UHF RFID Reader Antenna with Air Gap

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***Abstract*—a stacked patch reader antenna with air gap for radio frequency identification (RFID) applications is proposed in this paper. The objectives of this project are to design an air gap sequentially fed-stacked RFID reader antenna for ultra-high frequency (UHF) band, to design a circular polarized (CP) antenna with high gain at 9 MHz of ultra-high frequency band, and lastly, to achieve a minimum size of the antenna having optimum performance. The antenna is comprised of a single truncated main patch with a parasitic patch on top of it that fed by four sequential perfect electrical conductor (PEC) probes. The probes are directly connected to an air-gapped microstrip line which suspended above its ground plane. The design is simulated with the aid of Computer Simulation Technology (CST) microwave studio software. The resulted simulation shows that the antenna achieves a return loss of below -16 dB, gain of 8.917 dB, directivity of 8.857 dBi, voltage standing wave ratio (VSWR) of 1.36, and 3-dB axial ratio (AR) beamwidth of 70.5°.**

***Index terms*—RF identification (RFID), circularly polarized (CP), ultra-high frequency (UHF), sequential probes feed, 3-dB AR beamwidth.**

I. INTRODUCTION

RADIO Frequency Identification (RFID) is a technology which provides the capability of wireless identification detection and tracking system [1] . The RFID system is generally comprises of a reader as interrogator with an antenna, tags as transponder with an antenna, host computer and middleware such as software and data base. The general classifications of RFID system that categorized by the method of its power transfer between reader and tag are near-field and far-field. Both systems also have different approaches which is either it is inductively or capacitive coupling and the Electromagnetic (EM) wave capturing [2].

In recent years, UHF band attracts the most attention in RFID application due to its long range and high data rate [3]. There are also many researches that have been reported [4-5] for the UHF applications. However the antennas are limited with bandwidth and gain. In general, the RFID system works as the reader emit signals through its antenna to an RFID tag which passes within its reading range. The detected tag is interrogated for its content information in its microchip by the reader. The process is done by EM wave coupling via the antenna.

Tags in RFID system can be classified as "active", "passive" or "semi-active". These characterized by the presence of on-board power supply such as battery in order to support microchip during operation and to transmit data back to reader. For passive RFID tags, it needs power from signal emitted by reader to energize its operation and also use the power to transmit back its signal to reader antenna [2].

Hence, the reader must be able to transmit enough power to tags and the design to ensure this capability has been taken into account in this project. In addition, air gap concept for the antenna has advantages for higher gain, broader bandwidth, and low cost.

II. METHODOLOGY

This section explains on the methods that are used in designing the antenna. The project begins with an approximation of the design's dimensions with the use of few calculations. The main patch is a square patch with the following formula of its width, W;

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad \text{(1)}$$

f_r is the resonance frequency of the antenna which is 9 MHz and ε_r is the permittivity of air as the substrate being used.

The square patch is truncated on two of its diagonal corners at 45° angle with truncation width, ΔW_1 of 20 mm. The dimension of a parasitic patch used is initially the same to the main patch.

The microstrip line feed forms a square ring with initial truncation width, ΔW_3 of 20 mm on each of its corners at 45° angle. One end of the line feed is connected to inner conductor of a coaxial feed of SMA connector while another end is open-circuited. The initial size of ground plane used is 250 mm × 250 mm. The structures of the antenna from its perspective and side views are shown in Figure 1. The initial height of parasitic patch, h_1 is 10 mm while the height of main patch, h_2 and line feed, h_3 is 15 mm and 5 mm respectively.

