INVERSE PHI SHAPE SLOTTED PLANAR ANTENNA FOR RFID APPLICATION

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Abstract

The new inverse phi slotted planar antenna is a dual-band linear polarized antenna. Recent communication requirements continue to push for more bandwidth capabilities for antenna systems. In order to communicate with tags from different countries, the RFID system requires a separate set of antennas for reader application. As a result, our environments are infected by diverse kinds of antennas. This inverse phi slotted planar antenna is designed to obtain dual-band RFID reader operation at the UHF bands of 860MHz-960MHz and free ISM bands of 2.45 GHz. Therefore, this antenna is design to reduce the set of antenna in RFID system.

Keywords: *Radio Frequency Identification; Planar Antenna; slot; dual-band*

I. INTRODUCTION

Radio Frequency Identification (RFID) is well known for many applications such as identification, logistics, library system management [1], medical and many others. The antenna designs for both readers and tags are hot issues to improve their performance. The antenna at reader plays a vital role in communication between the reader and the tags.

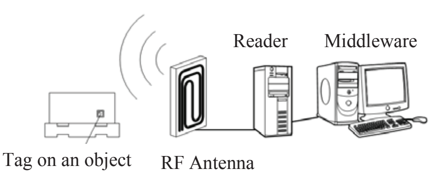


Figure 1: Basic components RFID system
-P. J. Sweeney (2005)

Most Ultra High Frequency (UHF) RFID readers are planar antenna. The planar antenna has the most variation compared to any other types of antenna. For instance, microstrip patch antennas have been extensively used due to the small size, low cost, light weight and ease of integration [3][4][5]. Due to its advantages, antenna manufacturers and researchers can come out with a novel design of antenna in-house which will reduce the cost of its development. Planar antennas are also relatively inexpensive to manufacture and design because of the simple 2–dimensional physical geometry. They are usually employed at UHF and higher frequencies because the size of the antenna is directly tied to the wavelength at the resonant frequency [2].

Many planar antennas have been discussed in the literature to achieve the requirement for different applications, one of which to increase the bandwidth. Numerous techniques have been developed for that purpose. These include the cutting of slots, decreasing the substrate permittivity, and increasing the patch height. Research papers on slotted antenna are described in dual-band slotted antenna [6], and right-angle modified U-slot antenna [7]. Other techniques to enhance the bandwidth are changing the shape of patch antenna [8]. The slotted shape is well known for enhance impedance bandwidth and also introduce multiple-band.

II. GENERAL REQUIREMENT OF RFID SYSTEM

A key consideration for RFID system is the frequency of operation. Just as television can be broadcast in VHF or a UHF band, so too can RFID systems use different bands for communication. RFID systems use many different frequencies, but generally the most common are unlicensed low frequency (LF), high frequency (HF), Ultra high frequency (UHF) and microwave.

To ensure the successful coexistence of the myriads of radio devices of our daily lives, the electromagnetic spectrum is divided into separate bands for different radio applications. Unfortunately, a global band for the UHF RFID does not exist, but the allocated bands vary from region to region. The frequency bands and allowed transmission (TX) power for a number of regions are summarized in Table 1.

The transmission power is expressed as equivalent isotropic radiated power (eirp), i.e., Peirp = GtxPtx, where Gtx is the transmitter antenna gain and Ptx the power fed to the antenna. The equivalent radiated power (erp) is similarly defined, but uses antenna gain over dipole (dBd). The two are related as Peirp = 1.64Perp.

Table 1: Radio regulations on UHF RFID in different regions [P. Pursula: 2008]

Region	Frequency (MHz)	Tx Power (max)	Regulation
Europe	869.4-869.65	0.5 Werp	EN 300 220
Europe	865-868	2.0 Werp	EN 302 208
USA	902-928	4.0 Werp	FCC Part 15
Korea	908.5-914	4.0 Werp	-
Japan	952-954	4.0 Werp	-
China	840.25-844.75	2.0 Werp	-
China	920.25-924.75	2.0 Werp	-

In addition to the radio regulations, the physical layer of RFID systems, including modulation, encoding etc., is standardized by the International Standardization Organization and EPC global. These have issued the UHF RFID air interface standards ISO 18000-6 and EPC Gen2 [9], respectively. The allocated frequency and the allowed power defined the fundamental limits of the RFID system read range.

