HIGH-GAIN ANNULAR RING WITH MEANDER SLOTS ANTENNA ARRAY FOR RFID APPLICATIONS

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ABSTRACT
In this paper, a high-gain annular ring with meander slots antenna array is presented. The proposed design is realized on two different substrate materials separated by a foam layer of 7.5 mm to enhance the operating bandwidth. The antenna is designed to operated as UHF-RFID reading antenna over center frequency of 915 MHz with operating bandwidth of 49.25 MHz (around 5.38%). The overall antenna optimized dimensions are 240x240x11.56 mm^3. An overall total realized gain of 12.5 dBi is achieved at the intended center frequency. The proposed antenna exhibits stable radiation capabilities over the operating band. Good agreement is obtained between both CSTMWS, and HFSS simulators.

Keywords: UHF-RFID, Meander slots, annular ring antenna, array antenna.

I. INTRODUCTION

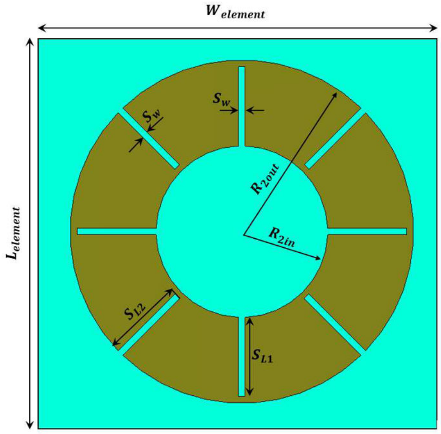
RFID “Radio Frequency Identification” is the technology that using RF signals to provide wireless identification and tracking capabilities. RFID systems consist of four principle items: reader, tag, antenna and host computer [1]. Antennas are the main link component from the tag to the reader. RFID has been used in many applications such as smart labels, preventing theft of automobiles, banking, animal tracking, managing traffic, automating park, ticketing, etc. [2]. RFID systems have different frequency bands for example low frequency band from 125 KHz to 134.5KHz, and the high frequency band works at central frequency about 13.56 MHz. The band from 433MHz to 960MHz has been used for ultra-high frequency (UHF-RFID) signal transmission [3]. The microwave range frequencies (2400–2485 MHz and 5725–5875 MHz) are increasable used recently, so RFID antennas become more complicated. Readers RFID antennas must satisfy some requirements such as good impedance matching, high gain, low cost, ease of fabrication, and low profile. A low profile, dual-band, circular array of four Inverted-F meandered monopoles polarized portable antenna for RFID reader is presented in [4]. Slits on the ground plane and slots in the patch antenna are applied on a simple circular patch to achieve circular polarization at dual frequencies [5-8]. Array techniques are also used to achieve a switchable near field and far field UHF-RFID antenna [9-10]. A compact circularly polarized antenna with a cross slot in the radiation patch is presented in [11]. Overall antenna gain is enhanced by applying complementary split ring resonator on a compact UHF RFID reader antenna is discussed in [12].

In this paper, a novel design of UHF-RFID reader antenna structure with apparent enhancement in the operating bandwidth and gain is proposed. The designed antenna has a high gain by using parasitic radiator elements printed on a second substrate on the upper layer and a widely bandwidth by using a foam layer in between the two substrate. This paper is organized as follows: Section II describes the designed main element radiator structure and the radiation mechanism. The complete antenna structure is presented in Section III. The results of optimization and a parametric study are introduced in section IV. Finally, the return loss and radiation pattern results are presented in section V. The results of the proposed antenna in RFID system are simulated using CSTMWS studio and verified by HFSS software. Good agreement is achieved between two simulation results.