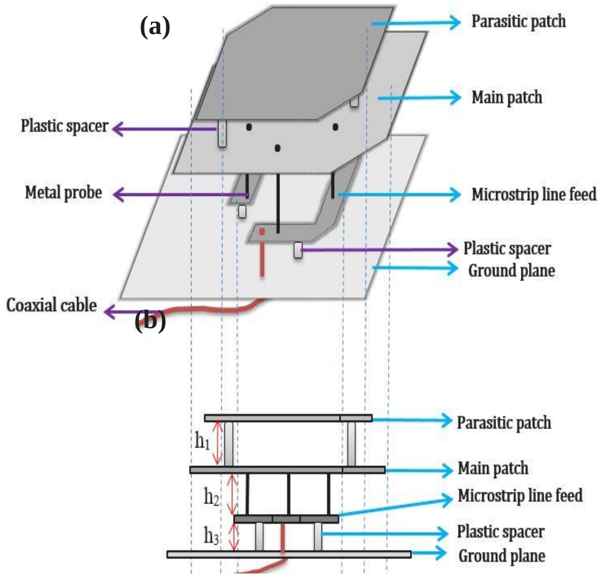
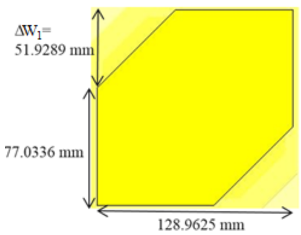


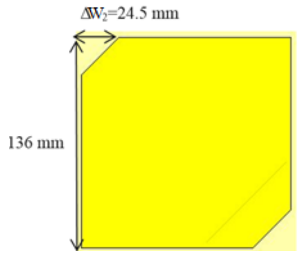
Figure 1-Structures of the designed antenna. (a) Perspective view. (b) Side view.

The simulations are carried out using the CST Microwave Studio software of version 2011. Necessary settings are set correctly with validations from that suggested by technical support team of CST developer. Initial approximations in calculations helped in the way that the design is ready for the first stage of simulation and the results are analysed and the design is improved according to the objectives of this project.

The method used to improvise the design is by varying parameters of the antenna and the trends of their effect on antenna's performance in terms of reflection coefficient, gain, and radiation pattern are observed and analysed. Necessary adjustments on the parameters are made to achieve the desired performance. A single parameter is varied at the same time during the simulation while other parameters are kept unchanged in order to gain clearer observation on the effects of the particular parameter to the overall performance of the antenna. Eventually, the final dimensions of the design are obtained based on parameters studied with optimum performance achieved. The final dimensions are illustrated as in Figure 2.



(a)



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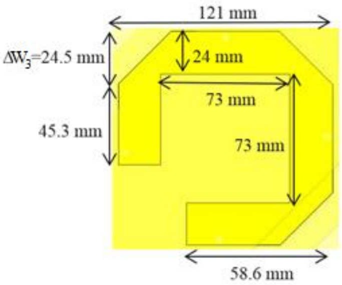


(c)

Figure 2-Final dimensions of the designed antenna. (a) Parasitic patch. (b) Main patch. (c) Microstrip line feed.

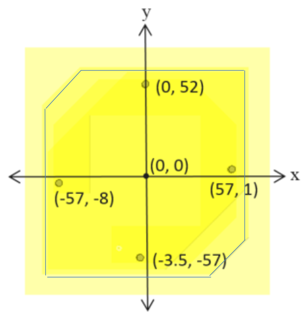


Figure 3-Final location of PEC probes at y-x axis centred on main patch.

The same initial thickness of 1 mm is applied for parasitic, main patch, line feed, and ground plane. After optimization of the antenna, the parasitic patch resulted to have a new thickness, t_1 of 0.85975 mm while that of the others are maintained. Transformation tool in the software is used to transform the dimension of the parasitic patch in accordance to the desired performance that can be achieved.

Figure 4 shows clearly the spacing labelling of the antenna. The initial spacing between parasitic, main patch, and line feed of the antenna is h_1=10 mm, h_2=10 mm, h_3=5 mm respectively. The final spacing between these elements as resulted from optimization is h_1=20.07013 mm, h_2=20 mm, and h_3=10 mm accordingly.

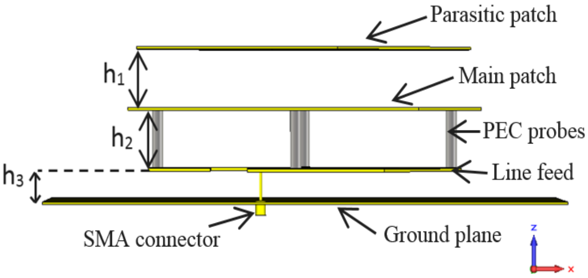


Figure 4- Side view of the antenna.

