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Slot incorporated high gain Printed RFID Reader Array antenna for 2.4 GHz ISM band applications

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Abstract. In this paper, a printed 1×8 array antenna operating at 2.4 GHz is proposed for radio frequency identification (RFID) Reader. The proposed array antenna is composed of eight identical modified patch elements. The radiating elements are fed in parallel via a simple 50 Ohm microstrip line matched with a quarter-wave impedance transformer using a T magic power divider to divide the input power into two equal quantities with the same phase. The suggested array configuration is designed using Rogers RT/duroid 5880 substrate having dielectric constant ε_r = 2.2, dielectric loss tangent = 0.0009, and substrate's height of 1.56mm. The overall dimension of the 1×8 array antenna is 117×475mm^2. The proposed array antenna shows good impedance matching, high gain and directional radiation patterns. The proposed array antenna has a high gain about of 14.61dBi, high radiation efficiency of 98.3%, and a good reflection coefficient S11 of -13.14dB and voltage standing wave ratio (VSWR) of 1.56 at 2.4 GHz.

Keywords: Microstrip patch antenna, Microstrip line, RFID Reader, T magic power divider, array antenna, Quarter-Wavelength Impedance Transformer.

1 Intoduction

In past few years, the tremendous growth of wireless communication has created meaningful impact in communication and manufacturing industries. The proper transmission and reception of information is essential for the successful establishment of communication systems. The conception, design and implementation of advanced antenna structures are required as key element for establishment of communication links by sending and receiving EM waves. Apart from new antenna design methods, improved impedance and radiation characteristics are highly needed to cope up with the advanced systems and to support multiple wireless applications. The microstrip patch antennas are the most sought antenna type due to their light weight, low cost, compact size [1-6]. But it suffers from low gain [7-11] problem which restricts its application possibility. So, well optimized array antenna structure solves the issue of low gain [12-13] for long distance communication applications. Another important aspect of wireless communication, that is the contactless communication has become very popular for the identification of person, animal and objects. At earlier time, based on paper, card, and other media, the task of identification was performed. But, the research efforts by the scientists and researchers across the globe brought revolution in this contactless technology with the innovation of radio frequency identification (RFID) technology. The RFID technology-based systems are contactless scheme exchanging information between a reader antenna and tag antenna via radio waves. In RFID systems, antennas are used in Tags and readers and provide an important concern for the detection system of objects. [14-17]. Many researchers have investigated different microstrip 1×2 array antenna for RFID applications that offers maximum gains of about 4.73dBi [18], 6.6 dBi [19], and 9.36 dBi [20]. Some configurations of 1×4 array antenna for RFID are also proposed with improved gain. A peak gain of 7.75 dBi is reported in ref. [21], ref. [22] reports a peak gain of 9.22 dBi and a maximum peak gain of 12.6 dBi is achieved by El Alami Ali et al. as reported in ref. [23].
So, in this work, the authors have aimed to design a well optimized planar 1×8 array antenna with simple ground plane structure that is capable to offer maximum average gain and peak gains by maintaining good impedance matching, less mismatch losses, high radiation

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efficiency, and directional radiation patterns. The 1.56 mm thick Rogers RT/duroid 5880 substrate with relative permittivity of 2.2 and loss tangent of 0.0009 is used for the antenna design purpose. The designed array antenna operates at 2.4 GHz unlicensed ISM band. The simulation results report a peak gain of 14.61 dBi and maximum radiation efficiency of 98.3% at the 2.4 GHz. The overall size of the array antenna is 117×475×1.56 mm3.Due to its well-fitted size and high gain, the proposed array antenna is perfectly suited to a fixed RFID reader, for detecting moving objects at a long distance.

2 The basic element antenna design

The structure of the proposed basic element antenna is shown in Fig1case I.The suggested basic element antenna is designed using Rogers RT/duroid 5880 substrate having relative permittivity ε_r= 2.2, loss tangent = 0.0009, and substrate's height = 1.56mm.The structure of the conventional rectangular patch has been modified through slot loading (coupled slot and circular slot) to obtain resonance at 2.4 GHz with improved return loss characteristics. A quarter wave impedance matching transformer is applied in between the modified patch and microstrip feed line to offer better impedance matching and thus to obtain minimum mismatch losses. The analytical equations which provide the dimensions of the rectangular patch antenna and quarter-wave impedance transformer are presented in references [26-27].Both the results are in good agreement. The geometrical dimensional parameters in millimeter are Lg = 85, Wg = 52, Lp = 42.78, Wp = 41.32, Lq=24.05, Wq = 0.72, Lf = 14, Wf = 4.84, d = 4.6, Ls = 25.3, Ws1 = 10, Ws2 = 2.5.

