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An Ixora-Shaped 4 Port High Gain-Dual Polarized Dual-Band Planar Antenna for use in X-Band Communication

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Abstract: *In this article, a novel Ixora-shaped planar structure has been introduced for use as a dual-band dual-polarized antenna. This structure comprises four highly isolated ports for transmitting/receiving (Tx/Rx) applications in X-band. Due to the shape of the antenna, a gain of 12dB in the high band [9.9-10.5GHz] and 7.16dB in the low band [8.6-8.9GHz] is achieved. The structure dimension of this antenna are twice the guided wavelength, concerning wavelength of higher frequency. Besides, antenna efficiency of 85% in the higher band and 65% in the lower band is retrieved. An antenna prototype has been fabricated and tested. The measurement results show that 15dB isolation has been achieved between different ports. This antenna can be fed with one port, two ports, three and four ports, and it can potentially work as dual polarization and circular polarization. The properties of this antenna make it a good candidate for two-way point-to-point radio communications, In two separate frequency bands, satellite communications, or radars.*

Keywords: *Circular polarization (CP), array integrated feeding network (AIFN), High Gain, X-Band Antenna, Ixora shape antenna (ISA).*

1. Introduction

Recently size and cost are probably the most important parameters in radio communication. In applications encounter size and weight limitations, the compact antennas that guarantee the link budget parameters are required. Also, in data communication, there is a need for two separate frequency bands, to create isolation between the transmitter and the receiver, this designed antenna is suitable.This article introduces a high gain, dual-polarization, and dual frequency X-band patch antenna.

X frequency band finds many applications in communication links to reduce the size and achieve a high data rate of up to 1GBbps [7]. According to link budget calculations, antenna gain, polarization, and size are very important. For instance, in [1], a dual circularly polarized patch antenna with high gain has been presented. The antenna in [1] supports one frequency band and needs a hybrid network to generate circular polarization. In [2,10], a compact high gain x-band patch antenna for cube and small satellite applications has been presented. The gain of this antenna is about 9 dBi, but it is not designed to support two frequency bands. [3,8] presents a dual-band e-shaped microstrip patch antenna for WiMAX and WLAN applications. The gain of this antenna is about 5.5 dBi in both bands, but it does not support circular polarization.

In [4], a compact E-shaped microstrip patch antenna (MPA) with high gain has been presented and proposed for X-band satellite applications. This antenna also shows about 6 dB gain and is recommended for use in satellites while circular polarization is not supported. Besides, we need a high gain one port patch antenna without an external combiner to array the patch antenna to achieve high gain.

Several dual-band and triple-band patch antennas have been introduced in the literature [11,12,13], but almost all of them use a defected ground to improve the bandwidth [16]. Meanwhile, considering the need for a feeding network in an array antenna, we prefer a not defected ground layer. To do it, the idea is a defected cross ellipse patch (DCEP) which is deducted from the original cross ellipse shape structure to provide a broad frequency band using a complete ground, as shown in Fig. 1 and Fig. 2. We name it the Ixora-Shaped Antenna (ISA) and we study its specifications and in section 2.

The proposed antenna is shown in Fig.1. This antenna facilitates high gain by exploiting the mode superposition of TM11 + TM1n and TM12 + TM1m, (n=1, 3 and m=2, 4) [6].

As a reference, we compare the parameters of the Ixora antenna with other antennas that have been published in recent years in TABLE 1.

