A Complete Planner Design of Microstrip Patch Antenna for a Passive UHF RFID Tag

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***Abstract*—A micro-strip patch antenna for a passive radio frequency identification (RFID) tag which can operate in the ultra high frequency (UHF) range from 865 MHz to 867 MHz is presented in this paper. The proposed antenna is designed and suitable for tagging the metallic boxes in the UK and Europe warehouse environment. The design is supplemented with the simulation results. In addition, the effect of the antenna substrate thickness and the ground plane on the performance of the proposed antenna is also investigated. The study shows that there is little affect by the antenna substrate thickness on the performance.**

Keywords-RFID; Passive Tag ; Tag antenna; Micro-strip patch antenna

I. INTRODUCTION

Radio frequency identification (RFID) technology [1] is growing tremendous demand in the supply chain management system. RFID is an automatic identification (Auto ID) technology [2]. It is a pervasive computing technology for collecting and gathering data from a tagged item. The data is stored in the mobile device called tag. When the tag comes in the reader's reading zone, the data is collected by the reader without any need of physical contact. The data in the tag may be the identification number, location information, or specification of product such as price, brand, date, etc. Unlike bar code technology, the RFID technology does not require light-of-sight and reads longer distance [3]. Such advantages help the supply chain to operate very fast and efficiently.

Recently, a passive RFID system that operates in ultra high frequency (UHF) band from 860MHz to 960 MHz [4] is getting considerable attention. Because passive tags are very cheap due to absence of onboard battery and using UHF band can provide longer reading range, high data rate and small sized antenna.

Currently, a label-type dipole antenna is commonly used as a tag antenna for a passive UHF RFID tag and it is printed on a very thin film at low cost [5, 6] to reduce the overall cost of the tag. The commercial passive UHF RFID tags are shown in Fig. 1. The passive tags are embedded in cardboard boxes, ID card, airline baggage strip, passport, clothing tags, etc. However, papers [7] and [8] have reported that these tags undergo a serious performance degradation when it is mounted or attached onto the metallic surface or in the presence of water. This is because their performances are optimised in the free space. When passive tags are mounted on the metallic surface, label-type dipole tag antenna is short-circuited by the metallic surface. This results in changes in the performance parameters such as radiation pattern, antenna impedance, gain and bandwidth of the RFID tag antenna. Therefore, when a passive tag is placed onto the metallic surface, it fails to be read by the reader within the normal reading zone. On other hand, there are still increasing demands on RFID technology in the supply chain application for tagging the metallic objects since most of the items in the wire house are made of metal or encased the metallic boxes or container.

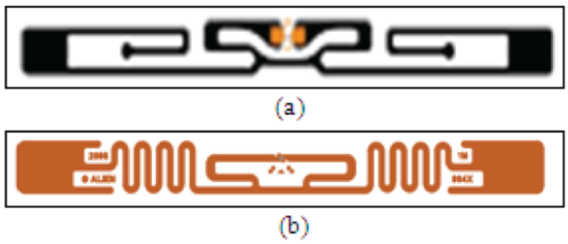

Figure 1. Commercial Passive UHF RFID tags (a) Avery Dennison tag [9] and (b) Alien Squiggle tag [10].

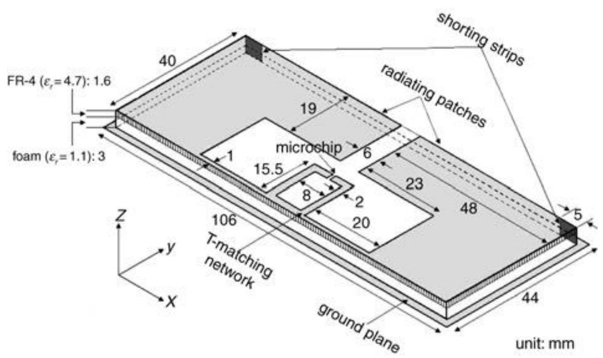

Figure 2. A micro-strip patch antenna that the antenna trace is shorted to the ground plane [11].