III. PROPOSED INVERSE PHI SHAPE SLOTTED PLANAR ANTENNA DESIGN.

Generally, RF antenna is a series or parallel resonance circuit of resistance (R), inductance (L) and capacitors (C). The relation of resonance components L and C is:

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

As description in formula, if the inductance increases to a special value, the matching capacitor needed in resonance circuit is very small.

A rectangular patch antenna is chosen to show the basic impedance and radiation characteristics, after which broadband techniques are described concisely. The techniques can be applied also to other planar antennas, either directly or after some modifications.

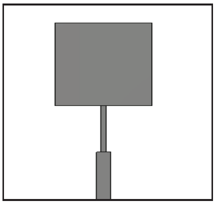


Figure 2: Basic rectangular microstrip patch antenna

A strip line to feed the patch antenna from its radiating edge with minimum antenna return loss has been employed. The first part of the design is to estimate the length (Le) and width (We) of the antenna using equations (2)-(7).

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{2}$$

$$L = \frac{c}{2fr\sqrt{\varepsilon_{eff}} - 2\Delta L} \quad (3)$$

Where W is the width of the patch, L is the length of the patch, f_r is the target frequency, c is the speed of light in a vacuum and the effective dielectric constant can be calculated by the equation:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (4)$$

Where, the dielectric constant of the substrate and h is the thickness of the substrate. The fringing field around the periphery of the patch electrically makes the antenna larger than its physical dimensions.   takes this effect in account and can be expressed as

$$\frac{\Delta L}{h} = \frac{0.412(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad (5)$$

Patch feed Width;

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right) \quad (6)$$

$$\frac{W}{h} = \frac{8e^A}{e^{2A} - 2} \quad (7)$$

Patch Feed Length is calculated using equation (4) and (5).

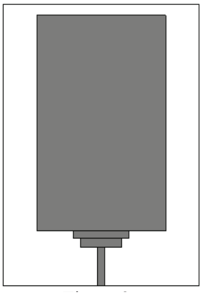


Figure 3:

Rectangular slots were added in the radiator element as shown in figure 4. The addition of slots is believed to be able to increase the bandwidth of the patch. The slot sizes were $\lambda/2$, $\lambda/4$, and $\lambda/8$ respectively. Parametric study will be conduct to determine the suitable location of rectangular slot.

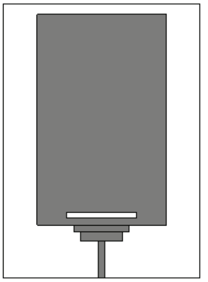


Figure 4: Insertion of rectangular slot at radiator element

To further improve the return loss parameters of the S11 port, the additional vertical slot is added to the horizontal slot on radiator element as shown in figure 5. The dimension of vertical slot is $\lambda/2$, $\lambda/4$, and $\lambda/8$.

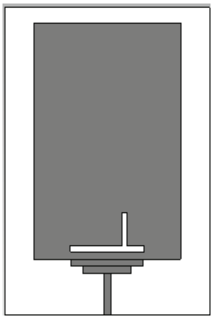


Figure 5: Additional slot on rectangular slot in the radiator element.

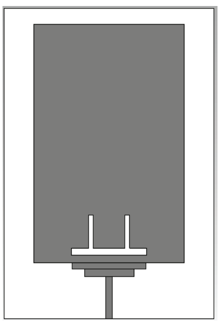
An inverse phi slot shape as shown in figure 6 is design to get dual band operation. The distance between two vertical slots is optimized from $\lambda/2$, $\lambda/4$, and $\lambda/8$.

The dual-band performance of the proposed antenna, with the optimal impedance matching, was achieved with its parameters selected as those in table 2.