1.1 Design Steps

The desired basic patch element of the proposed 1× 8 array antenna has been developed after three different stages of structural evolution as indicated in Figure 1. The corresponding reflection coefficients are depicted in Figure 2. The conventional rectangular microstrip antenna has been modified by incorporating connected rectangular slots and circular slot on the radiating patch to achieve resonance at 2.40 GHz for the aimed RFID applications. The suggested patch antenna is excited through a quarter wave impedance transformer integrated 50 Ohm microstrip feed line. It can be observed from Case I of Figure 1 that the conventional structure suffers from very poor impedance matching and adaptation characteristics. In order to obtain good adaptation and better reflection coefficient, the impedance matching of the conventional antenna is improved via implementing a quarter wave impedance matching transformer as presented in Case II. But in Case II, the resonance is achieved at 2.36 GHz with a narrow bandwidth of 30 MHz. Further, in Case III, due to the presence of the connected slots and circular slots, the desired resonant frequency of 2.40 GHz with S11 of about −24.57 dB is obtained for the intended RFID applications. So, the structure presented in Case III is considered as the proposed basic element patch antenna.

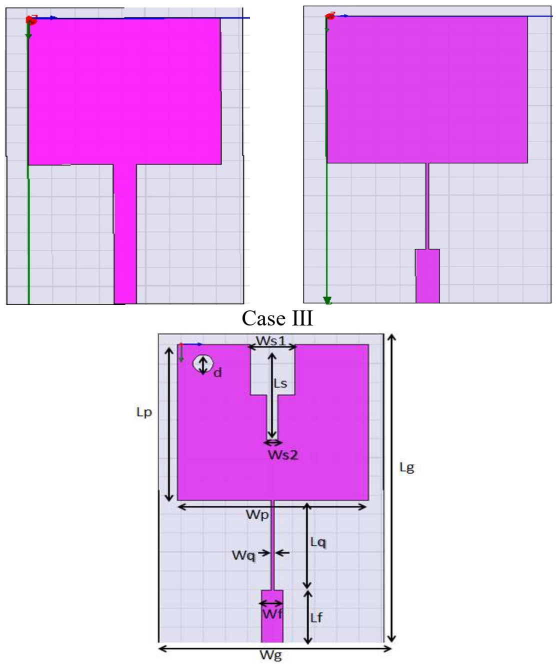

Fig. 1. Structural development stages of the basic element antenna

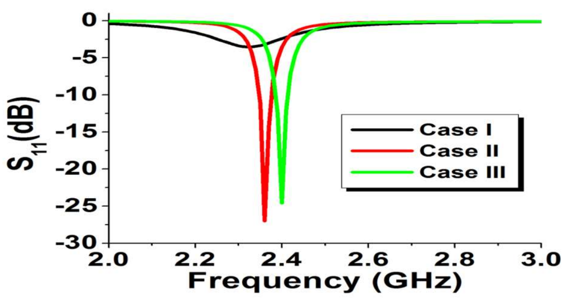

Fig. 2. S11 parameters for different stages of structural evolution

1.2 Simulation results and discussion of the basic element patch antenna

The simulation results such as reflection coefficient, Gain, Efficiency, and radiation patterns of the designed basic element antenna are discussed in this section. S11 parameter and voltage standing wave ratio (VSWR) are shown in Figures 3(a) and (b), respectively. The S11 vs. frequency plot indicates its resonance exactly at 2.40 GHz with good impedance matching characteristics attaining a reflection coefficient (S11 parameter) of −24.57 dB. The VSWR of 1.12 is obtained at 2.40 GHz which ensure minimum mismatch losses for the antenna. The performance of the single basic element antenna in terms of gain and radiation efficiency is quite satisfactory as depicted in Figures3 (c) and (d), respectively. Maximum peak gains of about 7.09 dBi and