Communication reliability between reader and tags are ensured by using circularly polarized (CP) reader antenna. This is due to the tags which normally linearly polarized since the tags are always arbitrarily oriented [1]. Hence circularly polarise reader is desired in this project.

The structure of the designed antenna by truncating two of its diagonal corners on the main patch has ensured to circularly polarise. The far-field settings in CST Microwave Studio software are used to clarify this important characteristic. The feeding structure of PEC probes applied helps in creating CP radiation pattern. Their adequate position on the line feed satisfy the basic operation principle of CP which is to radiate two orthogonal field components in phase quadrature that equal in amplitude.

The PEC probes are initially positioned at 1/3 offset from the edge of main patch and 1 from its nearest axis. The position of the probes is varied until CP radiation pattern is obtained. The line feed connecting the PEC probes to the main patch also designed accordingly and the final design of line feed is as shown in Figure 2 while Figure 3 shows the final location as resulted from the analysis of the simulation.

Initial square ground plane used was 10 mm larger in width than the main patch. The same technique by varying its dimension is used in order to achieve the desired performance of the designed antenna.

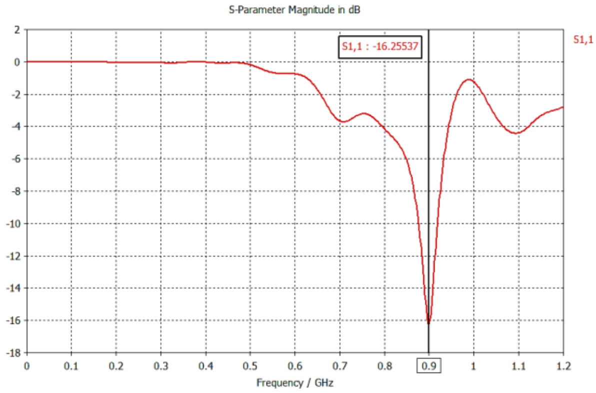
The radio frequency (RF) input for the antenna is designed such that the inner copper of simulated 50Ω SMA connector is directly connected to the microstrip line feed, while the Teflon with dielectric constant of 2.1 and the outer copper are both connected to the ground plane.

The whole performance of the designed antenna is analysed in terms of its S-parameter magnitude, $|S_{1,1}|$ (dB), VSWR, gain (dB), directivity (dBi), radiation pattern and AR beamwidth.

III. RESULT AND DISCUSSION

Results obtained from the simulation of the designed antenna with the aid of CST Microwave Studio software are presented and discussed throughout this section.

The antenna for UHF RFID reader is designed to resonate at the frequency of 900 MHz for Malaysia's UHF band which is at the range of 819-923 MHz.



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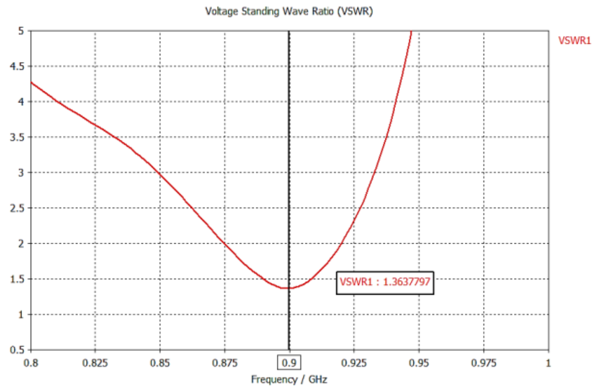


(b)

Figure 5- Simulated results of the designed antenna (a) Return loss (b) VSWR

Return loss expressed in decibels (dB) as shown in Figure 5 (a) resulted from simulation with less than -16 dB at resonant frequency of 900MHz. Maximum power transfer is ensured by smaller value than -10 dB of return loss achieved at its resonant frequency. Figure 5 (b) shows the VSWR reading at the frequency of 1.36 which is acceptable for an antenna at this resonant frequency. The closer value of VSWR to 1 simply indicates that the impedance matching at the input of the antenna is good. Thus 1.36 indicates an acceptable matching for operation of the antenna.

