Slotted RFID Tag Antenna for Metallic Objects

Apoorva Sharma, Azeemuddin Syed
Communications Research Center
International Institute of Information Technology
Hyderabad
apoorva.sharma@research.iiit.ac.in
azeemuddin.s@iiit.ac.in

A.R.Harish
Electrical Engineering Department
Indian Institute of Technology
Kanpur
arh@iitk.ac.in

***Abstract*— Designing RFID tag antenna for metallic objects is a challenging task as antenna parameters are highly affected by metallic surface. This paper presents a miniature slotted RFID tag antenna for metallic objects whose overall dimension is 33mm x 16mm x 3.2mm and it resonates at 864 MHz. Proposed design contains two patches which are electrically connected to the ground plane through Via. Multiple slots are created on these patches which help in improving overall antenna inductance. A non-connected metallic plate is present between ground and patches. The proposed design is simulated in the HFSS software. Here we show that the proposed design can be reused just by varying slot lengths, for different tag chips having different input impedance. Also this design has low interference in the presence of metallic surface.**

I. INTRODUCTION

Radio Frequency Identification (RFID) refers to the identification and tracking of objects wirelessly through radio waves and is gaining popularity for multiple applications in industries like automotive, aerospace, chemical, health care, transportation etc. An RFID system consists of a tag, a reader and a host computer. Globally the UHF band for RFID system range from 840-960 MHz where each country is allocated a different range. For example, the UHF band allotted for RFID applications in Europe is 866-869 MHz and for India is 865-867 MHz [1-2]. An RFID tag consists of antenna and a tag chip. Communication between tag and reader is achieved by modulated backscattering of the reader's carrier wave signal, like Amplitude Shift Keying (ASK) and Frequency Shift Keying (FSK) modulation [3].

Compared to barcode, the RFID tag has many advantages like, RFID tags need not to be on the surface of the carrying object. Read range of the RFID tag is greater than bar code [3]. Read time is less than 100ms and large number of tags can be read at the same time. RFID tags have read/write capability without being limited by the line of sight propagation, as used in barcodes. RFID tag is usually attached to different kinds of objects exhibiting various material properties. Among them, the metallic objects strongly affect the performance of antenna [4]. Therefore one of the biggest challenges here is to design RFID tag antenna for metallic objects with minimum interference effects.

Performance of tag is based on the antenna used. Hence an antenna design that performs efficiently for RFID tags is necessary with several other factors. It must be designed in such a way that it should have a small size, proper impedance matching with tag chip, high gain, good read range and low manufacturing cost [8]. As wire antenna consumes lot of space [7] patch antenna and printed antenna are the better choice for design.

Tag antenna must be designed in such a way that its performance does not degrade on metallic contact. Several designs have been proposed for RFID tag antenna mountable on metallic objects. RFID tag can have dipole antenna, loop antenna, patch antenna or planar inverted F-antenna (PIFA). Patch antenna and PIFA are preferred over dipole antenna as its efficiency reduces on contact with a metallic sheet [5-6].

In this paper, a slotted RFID tag antenna (33mmx16mm x3.2mm) for metallic objects is proposed with following characteristics: a) miniature size b) Usability of antenna with different tag chips without change in antenna length, width and height c) Reduction of interference due to metallic object for the given design. We also analyze the effect of floating plate on slotted antenna in the following sections. Rest of the paper is as follows. In section II we propose an antenna design followed by simulation with different design parameters in section III. This is followed by results and discussion of simulation in section IV.

II. PROPOSED ANTENNA DESIGN

The proposed design is based on a double mushroom like structure [9-10]. It consists of two rectangular symmetrical patches separated by 1mm gap as shown in Fig.1. These two patches are electrically connected to ground plate through copper via, whose diameter is 2mm. In between ground and patch layer there is a thin metallic layer called floating plate. On the floating plate two holes having diameter 3mm is created and copper via is passed through. This creates a gap of 0.5 mm between floating plate and via. Presence of floating plate helps in increasing antenna capacitance [10]. The insulation between metallic layers is provided by FR4 substrate whose relative permittivity is 4.4, relative permeability is 1 and dielectric loss tangent is 0.02. The tag chip (1mm x 1mm) is placed across the gap between two patches.

