Analysis of Low Profile UHF RFID Tag Antennas and Performance Evaluation in Presence of a Metallic Surface

Tashi Dendup[1, 2], Mohammad S. Hasan[2] and Hongnian Yu[2]

[1]Department of Electrical Engineering, College of Science and Technology, Rinchending, Phuentsholing, Bhutan
[2]Faculty of Computing, Engineering and Technology, Staffordshire University, Stafford, ST18 0AD, UK
[1]tashi@cst.edu.bt, [2]{m.s.hasan, h.yu}@staffs.ac.uk

Passive UHF RFID systems have drawn considerable attention because these can provide a long reading range, high data rate and small antenna size. However, a passive UHF RFID system has challenges in tagging a metallic object due to the effects of conducting materials on the tag antenna performance. This paper proposes two widely used label-type antennas: folded dipole antenna and meandered dipole antenna to optimise design parameters such as impedance matching, feeding techniques, size-reduction, bandwidth etc. The proposed low profile antennas can operate at 866 MHz which is suitable for the UK and Europe UHF RFID frequency band. The paper also presents an investigation and analysis of the effects of a metallic surface on the performance of the proposed dipole tag antennas. It studies the effects of distance between the metal and the tag, thicknesses of the metallic plate and antenna substrate. The performance is evaluated in terms of return loss, shift in resonance frequency and bandwidth. The simulation results show that when the tag antennas are mounted closer to a metallic surface, the return loss of the tag antennas is significantly increased and the resonance frequency is also shifted from the desired operating frequency. Although the size is reduced, these antennas might not be good choices for tagging metallic objects. An antenna that uses metallic surface as the ground plane e.g. Micro-strip patch antenna and planar inverted-F antenna (PIFA) might be a possible solution in this case.

***Index Terms*—folded dipole antenna, meandered dipole antenna, tag antenna performance, effect of metal.**

I. INTRODUCTION

The rapid increase in requirements of automatic identification in various areas such as item-level tracking, access control, electronic toll collection, vehicle security [1] etc. accelerates the demand for the radio frequency identification (RFID).

RFID is a pervasive computing technology [2]. It consists of a reader, tags and an application computer. The basic configuration of a passive RFID system is shown in Fig. 1. Based on the method of powering, an RFID system is classified as passive (without battery), active (with battery) and semi-active. An RFID system is also classified as the near-field and far-field system based on the method of coupling between the reader and tag. The near-field system works on the electromagnetic induction and operates at low frequency (LF) around 125-134 kHz or high frequency (HF) at 13.8 MHz [3]. On the other hand, the far-field system works on the backscattering propagation and operates at ultra-high frequency (UHF) around 860-960 MHz or microwave frequency (MWF) at 2.5 GHz [3].

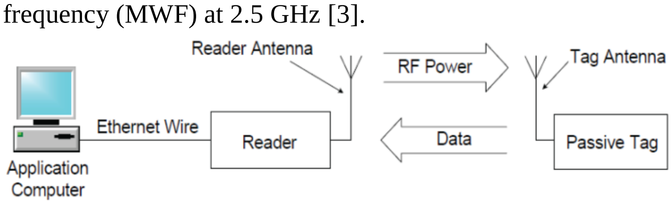

Fig. 1. Configuration of a passive RFID system.

In recent years, the passive UHF RFID system is getting considerable attention because it can provide a long reading range, high data rate and small antenna size. Many applications require the tag antenna to be of low profile and easy to be mounted or embedded on any objects. A low-cost label-type dipole antenna printed on a very thin film is commonly used as the tag antenna in passive UHF RFID applications [4, 5]. However, when mounted on a metallic object, the antenna parameters such as radiation pattern, bandwidth, gain, input impedance etc. change and the overall efficiency seriously degrades due to the change of the reactance of the antenna impedance [6, 7]. This results in degradation of the UHF RFID tag performance. In the worst case, the tag may not be detected by the reader within its normal reading range.

In this paper, two variants of dipole antenna: folded dipole and meandered dipole antenna are proposed to optimise design parameters e.g. size, bandwidth, impedance matching, feeding technique and to study the effect of metallic surface. First the proposed tag antennas are designed and analysed in free space. Then, the effects of a metallic surface on the proposed antennas in terms of return loss, shift in resonance frequency and bandwidth are analysed. The rest of the paper is organised as follows. Section II addresses the related works. Section III discusses the proposed tag antenna design requirements and approach. Section IV presents the proposed tag antennas designs. Section V discusses the simulation set-up and simulation results. Section VI addresses the performance of the proposed tag antennas near or on metallic surface. Finally, section VII draws some conclusions.

II. RELATED WORKS

In [8], the authors have investigated the ordinary dipole antenna and modified to reduce its length, broaden its bandwidth and the antenna is designed at 900 MHz resonance frequency.

The tag antenna problems for RFID systems are first reported by Foster and Burberry [9]. Only limited work on the effect of metal near the antenna has been published. The effect of a metallic reflector on the folded dipole antenna is simulated by Raumonen et al [10] and it has been reported that the signal strength decreases in radiation pattern when the antenna is taken closer to the metallic reflector.

Dobkin and Weigand [6] have shown the experimental set-up to measure the reading distance of a tag near metal plate and water filled container. They have reported that there is a decrease in reading distance when the tag is close to the metal surface. They have also reported changes in the tag antenna impedance when the tag is taken near a metallic surface.

In [7], the power and backscatter communication radio link budgets that allow the tag designer to quantify the effects of tag material attachment is studied. And they have reported a decrease in the tag antenna gain when it is placed near the metallic surface.

The effects on the antenna parameters when placed on paper and plastic is studied by Rida et al [11] and it has been reported that there are shifts in resonance frequency when the antenna substrate is changed.

