Design of a New Reflectarray Element to Enhance Bandwidth by using a Microstrip Array Antenna as Feed

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Abstract— the bandwidth behaviors of reflectarray elements are discussed in this paper to improve the intrinsic limitation of narrow bandwidth it offers. This is done by analyzing the relationship between bandwidth and phasing distribution and Reflection loss characteristics of the elements. Nine shapes of elements, i.e., Square, Circle, Ellipse, Triangle and loop of these elements have been investigated and a new shape has been proposed. Rogers RT/Duroid 5880 dielectric substrate (ε_r = 2.2 and tan δ = 0.0009) is used. These elements are designed to operate at X-band frequency range using CST microwave studio. In this paper, a microstrip array antenna instead of horn is used to feed the reflectarray antenna which is so lighter and is simple to manufacture compared to a horn. It has been demonstrated from this work that proposed element can offer the lowest reflection loss and reflection phase slope which can enhance bandwidth. So, the reflectarray antenna by using this element is considered in this paper which has 24.73 % (-3dB) bandwidth in X-band.

Keywords— bandwidth enhancement, reflectarray antenna, reflection loss parameter, phase range parameter, phase slope parameter.

I. INTRODUCTION

Nowadays, study on reflectarray antenna to replace the conventional parabolic reflector antenna is becoming a trend. Various advantages including flat surface, light weight and low cost to manufacture have made this antenna the choice of study. However, one major obstacle need to be faced is the bandwidth limitation.Various studies have been carried out to overcome this problem. Bandwidth can be increased using two layer grounded array of rings [1], whereas the linearity of reflection phase response are controlled by the diameter ratio of the ring [2-5]. Introduction of split concept into the element has also improved bandwidth significantly [6,7]. Thus, this paper discusses the basic design procedure using nine different shapes of element that is printed on Rogers RT/Duroid 5880 dielectric substrate and to study the phase performance of each resonant element.

II. DESIGN

A. Microstrip Array Design

We have designed an array of rectangular patch antenna of the center frequency 10 GHz, sweeping between 8-12 GHz(X-band). We have employed a hybrid structure where we are using Rogers RT Duroid 5880 as a substrate. The three essential parameters for the design of microstrip patch antenna are: 1) Frequency of operation (f_0): The resonant frequency of the antenna must be selected appropriately. 2) Dielectric constant of the substrate (ϵ_r) [7]. 3) Height of dielectric substrate (h): For the microstrip patch antenna the height of the dielectric substrate is critical since the antenna should not be bulky. The transmission line model will be used to design the antenna [8].The edge type feed is used in this design. The design characteristics of this array are shown in Table I.

TABLE I.DESIGN CHARACTERISTICS OF MICROSTRIP ARRAY ANTENNA

Frequency	10 GHz
Substrate	Rogers RT5580
Dielectric Constant, ε_r	2.2
Loss Tangent	0.0009
Substrate Height	1 mm
Conductor and Ground plane Thickness	0.02 mm

Individuial patch Design Calculations
A) Fringes factor:

$$\Delta L = 0.412h \frac{(\varepsilon_{reff} + 0.300)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{w}{h} + 0.800\right)}$$

B) Calculation of length:

$$L = L_{eff} - 2\Delta L$$

Where

$$L_{eff} = \frac{c}{2Lf_0\sqrt{\epsilon_{reff}}}$$

B) Calculation of Width:

For efficient radiation, the width W is given as[9]

$$w = \frac{c}{2f_0\sqrt{\frac{\epsilon_r + 1}{2}}}$$

B. Structure of Array Antenna

The 4x4 array is shown in Fig. 2. This array feeding method is corporate. Since there are multiple radiating elements, they have to connect in some sort of fashion. Corporate parallel feeding network are used to provide power splits for 2n elements which can be applied to the 16 elements. It was found suitable to select a thin dielectric substrate with low dielectric constant by considering the trade-off between the antenna dimensions and its performance.Thin substrate permits to reduce the size and also spurious radiation as surface wave, and low dielectric constant – for higher bandwidth, better efficiency and low power loss. After some calculations it was agreed to use Rogers RT duroid with ε_r=2.2 and the thickness of 1 mm for substrate. Also, structure of array in CST is shown in Fig .1. The ground plane dimensions are 79 mm x 79 mm .
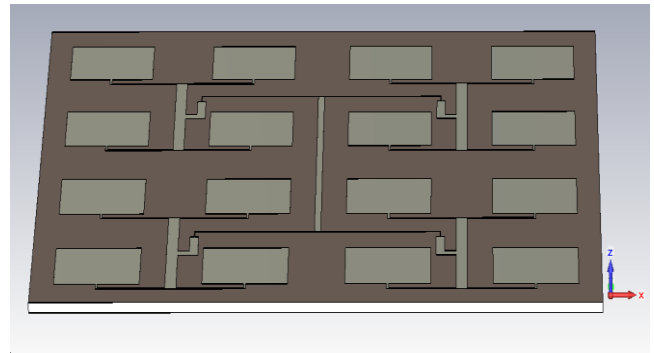

