High-Directivity and Circularly Polarized Compact Patch Antenna for UHF RFID Reader Devices

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Abstract. This paper presents the design, construction, and testing of a high directivity and circularly polarized small patch antenna for the RFID Base Stations (Readers) operating in the European UHF RFID band. The designed and optimized patch antenna structure has a 15cm ×15 cm × 0.6 cm compact size where the -3dB beam angle is reduced by using slotted ring embedded in the patch. The gain of the antenna at 862 MHz is 3.2 dBic with the E and H plain beam angle are 61.6º and 65.2º respectively. Finally, the designed antenna is compared to a single-layer patch antenna of the same cross-sectional dimensions as the proposed antenna structure.

1 Introduction

The aim of this study is to develop a new antenna structure for UHF RFID base stations. The sought criteria are compactness and a high directivity in order to allow an optimal compromise in the implementation of RFID solutions in the UHF band applications.
Different techniques used to increase the directivity of planar antennas are creating antenna array, increase the ground plane size, increasing antenna size, miniaturizing antennas and using superstrate [1, 2]. In [2] the electric field distribution on top surface above a superstrate has been used to determine its shape and size that minimize its edge diffraction.

Usually high gain and highly efficient antenna means higher directivity. Further enhancement of directivity is hardly possible without changing the antenna size because the half-power beam width (HPBW) is a function of antenna size. For this situation placing one or more superstrates can narrow the HPBW thereby increases the directivity of the patch. HPBW can be reduced by making antennas in an array. In UHF frequency band the antenna size is already too big. Hence, making array will lead the antenna size uncomfortable. This is cannot be a solution of compact size high directive antenna.

This study deals with the process of narrowing the half-power beam width (HPBW) of patch antenna in UHF frequency band. By high "directivity" we could mean either higher gain or narrower beam width. Both of these can only be achieved by increasing the aperture of the antenna, that is to say the size. In theory we could increase the efficiency of the antenna without increasing size thus gaining in both, but most well designed antennas are already over the 50% of efficient, so even if we could somehow increase efficiency we would not gain much. Reducing the HPBW may not increase the gain but the directivity may increase.

In our approach, we consider the problem of enhancing the directivity of a patch antenna based on a new configuration antenna with three dielectric layers and modified radiating element. We begin by studying a conventional single layer patch antenna fabricated on FR4 substrate and then defined and characterized the new form of the proposed antenna.

2 Design and simulation

The construction of the patch antennas under consideration is shown in Fig. 1. In fact we will consider here two antennas of Fig. 1(a) and (b). Fig.1 (a) shows a conventional single layer patch antenna on FR4 dielectric substrate. The second version is the proposed antenna and shown in Fig. 1(b) where two layers of FR4 are used; one for ground plane support and the other is for patch (radiading element) support. As shown in Fig. 1(b) there is an air gap separating the two previous layers of FR4. In addition of those two non equal rings are etched in the radiating element; one at the centre of the patch and the other around the feed position. For both the case the used thickness of FR4 is 1.6 mm, permittivity, with dielectric substrate, of 4.3 and the loss tangent is 0.021. For the antenna of Fig. 1(a) the ground plane size is 15 cm ×15 cm and the patch size is 8.15 cm × 8.15 cm. The antenna is diagonally feed for circular polarization. For the antenna in Fig. 1(b) the ground

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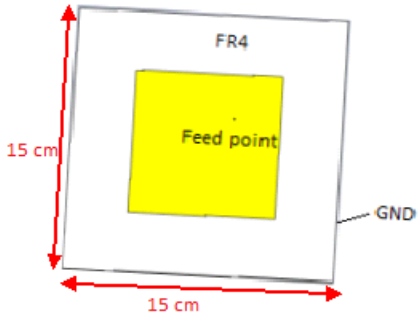
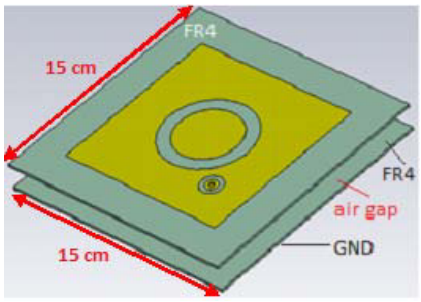
plane size remains 15 cm ×15 cm. A little slot ring is etched around the feed point. The second larger slot ring is etched at the center of the radiating element (patch).



(a)



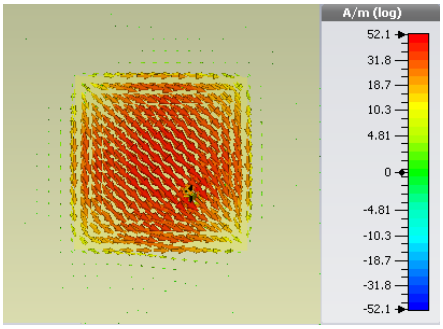
(b)

Fig. 1. Patch antennas: (a) conventional with single layer FR4 dielectric substrate and (b) proposed structure.