Mittra and Hoenschel [12] have designed a tag antenna that employs Electromagnetic Bandgap (EBG) surfaces substrate to have less sensitivity to the environment. However, their tag antenna parameters e.g. radiation pattern and impedance characteristics change little when placed on metal or glass.

The effect of the substrate, metal-line and surface material on the performance of RFID tag antennas is investigated in [13]. It reports that the readability of the tag drastically decreases when the tag is attached to a high permittivity and high loss target object.

Paper [14] has studied performance of the RFID tag antenna based on the antenna trace materials e.g. Copper, Aluminium and Sliver. It has been observed that Copper deposit and Silver inks are competitive materials compared to Aluminium when 1 mm antenna trace width is used. However, deposited Copper has superior conductivity and can work with much less deposited material than Silver and with narrow line widths.

III. The Proposed Tag Antenna Design Requirements and Approach

A. The Proposed Tag Antenna Performance Criteria

The return loss determines the impedance mismatch between the tag antenna and chip given by (1) which is taken from [15].

$$return\ loss = -20\log_{10}\left(\frac{Z_A + Z_C}{Z_A - Z_C}\right)\ dB \tag{1}$$

Here $Z_C = R_C + jX_C$ is chip impedance and $Z_A = R_A + jX_A$ is tag antenna impedance, R_C and X_C are chip input resistance and input reactance, respectively and R_A and X_A are tag antenna input resistance and input reactance, respectively. If the return loss is high, the power delivered to the chip will be less and it reduces the overall performance of the tag. The perfect impedance match will transfer maximum power from the antenna to the chip.

The bandwidth requirement of the tag antenna is at least 500 KHz as per the ISO/IEC 18000-7 standard [16] and it is measured at < -10dB return loss. The bandwidth of the proposed antenna [17] is determined by (2).

$$bandwidth = \frac{f_H - f_L}{f_0} \tag{2}$$

Here f_H and f_L are the upper and lower cut-off frequencies, respectively at -10 dB return loss and f_0 is the centre operating frequency.

The shift in the resonance frequency of the proposed antenna should be close to the operating frequency. If the resonance frequency response is widely diverted from the desired operating frequency, the antenna will not work at the target frequency band.

B. Design Requirements of the RFID Tag Antenna

A passive tag consists of an antenna and a chip. The chip is quantified by the integrated circuit (IC) manufacturers [18] and cannot be modified by the user. For a specific application with the prior selected chip and reader, the tag antenna has to be designed to get the maximum reading distance. The antenna must have the following features:

1. It should be very small and flexible to attach or fix on the required object like cardboard, smart card, airline baggage strips etc.
2. It should provide maximum power to the tag chip to have the maximised reading range.
3. It should be very cheap to achieve a low cost tag.
4. It should be mechanically robust to sustain very harsh environment e.g. temperature, humidity and stress from other physical objects coming in contact with the tag.

C. Selection of the Applications for the Proposed Tag Antennas

The proposed tag antennas are designed for a passive UHF RFID tag which is considered to use in a smart label for cardboard box tagging in the UK and Europe warehouse environment [19].

D. Selection of the Operating Frequency for the Proposed Tag Antennas

The proposed tag antennas should be easily tuneable from 865 MHz to 867 MHz range for the UK and Europe UHF RFID frequency band. The operating frequency (f_0) of the proposed tag antennas is selected as 866 MHz and the tag antenna parameters are designed based on the selected operating frequency.

E. Identification of the Type of Tag Antennas

In UHF RFID applications, the half wavelength (λ/2) dipole antenna is commonly used for the tag. But the size of the λ/2 dipole antenna will be bigger for the lower operating frequency and will be smaller for the higher operating frequency. This is because the wavelength is inversely proportional to the frequency. For example, at the 866 MHz operating frequency the wavelength is 346 mm. Hence, the length of antenna is equal to 173 mm which is too big for RFID tags. However, to reduce the size of antenna, the dipole antenna is modified as follows: folding the ends of dipole, capacitive loading of the dipole ends and folding the dipole into a meandered pattern. The folded dipole antenna and meandered dipole antenna are chosen for this study as these offer small antenna size for the RFID tag.

F. Selection of the Substrate Material for the Proposed Tag Antennas

A tag antenna is made up of conductors (radiation elements) and dielectric (substrate) [20, 21]. The materials used for conducting wires are Copper, Aluminium and Silver ink. The Silver and Copper are good conductors but they are very expensive. On other hand, Aluminium is cheap; however, it is a poor conductor.

The dielectric material such as paper, plastic or polymers can be used as substrate to reduce the tag cost. Commonly used substrates are polyethylene terephthalate (PET) and rigid printed circuit board (PCB) such as FR-4 (Flame Retardant type-4). The selection of a radiation element and substrate is a trade-off between cost and performance.

The conductor is etched, printed, coiled (wounded), or stamped on the substrate and then chip is attached on it. This assembly is called as an inlay [20]. The inlay is called a tag when it is attached to a cardboard box, airline baggage strip, smart card, printed label etc.

The commonly used thin polyimide substrate [4] with a dielectric constant (ε_r) of 3.5, loss tangent (δ) of 0.003 and thickness (t_s) of 0.05 mm is selected for the proposed antennas. This substrate is cheap and can be easily mounted to the cardboard box. The top antenna trace is printed on the polyimide and is made of Copper with a thickness (t_a) of 0.018 mm.

G. Selection of the Tag Chip and Impedance Matching for the Proposed Tag Antennas

The RFID tag antennas are designed based on the input impedance of the tag chip. For the proposed designs, the Alien Higgs-3 [22] chip is selected as it is widely used in the industry and is available in the lab during the design process.

