2$. Performance is analysed in terms of gain, read ranges and power reflection coefficients. UHF tag antenna is designed using aluminium on Polyethylene Terephthalate (PET) substrate. The proposed design aims to meet objectives of low cost and small size while maintaining high performance.**

Keywords: RFID, UHF, Passive tag antenna, smart cards, Polyethylene Terephthalate (PET)

I. Introduction

RFID is emerging as one of the most popular technology for many potential applications such as medical inventory, customer service, retail inventory, asset management, operational configuration and object identification by using active, semi-active or passive chipped UHF tag antennas. Globally UHF frequency range is from 860-960 MHz while the European frequency region is from 865.6-867.6 MHz. RFID technology is also rapidly gaining interest in scientific and commercial sectors due to many key features [1]-[2]. It is basically used for identifying physical objects through Radio Frequency (RF) radiations and is referred as Automatic Identification System[3]. RFID takes an advantage over barcode systems due to non-line-of-sight identification.

RFID system consists of an RFID reader, RFID tag and a host computer to manage the information as shown in Fig.1. Reader consists of an RF transceiver module, coupling element (antenna), controller unit and signal processor, and a serial interface to connect with the host computer. RFID tag consists of resonant tuned antenna and a low power CMOS IC[4]. This technique involves in the contactless reading and writing of data into the non-volatile memory of RFID tag through back scattered RF signals. The voltage which develops across the antenna terminal power up the chip and sends back information to the reader by varying the input impedance and modulating backscattered signals[5]. Some of the major factors that affect the responsiveness of a tag are impedance mismatch between tag antenna and chip, communication blind spots, multipath fading and orientation and location of tag within the RFID environment [6]. To acheive the maximum efficiency and read range, special attention should be paid to the design of the tag antenna[2]–[5].

In the past literature, many RFID tag antennas are designed using different substrates and metallic track materials [6]-[7]. Different tag antennas are designed based on different chips available in the market to operate at UHF frequency band regions [3]–[9] however, most of them are larger enough to fit in small areas such as bankcards with limited free space.

In this paper, the focus of our investigation is to design a tag antenna on PET substrate using aluminum etching that works at EU frequency band region with small size to ensure the placement in bank card as shown in Fig.2. The impedance of the tag antenna is matched with Monza R6 chip along with maintaining high read rates and performance. The rest of the paper is divided into the following sections: The second section introduces antenna design parameters, the third section represents the tag antenna design and characterization, the forth section presents results and discussion carried out using CST software platform, and the fifth section concludes this paper.

II. Antenna Design Parameters

The UHF tag antenna design should have a high gain, isotropic radiation properties and impedance matching with the chip to ensure maximum power transfer as shown in 1 [10].

$$Z_{ant} = Z^{*}{}_{chip} \tag{1}$$

Z_{ant} indicates the impedance of the UHF tag antenna while, $Z^{*}{}_{chip}$ shows the complex conjugate of the input impedance of the chip [8]. As microchips store energy so their input reactance shows a high capacitive behaviour. RFID UHF microchips mostly exhibit imaginary input reactance ranging from -70 to -400Ω, while the real part is mostly within 50Ω. Thus, for impedance matching tag antenna should have

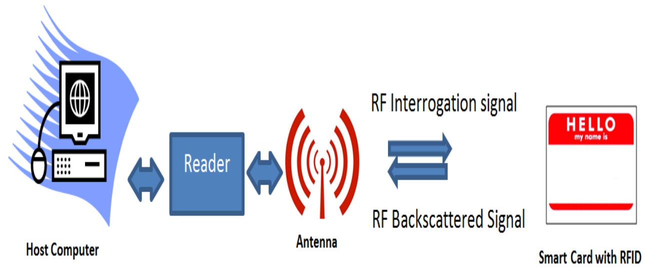

Fig. 1. RFID System Block Diagram

inductive impedance to achieve complex impedance matching. If antenna parameters are known, it is possible to calculate the RFID tag antenna read range as shown in 2 [8]:

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{P_T G_T G_R \tau}{P_{th}}} \quad (2)$$

Here, λ is the wavelength, P_T is the power transmitted by the reader, G_T is the gain of the transmitting antenna, the product of $P_T G_T$ is equivalent to EIRP, the effective radiated power of the reader, G_R is the gain of the receiving tag antenna, P_{th} is the minimum threshold power to activate the RFID tag chip. Whereas, τ is defined as the power transmission coefficient shown as [10]:

$$tau = \frac{4R_{chip}R_{ant}}{|Z_{chip} + Z_{ant}|^2} \qquad 0 \leq \tau \leq 1 \quad (3)$$

$Z_{chip} = R_{chip} + jX_{chip}$ is the impedance of the chip and $Z_{ant} = R_{ant} + jX_{ant}$ is the impedance of the tag antenna. Every country has its own regulations that specifies the UHF RFID frequency transmission ranges within that country. According to the latest regulatory status of RFID in the EPC Gen2 (860-960 MHz) band, the frequency ranges of RFID transmission in some countries are shown in TABLE1 [11]:

TABLE I
UHF BAND FREQUENCY AND POWER ALLOCATION

Country/Region	Frequency Range (MHz)	Frequency Range (W ERP)
Europe	865.6 – 867.6 915 – 921	4
USA	902 – 928	4
China	920.5 – 924.5	2
Japan	916.7 – 920.9	4

Recently, in November 16, another frequency band of 915-921 MHz is allocated to European region[11].