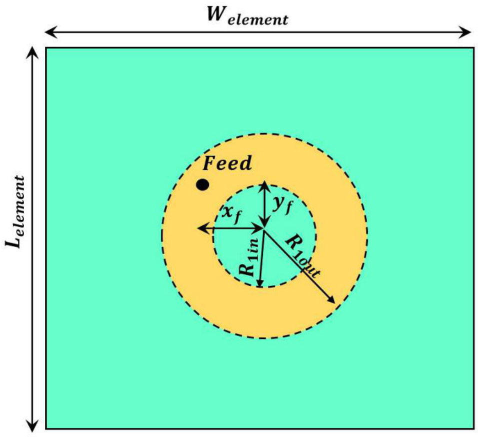
II. MAIN ELEMENT RADIATOR

A simple annular ring microstrip patch (AR-MSP) antenna is designed to operate at a central frequency 915 MHz for UHF-RFID applications. The patch antenna is printed on a grounded substrate of $Rogers\ TMM4$ with relative permittivity $\varepsilon_r = 4.5$, $tan\delta = 0.002$ and thickness $h_1 = 3.81mm$. The outer and inner radii of the annular-ring radiator are $R_{1out} = 3.6$cm and $R_{1in} = 1.8$cm , respectively as shown in Fig. 1 (a). The overall size of the main radiator element is ($130 \times 130 \ \times 3.81mm^3$). A coaxial probe feed is used to excite the designed AR-MSP antenna. An optimization process for the feed position ($x_f,\ y_f$) is introduced to select the 50-ohm matching point. An indirect coupling feeding radiation is carried out between the main annular ring patch and the meander slots stacked patch printed on the top substrate through the foam layer. The middle layer between the two substrates is chosen to be a foam with a thickness of $h_2 = 7.5mm$ and $\varepsilon_r = 1.01$ to enhance the overall antenna bandwidth.

The parasitic meander slots stacked patch is used to achieve more enhancement of the antenna bandwidth, impedance matching, and total realized gain of the antenna. It is placed on the second substrate (sub_2) of $Roger\ TMM10$ with $\varepsilon_r = 9.2$, $tan\delta = 0.0022$ and thickness $h_3 = 0.25mm$. This parasitic patch consists of an annular ring patch with eight meander slots is shown in Fig. 1 (b). The slots increase the current path to reduce the overall antenna size. The eight meander slots are divided to two groups and each group contains four slots. The first group is located vertically and horizontally with a dimension of $S_{L1} \times S_w$ and the second group is located diagonally with angle 45^o with a dimension of $S_{L2} \times S_w$. The main element radiator with the parasitic patch schematic is shown in Fig. 1. All the designed parameter dimensions of the main element radiator are summarized in Table1. The return loss of the main radiator with parasitic mender slots stacked patch is shown in Fig. 2. The bandwidth of the main element radiator is 8 MHz at -10 dB. The proposed design achieves a gain of 9.87 dB at a resonance frequency of 915 MHz. Fig. 3 shows the radiation pattern of the proposed main element radiator (E-plane and H-plane).



(a)



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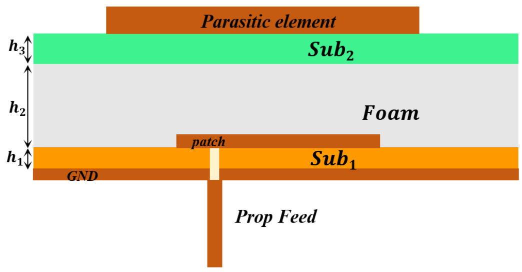


(c)

Fig. 1: (a) The annular ring microstrip radiator element (b) meander slots stacked patch and (c) Side view of the total radiator element structure

Table.1 Main element radiator dimensions

Parameter	S_{L1}	S_{L2}	S_w	R_{1out}	R_{1in}	R_{2out}	R_{2in}
Dimension (mm)	24.5	25	0.5	36	18	53	26.5
Parameter	$W_{element}$	$L_{element}$	x_f	y_f	h_1	h_2	h_3
Dimension (mm)	120	120	19.09	19.09	3.81	7.5	0.25

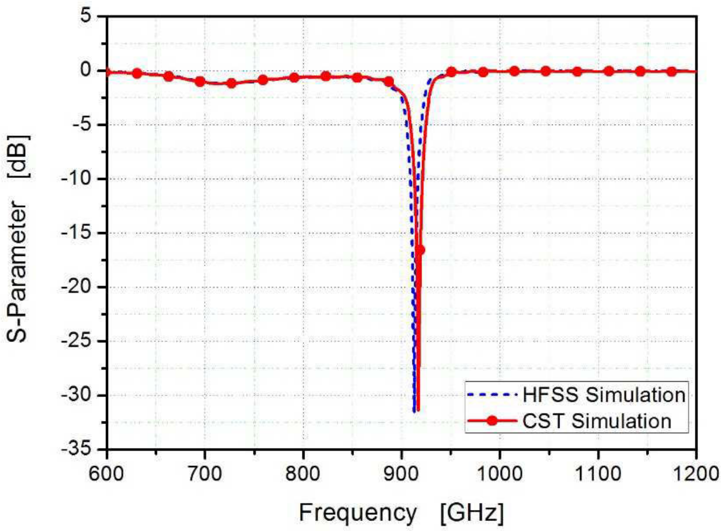


Fig. 2: The return loss of the main radiator with parasitic mender slots.