The Alien Higgs-3 is an integrated single chip for EPC (Electronic Product Code) Class 1 Generation 2 RFID tag manufactured by the Alien Technology. The Alien Higgs-3 exhibits an input impedance of Z_C = (31- j212) Ω at 866 MHz resonance frequency and requires a minimum of -14 dBm power to turn-on the chip. In order to deliver the maximum power from the antenna to the chip, the input impedance of the antenna, Z_A should be complex conjugately matched to the chip impedance, Z_C (i.e. $Z_C = Z_A^*$). Therefore, the proposed antenna design should have an input impedance of Z_A = (31 + j212) Ω.

The impedance mismatch between the tag antenna and chip is determined by the power transmission coefficient (τ) [4] given by (3).

$$\tau = \frac{4R_C R_A}{|Z_C + Z_A|^2}, \quad 0 \le \tau \le 1 \tag{3}$$

Here R_C is input resistance of a chip and R_A is input resistance of an antenna.

IV. The Proposed Tag Antenna Design

The proposed folded dipole and meandered dipole antenna designs are presented in the following sections.

A. The Proposed Folded Dipole Antenna Design

The geometry of the proposed folded dipole antenna is shown in Fig. 2. The proposed folded dipole antenna has two layers. The top layer is the radiating element (i.e. antenna trace) and the bottom layer is the antenna substrate. The radiating element has two elements: main radiating element and parasitic element. The main radiating element is used to radiate the electromagnetic field while the parasitic element is used to match the proposed folded dipole antenna input impedance to the tag chip input impedance. The key antenna parameters of the radiating element are: antenna length *L*, antenna breath *B*, antenna trace width *w*, folded arm length *a*, parallel distance *d* between the main element and the parasitic element and the separation gap between folded arm and parasitic element *s*. The bottom layer (i.e. antenna substrate) is used for holding the radiating element.

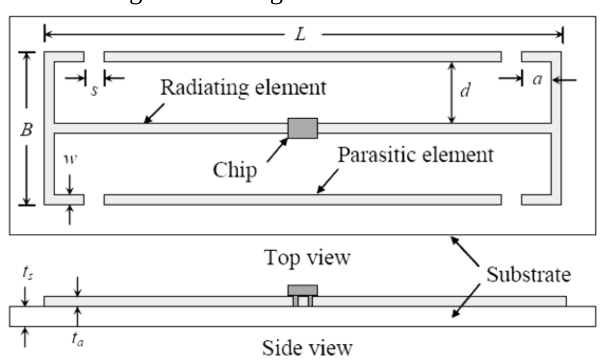

Fig. 2. Geometry of the proposed folded dipole antenna.

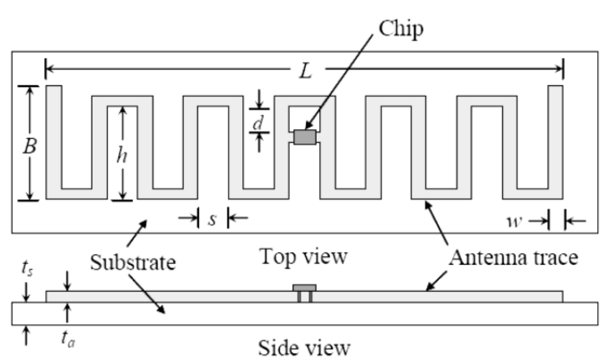

Fig. 3. Geometry of the proposed meandered dipole antenna.

B. The Proposed Meandered Dipole Antenna Design

The geometry of the proposed meandered dipole antenna is shown in Fig. 3. The proposed meandered dipole antenna also has two layers. The top layer is the radiating element is used to radiate the electromagnetic field. The bottom layer is the antenna substrate which is used for holding the radiating element. The radiating element has several key parameters: length of antenna *L*, meander step height *h*, meander step width *w*, conductor spacing *s*, length of last meandered conductor *B* and the separation distance between the feed element and main radiating element *d*. Here, the T-match feeding technique is used to feed the proposed antenna to match the antenna impedance to the chip impedance. By varying the geometry of the T-match feeding, the proposed meandered dipole antenna input impedance is matched to the tag chip input impedance.

V. Simulation Set-up and Results

A. Simulation Set-up

The proposed dipole antennas are simulated in the Sonnet Lite electromagnetic (EM) simulator [23] which simulates based on the method of moments (MoM). The Sonnet Lite is a 3D planar EM design software for circuits and antennas developed by the Sonnet Company.

The Sonnet EM simulation analysis is performed inside a four-sided lossless metal box. This box is divided into the three layers as shown in Fig. 4. The top and bottom layers are set as the free space layer and the middle layer is set as the substrate layer. The antenna radiating element is placed on the substrate layer at the centre of the box. While the four sidewalls provide a perfect ground reference as well as to use Fast Fourier Transform (FFT) to compute all circuit cross-coupling.

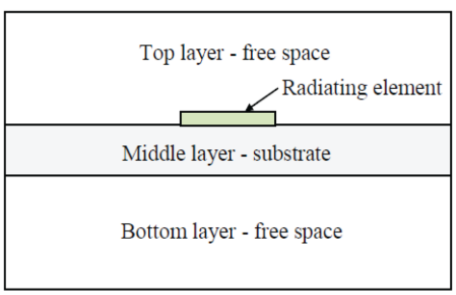

Fig. 4. Front view of the simulation set-up for the proposed tag antennas.

The sidewalls are set at 1.5 wavelengths (the Sonnet recommended to set one to three wavelengths) from the antenna trace to avoid the effects from the sidewalls. The wavelength of an 866 MHz signal is 346 mm and the proposed antenna is simulated for half wavelength which is 173 mm. This gives the box size of 1200 mm x 1200 mm. The top layer and bottom layer are set at 200 mm (the Sonnet recommended to set not less than or equal to the half wavelength) which is slightly more than half wavelength (i.e. 173 mm) to avoid the effect of fringing fields (i.e. near field). The middle layer is set at the height 0.05 mm with dielectric constant (ε_r) of 3.5 and loss tangent (δ) of 0.003. The antenna radiating element material is selected as a Copper (i.e. same as design) and set as Copper thickness (t_a) of 0.018 mm and conductivity of 58000000 siemens per meter. Finally, all the simulations are performed in the frequency sweep from 800 MHz to 980 MHz. The simulation results of the proposed folded dipole and meandered dipole antenna are presented in the following sections.

