A Planar Keyhole Shape UWB Antenna For Retransmission Based Chipless RFID

AKM Zakir Hossain, Win Adiyansyah Indra, Jamil Abedalrahim Jamil Alsayaydeh, Mohamad Zoinol Abidin Bin Abd. Aziz

Abstract: In the retransmission based chipless RFID, the receiving and transmitting antennas are an essential element and play a vital role for the tag performance and occupied area as well. In this article a new planar microstrip keyhole shape UWB antenna for retransmission based chipless RFID tag is proposed. The proposed antenna is a UWB antenna, covering from 3.45 GHz to 10.7 GHz and has a 7.25 GHz bandwidth with a dimension of only 32×20 mm^2. The antenna has the radiation efficiency between 96.5% to 99% within the bandwidth. The radiation pattern of the antenna is Omni-directional and the max realized gain is 4 dBi which is suitable for the transmitting and receiving antennas for chipless retransmission based RFID tags and readers as well.

Index Terms: retransmission based RFID, planar, microstrip, UWB, antenna, chipless RFID, tags, readers.

1. INTRODUCTION

THE Radio Frequency IDentification (RFID) is a term very well familiar in the industry. From toll collection to item tracking or product identification to inventory management, the RFID is omnipresent. In the course of trying to replace the barcode, every day, the RFID technology is adopted by many industries. The barcode is cheap but this technology is vulnerable to wear, tear and dent. Barcode is easy to tamper and it needs a clear line of sight (LOS) for detection/identification [1]. All these issues related to barcode system can be resolved by implementing the RFID system. There are three different branches of RFID in terms of the power supply on board, (i) Active RFID (fully battery assisted tag), (ii) Semi-active RFID (partially battery assisted tag) and (iii) the passive RFID (no battery on board of the tag). The 3rd kind is the cheapest and the only candidate so far to replace the barcode system. However, the passive RFID comes with two types: Chipped and chipless RFID and between these two type, the chipless types are at the forefront of the research to fully replace the barcode system due to its cheapness and easy to fabricate. The chipless tags my come with or without antenna(s). Chipless RFIDs which are without antenna are basically radar cross section (RCS) or backscatter based. The other type that comes with antenna is called the retransmission based chipless RFID. However, due to the size of the antenna on board of the tag, the overall dimension of the tag gets comparatively bigger than the RCS based tags. It is still a challenge for the RFID design researchers to make the receiver (Rx) and transmitter (Tx) antenna as small as possible while keeping the performance as standard as possible.