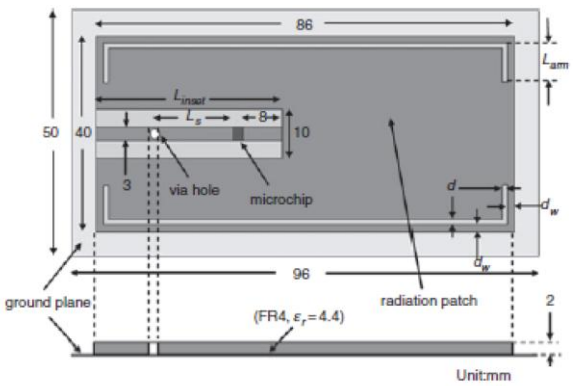

Figure 3. A micro-strip patch antenna that the feeding is shorted to the ground plane [12].

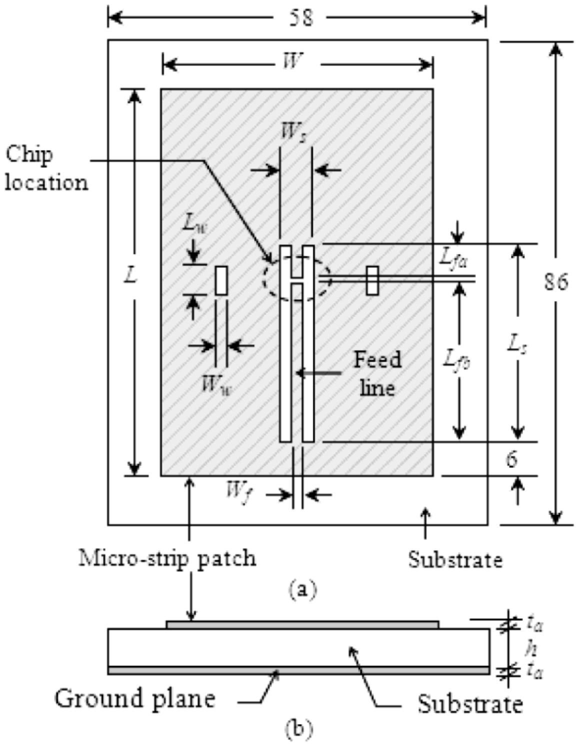

Figure 4. Geometry of the proposed micro-strip patch antenna (a) top view and (b) side view.

This problem may be solved by using an active RFID tag, but it will be very costly. The alternative solutions are by keeping enough separation gaps between the tag and the metallic surface or by designing a tag antenna that can operate using the ground plane. Micro-strip patch antenna and planner inverted-F antenna (PIFA) are attractive choices as both antennas use the ground plane. From the literature review, RFID tags are employed using the micro-strip patch antenna in [11-18] and the PIFA in [19-21]. All these tag antennas have an electrical connection between the antenna trace and the ground plane (e.g., [11] shown in Fig. 2). In some cases there is an electrical connection between the feeding line and the ground plane (e.g., [12] shown in Fig. 3). This leads to the cross-layered construct of tag antennas. In some PIFA, the tag antenna has multilayered construction (e.g., [20]). Such design presents complex and costly antenna structure. For small size, easy installation, lower cost and easy manufacturing in bulk, tag antennas are preferred to be completely planner so that it can be directly printed on the antenna substrate without having any cross and multilayered construction.

In this paper, a micro-strip patch antenna is proposed as a tag antenna for a passive UHF RFID tag that can be used for tagging the metallic containers or metallic boxes in the warehouse environment. The fundamental characteristic of the proposed antenna is that the antenna trace (patch) is suspended above the ground plane without any electrical connection between the antenna trace and the ground plane. This eliminates the cross and multilayered construction without compromising its performance. Therefore, the proposed antenna is completely planner with low antenna profile and is easy to fabricate. The rest of the paper is organised as follows. Section II discusses the proposed tag antenna design. Section III presents the simulation results of the proposed antenna. Finally, section IV addresses the conclusion.