B. Simulation Results of the Proposed Folded Dipole Antenna

To achieve small tag size, the width *B* of the proposed folded dipole antenna is kept constant to 28 mm and a parameter sweep operation is performed in Sonnet for length *L* from 80 mm to 160 mm with the step size of 2 mm. In each step, the Sonnet Adaptive Band Synthesis (ABS) analyses the *L* for frequency ranging from 800 MHz to 980 MHz which is wider than the UHF frequency band i.e. 860 MHz to 960 MHz. It ensures that the whole UHF RFID frequency response can be plotted inside the simulation output for analysis. Once parameter sweep is completed, the Sonnet plots return loss vs. frequency for each step of *L*.

Generally, the return loss bandwidth is either measured at -3 dB or -10 dB [16]. In order to have wider return loss bandwidth and less reflection power between the chip and the antenna, the maximum return loss is chosen to be less than or equal to -18 dB at the desired resonance frequency i.e. 866 MHz. After performing several parameter sweep simulations and examining each result, the final optimised parameters of the proposed folded dipole antenna are given in Table I. To match the proposed folded dipole antenna impedance Z_A to the chip impedance Z_C, the separation gap, *s* between the folded arm and the parasitic element is varied from 1 mm to 10 mm with the simulation step size of 1 mm.

Table I

Parameters of the proposed folded dipole antenna (Dimension in mm)

Parameters	***L***	***B***	***s***	***w***	***a***	***d***
Values	108	28	4	2	6	12

Fig. 5 and Fig. 6 show the input resistance and reactance, respectively against UHF frequency of the proposed folded dipole antenna with various separation gaps, *s*. It is clear that the input resistance and reactance can be increased or decreased by varying *s*. After examining the simulation results it is found that when *s* = 4 mm, the antenna input resistance, R_A is 30 Ω and antenna input reactance, X_A is 210 Ω. This shows that the proposed folded dipole antenna input impedance is complex conjugately matched to the input impedance of the chip i.e. R_C is 31 Ω and X_C is 212 Ω.

Fig. 7 presents the return loss of the proposed folded dipole antenna at 866 MHz resonance frequency. The minimum value of the simulated return loss (S_{11}) at resonance frequency is -21.59 dB. At half-power return loss (i.e. < -3 dB), the proposed folded dipole antenna covers entire UHF RFID frequency range (i.e. 860 MHz to 960 MHz) and the proposed antenna can be used in the world wide UHF RFID system. The simulated < -10 dB bandwidth of the proposed antenna is 67.5 MHz (7.79%), from 836 MHz to 903.5 MHz which can easily operate in the UK and Europe UHF RFID system. Both -3 dB and -10 dB bandwidths meet the requirement (500 kHz) of the ISO/IEC 18000-7 standard [16].

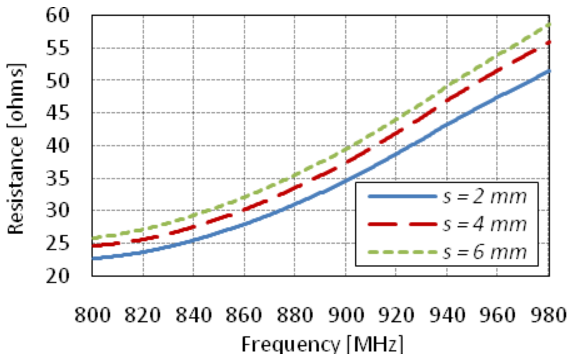

Fig. 5. Simulated input resistance against UHF frequency of the proposed folded dipole antenna with various separation gaps, *s*.

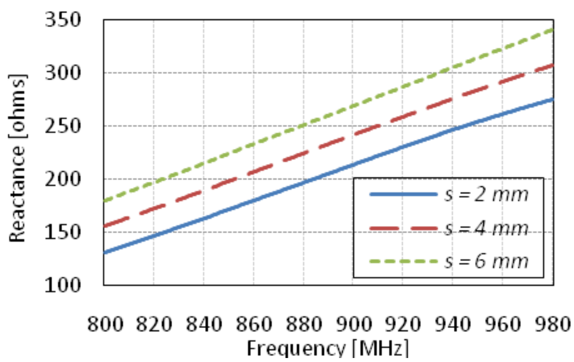

Fig. 6. Simulated input reactance against UHF frequency of the proposed folded dipole antenna with various separation gaps, *s*.

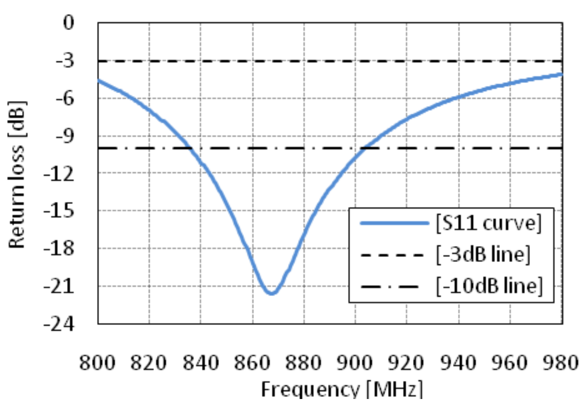

Fig. 7. Simulated return loss of the proposed folded dipole antenna at 866 MHz resonance frequency.

C. *Simulation Results of the Proposed Meandered Dipole Antenna*

The length *L* and width *B* of the proposed meandered dipole antenna are determined by performing numerous parameter sweeps. Keeping meander step height *h*, width *w* and conductor spacing *s* constant, a parameter sweep is performed for *L* from 40 mm to 120 mm and *B* from 10 mm to 40 mm with the simulation step size of 2 mm in both cases.