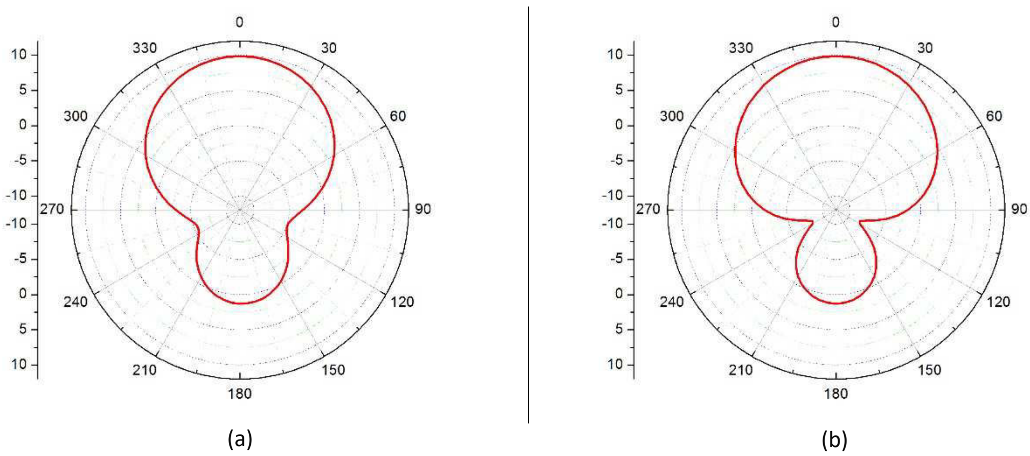


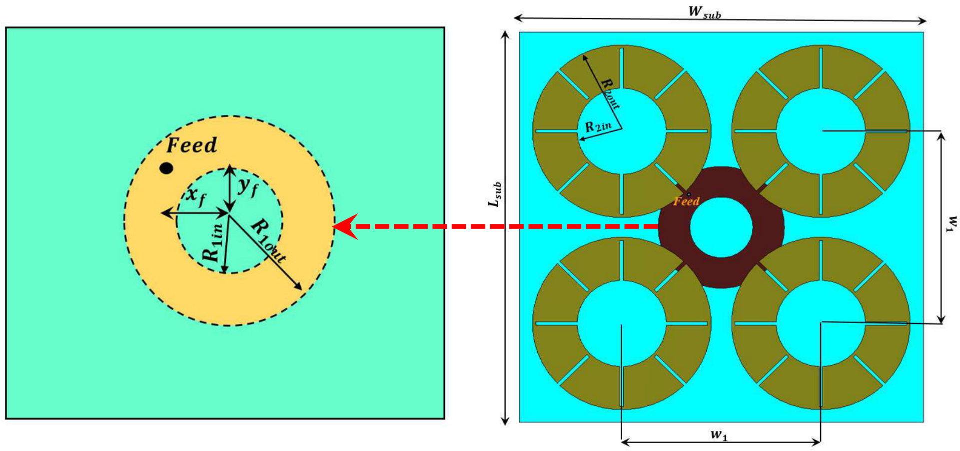
Fig. 3: The radiation pattern of the proposed main element radiator (a) E-plane, and (b) H-plane.

III. Complete Antenna Array Design

In this section, a configuration of RFID meander slots annular ring antenna array is introduced. The overall optimized size of the designed annular ring with meander slots radiators is ($240 \times 240 \times 11.56\ mm^2$). An 2x2 array of meander slots stacked patches is printed in the top layer of the designed antenna, as shown in Fig. 4 (a), to achieve better gain and stable radiation characteristics. The center-to-center spacing distance between the array meander slots radiator (w_1) is equal to $118\ mm$. A parametrical study is applied to adjust the separation distance between the four meander slots patches. In Fig. 4 (b), the side view of the proposed antenna is presented. The coaxial probe feed is realized on the bottom layer which optimized to determine the best matching point location for the antenna array.