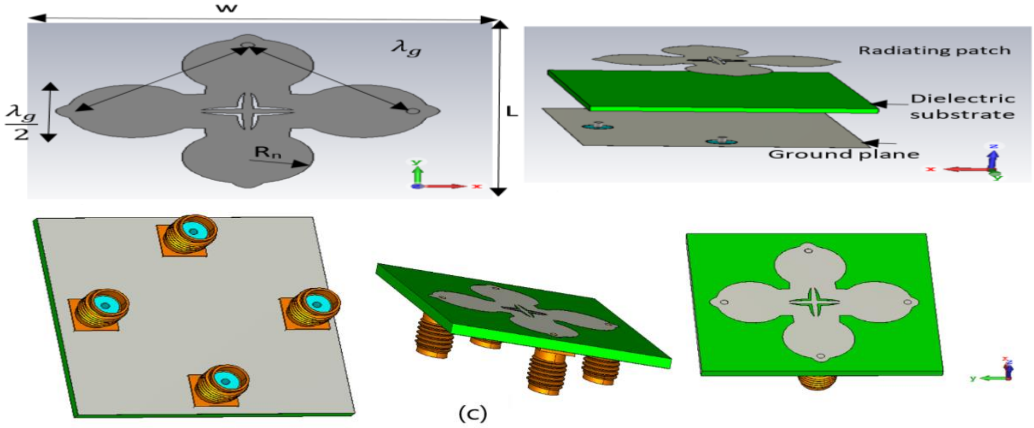


Fig1. *Antenna configuration, (a) radiating patch. (b) Three layers of expanded antenna structure, (c) 4 port configure.*

Table1. *Comparison of Ixora Antenna Parameters and some Other Studies in Recent Years*

REF.	Dual band frequency	Gain (dBic)	Dual polarization	Description
Ixora (ISA)	√	12	√	Planer, single layer, four feed connector
[1]	×	12.5	√	Two-layer, hybrid network
[2]	×	9	√	SIW cavity patch
[3]	√	5.5	×	Dual Band E-shaped Microstrip Patch
[5]	√	4	×	Microstrip 2× 4 elements array antenna

2. ANTENNA STRUCTURE

In Fig. 1, the configuration of the proposed antenna is shown. As can be seen, the structure is comprised of patch and ground layers fabricated on an RTduroid 5870 Rogers substrate with and thickness of and overall dimension of.

The shape of the antenna reminds us of the Ixora flower, with four circular parts. The evolution of the antenna is shown in Fig. 2.

As it is seen, the antenna is formed by four circles and six ovals. The diameters of the ovals are determined according to the working frequency of the antenna, the large diameter is about and the small diameter is. The choice of diameters is such that the distance between two opposite feeds is equal to. The return loss for each step of progress according to Fig. 2 is shown in Fig. 3. The final gain increases from 6dBi to 12dBi for the structure (a) to (d).

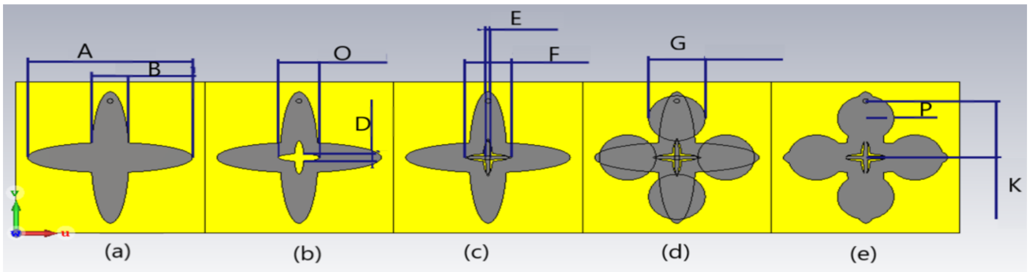


Fig2. *Stages of antenna structure evolution*

The two ellipse-shaped slots in the center of the structure cause a meaningful increase in bandwidth which is discussed in the following.

In the third step, two cross ellipses are created to fill partially the created slots as shown in Fig. 2c, this will create a two-band frequency response with a symmetrical propagation pattern.