Table II presents the final optimised parameters of the proposed meandered dipole antenna. To match the proposed meandered dipole antenna impedance Z_A to the chip impedance Z_C, T-match feeding is used. The impedance is matched by varying the separation distance *d* between the radiating element and feed element from 1 mm to 10 mm with simulation step size of 1 mm.

Table II

Parameters of the proposed meandered dipole antenna (Dimension in mm)

Parameters	*L*	*B*	*h*	*w*	*s*	*d*
Values	68	22	18	2	4	5

Fig. 8 and Fig. 9 show the simulated input resistance and reactance, respectively against UHF frequency of the proposed meandered dipole antenna with various separation distances, *d*. It is clear that the input resistance and reactance can be increased or decreased by varying *d*. After examining parameter sweep results it is observed that when *d* = 5 mm, the antenna input resistance, R_A is 35 Ω and input reactance, X_A is 215 Ω. This shows that the proposed meandered dipole antenna input impedance is complex conjugately matched to the input impedance of the chip i.e. R_C is 31 Ω and X_C is 212 Ω.

Fig. 10 presents the return loss of the proposed meandered dipole antenna at 866 MHz resonance frequency. The minimum value of the simulated return loss (S_{11}) at the resonance frequency is -22.76 dB. The half-power bandwidth (i.e. < -3 dB) is 77 MHz (8.89%), from 829.5 MHz to 906.5 MHz. The simulated < -10 dB bandwidth of the proposed antenna is 25 MHz (2.89%), from 855 MHz to 880 MHz. Both at -3 dB and -10 dB return losses, the proposed tag antenna can be used in the UK and Europe UHF RFID system. Also -3 dB and -10 dB bandwidths of the proposed antenna meet the requirement (500 KHz) of the ISO/IEC 18000-7 standard [16].

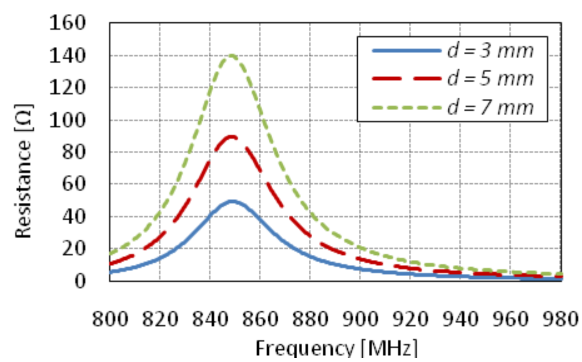

Fig. 8. Simulated input resistance against UHF frequency of the proposed meandered dipole antenna with various separation distances, *d*.

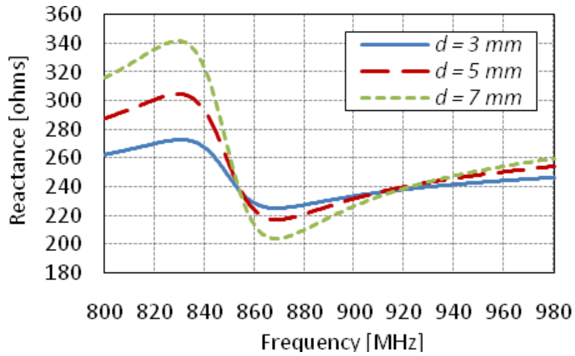

Fig. 9. Simulated input reactance against UHF frequency of the proposed meandered dipole antenna with various separation distances, *d*.

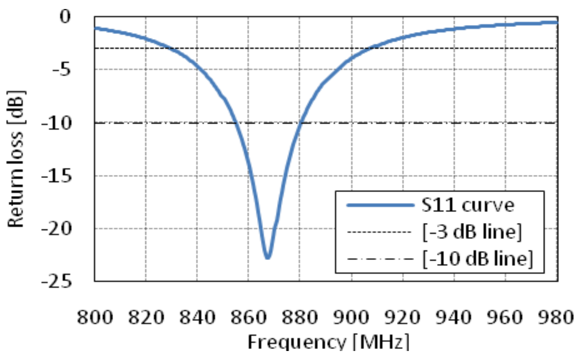

Fig. 10. Simulated return loss of the proposed meandered dipole antenna at 866 MHz resonance frequency.

D. *Comparison of the Proposed Folded and Meandered Dipole Antenna*

The proposed folded dipole and the meandered dipole antennas in this paper are designed to operate at 866 MHz resonance frequency and have been compared to [8] in terms of size (area) and bandwidth. This is because the motive in [8] and the proposed design is to reduce the size of the dipole antenna.

Fig. 11 shows the area comparison of the proposed folded and the meandered dipole antenna with the modified dipole antenna in [8]. The proposed folded dipole antenna and the meandered dipole antenna exhibit area reductions of 11.32% and 56.13%, respectively. It is clearly shown that the meandered dipole antenna would offer a compact and robust passive tag than the folded dipole antenna and modified dipole antenna which is demanded by most of the RFID applications. However, the proposed meandered dipole antenna has a narrower bandwidth than the modified dipole antenna in [8] as shown in Fig. 12. It is because the modified dipole antenna in [8] is designed to operate in the entire UHF RFID frequency band (i.e. 860 MHz to 960 MHz). On the other hand, the proposed meandered dipole antenna is designed to operate in the UK and Europe UHF RFID frequency band (i.e. 865 to 867 MHz and has narrower bandwidth).

Therefore, a trade-off among the area, bandwidth and performance parameters is needed based on the type of tag antenna and the RFID applications. For example, if the size of tag requirement for RFID is a crucial factor, then the meandered dipole antenna can be used.