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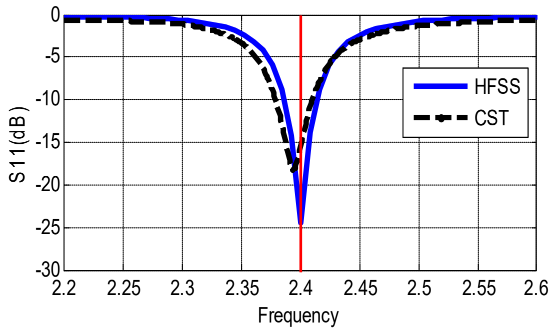
peak radiation efficiency of about 97.19% are obtained at 2.40 GHz. The E and H plane radiation patterns are shown in Figures 3 (e) and (f), respectively. The antenna has directional E and H plane patterns with main beam along the broadside direction.

a



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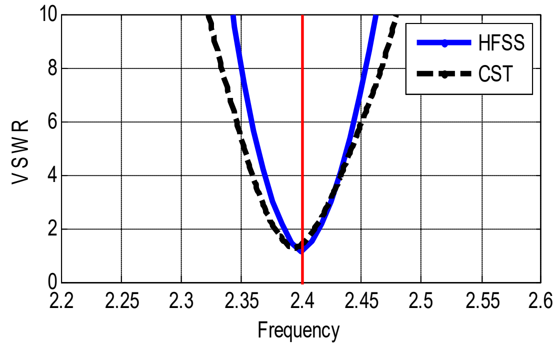

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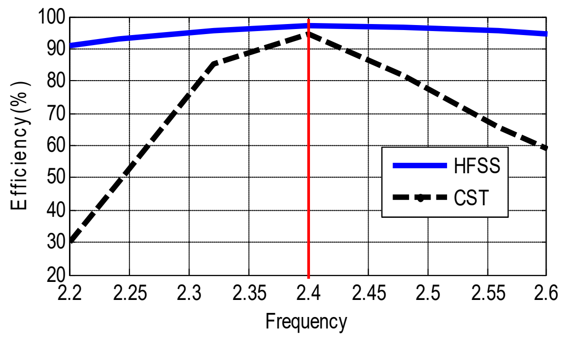

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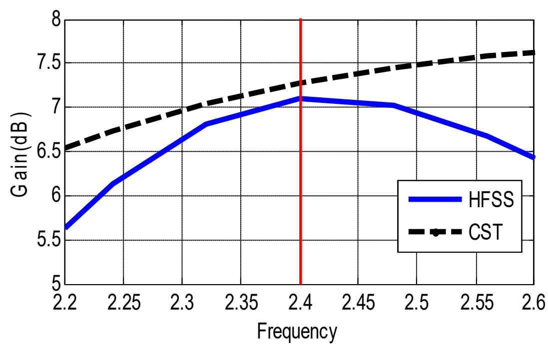

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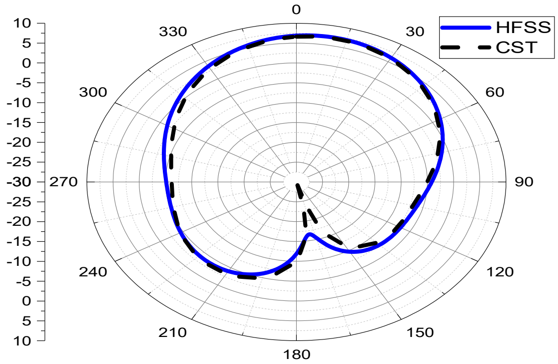

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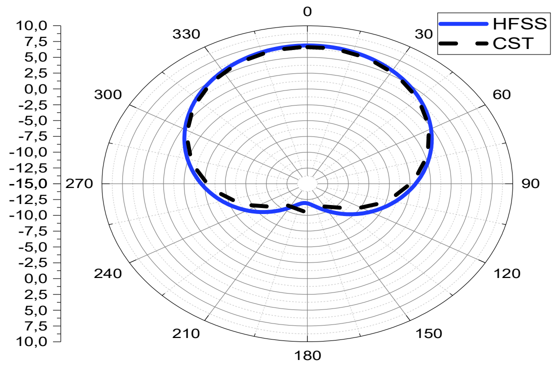

Fig. 3.**(a)** S11 parameter vs. frequency; **(b)** VSWR vs. frequency; **(c)** Gain vs. frequency; **(d)** Rad. Efficiency vs. frequency; **(e)** E plane radiation patterns at 2.4GHz; **(f)** H plane radiation patterns at 2.4GHz