The final step involves the addition of four circles with a radius at the end of the ellipse, as shown in Fig. 2d. The final shape of the dual-band antenna is shown in Fig. 2e. Furthermore, by changing the radius of the circles , the resonant frequency of the antenna changes. As shown in Fig. 4, the relation of radius to other antenna parameters and frequency is derived by equation 1. It can be seen that the variation of 0.5 mm in , the frequency response is shifted to about 400 MHz.

$$R_n = \frac{6}{\pi wlc} f_n \sqrt{\varepsilon r_{eff}} \qquad (1)$$

where, R_n is the radius of added circles, w and l are the dimensions of ISA, f_n is the operation frequency, c is the speed of light in free space and εr_{eff} is the effective dielectric constant of the substrate. Substrate manufacturers provide the effective dielectric constant for each substrate with a different dielectric coefficient. Based on the assumption, the obtained frequency from eq.1 is. the scattering parameter is simulated and shown in Fig. 7. ¬As shown in this figure, a good agreement is achieved. ¬Each petal of the ISA occupies a length of, and they are separated by , as well. So, we can assume the ISA is a 2×2 array somehow. The co-polarization and cross-polarization of the antenna radiation pattern are also shown in Fig. 5.

The feeding mechanism of the antenna is such that the current distribution is uniform in all four parts according to the symmetrical boundary conditions of the structure.

The idea is to use a defected cross ellipse patch (DCEP) that is deducted from the original E-shape structure to provide a broader frequency band using a complete ground surface. This idea is derived from two perpendicular ellipses; circular polarization can be achieved with this symmetrical arrangement.

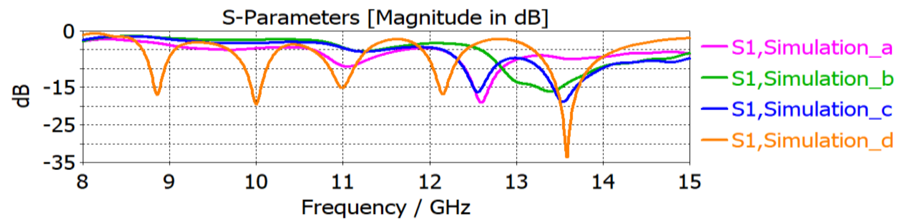


Fig3. *Return loss in the evolutionary process for Fig. 2. (a) to (e)*

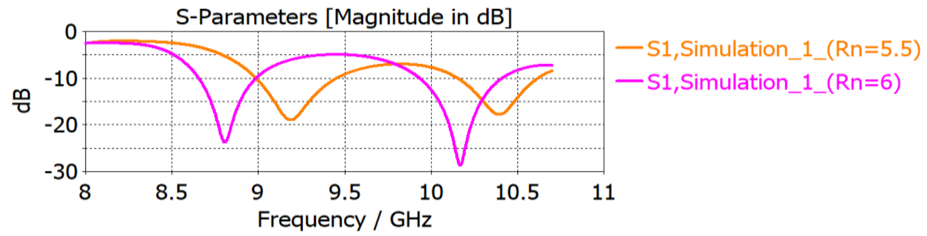


Fig4. *For every 0.5 mm change in the circle diameter, the frequency response is shifted about 400MHz.*

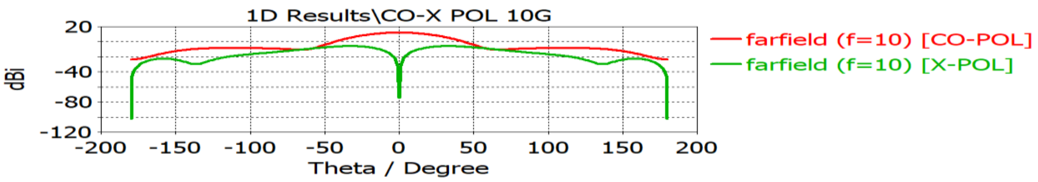


Fig5. *Co and cross-polarization diagram for 8.86 GHz and 10 GHz*

3. Performance Analysis and Discussion

To study the effect of substrate thickness, we designed an ISR for frequency bands of 8.88GHz and 10.165GHz on RTduroid 5870 with a thickness of 0.7874mm. The physical dimensions of the antenna are shown in Table 2. As a result, due to the reduction of the thickness of the substrate, the bandwidth decreases as shown in Fig. 6.