II. The Prosposed Tag Antenna Design

The proposed micro-strip patch antenna for a passive UHF RFID tag is considered to operate in the UK and Europe warehouse environment for tagging the metallic boxes or metallic containers. The tag shall be easily tuneable from 865 MHz to 867 MHz range which is UHF RFID frequency band for the UK and Europe. The operating frequency of proposed antenna is selected as 866 MHz which is the centre frequency of the band.

Passive tags consist of a chip and an antenna. In this proposed design, the Alien Higgs-3 [22] for EPC Class 1 Gen 2 RFID tag chip is selected. The Alien Higgs-3 exhibits an 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 is designed for Z_a = (31 + j212) Ω.

The geometry of the proposed antenna is shown in Fig. 4. The top layer is antenna trace and bottom layer is the antenna ground plane. Both layers are copper with the same thickness (t_a) of 0.0358 mm. The middle layer is FR4 substrate with thickness (h) of 1.6 mm, dielectric constant (ε_r) of 4.9 and loss tangent (δ) of 0.025. The FR4 substrate and ground plane has the same length and width of 86 mm and 58 mm, respectively. The antenna trace (patch) is slotted in rectangular shape with slot length L_s = 40 mm and slot width W_s = 6 mm. The rectangular slot is particularly for inserting the feeding line inside the patch to reduce the size of tag antenna. There are also two small slots on the patch which are called window and these have length L_w = 6 mm and width W_w = 2 mm. The window is designed for fine tuning of the patch resonance frequency at the desired operating frequency without changing other parameters of the patch.

Traditional micro-strip patch antenna is single feed that can be designed as direct feed type or coupled feed type and keeping reference with respect to the ground plane [23]. Such feeding methods require a cross-layered construction in order to attach the chip. To avoid cross-layered structure, T-match is proposed in this design. The T-match feeding lines are inserted inside the rectangular patch slot. There is no electrical connection between the patch and the ground plane. The chip location is fixed at the centre of the patch (i.e. at the origin of principle x-y plane of the proposed antenna). The RF port-1 of the RFID chip is connected to the patch with feeding line length L_{fa} = 6.5 mm and the RF port-2 (i.e. ground) is connected to the patch with feeding line length L_{fb} = 32.5 mm. Both feeding line has width W_f = 2 mm. The input impedance of the proposed antenna is tuned by changing geometry parameters of T-match feeding line.

III. Simulation Results of the Proposed Tag Antenna

The proposed micro-strip patch antenna design is simulated in Sonnet Lite version 12.52, electromagnetic (EM) simulator [24] and in AWR Design Environment version 9.04 [25] and the results are compared for validation. Both EM simulators work based on the method of moments (MoM).

A. *Input Impedance*

Fig. 5 and Fig. 6 show the simulated input resistance and input reactance, respectively against UHF frequency of the proposed micro-strip patch antenna. Both EM simulators results are closely matched.

B. *Return Loss*

Fig. 7 shows the return loss of the proposed micro-strip patch antenna at 866 MHz resonance frequency. The Sonnet simulation results also compared to the AWR simulation result and both show strong agreement. The minimum value of the simulated return loss (S_{11}) at the resonance frequency from the Sonnet is -21.03 dB. The half-power bandwidth (return loss < -3 dB) is 46 MHz (5.31%), from 843.50 MHz to 889.50 MHz. The simulated < -10 dB bandwidth of the proposed tag antenna is 15 MHz (1.73%), from 858.50 MHz to 873.50 MHz. Both bandwidths satisfy the design goal of the proposed tag antenna which is 2 MHz (i.e. from 865 MHz to 867 MHz) as well as meet the requirement bandwidth (500 kHz) of the ISO/IEC 18000-7 standard. Fig. 8 shows the current distribution over the proposed patch antenna at 866 MHz operating frequency.