2 Structure of the proposed 1×8 array antenna

In this section, the structure of the proposed 1×8 array antenna is presented along with a detailed discussion on the obtained results. Based on the structure of the designed basic element patch antenna, to enhance the gain and radiation efficiency up to a certain extent, an array antenna consisting of eight radiating elements is proposed [see Figure 4]. The structure of the proposed high gain 1×8 array antenna is designed on a 117×475mm2 Rogers RT/duroid 5880 substrate having relative permittivity ε_r= 2.2, loss tangent = 0.0009, and substrate's height = 1.56mm. An optimized feed network is required for the proper excitation of the array antenna. For this purpose, after several iterative processes, a simple structure of power divider with a characteristic impedance of 50 ohm at its input terminal is designed to offer better impedance matching leading to the improvement in the radiation characteristics parameters (gain and radiation efficiency) of the array antenna. The analytical equations which provide the calculation of the power divider's dimensions and impedances of each arm ports are available in reference [27]. Initially, the simulation studies of the designed antenna have been performed using HFSS simulator and the results are verified with CST EM simulator as well. The results are in good agreement, which validates the suggested antenna model. The finalized structural dimensions of

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the array antenna are given in millimeter, Lg = 117, Wg = 475, Lf1 = Lf2 = Lf3 = 14, Wf1 = Wf2= 4.84, =14, Wf3 = 3, d1 = 250.38, L1 = L2 = L3 = 2, d2 = 123, d3 = 60.7.

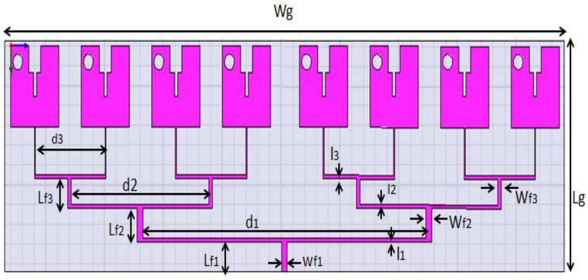
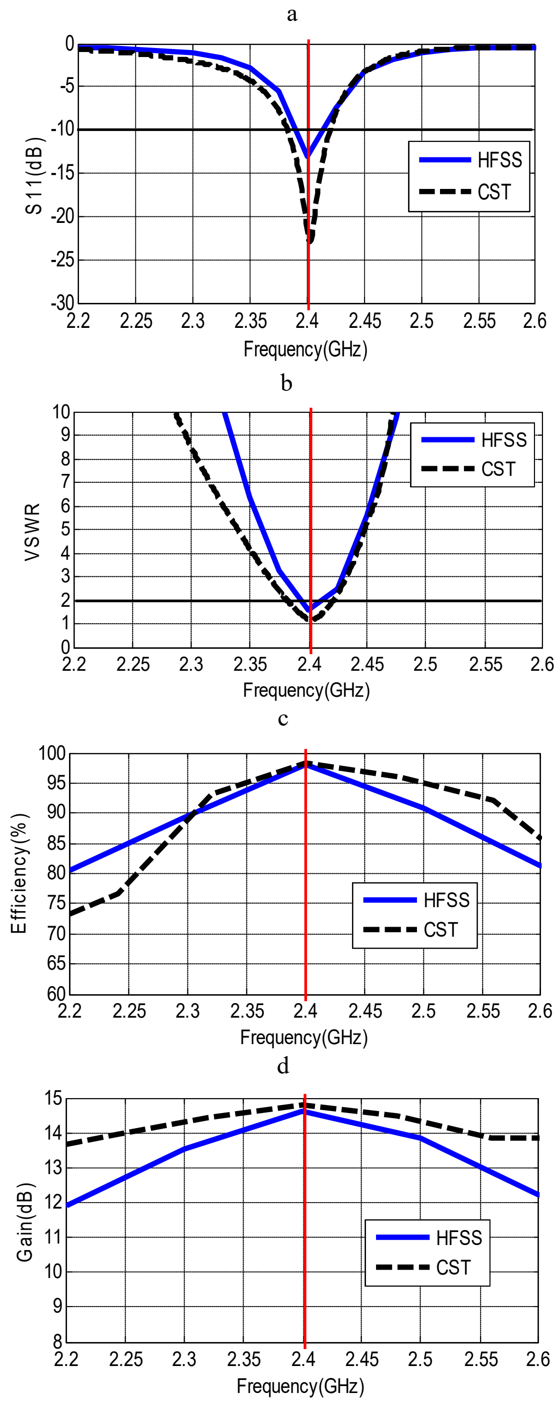