To increase inductance of the antenna, slots are created on every patch. Slots act as an inductor because it cuts off the flow path of the electrical current. The current has to flow around the slot and the equivalent length of current patch gets longer [11]. This achieves the desired property.

Slot inductance is dependent on slot length and width of the antenna [12]. From this we can infer that in cases where tag chip's input impedance has high capacitive value, the slot length should increase for proper matching. Similarly if the tag chip's input impedance has low capacitance then the slot length should be low.

Another advantage of having slots on antenna is that it leads to reduction of resonant frequency. Resonant frequency of the antenna is determined by:

$$f = 1/(2\pi\sqrt{LC}) \quad (1)$$

Where f is resonant frequency, L is inductance and C is capacitance. Here we can see that the resonant frequency has an inverse relationship with product of inductance and capacitance. Therefore as the number of floating plates increase, the capacitance of antenna increases whereas increase of slot length results in the increase of inductance. These parameters result in decrease of resonant frequency. In this way miniature design of the antenna can be achieved.

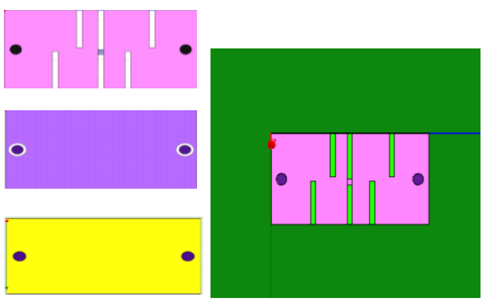


Figure 1 : a) Different layers b) Top View

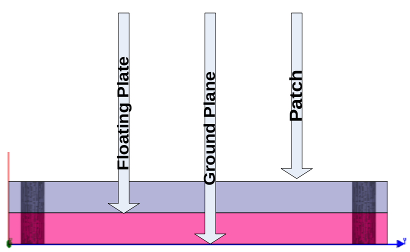


Figure 2: Front View

III. Simulation

Numerical Modeling software High Frequency Structure Simulator (HFSS) is used for simulation of the proposed design. Dimensions of the antenna are shown in *Table 1*.

Two typical tag chips: Alien 9440 [13] and NXP RFID IC SL3S10 01 FTT UCODE EPC G2 TSSOP8 package [14] were used to model the slotted antenna in the presence of a 20cm x 20 cm metallic sheet keeping a gap of 0.2 mm between them. Design parameters of slotted antenna used for both tag chips are also shown in *Table 1*. The slot length of NXP Tag is taken as 13 mm whereas the slot length of Alien 9440 Tag is considered to be 7 mm since the capacitance of NXP Tag is higher than Alien 9440.

Table 1: Parameters

Parameter	**Alien 9440**	**NXP Tag**
Input Impedance of Tag Chip	6-j125 Ω	22-j404 Ω
Antenna size	33mmx16mmx3.2mm	33mmx16mmx3.2mm
Patch size	15.5mmx 16mm	15.5mmx 16mm
Via Diameter	2mm	2mm
Floating plate	33mm x 16mm	33mm x 16mm
Slot length	7 mm	13 mm
Tag chip dimension	1mmx1mm	1mmx1mm

IV. Results and Discussions

A. *Resistance Vs. Reactance Plot for Unslotted Antenna and Slotted Antenna*

For maximum power transfer, antenna's input impedance must be in conjugate with tag chip's input impedance. Generally tag chip is capacitive in nature [12]. Hence for proper matching, antenna should be inductive in nature. In order to incorporate this, the given design in [9] for unslotted antenna was simulated at 865 MHz for various lengths and width. The slotted RFID antenna was simulated for various lengths, widths and slot length values to check range of inductance and resistance so the same design can be used for other tag chips. In Fig. 3 and 4, the reactance values are plotted against resistance for unslotted antenna and slotted antenna respectively. It is clear from the figure that spread of influence in resistance vs. reactance plot of unslotted design is very low as compared to slotted design.

Design given in [10] has low resistance and low inductance around i.e. 7.7+ j114 Ω at 925 MHz. Suppose a tag chip has high capacitance and low resistance like NXP RFID IC SL3S10 01 FTT UCODE EPC G2 TSSOP8 package whose input impedance is 22-j404 Ω at 867 MHz [14]. Then the unslotted double mushroom design will not work even after increasing antenna width and length. In Fig. 3 unslotted double mushroom design is simulated by varying antenna width from 13mm to 23mm and antenna length from 25 mm to 35 mm. It is clear from the plot that at low resistance the corresponding impedance is low whereas for high resistance the resultant impedance is high. This shows a linear relationship between resistance and reactance. Hence this design will not work for high impedance and low resistance. To overcome this problem, slots are created on the antenna. Therefore by adjusting slot length inductance value can be increased or decreased.