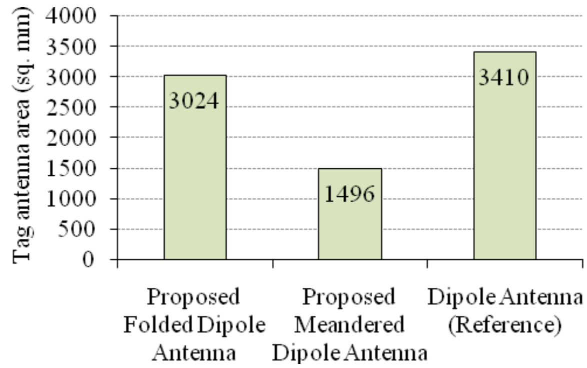

Fig. 11. The area comparison of the proposed tag antennas.

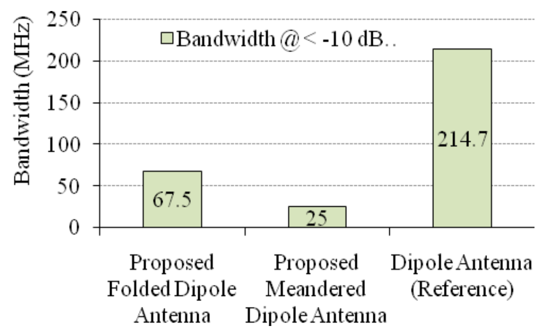

Fig. 12. The bandwidth comparison for the proposed tag antennas at < -10 dB return loss.

VI. Performance of the Tag Antenna When Placed near a Metallic Surface

The simulation environment to investigate the performance of tag antenna when mounted on a metallic surface is set-up in the Sonnet Lite EM simulator.

Fig. 13 shows how a tag antenna is mounted on a metallic surface in the EM simulator to evaluate the effect of a metallic surface. The tag antenna is placed above the metallic surface keeping air as the medium between them. The separation gap between the tag antenna and metal is *D*. The infinite ground plane of the EM simulator is used as a metallic surface which is 0.2 mm thick. The type of the metallic surface is considered as Copper for this analysis. The metallic surface is taken closer to the tag antenna by a step of 10 mm. At every step, the return loss value, bandwidth and resonance frequency are examined.

After performing a numerous number of simulations, it is observed that when the tag antenna is placed above the metallic surface more than the quarter wavelength of the antenna's resonance frequency, there is not much effect by the metallic surface. Therefore, the performance evaluation emphasises when the distance between the tag antenna and a metallic surface is less than quarter of the wavelength.

Fig. 14 and Fig. 15 show the simulation results of the proposed folded dipole and meandered dipole antenna, respectively for various separation gaps *D*. In both cases, when the tag is taken closer to a metallic surface by a step of 10 mm, there is a significant increase in the return loss and shift in the resonance frequency from the desired frequency. For example, for the separation gap of 20 mm and 50 mm, the resonance frequency is 845 MHz and 855 MHz, respectively as shown in Fig. 15. When *D* is less than 40 mm, the return losses of the proposed antennas are greater than -3 dB and the tag antenna may not work at all since it is short circuited by the metallic surface and suffers from a high return loss. The increase in the return loss is due to the change in the antenna impedance according to (1).

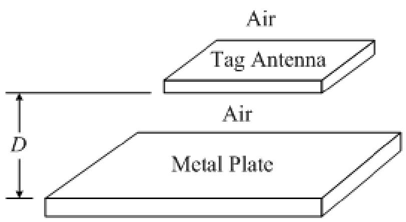

Fig. 13. The isometric view of the simulation model set-up to investigate the performance of a tag antenna on metallic surface.

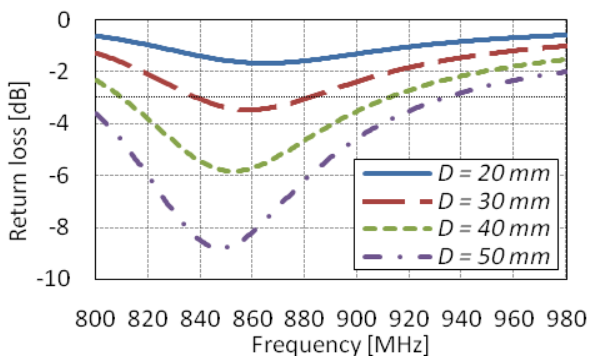

Fig. 14. The return loss of the proposed folded dipole antenna for various separation gaps, *D* between the antenna and metallic surface.

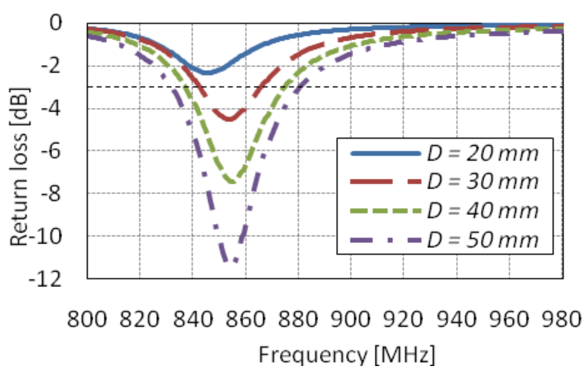

Fig. 15. The return loss of the proposed meandered dipole antenna for various separation gaps, *D* between the antenna and metallic surface.

Fig. 16 and Fig. 17 show the simulated results of UHF frequency vs. return loss of the proposed meandered dipole antenna at *D* = 50 and *D* = 30 mm, respectively for various metallic plate thickness, t_m. All other parameters are kept constant. Both figures show that the thickness of the metallic plate does not affect the performance of the tag antenna. Similar simulations are also performed for the proposed folded dipole antenna and similar results are found.