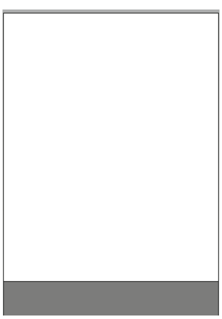
Table 2: Parameter design

W	= 56mm
L	= 92mm
HSlot	= 2 x 30.62mm^2
VSlot	= 2 x 15.31mm^2
Ds	= 12.6mm
St1	= 2 x 20mm^2
St2	= 2.5 x 30mm^2
F	= 2.9 x 16.36mm^2
Wg	= 85mm

The proposed dual-band antenna is shown in figure 6. The antenna is fed by microstrip line. The thickness of the proposed antenna is about 1.6mm, while the maximum dimension of the planar radiator element is less than $\lambda/2$, where λ is the wavelength at the highest frequencies of interest (2.45GHz). The overall antenna dimensions are smaller than the normal $\lambda/2$ microstrip antenna without shorting-pins.



(a)



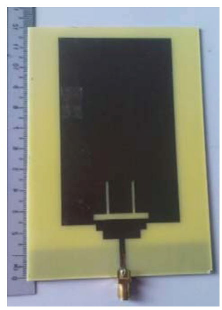
(b)

Figure 6: Final proposed design (a) front view (b) back view

IV. RESULTS AND DISCUSSION

After intensive investigation for various slotted insertion to the planar monopole antenna and observing their performance with regard to the RFID antenna requirements, there is dual-band slotted planar antenna resulted from this study, the inverse phi shape slotted planar antenna with partial ground plane. The proposed antenna have been developed and tested.

This selection is based on the best performance given in terms of resonance frequency, impedance bandwidth, current distribution, slots effect, permittivity and radiation pattern. For dual band slotted planar antennas, it is shown from the simulation results that by modifying the distance of slots of antenna, it provides the band notched characteristics without major modification by using one antenna. The simulation results of proposed antenna will be further discussed and compared to the experimental works.



(a)

(b)

Figure 7: prototype of Inverse phi shape slotted dual-band planar antenna

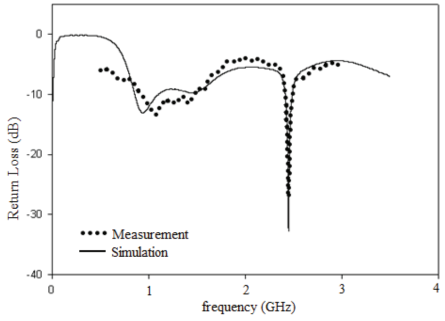


Figure 8: Simulated and measurement return loss of planar antenna with inverse phi shape

There is good agreement between the measured and predicted return loss for the antenna. The measured return loss is slightly bigger than the predicted. These differences between simulated and measured values are occur cause by loss from fabrication, transmission devises and connection.

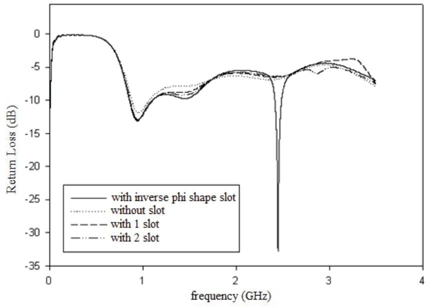


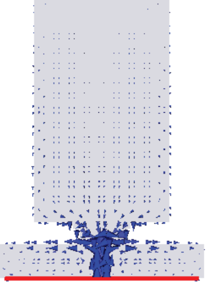
Figure 9: effect on insertion slotted shape planar antenna to the return loss

The effect of insertion slotted shape on return loss data was tabulated in table 3. With addition of slot to the design, the return loss of antenna improve from -13.76dB to the 15.26dB. When the inverse phi shape slot shape is added to the design, the frequencies resonate at dual-band where the return loss is -12.52dB at lower frequency and -30.32dB at high frequency.

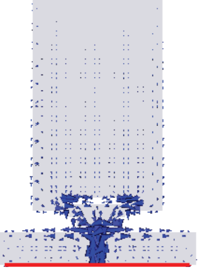
Table 3: Return Loss comparison.

Prototype	Return loss at 910MHz	Return loss at 2450MHz
Without slot	-13.76dB	-6.84dB
With 1 slot	-15.26dB	-6.49dB
With 2 slot	-16.40dB	-6.37dB
With Inverse phi shape slot	-12.52dB	-30.32dB

Figure 10 shows the simulated surface current distributions of the antenna with and without the slot at 910MHz. It is seen that for the antennas with and without the slot, the surface current distributions basically are similar, but the one for the antenna with the slot has stronger excitation in the lower part of the monopole, which results in a good monopole-like radiation for the 910MHz band.