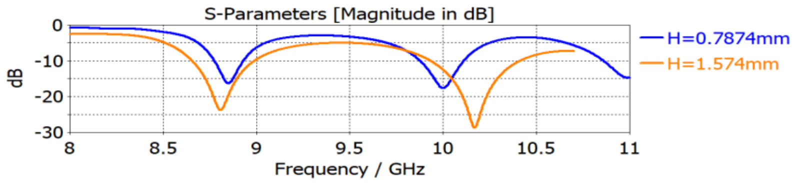


Fig6. *Frequency response* S_{11} *for a substrate with two thicknesses of 0.7874mm and 1.575mm*

The bandwidth of 400 MHz and 500 MHz can be measured for lower and upper-frequency bands, respectively. The dimensions of this antenna are twice the wavelength as explained before .It can be said that four elements of the antenna are arrayed together. The noteworthy point is the combination method.

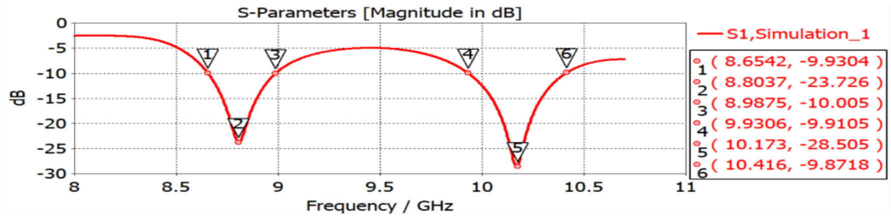


Fig7. *Diagram* S_{11}, *the frequency response for two frequency bands*

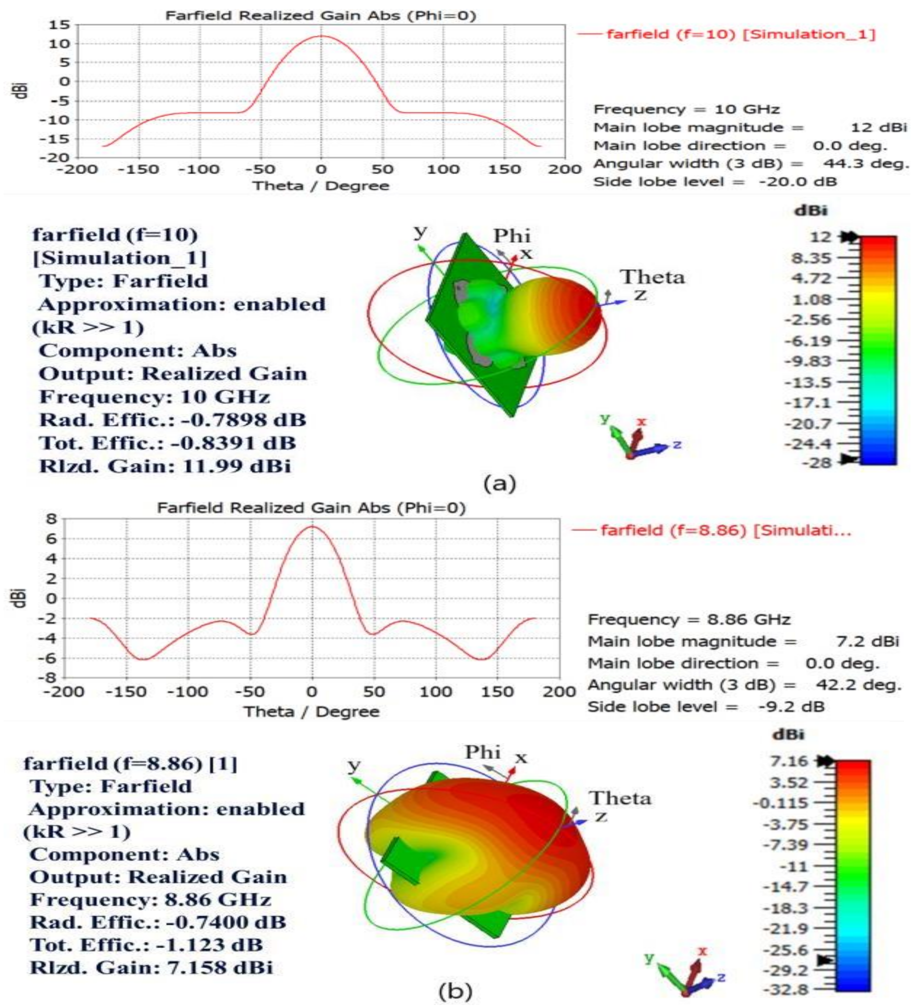


Fig8. *The antenna radiation pattern for two frequency bands (a)8.9 GHz and (b)10 GHz in Cartesian and 3D coordinate.*