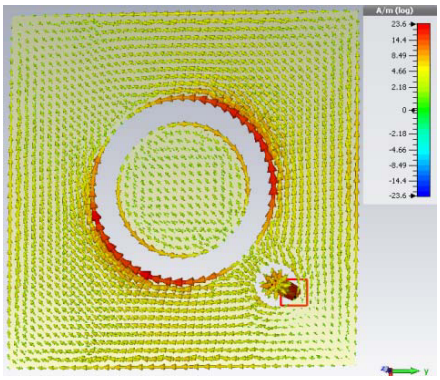
The optimisation of the different dimensions, such as the dimensions of the radiating elements, the height of the air gap and those of the slots, were carried out by using both CST microwave studio simulator and Ansoft HFSS simulator.
The surface current distribution, on the radiated elements, is shown in Fig. 2 at the resonant frequency of the antennas. A better distribution of the current density can be observed in the case of the proposed structure.

3 Experimental results

In order to compare and validate the properties of the proposed antenna structure, the double-sided FR4 substrate was used for the conventional patch antenna etching and the single-sided FR4 substrate for the construction of the new structure.



(a)

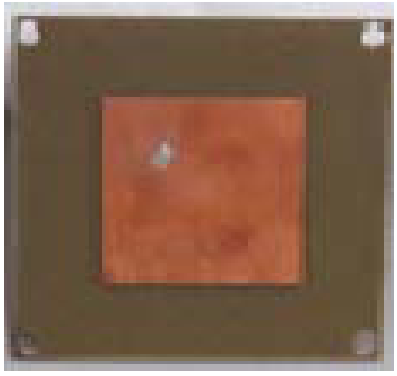


(b)

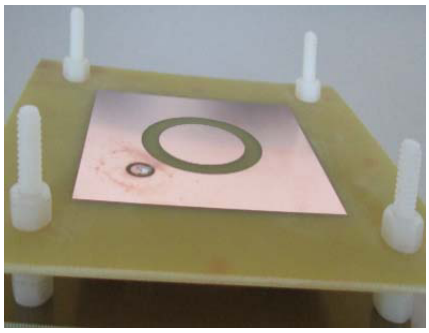
Fig. 2. Surface current distribution on the antennas radiating element : (a) conventional patch antenna and (b) proposed antenna.

The photos of the fabricated prototypes of the patch on single layer Fr4 and the proposed patch antenna are shown in Fig. 3 (a) and (b) respectively.
As shown in Figure 3, the two feed points are located along the diagonal line of the radiating elements. Their positions have been optimized to provide a circularly polarized radiation pattern and to allow an optimal matching of their input impedance.

The measurements of the both antennas are carried out in the ESEO anechoic chamber antenna testing setup.
The single layer antenna (conventional patch antenna) resonates at 866 MHz with the S_{11} value of -28.35 dB. The second antenna resonates at 862 MHz with the measured S_{11} value of -25 dB (Figure 4). The observed discrepancy between the measurement and the simulation can be partly explained by the precision of the proposed structure assembly.



(a)



(b)

Fig. 3. The photo of the fabricated prototypes : (a) Conventional antenna and (b) proposed structure.

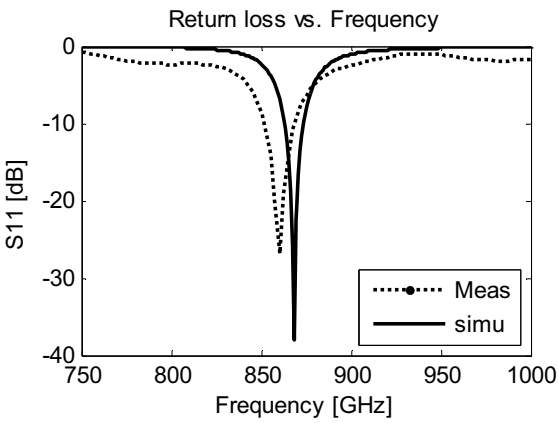


Fig. 4. Simulation and measurement comparison of the proposed antenna return loss vs. frequency.

The Fig. 5 and 6 show the measured E-plane and H-plane radiation patterns for the two fabricated antennas (Fig. 3). The E-plane – 3db beam of the conventional and the proposed antennas are 68.6 degree and 61.6 degree respectively. The H-plane – 3db beam of the conventional and the proposed antennas are 73.1 degree and 65.2 degree respectively.

As shown in Fig. 5 and 6, the proposed antenna radiation pattern is improved by 7.17 dB in E-plane and 6.53 dB in H-plane compared to conventional patch antenna radiation. Hence the directivity of the proposed antenna embedded with two slots is increased by 6 dB.