The radiation pattern of the antenna at two different planes are simulated for better understanding and shown as in Figure 6 where farfield A (Abs, Phi=0) and farfield B (Abs, Phi=90) is at x-z and y-z plane respectively. Wide-angle AR and symmetrical patterns can be observed as the results of sequential feed arrangement. The 3-dB AR beamwidth measured at x-z plane is 70.5^0 which is desirable for wide-coverage RFID applications. As shown in Figure 6, the antenna radiates at 0^0 to z-direction with magnitude of main lobe of 8.9 dB which is comparably bigger than its back lobe with magnitude of -10.6 dB. High magnitude of the main lobe shows high intensity of EM for the signal. Hence, a wide and high magnitude of main lobe is desirable for efficient signal coupling especially emitted from a reader antenna. The side lobes are minimized by the feeding structure applied where it cancelled out the unwanted cross polarization radiation. The short-circuit microstrip line feed has also minimized the side lobe of the antenna.

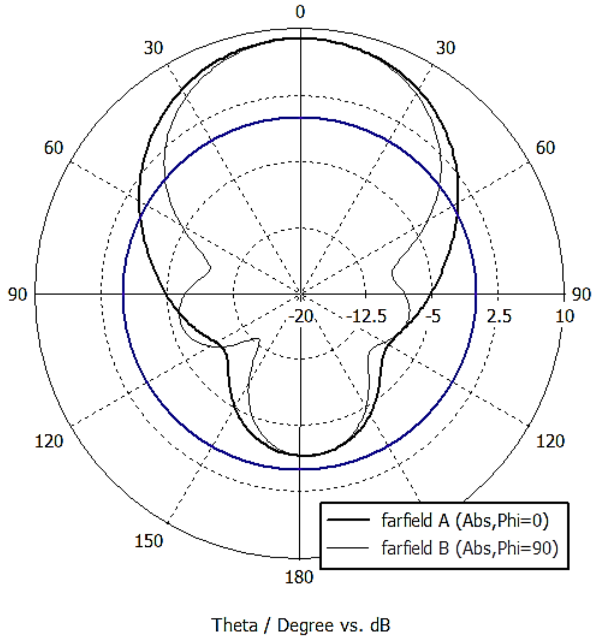
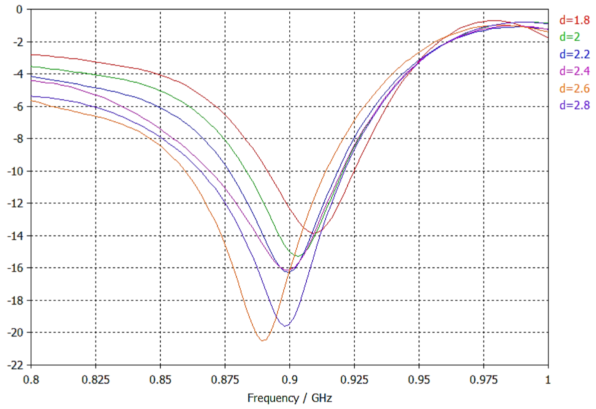


Figure 6- Radiation pattern at x-z and y-z plane.

The simulated far-field results obtained from the software shows that the designed antenna has achieves a gain of 8.917 dB and directivity of 8.857 dBi as desired for good performance of the antenna. Such high gain is obtained as a result of implying air-gap for the antenna since low permittivity of air as the substrate used helps in improving the gain of an antenna. High directivity is desirable for a reader antenna since the tags are usually aligned at the front of the reader.

IV. PARAMETRIC STUDIES

This section will presents the simulated results where few parameters of the designed antenna are varied in order to gain better understanding on the antenna and their effects on the overall performance of the antenna.