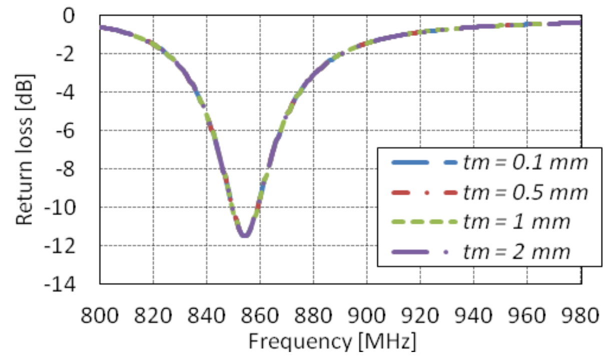

Fig. 16. The UHF frequency vs. return loss of the proposed meandered dipole antenna at *D* = 50 mm for various metal plate thickness, t_m.

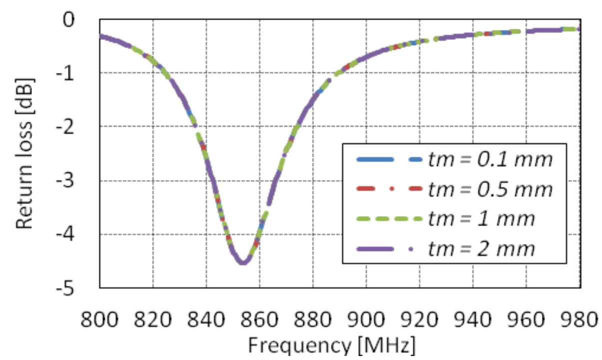

Fig. 17. The UHF frequency vs. return loss of the proposed meandered dipole antenna at *D* = 30 mm for various metal plate thickness, t_m.

Fig. 18 and Fig. 19 show the simulated results of UHF frequency vs. return loss of the proposed folded dipole and meanderd dipole antenna, respectively for various the substrate thickness, t_s. These results present the performances without the ground plane or a metal near to the antenna and keeping other antenna parameters constant. Both figures show that when the antenna substate thickness increases, the resonance frequency decreases and the return loss increases slightly. Thus, the variation of the thickness of the antenna substrate also affects the performance of the tag antenna.

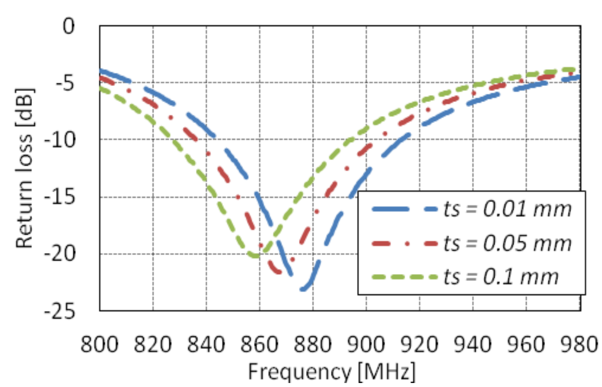

Fig. 18. The substrate thickness, t_s vs. the return loss of the proposed folded dipole antenna.

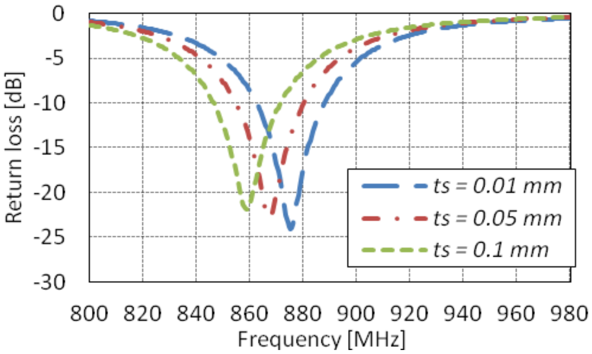

Fig. 19. The substrate thickness, t_s vs. the return loss of the proposed meandered dipole antenna.

VII. Conclusion

In this paper, a folded dipole and a meandered dipole antenna are proposed on a very low profile for a passive UHF RFID tag. The simulation results show that the meandered dipole antenna structure offers a compact and small tag size. However, it suffers from the narrower bandwidth. The performances of the proposed tag antennas on a metallic surface are studied and analysed. The study shows that when the tag antenna is taken closer to a metallic surface, the antenna return loss increases and thus degrades the performance of the tag antenna. The investigation also reveals that when the antenna substrate thickness increases, the resonance frequency decreases and the return loss increases slightly. Thus, the variation of the thickness of the antenna substrate also affects the performance of the tag antenna. Therefore, the possible solution to improve the performance may be by designing an antenna which uses metallic surface as the ground plane e.g. Micro-strip patch antenna and planar inverted-F antenna (PIFA). The research team has already done some investigations on designing a micro-strip patch antenna prototype for passive UHF RFID tag which has been published in another paper.

Acknowledgment

This work was supported by the eLINK (east-west Link for Innovation, Networking and Knowledge Exchange) (EM ECW-ref.149674 -EM-1-2008-1-UK-ERAMUNDUS) project.

References

[1] K. Finkenzeller, *RFID Handbook Fundamentals and Applications in Contactless Smart Cards and Identification* Chichester: John Wiley and Sons Ltd, 2003.

[2] R. Want, "An introduction to RFID technology," *IEEE Pervasive Computing*, vol. 5, no. 1, pp. 25-33, 2006.

[3] G. Backhouse, "RFID: Frequency, standards, adoption and innovation," 2006, Available: http://www.jisc.ac.uk/media/documents/techwatch/tsw0602.pdf, 29 Jan 2011.

[4] K. V. S. Rao, P. V. Nikitin, and S. F. Lam, "Antenna design for UHF RFID tags: a review and a practical application," *IEEE Transactions on Antennas and Propagation*, vol. 53, no. 12, pp. 3870-3876, 2005.

[5] C. Cho, H. Choo, and I. Park, "Broadband RFID tag antenna with quasi-isotropic radiation pattern," *Electronics Letters*, vol. 41, no. 20, pp. 1091-1092, 2005.