C. *Radiation Patterns*

Fig. 9 shows the simulated radiation patterns of the proposed micro-strip patch antenna at 866 MHz in the E-plane (x-z plane). It is also called elevation plot in 2D. The 3D radiation pattern of the micro-strip patch antenna will look like dome shape. Fig. 10 shows the simulated radiation patterns of the proposed micro-strip patch antenna at 866 MHz in the H-plane (x-y plane). It is also called azimuth plot. At zero degree, E-plane has a maximum radiation of 3.28 dB and H-plane has maximum radiation of 3.29 dB. The radiation patterns are almost omnidirectional in the E-plane and almost bidirectional in the H-plane.

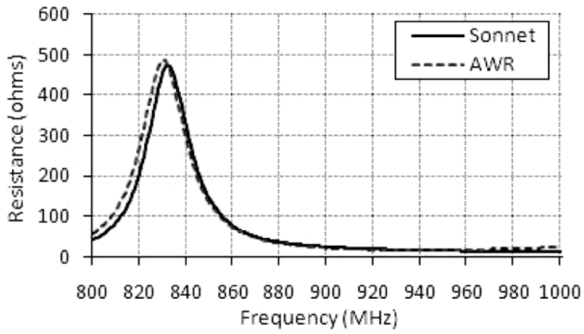

Figure 5. Simulated input resistance against UHF frequency for the proposed micro-strip patch antenna.

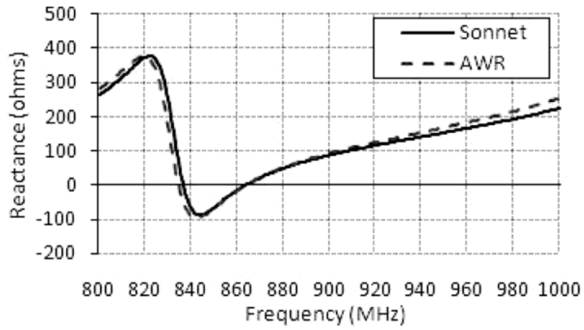

Figure 6. Simulated input reactance against UHF frequency for the proposed micro-strip patch antenna.

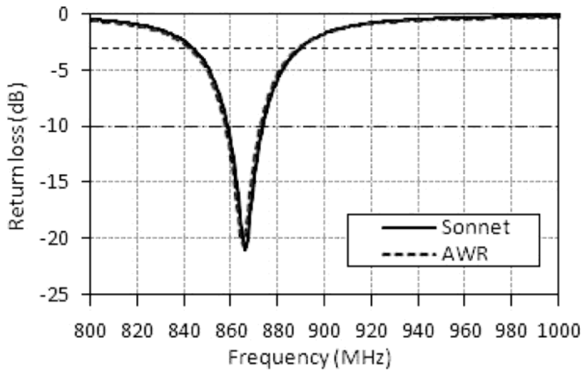

Figure 7. Simulated return loss against UHF frequency for the proposed micro-strip patch antenna.

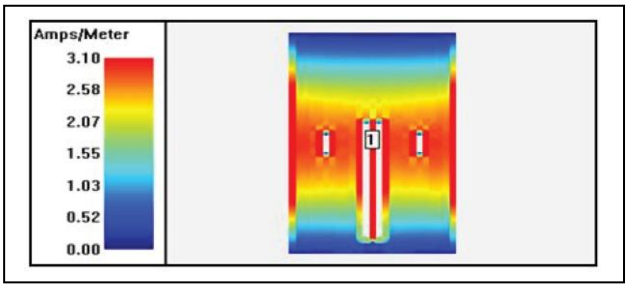

Figure 8. Simulated current distribution over the proposed micro-strip patch antenna at 866 MHz resonance frequency.