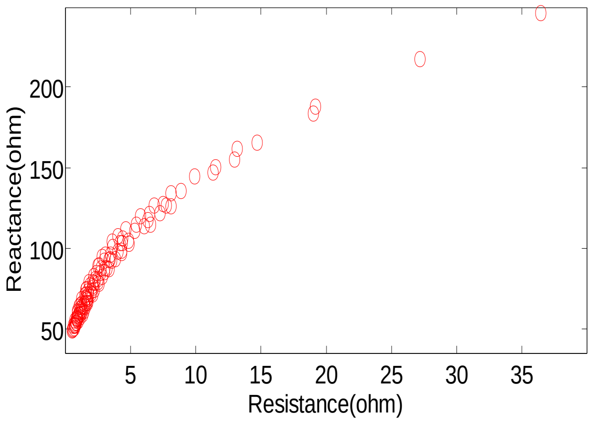


Figure 3: Resistance vs. Reactance Plot for Un-slotted Antenna

Slotted antenna was simulated by varying slot length from 1mm to 15mm, antenna width from 13mm to 23 mm and antenna length from 25 mm to 35mm. It is clear from Fig. 4 that same design can give low impedance as well as high impedance for example 22+350j as well as 22+150j by simply adjusting the slot length.

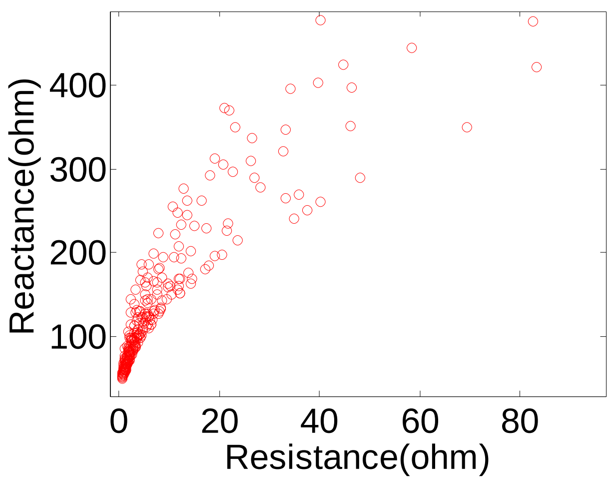


Figure 4: Resistance vs. Reactance Plot for Slotted Antenna

B. *Reflection Coefficient Plot for two tag chips*

Slotted designs were simulated for two different slot lengths with the two tag chips mentioned earlier. It can be noticed from Fig. 5 that the reflection coefficient is -38 dB when slot length is 13mm and antenna is matched to NXP tag. The reflection coefficient is -34 dB when antenna is matched to Alien Tag 9440. Hence we can say that same design can be used for different tag chips by adjusting slot length without changing its dimensions i.e. its length, width and height (33mm x 16mmx 3.2mm).

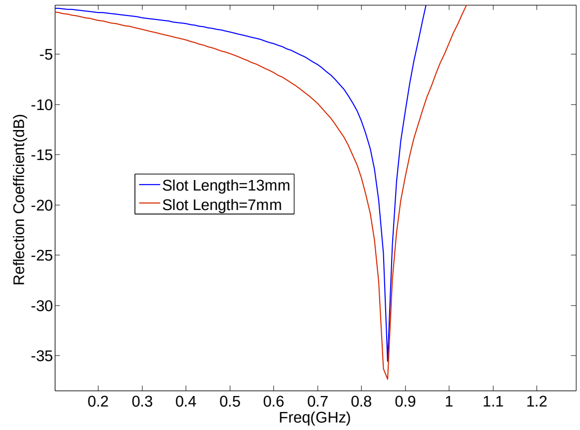
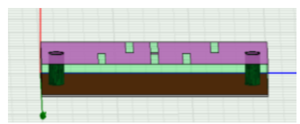
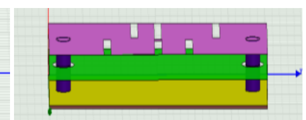