Fig .1 Design array antenna in CST

TABLE II.DIMENSION OF EACH ELEMENT

Element/dimensions(mm)	a	x	y	W	z	u	v	R
Square	15	6.5	–	–	–	–	6.5	–
Circle	15	–	–	–	–	–	–	4.87
Ellipse	15	3.04	4.46	–	–	–	–	–
Triangle	15	6.56	6.56	–	4.35	–	–	–
Square ring	15	11.2	8.05	–	–	–	–	–
Circular ring	15	6.68	3.04	–	–	–	–	–
Elliptical ring	15	3.86	5.86	2.1	4.1	–	3.86	–
Triangular ring	15	6.89	6.89	12.29	12.29	5.81	11	–
Proposed	15	10.12	7.54	1.03	3.51	–	2.14	–

Fig. 2 Corporate Feeding Method for Array

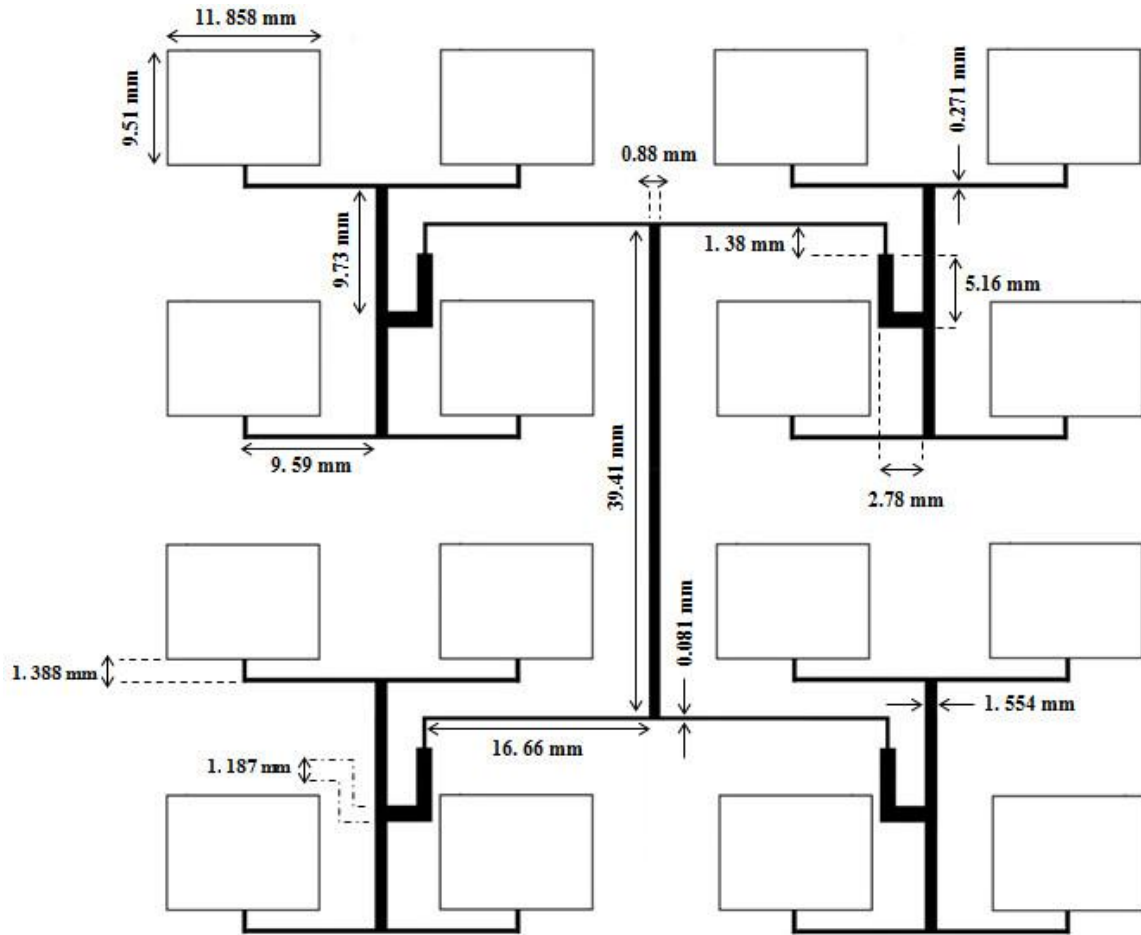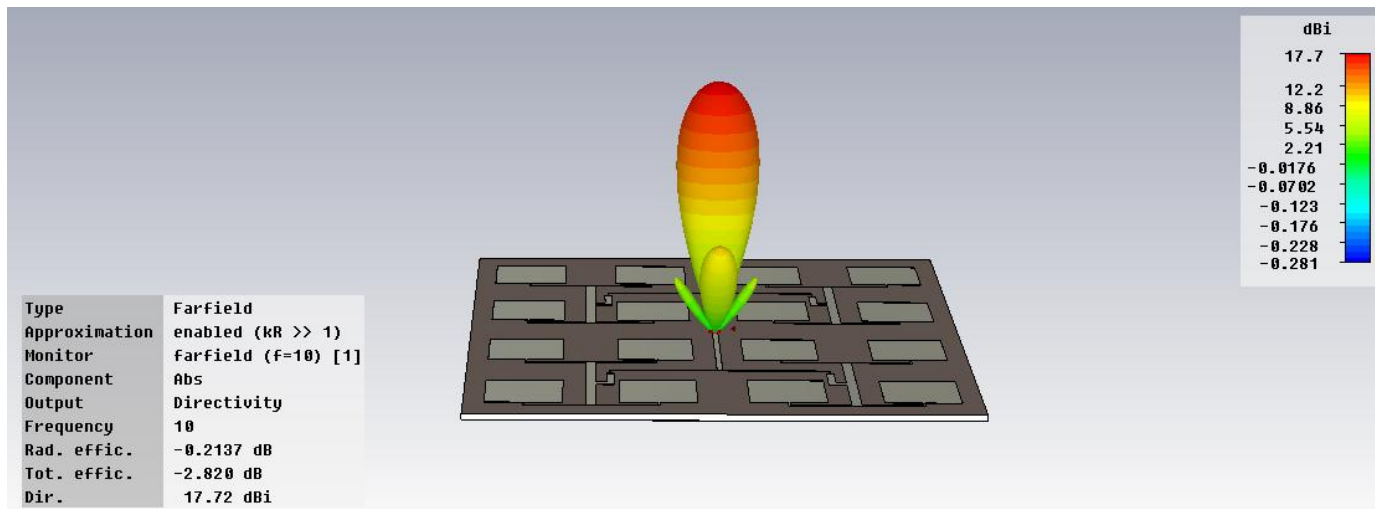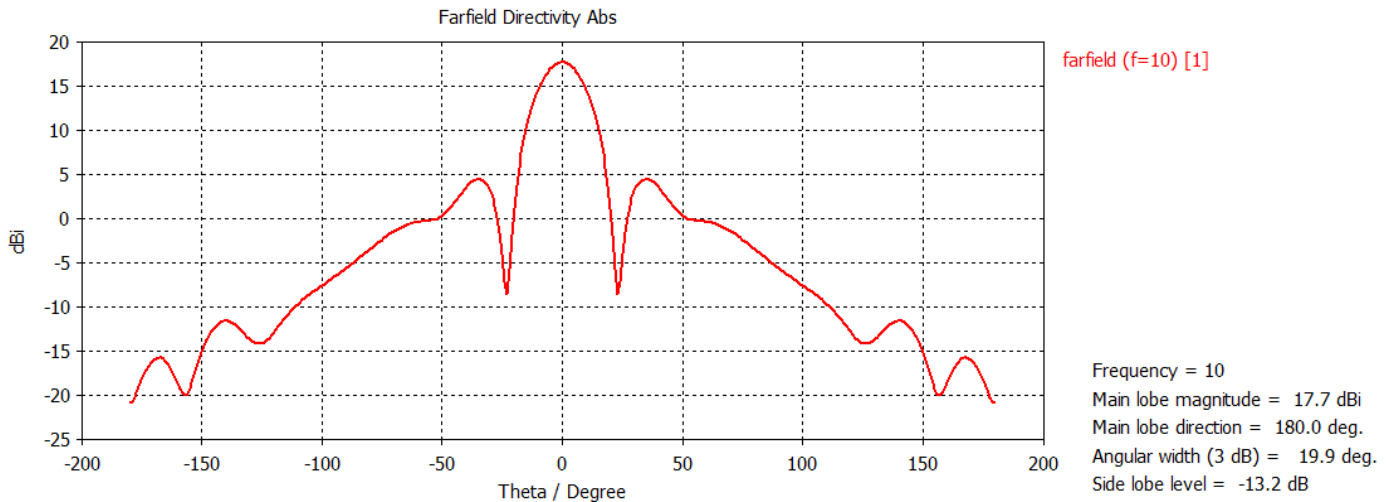| Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=10) [1]
Component	Abs
Output	Directivity
Frequency	10
Rad. effic.	-0.2137 dB
Tot. effic.	-2.820 dB
Dir.	17.72 dBi

Fig. 3 3D polar plot of patch array antenna

Fig. 4 Cartesian plot of patch array antenna

From the figure above, the acheived gain was 17.7 dB for peak gain at 10GHz. This is absloutely a considerable amount which is completely better than a horn. The reason is hardship in making a horn witch consist of a waveguide and an aperture cost so much time and also needs more financial budget compared to microstrip antenna array. Therefore, this kind is a suitable choice as feed.