[6] D. M. Dobkin and S. M. Weigand, "Environmental effects on RFID tag antennas," presented at IEEE MTTS International Microwave Symposium Digest, Long Beach, CA, USA, pp. 135-138, 2005.

[7] J. D. Griffin, G. D. Durgin, A. Haldi, and B. Kippelen, "RF Tag Antenna Performance on Various Materials Using Radio Link Budgets," *IEEE Antennas and Wireless Propagation Letters*, vol. 5, no. 1, pp. 247-250, 2006.

[8] A. M. A. Sabaawi and K. M. Quboa, "Wideband modified dipole antenna for passive UHF RFID tags," presented at the 7th International Multi-Conference on Systems Signals and Devices (SSD), pp. 1-4, 2010.

[9] P. R. Foster and R. A. Burberry, "Antenna problems in RFID systems," presented at IEE Colloquium on RFID Technology pp. 3/1-3/5, 1999.

[10] P. Raumonen, L. Sydanheimo, L. Ukkonen, M. Keskilammi, and M. Kivikoski, "Folded dipole antenna near metal plate," presented at Antennas and Propagation Society International Symposium vol. 1, pp. 848-851, 2003.

[11] A. H. Rida, Y. Li, S. Serkan Basat, A. Ferrer-Vidal, S. Nikolaou, and M. M. Tentzeris, "Design, Development and Integration of Novel Antennas for Miniaturized UHF RFID Tags," *Antennas and Propagation, IEEE Transactions on*, vol. 57, no. 11, pp. 3450-3457, 2009.

[12] R. Mittra and A. Hoenschel, "Some Novel Designs for RFID Antennas and their Performance Enhancement with Metamaterials," presented at IEEE International Workshop on Anti-counterfeiting, Security, Identification, pp. 1-3, 2007.

[13] C. Chihyun, K. Dokyun, C. Hosung, and P. Ikmo, "Effect of the substrate, metal-line and surface material on the performance of RFID tag antenna," presented at Antennas and Propagation Society International Symposium, pp. 1761-1764, 2007.

[14] A. Syed, K. Demarest, and D. D. Deavours, "Effects of Antenna Material on the Performance of UHF RFID Tags," presented at IEEE International Conference on RFID, pp. 57-62, 2007.

[15] T. S. Bird, "Definition and Misuse of Return Loss [Report of the Transactions Editor-in-Chief]," *IEEE Antennas and Propagation Magazine*, vol. 51, no. 2, pp. 166-167, 2009.

[16] L. Xu, B. J. Hu, and J. Wang, "UHF RFID tag antenna with broadband characteristic," *Electronics Letters*, vol. 44, no. 2, pp. 79-80, 2008.

[17] C. A. Balanis, *Antenna theory: analysis and design*, 3rd ed., Hoboken, N.J.: Wiley-Interscience, 2005.

[18] RFIDTags.com, "RFID Tag Manufacturers ", Available: http://www.rfidtags.com/provider-directory.php, 05 Jan 2010.

[19] K. V. S. Rao, S. F. Lam, and P. V. Nikitin, "UHF RFID tag for metal containers," presented at Microwave Conference Proceedings (APMC), 2010 Asia-Pacific, pp. 179-182, 2010.

[20] H. Lehpamer, *RFID design principles* Norwood, MA ; London: Artech House, 2008.

[21] S. Tedjini, T. P. Vuong, and V. Beroulle, "Antennas for RFID tags," presented at the joint conference on Smart objects and ambient intelligence: innovative context-aware services: usages and technologies, Grenoble, France, pp. 19-22, 2005.

[22] Alien, "RFID ICs," 2010, Available: http://www.alientechnology.com/docs/products/DS_H3.pdf, 12 Dec 2009.

[23] C. Blair and J. C. Rautio, "RFID design using EM analysis," presented at the Long Island Systems Applications and Technology Conference (LISAT), pp. 1-6, 2010.

Authors Biography

Tashi received Bachelor of Engineering in Electrical and Electronics Engineering from Anna University, Chennai, Tamil Nadu, India in April 2007 and Master by Research in Computing Science from Staffordshire University, Stafford, England in June 2011. He had worked as Supervisor in Electricity Service Division, Bhutan Power Corporation, Punakha, Bhutan from July 2002 to August 2004. In January 2008, he joined as a Lecturer in College of Science and Technology, Rinchending, Phuentsholing, Bhutan, under Royal University of Bhutan. He currently teaches “Electrical Network Theory”, “Digital Electronics and Logic Designs” and “Electronics Circuits and Devices”. His research is mainly directed towards the modelling and designing of an antenna for UHF RFID applications.

Mohammad S. Hasan received his BSc and first MSc in Computer Science. He obtained his second MSc in Computer and Network Engineering from Sheffield Hallam University, UK. He has been awarded a PhD at Staffordshire University, UK in Networked Control Systems over Mobile Ad-hoc Network (MANET). He worked as a full time Assistant Professor in the department of Computer Science and Engineering at the University of Dhaka in Bangladesh. Currently he is a full time Lecturer and a member of the Mobile Fusion (MF) Applied Research Centre (ARC) at Staffordshire University. His research interests include computer networks, networked control systems, remotely controllable mobile robot systems, real time systems, wireless sensor networks etc.

Hongnian Yu is currently a Professor of Computer Science at Staffordshire University. He has extensive research experience in modelling and control of robots and mechatronics devices and neural networks, mobile computing, modelling, scheduling, planning and simulations of large discrete event dynamic systems, RFID with applications to manufacturing systems, supply chains, transportation networks and computer networks. He has published over 200 research papers and held several grants from EPSRC, the Royal Society, and other funding bodies. He is a member of the EPSRC Peer Review College and serves on various conferences and academic societies.