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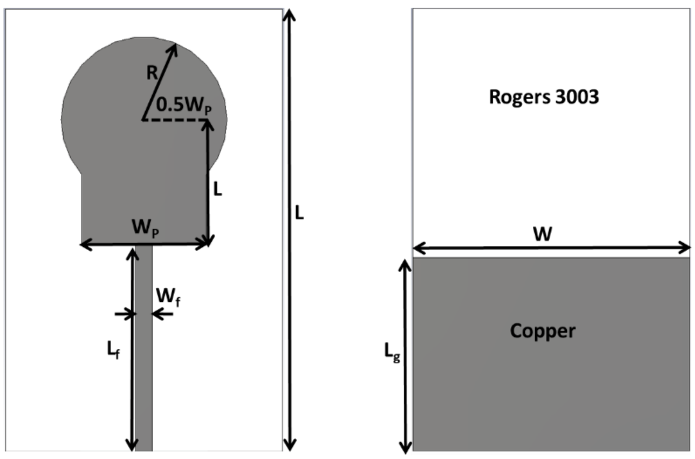
In 2009, the authors in [2] have proposed a novel retransmission based chipless RFID system. In that system rectangular spiral resonators have been used for coding element along with two separate Rx and Tx antennas. The antennas were microstrip disc loaded monopole type with partial ground plane (PGP). The bandwidth (BW) of that antenna covered the whole UWB (3.1-10.7 GHz) spectrum. The size of the antenna was 66 × 60 mm^2 (Length × Width). Even though there was no 3D pattern and the gain Vs frequency response provided, from the 2D radiation pattern it is seen that the gain is around 0 dB which is very low considering the size of the antenna. The same disc loaded monopole antenna also has been used in [3] with the multi state rectangular spiral resonator based tag which had a dimension of 90 × 60 mm^2. However, no gain and radiation pattern information has been included in that proposal. Similarly, in [4] a rectangular UWB microstrip antenna has been proposed for a complementary split ring resonator (CSRR) based chipless tag. The authors have used babinet's principle to design that antenna. The size of the antenna was 36 × 23 mm^2 with a maximum gain of 2.45dBi at 7 GHz. The same antenna has been modified and used in [5] for a 3-state rectangular resonator based tags. However, the dimensions are comparatively big (74.62 × 25 mm^2) with maximum gain of 4.9dB. However, the comparatively high gain is due to the size of the antenna. In [6], a co planar waveguide (CPW) semi-circle monopole antenna has been proposed for the chipless tag. The antenna dimensions are 32 × 35 mm^2 and had a omni-directional pattern. However, the information on the realized gain have been missing in that proposal. Another CPW elliptical disc loaded monopole UWB antenna has been proposed in [7] for a modified circular split ring resonator (MCSRR) based chipless RFID tag. The peak gain is around 2 dBi for that antenna. However, the actual dimensions (total length and width) of the antenna were missing. The same CPW structure has been utilized for a CPW disc loaded monopole on the flexible Kapton film for a CPW rectangular spiral resonator based chipless RFID tag sensor to measure liquid concentration [8]. The dimension of the antenna was 51.1× 40.6 mm^2. However, form the provided gain pattern it has been seen that the gain is around 0 dB. For all there above antenna, some has good gain but due to the large size and other has smaller dimensions, however, suffered a low gain for the chipless RFID system. In this article a microstrip keyhole shape antenna has been proposed, designed and simulated for comparatively small size and higher realized gain to overcome this issue.

2 ANTENNA DESIGN

The antenna named as the 'Keyhole' shape as the shape of the antenna patch mimics the keyhole structure. The design structure (both front and back side) of the antenna is illustrated in Fig 1 with detailed dimensions. The substrate is used here as Rogers 3003 with a dielectric constant $\varepsilon_r = 3.0$, substrate height, h = 0.51 mm and the loss tangent, $tan\delta = 0.001$. Fig 1(a) shows the front view of the antenna and Fig 1(b) shows the back view of the antenna with PGP dimensions. The steps of the design are illustrated in Fig 2. To come up with this design at first a rectangular patch has been drawn (step 1). Later, a circular shape (radius, R = 6 mm) has been introduced with the rectangular patch and marge with it (step 2). Finally, the 50 Ω transmission feed line is introduced and added with the keyhole shaped patch to finalize the design. The software used to simulate the design is CST MWS 2020.



(a) (b)

Fig 1. *(a) the front and (b) the back view of the antenna (R=6 mm, W_P= L_P = 9mm, L_f =15mm, W_f =1.2 mm, L_g = 14 mm, W = 20 mm and L= 32 mm)*

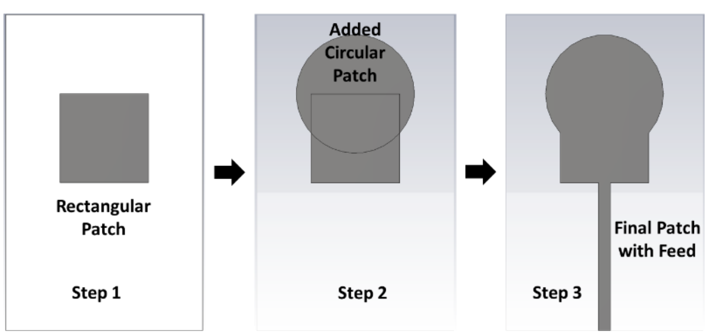


Fig 2. *Steps of the antenna structure design*

All the dimensions such as the length of the patch (L_p) and the width of the patch (W_p) have been calculated from equations (1) to (5) as follows [9,10],