C. Reflectarray Element Design

 The reflectarray elements are designed to be operated at X-band with nine different shapes comprising Square, Circle, Ellipse, Triangle and loop of them. Fig. 5 shows the details design for each element used in this experiment. Each design has passed through an optimization process to get the exact nominal value so that all designs are resonated around 10 GHz frequencies. Table 2 shows the detail dimensions of each design respectively. Fig. 5 shows nine different elements shape and dimensions in parameters which are given in Table 2. The Rogers RT/Duroid 5880 substrate layer of 1 mm thickness is used to support above layer which is conductor thickness t=0.02 mm

(PEC is used for patch material). Meanwhile, PEC layer at the bottom of the RT 5880 substrate acts as a ground plane which has the same thickness as conductor layer.

III. RESULTS AND DISCUSSIONS

The study focuses on two main criteria, namely the static linear phase range and the bandwidth obtained from the S-shaped curve of each element[10]. Investigation on these parameters will determine the best element which has the low loss performance and low phase slope to be selected as the reflectarray element candidate. Fig. 7 and Fig. 8 show the reflection phase curve and reflection loss of the nine different elements that have been analyzed using the commercial full-wave electromagnetic software CST Microwave Studio. The results show three resonant elements including Square ring, Circular ring and Proposed shape have very close value of linear phase range .Also, proposed patch has smoothest slope compared to other elements which is so important to increase bandwidth.
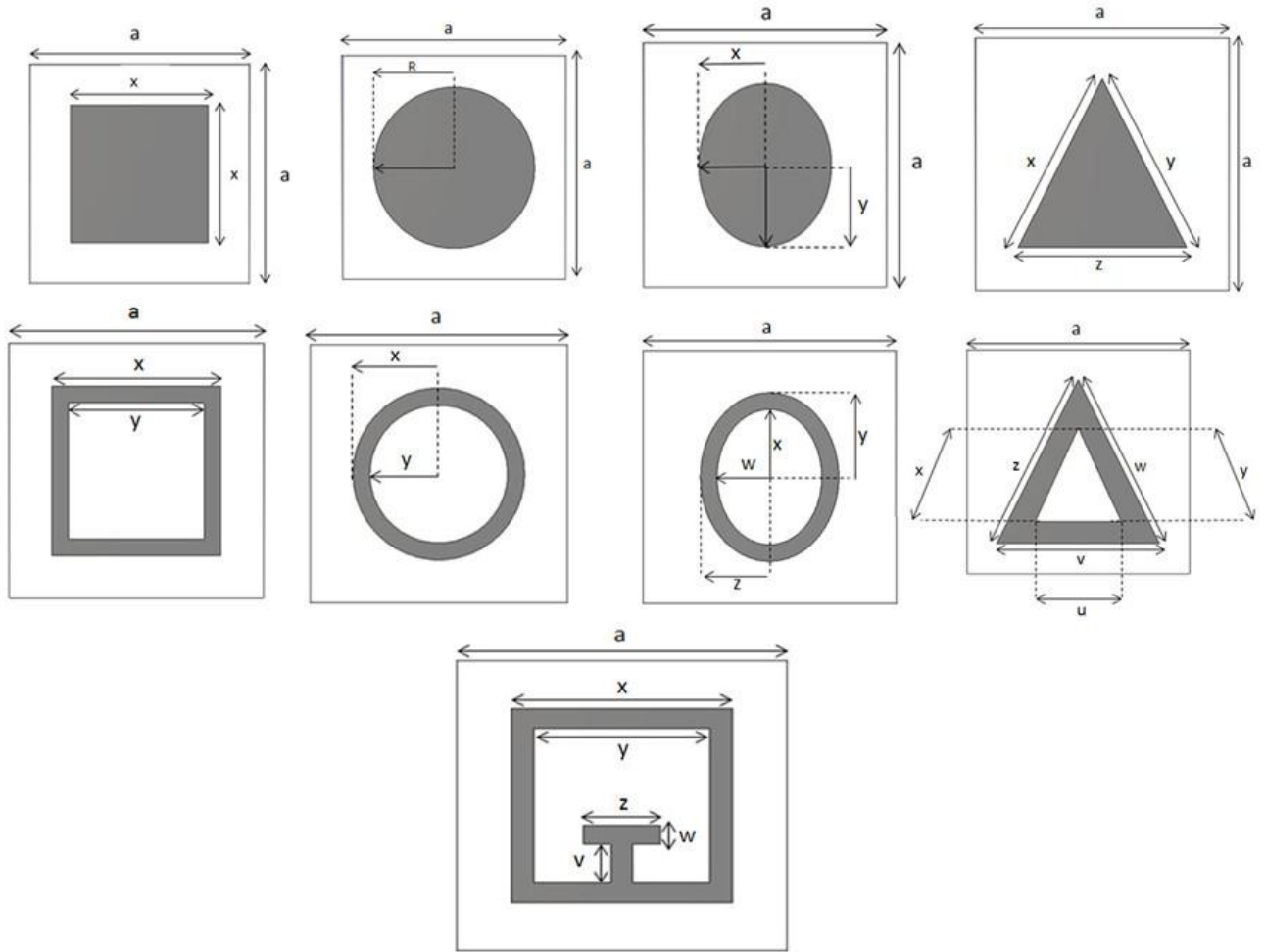
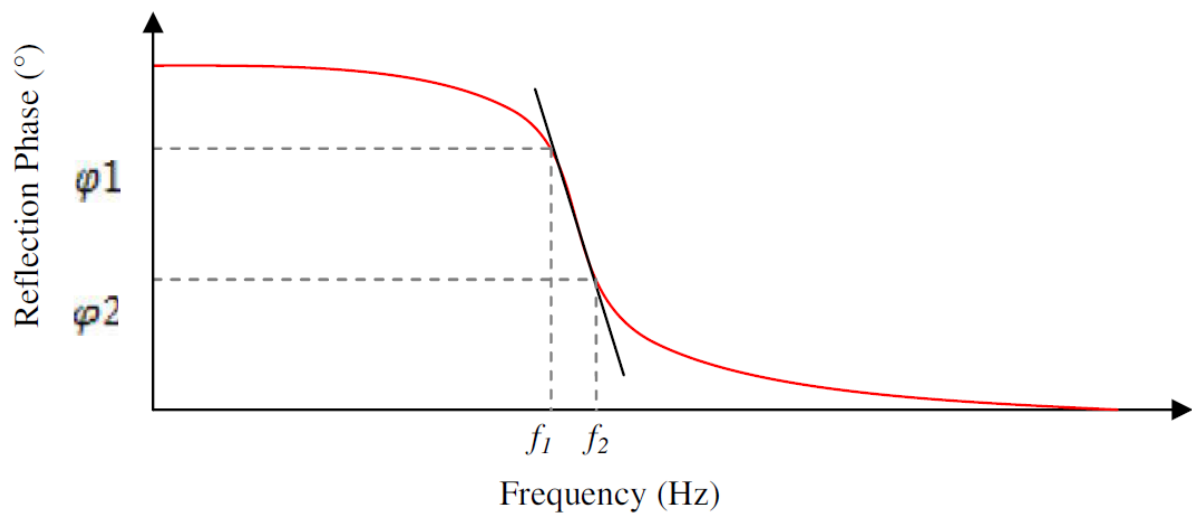Fig. 5 Geometries of nine elements with different shapes
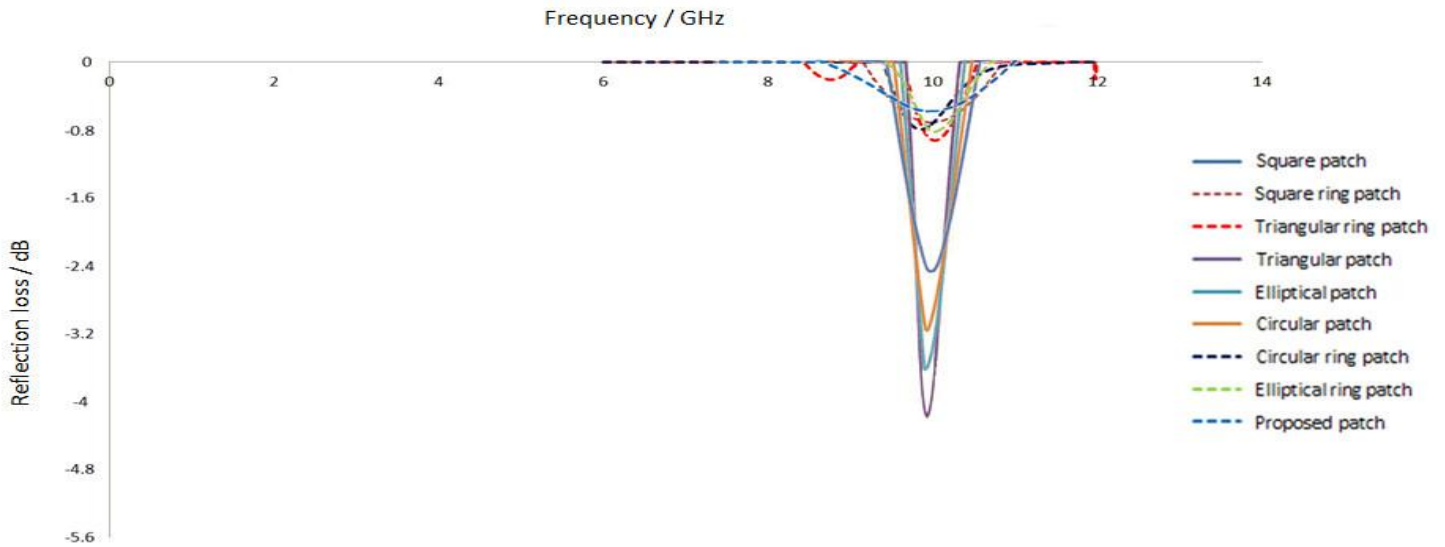