IV. Parametric Study Design

In order to address the effects of the design parameters, multiple parametrical studies are carried out using CSTMWS simulator. Fig. 5 shows some of the parametric studies for slots length (S_L), slots width (S_w), foam substrate height ($Hight$) and outer radius of the upper rings (R_{out}). It can be concluded that, increasing in slots width, slots length or outer radius of the upper rings tend to decreasing the resonance frequency, while increasing the foam substrate height tends to increase the resonance frequency location.



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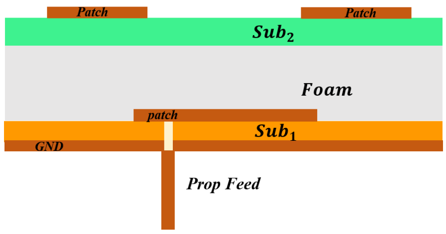

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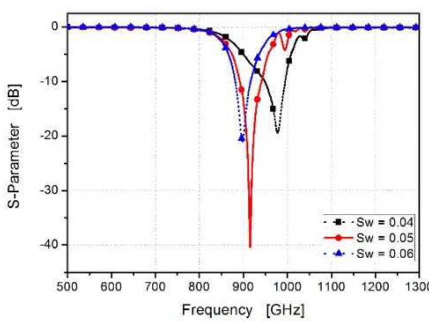
Fig. 4: (a) The top view of the upper layer with meander slots annular rings, and (b) the side view of the proposed structure.



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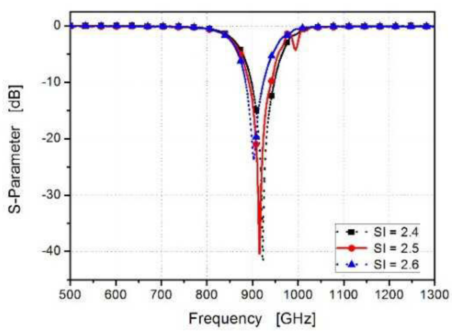

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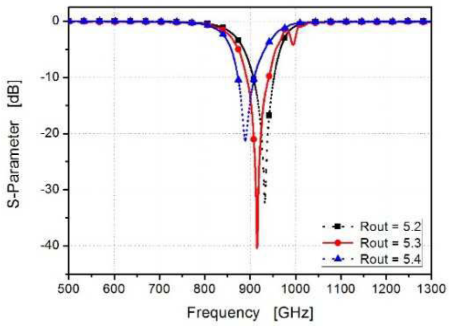

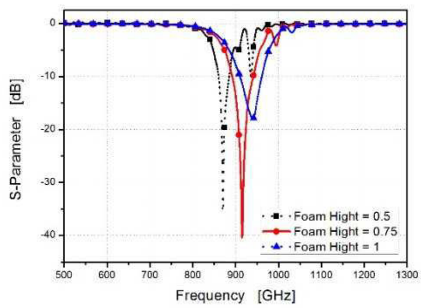

Fig. 5: The effect of (a) the slots width, (b) the slots length, (c) the outer radius of the patch antenna, and (d) the foam substrate height on the reflection coefficient (S_{11}).

(c) (d)

V. Results And Discussions

The proposed antenna is constructed to operate as RFID reader in the UHF band at a resonance frequency of 915 MHz. The antenna structure is designed, simulated, and optimized using a commercial electromagnetic simulation (CSTMWS). The antenna results are verified by the results of HFSS software. Fig. 6 shows the return loss (S_{11}) results of the proposed structure for both CSTMWS and HFSS simulators. Maximum return loss obtained at the central frequency is -40.44dB (-30.3dB in HFSS simulator). The bandwidth of the designed antenna for -10dB bandwidth is 49.25 MHz, as it extends from 892 MHz to 941.25 MHz (50.75 MHz from 891.5 MHz to 942.25 MHz in HFSS), achieving around 5.38% bandwidth compared with 8 MHz bandwidth for a single element antenna. The radiation pattern of the proposed structure is simulated in CSTMWS and compared with HFSS results. The antenna achieves a high gain of 12.5 dBi at a designed frequency with increasing in the gain by 2.63 dBi compared with the gain for a single element antenna. The E-plane and H-plane radiation patterns are obtained as shown in Fig. 7.