$$W_p = \frac{C_0}{2f_c\sqrt{\frac{(\varepsilon_r + 1)}{2}}} \tag{1}$$

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W_p}\right]^{-\frac{1}{2}} \tag{2}$$

$$L_e = \frac{C_0}{2f_c\sqrt{\varepsilon_e}} \tag{3}$$

$$\Delta L = 0.412h\frac{(\varepsilon_e + 0.3)(\frac{W_p}{h} + 0.264)}{(\varepsilon_e - 0.258)(\frac{W_p}{h} + 0.8)} \tag{4}$$

$$L_p = L_e - 2\Delta L \tag{5}$$

Where, ε_e is the effective dielectric constant, L_e is the effective length of the patch, C_0 is the speed of the light at vacuum and f_c is the resonant/center frequency. The length (L_g) and width (W_g) of the PGP have been calculated from the equation (6) and (7) respectively. As the guided wavelength, $\lambda_g = 24.4$ mm, the approximated length of the final antenna, L= $4\lambda_g/3$=32 mm.

$$L_g = 6h + L_p \tag{6}$$

$$W = W_g = 6h + W_p \tag{7}$$

3 RESULTS AND DISCUSSIONS

Fig 3 illustrates S-parameter responses for the different stages of the antenna design. At the stage 1, the antenna has only the rectangular patch with full GP. The patch has been added with the feed line and simulated. It can be seen that the S-Parameter value is almost constant around 0 dB. It implies that there is no resonance(s) from 1 GHz to 11 GHz. At stage 2, the circular patch has been added and simulated again keeping the same full GP. It is seen that there are still no resonances in the spectrum. Finally, at the stage 3, the full GP has been truncated and made as a PGP. This move made the key difference for the design. The S-Parameter response shows that the -10 dB value starts around 3.45 GHz and it remains below -10 dB throughout the rest of the UWB region until 10.7 GHz. This made this design achieving a bandwidth (BW) of 7.25 GHz with the center frequency is approximately at 7.1GHz. The WSWR response is shown in Fig 4. The response fully tally with the S-Parameter response as the value is always below 2 from 3.45 GHz to 11GHz. Similarly, Fig 5 shows the high surface current accumulation of the antenna at 7.1 GHz, justifying the design quality. Since the determination of the antenna's resonance and the BW is justified, the next step is to investigate the performance of the antenna.