Fig 4. The structure of the proposed high gain 1×8 array antenna

2.1 Results and discussion

As displayed in Figure 4 (a), the resonant frequency is achieved at 2.40 GHz with a reflection coefficient of −13.14 dB. The voltage standing wave ratio of the proposed array configuration is shown in Figure 4 (b), which indicates its value <2 for the working frequency band (2.385 GHz-2.415 GHz). The variations of the gain and radiation efficiency are plotted in Figures 5 (c) and (d) respectively. The peak gain of about 14.61 dBi is achieved at the operating resonant frequency 2.4 GHz. The array antenna also offers very attractive radiation efficiencies above 97.5% throughout the operating band. The designed array antenna reports a peak radiation efficiency of about 98.3% at 2.4 GHz. The radiation pattern characteristics in the E and H planes are presented in Figures5 (e) and (f) respectively. The E plane pattern is directional with high gain. Whereas, in the H-plane, it represents multi-beam and the direction of the main beam is focused at 0°.

The performance parameters of the proposed array antenna are compared with some other reference works for RFID applications and summarized in Table 1. It can be seen that the high gain and size of the proposed array antenna is suitable for RFID reader. Hence, the high gain, high radiation efficiency, low mismatch loss, desirable reflection coefficient, and directional radiation patterns ensure the applicability of the antenna for the intended RFID applications.



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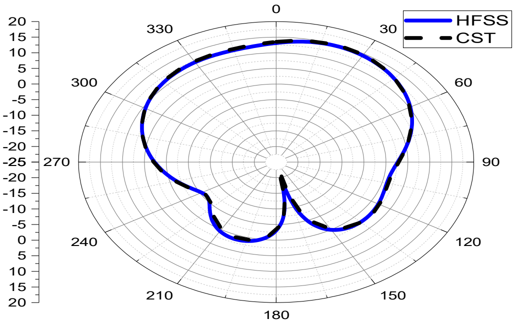

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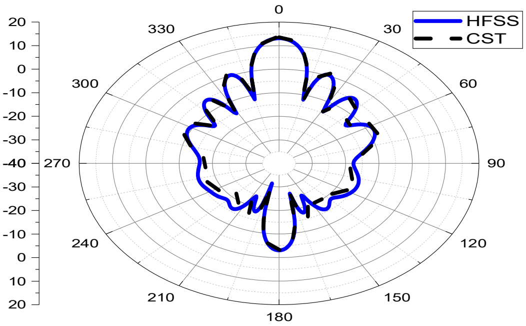

Fig. 5.**(a)** S11 parameter vs. frequency; **(b)**VSWR vs. frequency; **(c)**Gain vs. frequency **(d)** Rad. Efficiency vs. frequency; **(e)**E plane radiation patterns at 2.4GHz; **(f)** H plane radiation patterns at 2.4GHz

Table 1.Comparison of the proposed array antenna with other works

Works	Frequency (GHz)	Size(mm^2)	Gain(dBi)	Efficiency
[17]	2.45	75x95	4.73	55.05%
[18]	2.45	135x114	9.65	99.8%
[19]	2.40	83x110.5	9.22	-
[20]	2.45	95.9x227	7.75	-
[21]	2.45	91x161	6.6	60%
[22]	2.40	98x223.9	12.6	-
This work	***2.40***	***117x475***	***14.61***	***98.3%***

3 Conclusion

In this article, a high gain 1×8 array antenna with directional radiation pattern is proposed for 2.4 GHz RFID Reader applications.The designed array configuration offers improvement in peak gain. Initially a single element antenna is designed by incorporating slots within the radiating patch and a quarter wave transformerintegrated feed line to improve the impedance matching. Finally, an eight element array antenna is configured with identical patch elements. The design and results are analyzed using HFSS software. The proposed planar 1×8 array antenna resonates at 2.40 GHz with significant reflection coefficient and VSWR. Furthermore, high gain of 14.61dBi, peak radiation efficiency of 98.3% and directional radiation pattern confirms its suitability for RFID reader applications.

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