Fig. 8 shows the overall gain verses frequency for both CSTMWS and HFSS simulators. In Fig. 9, the 3D radiation pattern of the proposed structure at a resonance frequency (915MHz) is presented. The overall antenna gain versus frequency is also calculated. Fig. 10 shows the current distribution for the proposed structure. A comparison between the proposed work and others work is presented in Table 2. It can be noticed that, our design shows much higher gain compared with others designs, which gives it a superior performance in RFID tag reading /writing.

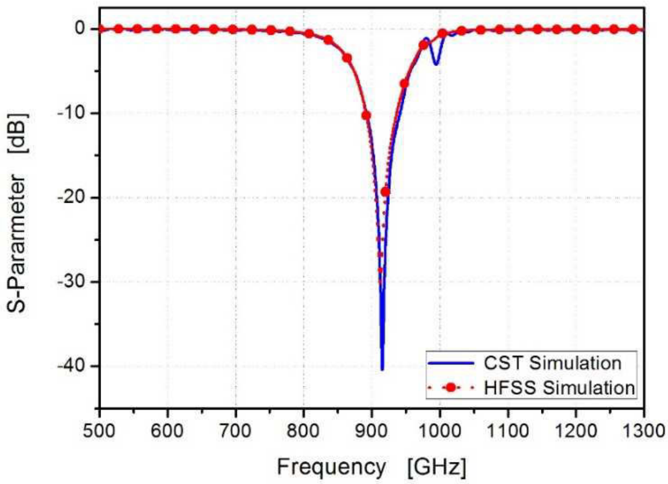

Fig. 6: The return loss results of the proposed structure for both CSTMWS and HFSS simulators.

Table 2: A comparison between the proposed structure and previous reported designs.

Ref.	Resonance Frequency (MHz)	Gain (dBi)	S_{11} (dB)	Antenna Size (mm^3)	Bandwidth (MHz)
[4]	915	0.6	-22	60x60x7	26
[9]	915	7	-37	280x280x30	26
[11]	915	5.52	-40	110x110x15	207
[12]	921	11	-22.18	208x208x1.6	8.825
This Work	**915**	**12.5**	**-40.44**	**240x240x11.56**	**49.25**

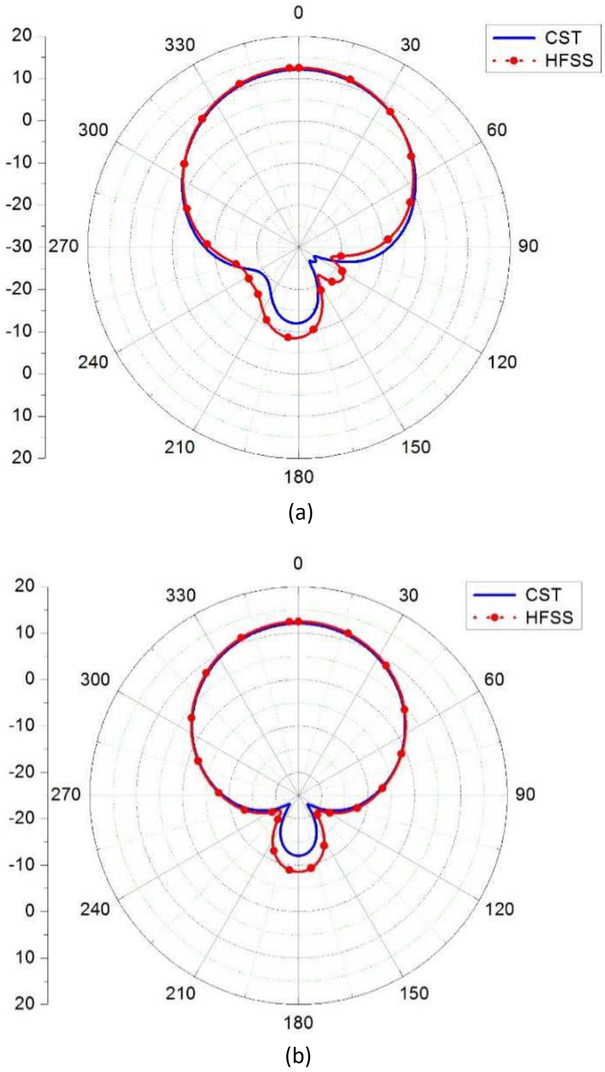

Fig. 7: The radiation patterns of the proposed antenna, (a) E-plane, and (b) H-plane.