(a)



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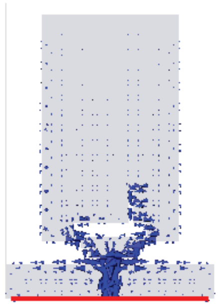
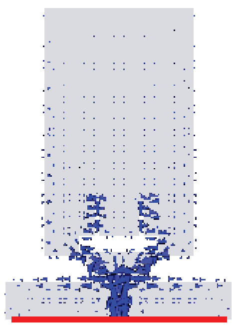
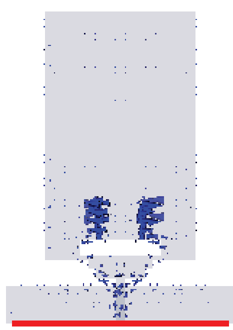


(c)

Figure 10: Simulated surface current distributions of the antenna (a) without and (b) with the single slot (c) with 2 slots at frequency 910MHz.



(a)



(b)

Figure 11: effect on insertion slotted shape planar antenna to the surface current.

From table 4, we can see the slot bring effect to the gain of the antenna. Prototype without slot produce moderate gain 2.359dB at frequency 910MHz. Additional slot on radiator element for prototype with 1 slot lead to increasing gain from 2.359dB to 2.365dB. To further improve the gain 2.371dB, additional slot on rectangular slot is applied. Finally, an inverse phi shape slot increase the gain value 2.427dB at frequency 910MHz and 3.765dB at frequency 2450MHz. The simulated maximum gain of compact multiband antenna varies from 2.3 to 3.7 dBi. The lower gain is obtained due to the antennas exhibit omnidirectional radiation pattern.

Table 4: Gain Comparison

Prototype	Gain at 910MHz	Gain at 2450MHz
Without slot	2.359dB	-
With 1 slot	2.365dB	-
With 2 slot	2.371dB	-
With Inverse phi shape slot	2.427dB	3.765dB

4.2 RADIATION PATTERN

Once the resonance frequencies were identified, principal radiation patterns were taken to characterize the operational performance of antenna.

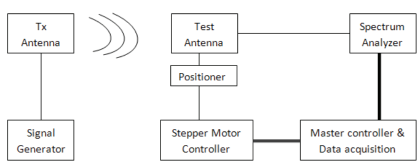


Figure 12: Block diagram of radiation pattern measurement.

Antenna radiation patterns are graphical representations of the distribution of radiated energy as a function of direction about an antenna. Typical patterns in two orthogonal planes at the two resonant frequencies are presented in figure 13 and 14 for measurement result. The measured designed antenna produce broadside or Omni directional radiation pattern. It is seen that good broadside radiation characteristics with the same polarization planes are obtain, and the cross-polarization radiation is well below -15dB. The measured results agree with the simulated result.

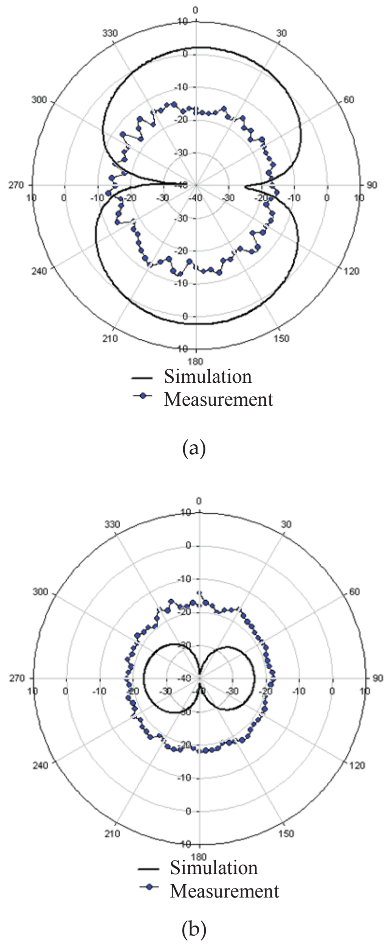


Figure 13: Simulated and measured result (a) e-plane and (b) h-plane radiation pattern of 910MHz.