III. UHF TAG ANTENNA DESIGN CHARACTERIZATION

The tag antenna design is the most complex stage in passive UHF RFID systems. As mentioned before, the tag antenna transfers radiated energy from reader antenna to the chip to turn it on. The current UHF tag design is optimized to work with the commercial Monza R6 chip from Impinj manufacturers. TABLE2 is showing the chip parameters [12]:

TABLE II
CHARACTERISTICS OF RFID MONZA R6 CHIP

C_p (pF)	R_p (Ω)	C_{mount} (pf)	$ChipReadSensitivity$ (dBm)	C_{mount} (dBm)
1.23	1.2	0.21	-20	-16.7

Where, C_p is parallel chip capacitance, R_p is the parallel resistance of chip. C_{mount} is defined as the typical capacitance due to adhesive mount parasitics. The total load capacitance offered to antenna model is $C_T = C_p + C_{mount}$. Impedance of the chip is calculated using R_p , C_p and C_{mount} by the using following equations:

$$R_{chip} = \frac{(R_1R_2 - X_1X_2)(R_1 + R_2) + (X_1R_2 + X_2R_1)(X_1 + X_2)}{(R_1 + R_2)^2 + (X_1 + X_2)^2} \quad (4)$$

$$X_{chip} = \frac{(X_1R_2 + X_2R_1)(R_1 + R_2) - (R_1R_2 - X_1X_2)(X_1 + X_2)}{(R_1 + R_2)^2 + (X_1 + X_2)^2} \quad (5)$$

$$Z_{equ} = \frac{Z_1Z_2}{Z_1 + Z_2} = \frac{(R_1 + jX_1)(R_2 + jX_2)}{(R_1 + R_2)(X_1 + X_2)} = R_{chip} + jX_{chip} \quad (6)$$

Here, $R_1 = 1200\Omega$, $X_1 = 0, R_2 = 0\ and\ X_2 = j128\ \Omega$, the equivalent chip impedance is calculated as:

$$Z_{equ} = 13.5 - j126.56\ \Omega \quad (7)$$

To achieve maximum power transfer from tag antenna to chip, the real part of tag antenna impedance R_{ant} should be equal to the real part of chip impedance R_{chip}, likewise the complex part of tag antenna impedance X_{ant} should be a complex conjugate of the chip impedance X_{chip} as shown in 1. Fig.2 represents the layout of the smart card available area for UHF tag, the red lines are showing the NFC tag tracks around the bank card, yellow lines are depicting the free available space for RFID UHF tag while, the green coloured hatched area is showing the area occupied by the EMV chip and card embossment. As the UHF tag antenna geometry is dipole so for symmetrical design the rectangular blue hatched area is allocated for UHF tag design with area of $20.41x50.41mm^2$.

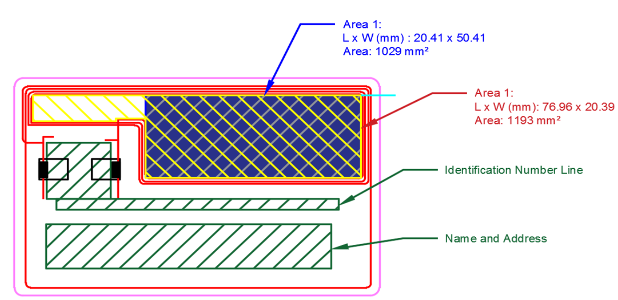

Fig. 2. Graphical Representation of Area Allocation for RFID UHF Tag

The layout of UHF tag antenna is shown in Fig.3 with dimensions of 17.90 x 49.14 mm^2. The design is simulated in CST (Computer Simulation Tool) using aluminium with conductivity of 3.56 x 10^7 S/m and the thickness of 0.01 mm on PET due to mechanical flexibility and high electrical performance. The thickness of PET substrate is 0.05 mm with relative permittivity of $\epsilon_r = 3$ [8] and dielectric loss tangent of 0.021. The dimensions of the inductive loop are designed to match the tag antenna imaginary impedance with the imaginary part of chip, while the design of UHF tag with meander lines and bent edges are made to match the real impedance with chip. The rectangular bars are introduced on all sides of the design to shift the resonance frequency to European frequency band region. The length and width of the meander structure are optimized after performing parametric analysis and simulations, the optimum dimensions are achieved and shown in TABLE3.