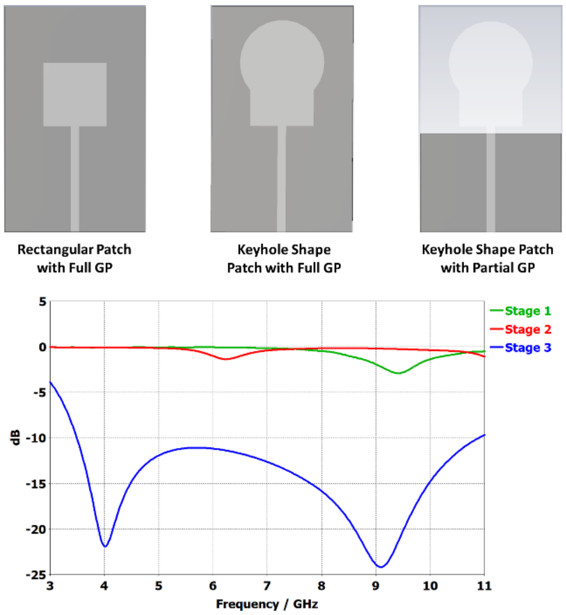


Fig 3. *S-Parameter Response for different stages of design*

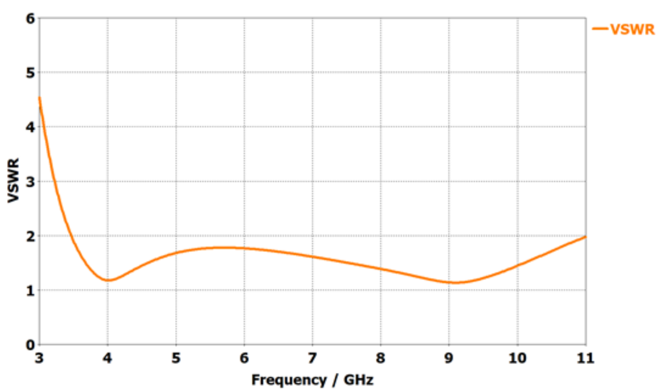


Fig 4. *VSWR response of the antenna*

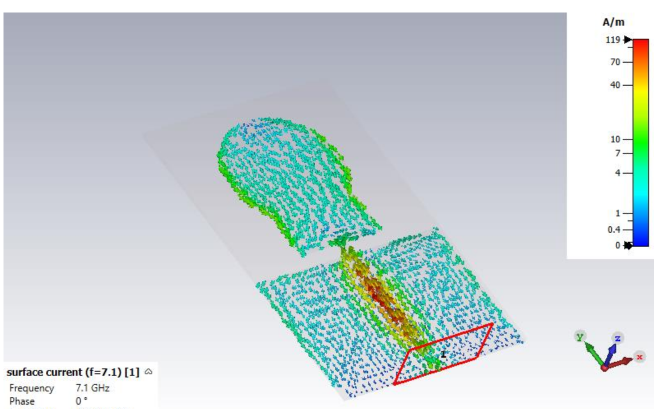


Fig 5. *VSWR response of the antenna*

Fig 6 comprise the radiation efficiency of the antenna. It can be seen that this design exhibits an excellent radiation efficiency keeping between 96.5% to 99% throughout the entire BW. It indicates the less loss in the conversion from signal to radiation of the antenna. Fig 7 illustrates the 3D radiation pattern (normalized realized gain) of the antenna. From the 3D pattern it can be seen that most of the radiation is at the circumference of the radiation sphere. This shows that the radiation has an Omni-directional pattern. However, it necessary to check the E and the H-plane polar 2-D pattern to get the confirmation.

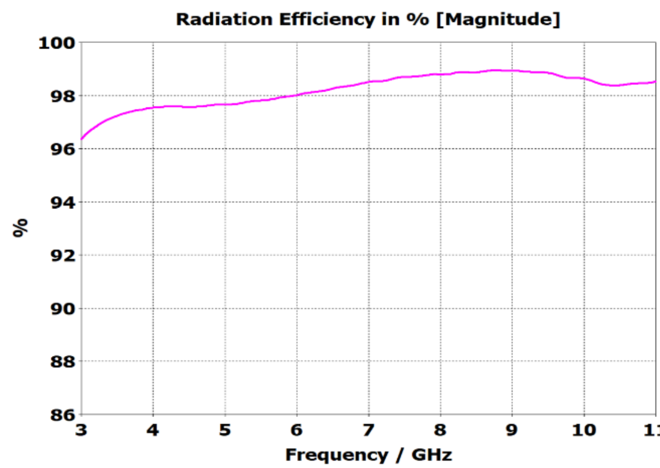


Fig 6. *The radiation efficiency of the antenna*

Fig 8 and Fig 9 include the E and the H-plane of the antenna respectively. The E-plane is supposed to be a bidirectional shape and Fig 7 shows exactly the same. Similarly, the H-plane pattern response also shows a full circular shape as comprises in Fig 8. All these 3D and 2-D pattern responses prove that the