Fig. 6 Reflection phase versus frequency

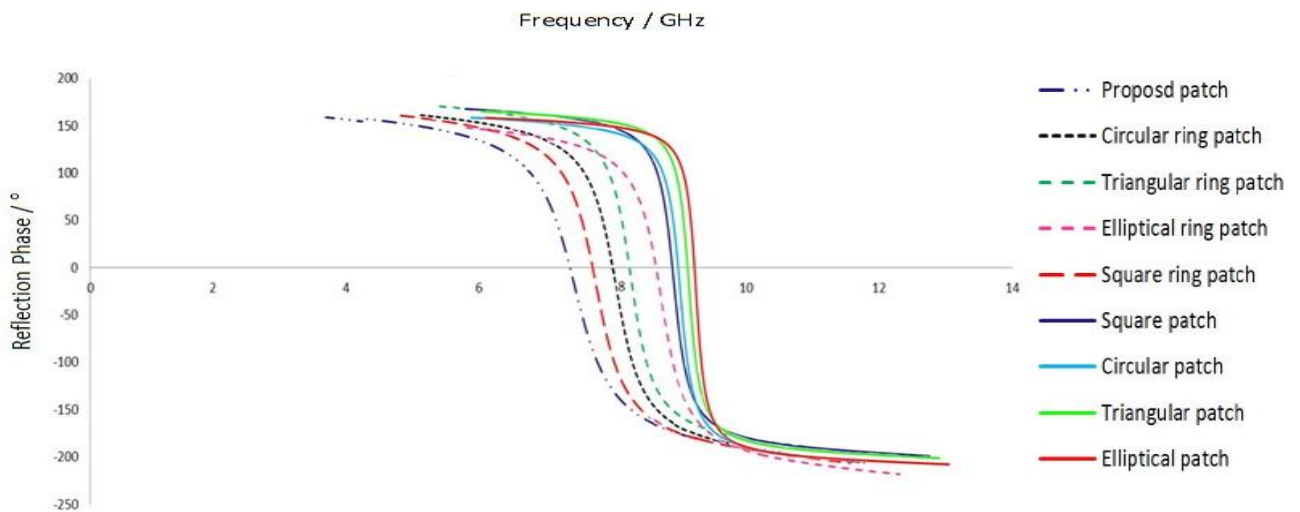Fig. 7 Comparison of simulated results among different reflectarray elements reflection loss vs frequency

Fig. 8 Comparison of simulated results among different reflectarray elements reflection Phase vs frequency

Fig. 6 shows the reflection phase versus frequency which can be used to calculate the phase slope of each element. the phase slope can be obtained by Equation 1

$$\alpha = \frac{\varphi 2 - \varphi 1}{f2 - f1}$$

Table III summarizes the detail results of the phase range as well as the reflection loss values for each element. It can be observed that triangular element has the highest reflection loss of -4.18 dB which has the lowest bandwidth. Meanwhile, it is observed that highest bandwidth offered by proposed element which has the lowest reflection loss. Conversely, the lowest bandwidth happens at triangular element as it

contributes the largest loss. Also, the propped element has the lowest slope which is about -2.55 that has an important effect on increasing bandwidth. In addition, the Elliptical element has steepest slope which is -10.709 that can have destructive influence on bandwidth. Therefore, the proposed element can be a suitable candidate as a reflectarray element.

Now we are going to design reflectarray antenna using the proposed element. The reflectarray antenna consists of 100 elements which are shown in Fig. 7. Rogers RT/Duroid 5880 with ε_r=2.2 is used as substrate and the thickness is 1 mm. The center frequency is 10 GHz, so the wavelength is about 3 cm. Also, length and width of each unit cell in the reflectarray is about 15 cm. The suitable position for microstrip array feed is in offset mode witch is completely out of the region of reflectarray antenna.

The fact is feed blockage can be omitted when using the feed in offset position. So, antenna parameters such as gain, directivity… will have better characteristics in this situation.

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Table III
Simulated phase range, reflection loss and phase slope of different resonant elements.