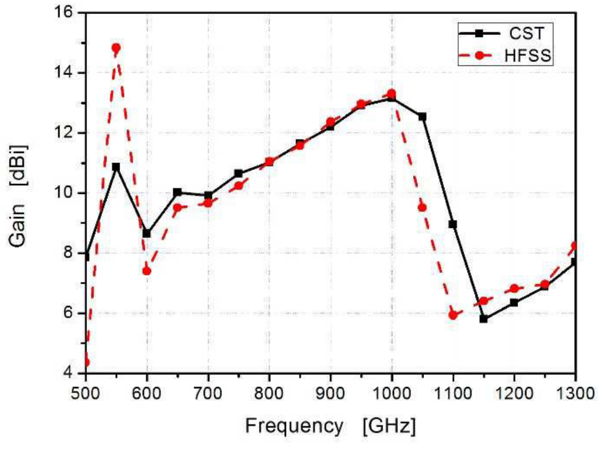

Fig. 8: The overall gain verses frequency for both CSTMWS and HFSS simulators.

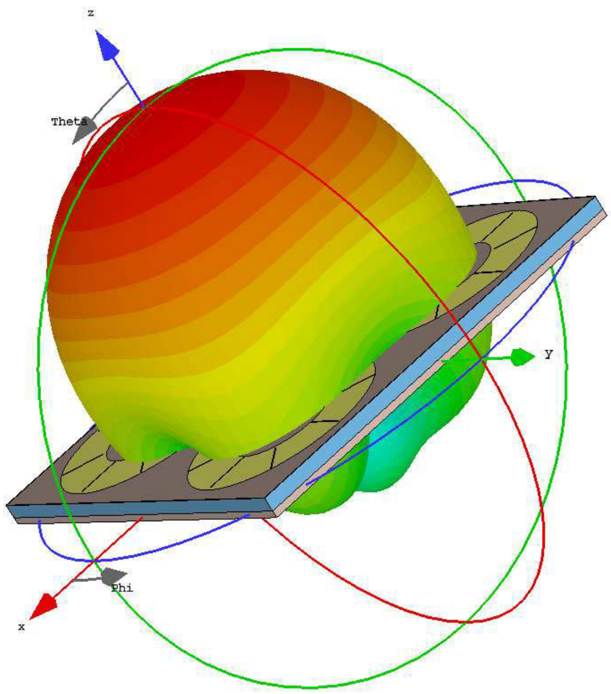

Fig. 9: 3D radiation pattern of the proposed structure at a resonance frequency (915MHz).

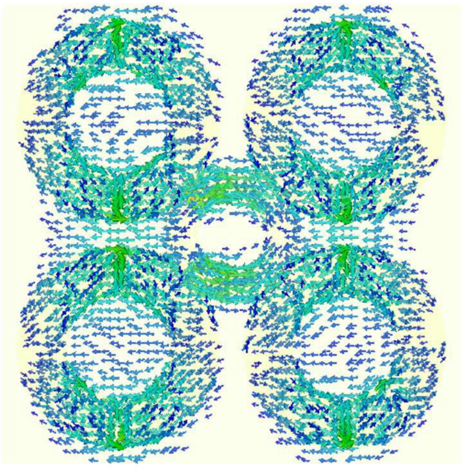

Fig. 10: The current distribution of the proposed structure.

VI. CONCLUSION

A high-gain, annular ring stacked antenna array with meander slots is introduced for UHF-RFID applications. The design achieves wide bandwidth of 5.38% around the operating center frequency of 915 MHz. Annular ring is used as feeding element for the four-element antenna array through indirect coupling. Two independent software's CSTMWS, HFSS are used to verify the proposed design. The antenna array shows remarkable radiation characteristics and high-gain of more than 12.5 dBi that make this antenna as very good candidate to operate as a reading / writing antenna in any RFID system.

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