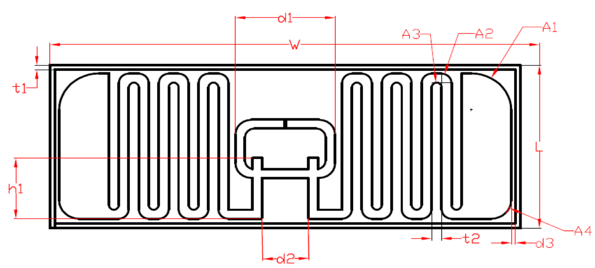

Fig. 3. UHF Tag Antenna Layout

TABLE III
DIMENSIONS OF UHF TAG

Parameters	Dimensions
L	17.90
W	49.14
t1	0.5
t2	1.0
h1	6.70
d1	10.01
d3	0.41
d2	4.63
A1	4 degree
A2	1 degree
A3	0.5 degree
A4	2 degree

IV. RESULTS AND DISCUSSION

The simulated S parameters are shown in Fig.4. It can be seen that the UHF tag is resonating at 865.8 MHz with S_{11}= -30.71 dB. The half power beam width (reflection coefficient <-3 dB) is almost 8 MHz covering the whole European frequency band region. While, Fig.5 is showing the omni-directional radiation pattern of UHF tag antenna in free space with the computed peak gain of around 1.7 dB at 866 MHz.

From simulated results, $Z_{ant} = 12.88 + j127.68\ \Omega$ which shows a good agreement with 7. The theoretical read range of UHF tag is calculated as 12.66 m by using equation 2

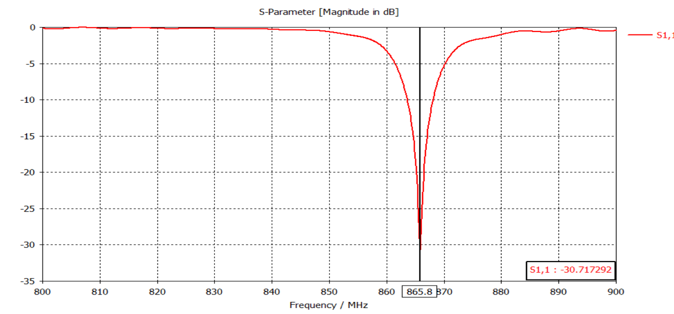

Fig. 4. Power Reflection Coefficient

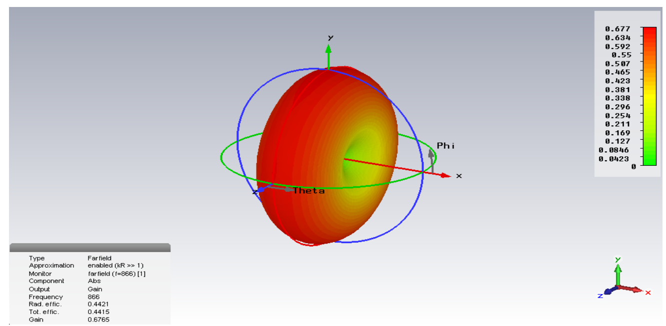

Fig. 5. Radiation Pattern of UHF Tag Antenna in Free Space

and 3. The Effective Isotropic Radiated Power (EIRP) has the maximum value allowed by European Telecommunications Standards Institute (ETSI) is $EIRP = 3.3$ Watts. The simulated gain of the tag $G_R = 1.7dB$ and transmitted power by the reader $P_T = -20dBm$.

TABLE IV
COMPARISON OF PROPOSED UHF TAG WITH PREVIOUS PUBLISHED WORK

Parameters	Dimensions mm^2	Reflection Coefficient S_{11}	Read Range m	Gain dB
[13]	91x27	-14.5	7.32	1.75
[14]	84.6x28	-35	6.2	1.8
[15]	77.33x77.4	-12.75	6.47	1.97
[16]	78x30	-20	5	1.11
Proposed design	49.14x17.90	-30.71	12.66	1.7

TABLE4 is showing the comparison of the proposed UHF tag design in terms of dimensions, reflection coefficient, read range and gain with previous published work. It can be seen that the proposed design is much smaller in dimensions with very good reflection coefficient values with high antenna gain and read range.

V. CONCLUSION

In this paper, we have presented a novel design of UHF RFID tag antenna using PET substrate and aluminium as the metallic track. This antenna has small size as compared to most of the previous work done in literature. It can be easily fit in limited space of bank cards for introducing tracking feature along with EMV chip and contact less payment facility. The simulated reflection coefficient is -30.71 dB at 865.8 MHz with the bandwidth of 8 MHz. The gain of the proposed tag antenna is 1.7 dB with computed maximum read range of 12.66 m. It can be adopted in other wireless applications with the ability to operate at European frequency band region.

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