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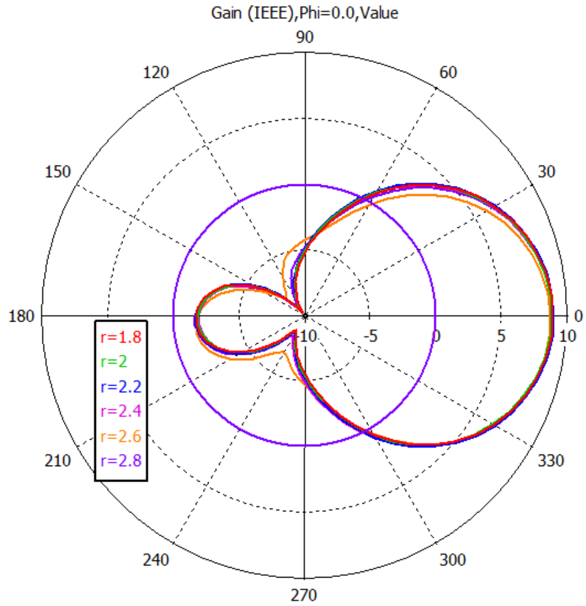


(b)

Figure 7- Results from variation of the diameter of PEC probes. (a) Return loss (b) Radiation pattern at x-z plane.

A. Diameter (d) of PEC probes

The comparison can be clearly seen as in Figure 7 (a) that smaller diameter of PEC probes will degrades the overall performance of the antenna since the return loss degrades significantly. On the other hand, larger diameter improves the return loss as it provides better feeding structure for input flow to the main patch. Improved return loss indicates better overall performance. The frequency shifting is directly related to the overall volumes of the antenna whereas the smaller antenna will shift its frequency to higher frequency and vice versa. The diameter of the PEC probes feed give less impact on the radiation pattern of the antenna as shown in Figure 7 (b). Hence, larger diameter is recommended. However, overall volume of the antenna must takes into account.

B. Truncation width (ΔW_1) of the parasitic patch

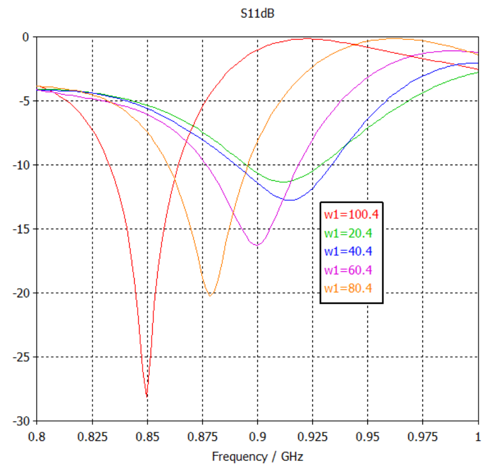
Results of varying the truncation width, ΔW_1 of the parasitic patch are shown in Figure 8. It brings a significant effect on return loss where larger truncation width will improve the return loss however shifted down the frequency. Over truncation will greatly reduce size of the antenna hence caused the frequency to shifted down but creates larger side lobes in radiation pattern as shown in Figure 8 (b). The truncation width of 60.4 mm of the parasitic patch is desirable in order to resonate the antenna at the frequency of 900 MHz. Small truncation width will only degrades the overall performance of the antenna and thus not recommended.

C. Truncation width (ΔW_2) of the main patch

Figure 9 shows the effects on varying the truncation width, ΔW_2 of the main patch to the return loss and radiation pattern of the designed antenna. The initial truncation width of 24.5 mm is the ideal at the frequency of 900 MHz. The small truncation width of the main patch improves the return loss of the antenna but does not shift the frequency and increases side lobes in its radiation pattern. While further increase in truncation width of the main patch will only degrades the overall performance.

D. Truncation width (ΔW_3) of the microstrip line feed

The truncation width, ΔW_3 on microstrip line feed affects the overall performance of the designed antenna as shown in Figure 10 where more truncation width resulted to improve the return loss and shift the frequency to higher frequency as the increased truncation width will simplify the antenna structure and reduces antenna's size. Thus, higher truncation width on the line feed is recommended.