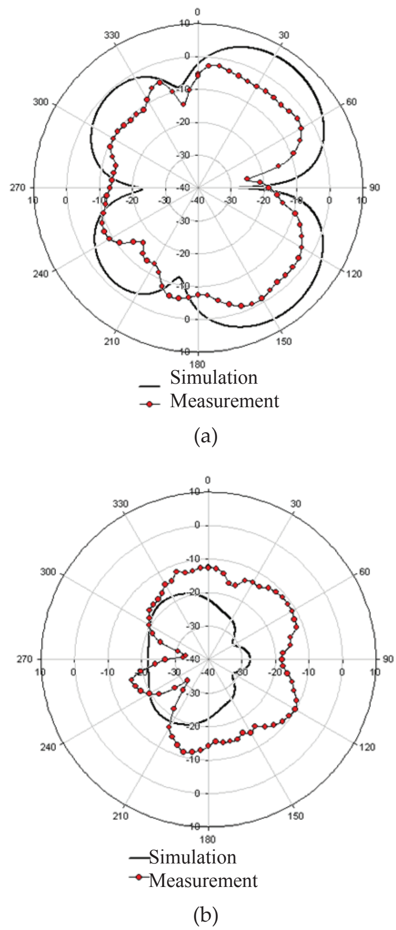
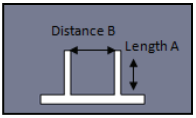


Figure 14: Simulated and measured result (a) e-plane and (b) h-plane radiation pattern of 2.45GHz.

The measured radiation patterns compared with the simulated ones at f = 910MHz and 2.45GHz are demonstrated in Figs. 13(a), (b), and 14(a), (b), respectively. It is shown that the measured co-polarization patterns are in very good agreement with the simulated ones for the 2.45GHz band. Meanwhile for 910MHz, a slight variation patterns for measurement and simulated.

Parametric studies have been performed to facilitate more elaboration of the design and optimization processes for readers. Various parameters are investigated to examine the effects of the antenna parameters on return loss as well as the impedance bandwidth of the antenna. This study covers the influences of varying the length of vertical slots, and distance between two vertical slots. For better convenience of the effect on the performance of the antenna upon changing the parameters, only one parameter is changed at a time, while keeping others unchanged.

Figure 15 shows the relationship between the resonant frequency and the lengths of vertical slots. It is seen that at $\lambda/8$ (proposed length), the antenna resonate at both upper band and lower band better than $\lambda/2$ and $\lambda/4$.



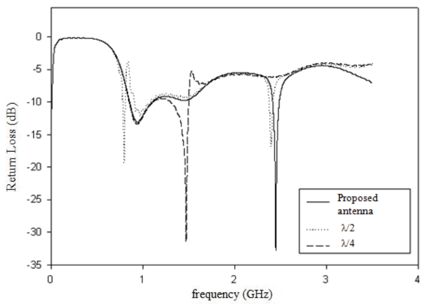


Figure 15: The return loss versus frequency for different value of Length A

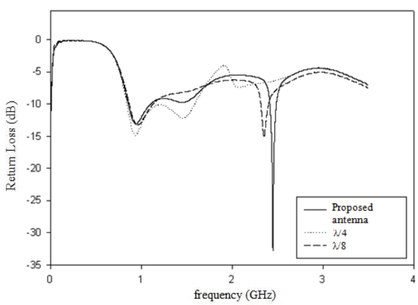


Figure 16: The return loss versus frequency for difference value of Distance B

Figure 16 illustrate the consequence of changing the distance between two vertical slots. Larger lower frequency bandwidth is acquire when the distance of the slot is $\lambda/4$, but in the same time the upper frequency resonate at 1.5GHz. When the distance of the slots is $\lambda/8$, dual band operation is obtained but the upper frequencies resonate at 2.35GHz. The proposed distance, optimized from $\lambda/8$ improved return loss result for lower frequency and upper frequency.

V. CONCLUSION

A slotted planar antenna with multiband and broadband characteristics has been successfully demonstrated. Slots insertion is added to further improve the impedance bandwidth. Multiband characteristics of proposed antenna are also observed. The antenna is compact, simple to design and easy to fabricate. A moderate gain is achieved.

ACKNOWLEDGEMENT

This work has been supported by Universiti Teknikal Malaysia Melaka under short term grant (PJP/2009/FKEKK (2D) - S538).

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