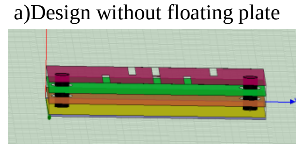
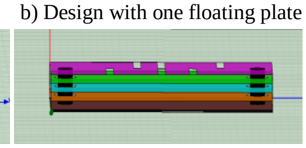
Figure 5: Reflection Coefficient Plot

C. *Effect of floating plate on Slotted Antenna*

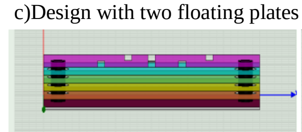
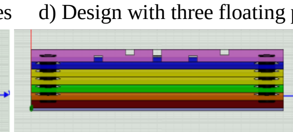
Antenna was simulated for different number of floating plates ranging from one to six as shown in Fig. 6. Fig 6(a) does not contain any floating plate. In all the cases shown the antenna height, length, width remains the same.

a)Design without floating plate b) Design with one floating plate

c)Design with two floating plates d) Design with three floating plate

e)Design with four floating plates f) Design with five floating plate

Figure: 6 Antenna Designs

Table 2

No. of Floating Plates	Resonant Frequency	Bandwidth
Zero	1.14 GHz	440 MHz
One	870 MHz	245 MHz
Two	745 MHz	165 MHz
Three	665 MHz	120 MHz
Four	605 MHz	105 MHz
Five	565 MHz	85 MHz
Six	525 MHz	70 MHz

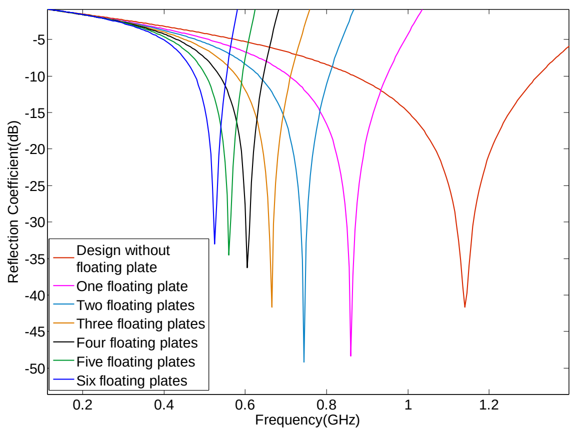


Figure 7 : Comparison Plot

It was found through simulation that an increase in the number of floating plates between ground and patches has the following consequences: a) Decrease in the bandwidth. In the absence of floating plate, the bandwidth is 404 MHz whereas and in the presence of six floating plates the bandwidth decreases to 70 MHz. b) Decrease in resonant frequency is also observed. Resonant frequency is 1.14 GHz in the absence of a floating plate whereas it decreases to 525 MHz in case of six floating plates. c) Gap between the peak resonating frequency decreases with the increase in the number of floating plate as shown in Fig. 7.

Hence we can conclude that by inserting more plates the antenna size can be reduced with various trade-offs.

D. Effect on Gain due to Floating Plates

It is clear from Fig. 8 and table 3 that gain decreases as floating plate increases. Antenna gain is maximum when no floating plate is there in the design. As we keep on increasing floating plate then gain starts to decrease.

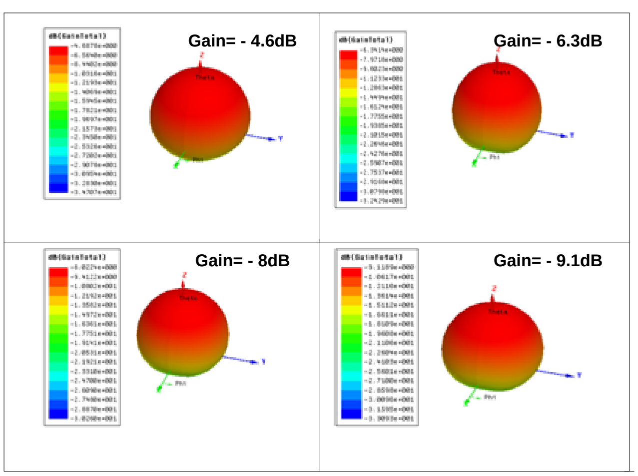


Figure 8: Gain Pattern

Table 3: Gain Table

No of floating plates	Gain(dB)
Zero	-4.6
One	-6.3
Two	-8
Three	-9.1
Four	-9.9
Five	-10
Six	-11

E. Interference Effect due toMetallic sheet

To explore the interference effect due to metallic object design was simulated by taking different metal sizes by keeping a constant distance of 0.2mm between antenna and the metallic sheet. In this simulation metal sheet size varies from 3 cm to 35 cm. It can be noticed from the fig.9 that the effect of metal plate on antenna is very low because frequency shifting due to metallic sheet is very low.