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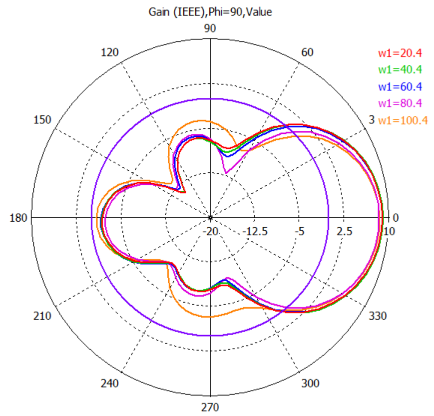
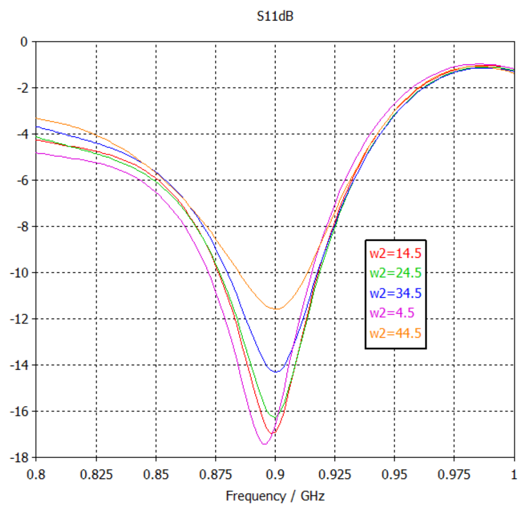


(b)

Figure 8- Results from variation of the truncation width, ΔW_1 on main patch. (a) Return loss (b) Radiation pattern at y-z plane.



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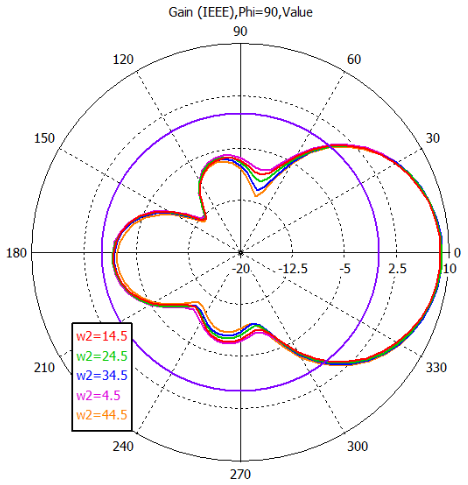
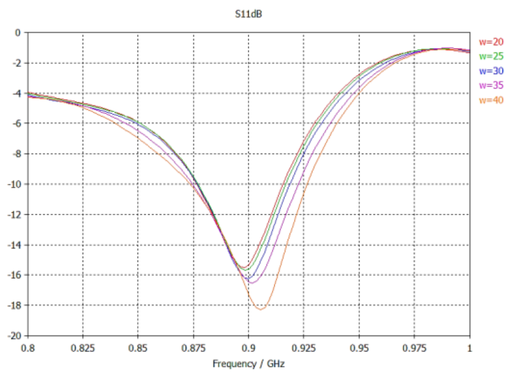


(b)

Figure 9- Results from variation of the truncation width, ΔW_2 on main patch. (a) Return loss (b) Radiation pattern at y-z plane.

E. Height (h_1) of the parasitic patch.

The spacing between the parasitic patch is varied with resulted simulation as shown in Figure 11. Smaller spacing between the patches resulting in massive improvement of return loss with below than -30 dB. However it shifted up the frequency as the size of the antenna is also reduced. On the other hand, further increase of the spacing will degrade the performance and also shifted down the resonating frequency since the antenna's size has increased. The larger spacing of between the parasitic patch and the main patch has greatly creates bigger radiation pattern as the volumes of the antenna increases but a maintained size of the main lobe. Hence proper height of parasitic patch is crucial with optimum performance.