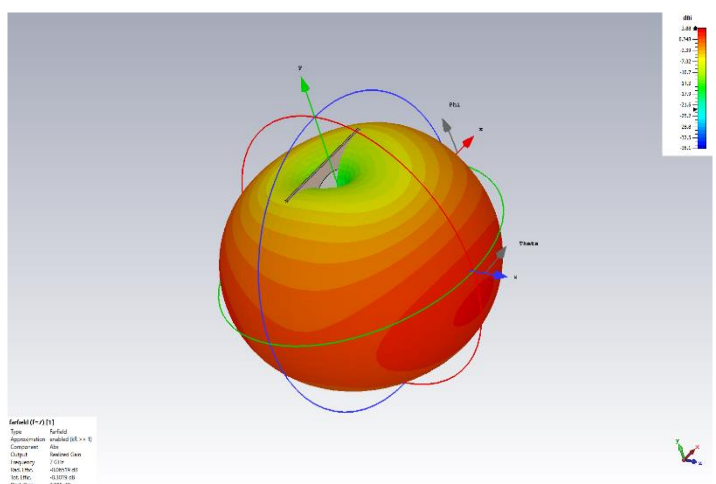


Fig 7. *The radiation efficiency of the antenna*

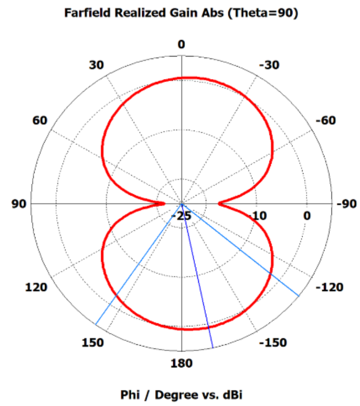


Fig 8. *E-Plane radiation pattern*

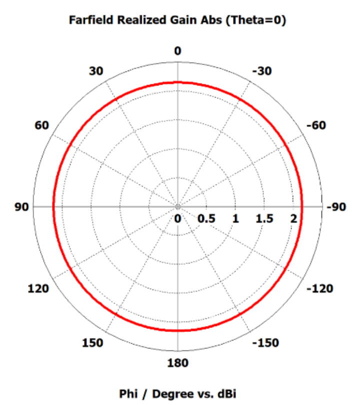


Fig 9. *H-Plane radiation pattern*

antenna exhibits an Omni-directional radiation pattern which is necessary for the chipless retransmission type tags. Fig 10 illustrates the realized gain Vs frequency response of the antenna. It is seen that it has a relatively good gain throughout the entire BW keeping the value between 2 to 4 dBi. With all these parameters it can be concluded that the antenna is a

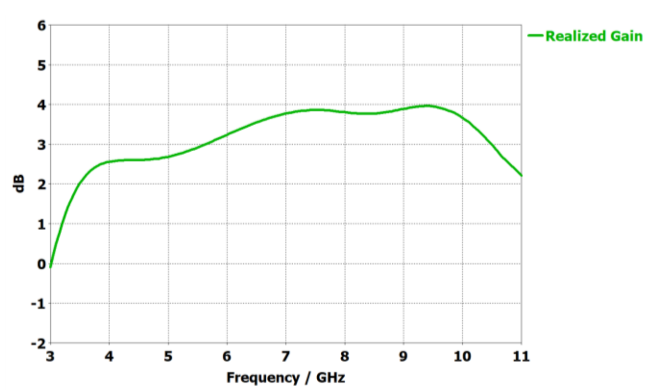


Fig 10. *Realized gain Vs frequency*

TABLE 1
Comparison between existing and proposed work

Ref	Dimensions (L× W) mm^2	Realized Gain dBi
[2]	66 × 60	0
[3]	90 × 60	na
[4]	36 × 23	2.45
[5]	74.62 × 25	4.9
[6]	35 × 32	na
[7]	na	2
[8]	51.1× 40.6	0
This work	32×20	4

suitable candidate to work as the Rx/Tx antenna for UWB chipless RFID tag and also for readers. Table 1 summarizes the comparison among the existing chipless RFID tag antennas and this proposed work. From the Table 1 it can be seen that the proposed work has the smallest size among all other existing works and exhibits max realized gain 4 dBi.

4 CONCLUSION

A planar keyhole shape microstrip UWB antenna for the chipless UWB RFID tag has been designed and realized here. The antenna is comparably smaller in size while maintaining a comparatively good gain throughout the UWB spectrum reaching up to 4dBi. This designed antenna is suitable for any tag and as well as reader Tx and Rx applications for retransmission based chipless RFID systems.

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