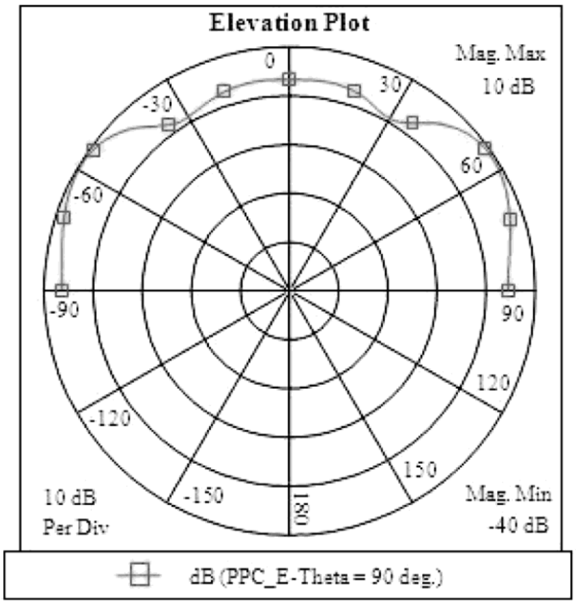

Figure 9. Simulated radiation patterns at 866 MHz for the proposed micro-strip patch antenna in E-plane.

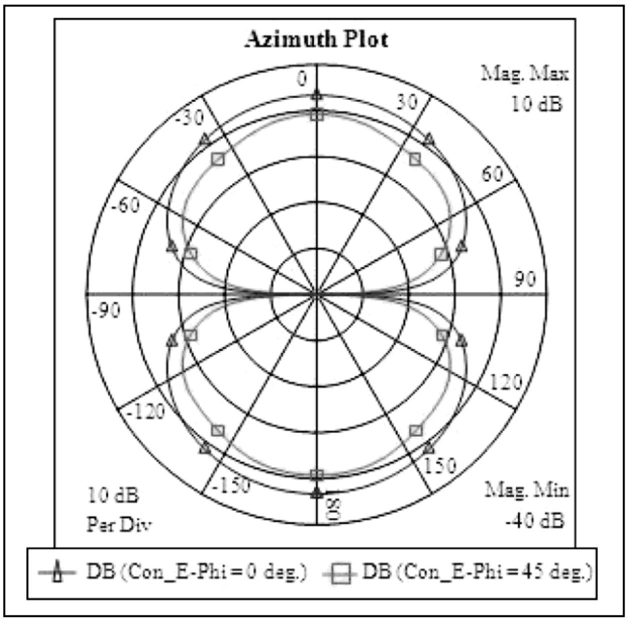

Figure 10. Simulated radiation patterns at 866 MHz for the proposed micro-strip patch antenna in H-plane.

D. *Effect of Substrate Thickness*

Fig. 11 shows the simulated return loss against UHF frequency of the proposed micro-strip patch antenna for different thickness (*h*) of substrate while keeping other parameters the same. The proposed antenna exhibits an optimised performance for h = 1.6 mm. It shows that when the antenna substrate thickness (*h*) increases, the return loss is significantly increased and thereby reduces the performance of the antenna. So the selection of the substrate thickness for micro-strip patch antenna is very important.

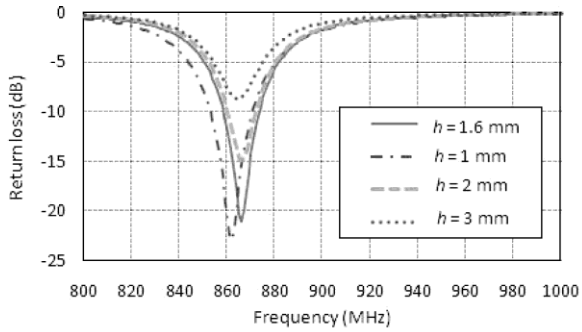

Figure 11. Simulated return loss of the proposed micro-strip patch antenna for different thickness (h) of the substrate while keeping other parameter same.