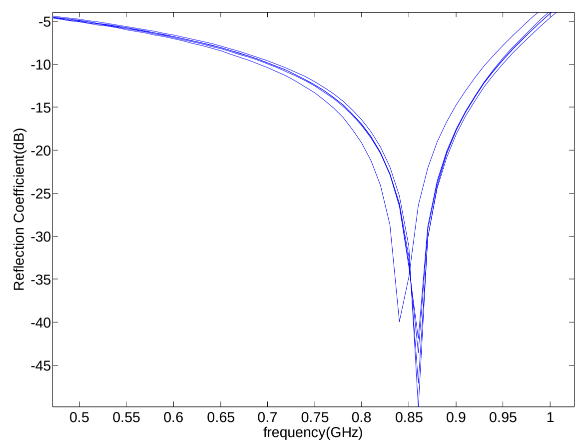


Figure 9: Comparison Plot

V. Conclusion

A miniature RFID tag antenna has been developed in this work. The miniature design is achieved by inserting a floating layer between patch and ground. The simulated results show the following: a) interference due to metallic sheet is low b) antenna gain decreases as the floating plate increases c) antenna bandwidth and resonating frequency decreases as floating plate increases. It was also shown that the same design can be used with wide range of tag chips by varying slot length.

REFERENCES

[1] MingYin Lai, RongLin Li(2010): A Low Profile Broadband RFID Tag Antenna for Metallic Objects

[2] Bill Glover , Himanshu Bhatt(2006), RFID Essentials, ISBN 0-596-00944-5

[3] Stephen Shepard(2005): Radio Frequency Identification, ISBN 0-07-144299-5

[4] Cho, C., H. Choo, , and I. Park (2008): Design of Planar RFID Tag Antenna for metallic objects, *Electronics Letter*, Vol. 4, pp. 175-177.

[5] Wonkyu Choi,Jeong-Seok Kim, Ji-Hoon Bae, Gil-Young Choi, Jong-Soek Chae(2008): Small RFID Tag Antenna for Metallic Objects, *IEEE Antenna and Propagation Society International Symposium*, pp. 1-4

[6] M. Hirvonen, P. Pursula, K. Jaakkola, K. Laukkanen(2004): Planer Inverted-F Antenna for Radio Frequency Identification, *Electronic Letters*, Vol. 40, pp. 848-850.

[7] Sharma Apoorva, Syed Azeemuddin(2010), Non-linearity between frequency bands and segmentations of meander antennas, *SIBIRCON 2010*

[8] Luhong Mao, Ruiliang Song, Yanming Li, Liying Chen(2008), UHF RFID Tag Antenna Design and A Novel Antenna Verification Development Platform, *4th International Conference on Wireless Communications, Networking and Mobile Computing*, pp. 1-3

[9] Chen, Sung-Lin (2008): A Slim RFID Tag Antenna Design for Metallic Object Applications, *IEEE Antennas And Wireless Propagation Letters*, pp. 729 - 732

[10] Chen, Sung-Lin (2009): A Miniature RFID Tag Antenna for Metallic Objects Applications, *IEEE Antennas And Wireless Propagation Letters*, pp. 1043 - 1045

[11] 3. Reed, S. (2001): Patch Antenna Size Reduction by means of Inductive Slots, *Microwave Optical Technology Letter, John Wiley & Sons, Inc*.

[12] Equivalent Series inductively

[13]

[14] Harish, A.R., Anshu Gupta, Hemant Purohit, Gurpreet Singh Lamba, Nikhil Grover (2008): Performance Analysis of RFID Tag Antennas, *International Journal on Wireless and Optical Communications*, Vol. 5, Issue 1, pp. 60 -68 .