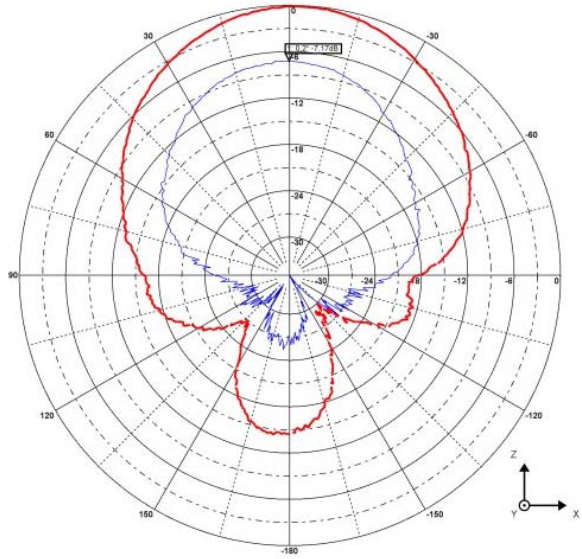


Fig. 5. Measured E-plane radiation patterns of the two antennas : (------) conventional patch antenna and (------) proposed antenna structure.

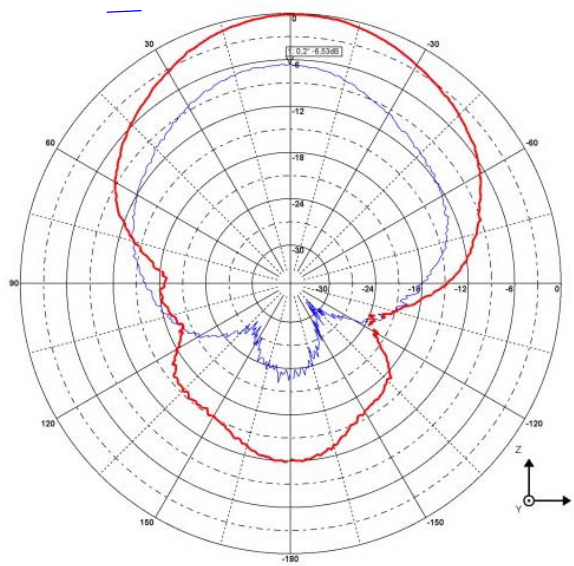


Fig. 6. Measured H-plane radiation patterns of the two antennas : (——) conventional patch antenna and (——) proposed antenna structure.

The simulation and measurement comparison of the proposed antenna gain versus frequency curves, in E and H planes, are shown in Fig. 7 and 8 respectively. Measurement results agree well with the simulation ones.

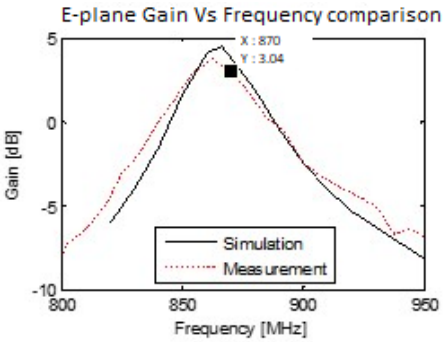


Fig. 7. Simulation and measurement comparison of the proposed antenna gain versus frequency in E plane.

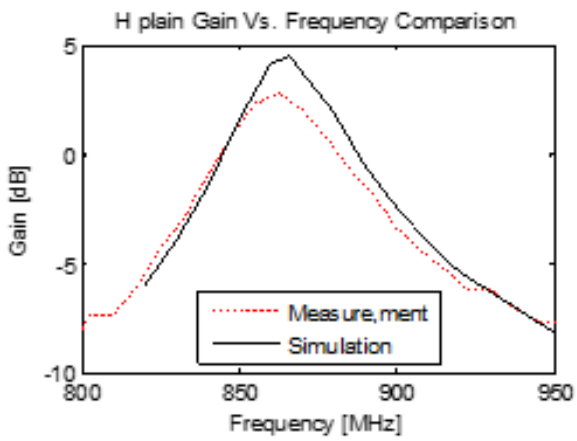


Fig. 8. Simulation and measurement comparison of the proposed antenna gain versus frequency in H plane.

Table 1 summarizes the obtained experimental results for the designed antenna structure. The various obtained values confirm the interesting characteristics of the antenna structure developed in this study.
Such a structure will make it possible to overcome certain constraints in the deployment of RFID in indoor.

Table 1. Experimental results of the proposed antenna

	Gain	HPBW	Back radiation
E plane	3.22 dBi	61.6°	-15.5 dB
H plane	3.01	65.2°	-15.8 dB

4 Conclusion

We have presented a technique to enhance the gain and directivity of patch antenna for EU UHF RFID reader applications. The proposed antenna size remains same of the conventional patch structure, taken as reference, but but increasing the height to an optimal value of 0.6 cm generates the gain enhancement of 7.17 dB in the E plain and 6.53 dB in the H plain. Hence this technique is a good candidate to enhance antenna gain and directivity without increasing the antenna volume too much as for example in the case of gain enhancement of patch antenna with superstrate layers. The measurement results show that the half power angles of the proposed patch antenna structure reduced by 7 degree in the E plane and 7.9 degree in the H plane compare to the original patch on single layer FR4. Hence the method is suitable to increase the directivity and gain of patch antenna without increasing the antenna size.
The developed structure can allow to overcome certain constraints in the deployment of RFID in indoor.

References

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