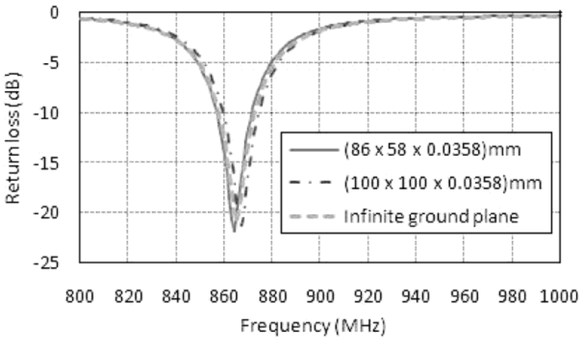

Figure 12. Simulated results return loss of the proposed micro-strip patch antenna for different size of the ground plane while keeping other parameters same.

E. *Effect of Ground Plane*

The antenna is designed on the infinite ground plane and substrate in both the Sonnet and AWR EM simulator environment. When the infinite ground plane and substrate are replaced by the finite ones in real world application, there are affects of the ground plane on the radiation patterns and resonance frequency of the micro-strip patch antenna [15, 19]. The effect of the ground plane on the return loss of the proposed tag antenna is studied by using three different ground plane sizes e.g. 86 mm x 58 mm x 0.0358 mm, 100 mm x 100 mm x 0.0358 mm and infinite ground plane. The substrate length and breadth are taken as same as ground plane with the thickness of 1.6 mm in all the cases. Fig. 12 shows the simulated return loss against UHF frequency of the proposed micro-strip patch antenna while keeping other parameters the same. The change in bandwidth and shift in resonance frequency due to different ground planes are presented in Table I. The change in bandwidth is evaluated based on the half power (< -3 dB) and < -10 dB return loss bandwidth. There is not much effect on the bandwidths but there are shifts in the resonance frequencies. However, the entire range of shifts in the resonance frequencies is within the desired goal of the proposed tag antenna.

TABLE I. SIMULATED RETURN LOSS AND BANDWIDTH FOR DIFFERENT SIZE OF THE GROUND PLANE.

Return loss (dB)	Ground plane size (mm)	Frequency range (MHz)	Bandwidth (MHz)	Resonance frequency (MHz)	Minimum return loss (dB)
- 3	86 x 58 x 0.0358	843.5 – 889.5	46	866	-21.03
	100 x 100 x 0.0358	843.82 – 890.51	46.69	867.12	-21.06
	Infinite	841.34 – 887.28	45.94	864	-21.86
- 10	86 x 58 x 0.0358	858.5 – 873.5	15	866	-21.03
	100 x 100 x 0.0358	859.44 – 874.51	15.04	867.12	-21.06
	Infinite	856.71 – 871.36	14.65	864	-21.86

IV. CONCLUSION AND FUTURE WORK

Micro-strip patch antenna is proposed as antenna for a passive UHF RFID tag. The proposed tag is designed for tagging the metallic containers in the UK and European warehouse environment. The proposed antenna is designed to operate at centre frequency of 866 MHz and it is tuneable from 865 MHz to 867 MHz UHF frequency band. The design is supplement by the simulation results. The paper also presents the effects of the substrate height and the ground plane on the antenna performance. The maximum return loss of the proposed antenna loss (S11) is -21.03 dB. The half-power bandwidth (return loss < -3 dB) is 46 MHz (5.31%), from 843.50 MHz to 889.50 MHz. The simulated < -10 dB bandwidth of the proposed antenna is 15 MHz (1.73%), from 858.50 MHz to 873.50 MHz. Both return losses bandwidth satisfy the design goal. In the future work, the micro-strip antenna for a passive UHF RFID shall be fabricated using the design proposed in this paper. Then the prototype micro-strip patch antenna will be implemented and its reading range can be analysed in presence of a metallic surface.

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