In an array, if each element is excited with the same phase and amplitude, we have a uniform distribution and the side-lobe-level will be 13.4dB. However, in the proposed antenna, the side lobe level is about -20 dB, (a) and(b) in (Fig. 8).

Due to the symmetrical structure of the antenna, in the place where the antenna is fed, it creates a phase difference compared to the other three corners. It can be said that the four antennas in the array structure do not come together in phase. This lack of phase distribution causes the distribution It flows non-uniformly, which is the result of reducing the level of the side lobe.

The width of the patch antenna can be increased to increase the bandwidth, but with this method, the higher modes are stimulated and cause disturbance. Defected ground plane will also increase the bandwidth, but due to the limitation of the installation location in some applications, this will not be the answer. The proposed four-element Ixora shape antenna (ISA) does not need a defected ground or increase the width of the patch. Not using the feeding network to array the antennas results in no additional radiation from the feeding network and therefore orthogonal polarization.

Due to the geometric structure of the antenna, it is possible to feed the antenna in four identical places. Therefore, the antenna can be used for two separate frequency bands at the same time.

To use circular polarization, two antenna ports with a phase difference of 90 degrees could be excited. Using all four ports, we can use two frequency bands with circular polarization at the same time. Single-port, two-port, and four-port models have been fabricated and tested. Fig.9 shows the fabricated antennas and the measurement and simulated results are shown in Fig. 10 and Fig. 11, respectively. The isolation between the orthogonal ports in all the desired frequency bands is about 23 dB [15], as shown in Fig. 10.

Table2. *Dimension of the Proposed Ixora Antenna (Dimension (Mm))*

W=L	D	*P*	*A*	*B*	*O*	*E*	*F*	k
40	1.95	10.43	34.85	8	8.71	1	10	15

Due to the symmetry of the structure, the amount of isolation is the same for all four ports and this value is between 15 and 25 dB in the entire frequency range. The measurement results of the S_{11} parameter compared to the simulation results are shown in the Fig. 10.

One way to increase the bandwidth of this antenna is to create an aperture coupler in the feeding area of the antenna. If we use the aperture coupling method instead of feeding the antenna, the bandwidth will increase by 30% [14,17]. To prove this claim, we made the feeding model of the discussed antenna with aperture coupling and compared the results with the case without aperture coupling (Fig. 12).

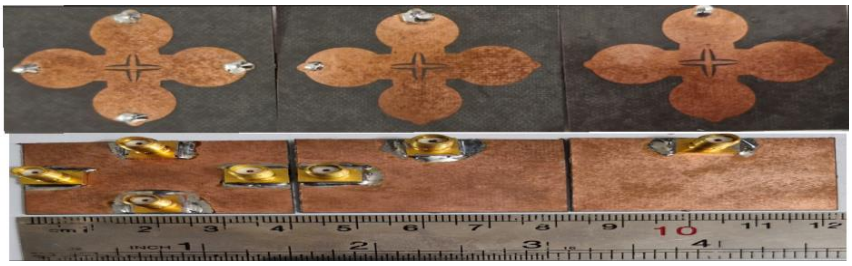


Fig9. *Built-in antenna structure with one, two, and four ports*

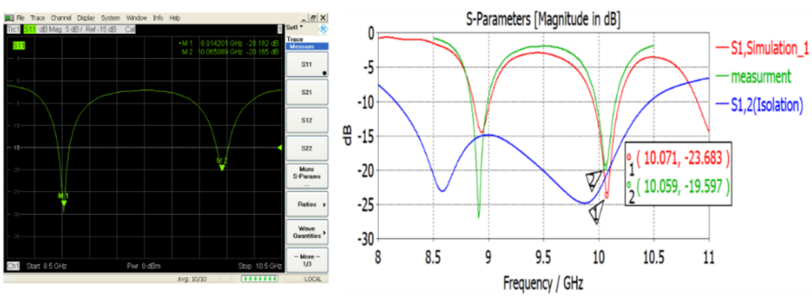


Fig10. *Return loss and isolation for two ports, frequency response for two bands, and measurement result.*