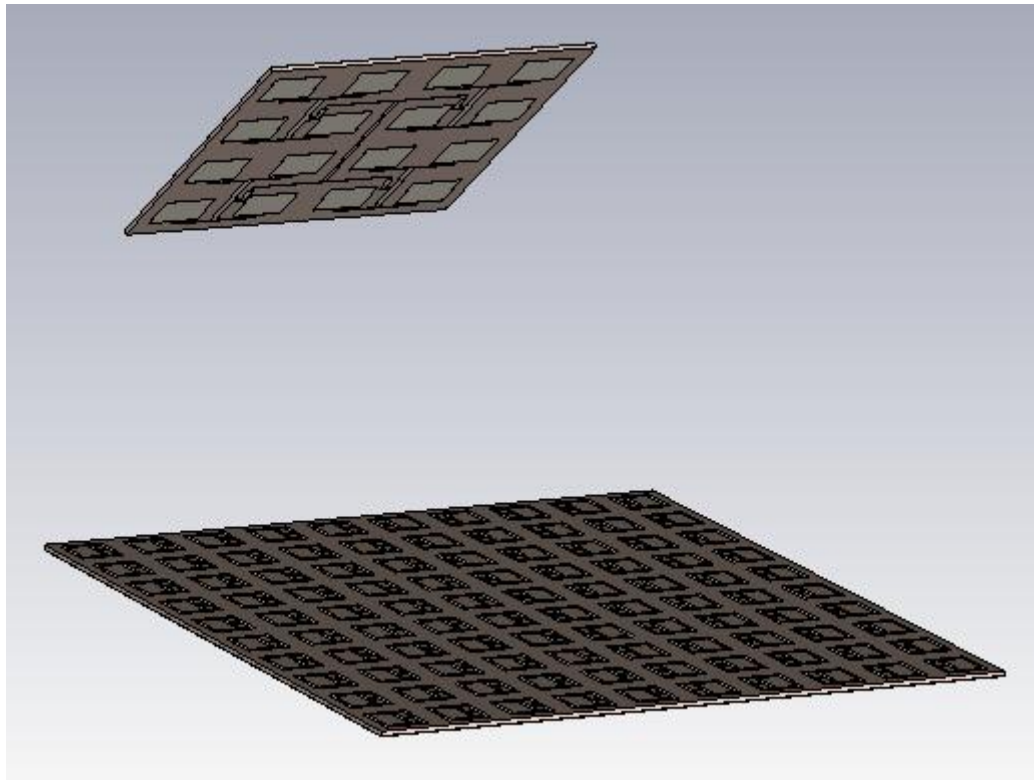| Element	Phase Range / °	Reflection Loss/dB	Phase Slope(α)
Square	366.69	-2.65	-6.23
Circle	366.52	-3.19	-7.92
Ellipse	366.007	-3.58	-10.709
Triangle	366.28	-4.18	-9.42
Square Ring	367.14	-0.76	-3.02
Circular Ring	367.164	-0.8	-3.05
Elliptical Ring	367.22	-0.95	-3.93
Triangular Ring	367.174	-0.98	-3.36
Proposed patch	369.162	-0.41	-2.55

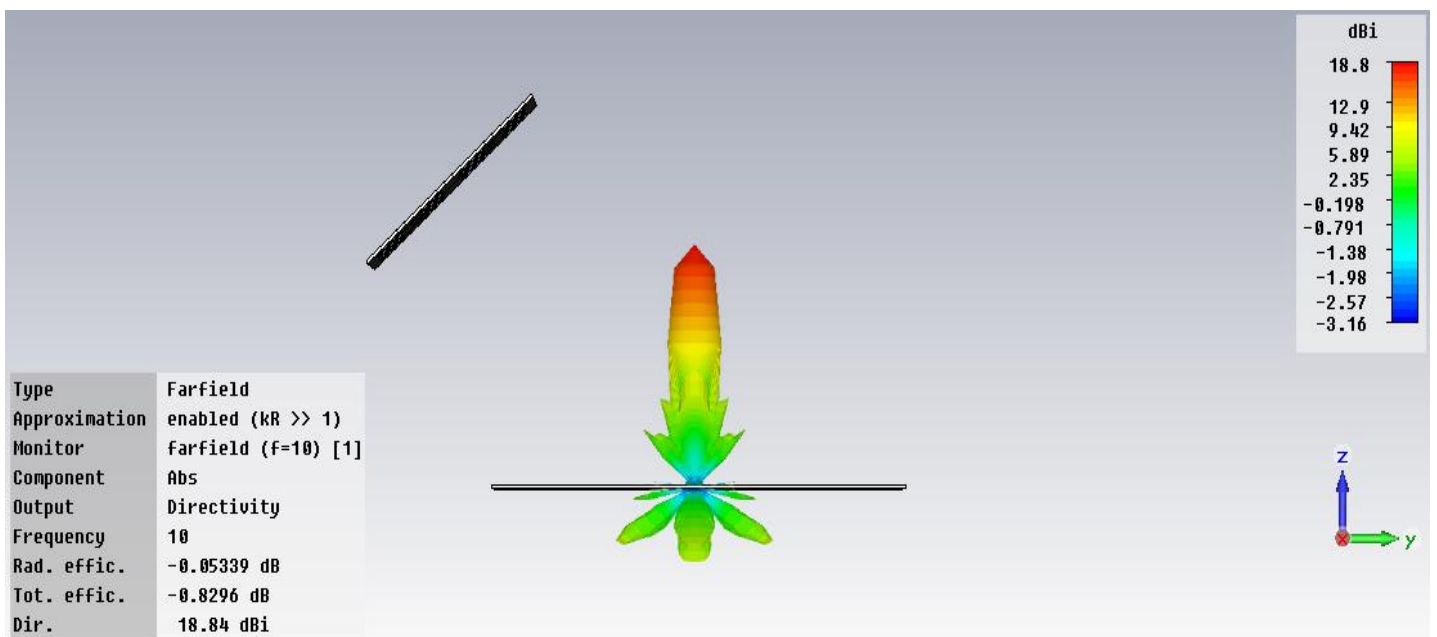Fig. 9 the reflectarray antenna using proposed element and the microstrip array feed