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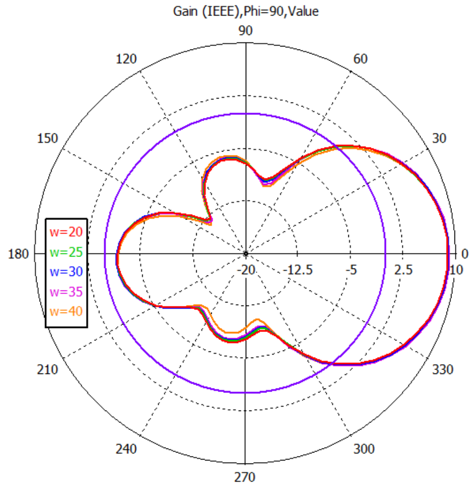

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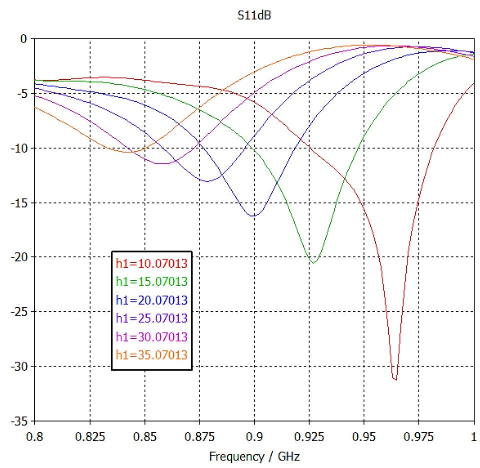
Figure 10- Results from variation of the truncation width, ΔW_3 on microstrip line feed. (a) Return loss (b) Radiation pattern at y-z plane.



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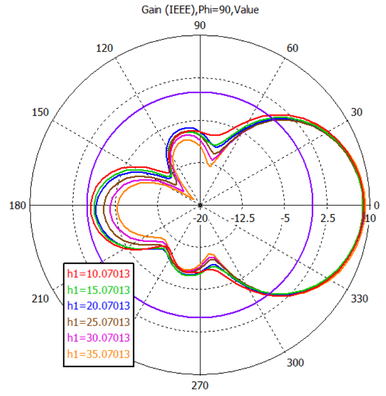

(b)

Figure 11- Results from variation of the height, h_1 of the parasitic patch. (a) Return loss (b) Radiation pattern at y-z plane.

V. RECOMMENDATIONS

The proposed antenna has achieved a satisfaction return loss of below -16 dB. However, the size of the antenna can be reduced for practical implementation. Thin substrate between the microstrip line feed and the ground plane can be inserted for that purpose. Thinner patches and microstrip line feed also helps in antenna's reduction in size. Thicker diameter of PEC probes with suitable width of microstrip line feed is also recommended for better performance.

VI. CONCLUSION

The design of UHF RFID reader antenna with air gap is presented in this paper with successful performances simulated. The antenna with air gap sequential PEC probes feed arrangement has achieved the desired performance with return loss of below -16 dB, gain of 8.917 dB, directivity of 8.857 dBi, voltage standing wave ratio (VSWR) of 1.36, and 3-dB axial ratio (AR) beamwidth of 70.5^0. The designed antenna which being simplified with truncation on its patches has fulfilled the required performance of a RFID reader antenna with an optimum size. The implemented air-gap feeding structure not only reduces the overall cost of the antenna and easier for fabrication, but also improves gain and side lobes of the radiation pattern of the antenna. The parametric studies involving few parameters of the antenna have showed tremendous effects to the performance of the antenna. The analysis of these parameters effects will be a benefit and helpful information in future RFID reader antenna design especially implementing the air-gap feeding structure.

VII. ACKNOWLEDGEMENT

In the name of Allah s.w.t and He the most merciful with salawat and salaam to Prophet Muhammad s.a.w. Alhamdulillah thanks to Him with the help and His permission giving us the idea and health, also the opportunity to successfully completed this project of designing a UHF RFID reader antenna with air gap. I would like to express my gratitude to those who have been very supportive and helpful with their constructive advises especially my project's supervisor, Dr. Mohd Tarmizi Ali for his guidance, time, attention and advises throughout the process in completing this project.

VIII. REFERENCES

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