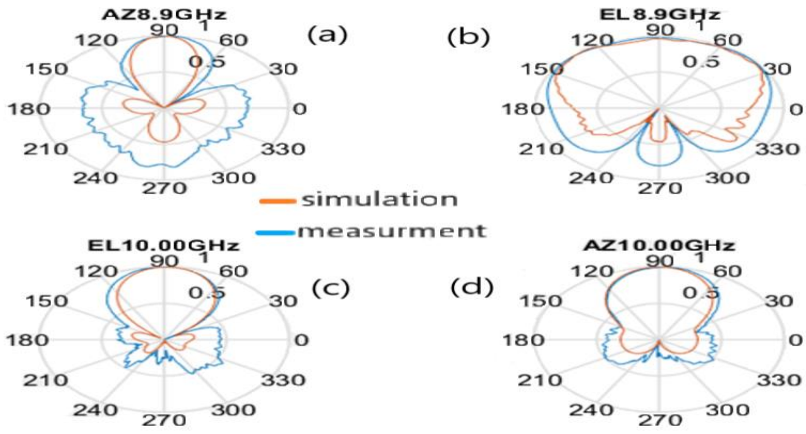
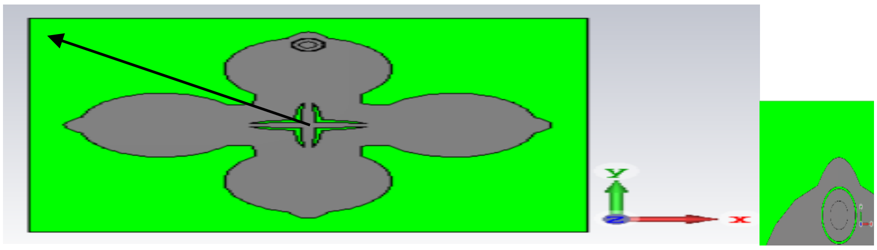


Fig11. *The measured pattern compared to the simulated results*



(a)

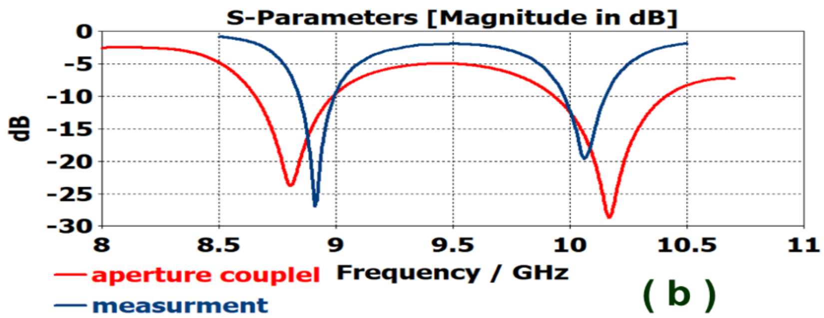


Fig12. *Antenna shape with aperture coupler feeding (a), and S11 parameter response compared to without aperture coupler (b).*

4. Conclusion

A new dual-band antenna element with high gain, simple structure, and without a discrete feeding network in the layer behind the antennas has been introduced. Compared to conventional antenna elements, we have reached a high gain equivalent to four antenna arrayed together with elements arrayed with the intra-structure summation method with one feeding port. Due to the dual frequency response of the antenna, it can be used for different applications such as point-to-point radios, two-way antennas for satellite control telemetry links, and search and tracking in radars. Due to the isolation between the two ports for using two separate frequency bands, it eliminates the need to use a circulator or duplexer

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