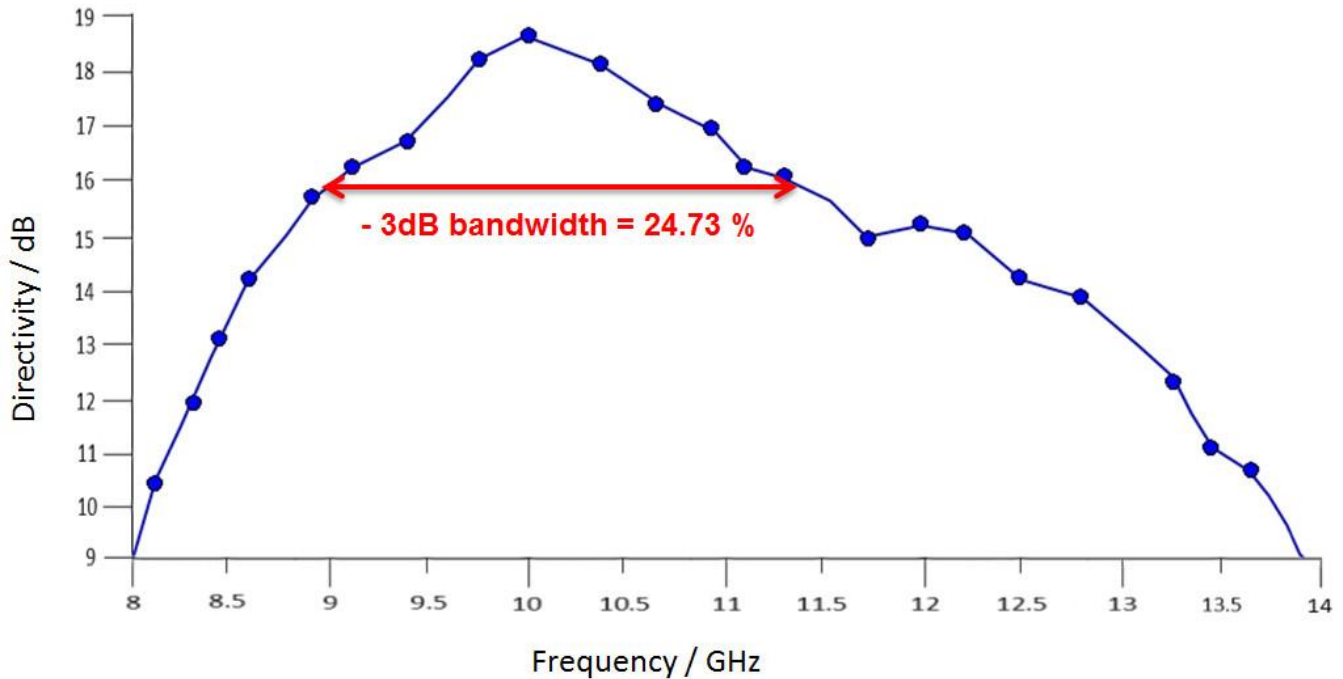Fig. 10 The pattern of the reflectarray antenna

Fig. 11 -3dB bandwidth of the reflectarray antenna

As can be seen in Fig. 10 the directivity of this antenna is about 18.84 dB. Also, -3dB bandwidth is about 24.73 % which is suitable compared to other elements(Fig. 11).

IV. CONCLUSION

By considering this paper it was concluded that the proposed element is a suitable choice as a reflectarray element. Also, a proper -3dB bandwidth was achieved which is about 24.73 %. The reason is that the bandwidth of the whole antenna depends on the individual element. Therefore the bandwidth is influenced by the element.

V. REFERENCES

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