Design of High Performance Dual Frequency Concentric Split Ring Square Element for Broadband Reflectarray Antenna

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Abstract **─** An analysis of phase variation and phase range of concentric split ring square element for broadband reflectarray antenna is presented in this paper. This element is the combination of a splitted single square and ring element whereas the square element is the modification of the conventional annular ring in which, instead of using annul as the hole, this new idea presents a square as the hole in the ring. This will modifies the current distribution in the element which will then improve the performance of the bandwidth as the objective of this work. The physical interpretation of the elements is presented and variety of frequency responses pattern is described and analysed. The design procedure and critical parameters consist of phase range and phase slope (or variation) are also discussed. The proposed antenna element effectively covers two frequency operations (13.44 GHz and 18.36 GHz) in Ku-band range. Bandwidth broadening is achieved by introducing the ring square combination of element and the practical phase range is achieved through the use of RF35 (thickness = 1.524 mm) as the substrate. The new concept of split initiates to a wider bandwidth (up to 67.6%) for the antenna and can applied to any two frequency operations of Ku-band applications.

Index Terms **─** Broader bandwidth, dual frequency, Ku-band, reflectarray antenna.

I. INTRODUCTION

Microstrip reflectarrays present an alternative to the conventional parabolic reflectors [1, 2]. As its name implies, a reflectarray antenna combines some of the best features of reflector and array antennas. In its basic form, a microstrip relfectarray consists of a flat array of microstrip patches or dipoles printed on a thin dielectric substrate. A feed antenna illuminates the array whose individual elements are designed to scatter the incident field with the proper phase required to form a planar phase surface in front of the aperture, as shown in Fig. 1. A large reflectarray antenna is made of thousands antenna elements printed on the flat surface and illuminated by a feed horn [3, 4,11].

A plane wavefront can be obtained by controlling the scattering properties of each element. The basic design procedure entails the use of phase-design curves. Various approaches

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have been proposed in the past which include the use of variable size patches and identical patches with variable size stubs for obtaining the required phase shift [4, 5].

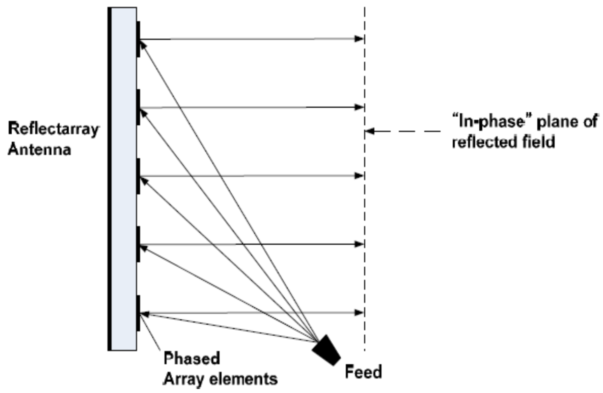

Fig. 1. Geometrical view of a reflectarray antenna.

The microstrip reflectarray has several applications due to its low-profile and small mass characteristic. One of the applications is that the flat reflectarray can be surface-mounted on a building side wall as a Ku-band Direct Broadcast Satellite (DBS) antenna. It also can be mounted on the rooftop of a large vehicle for satellite reception [4]. Recently, researchers have much interest in designing antenna which covers two frequency operations as been done in [6] and [7]. As stated in [6], the dual frequency covers X and Ka-band with the used of one layer substrate only while in [7], the dual frequency operation is achieved at 10 GHz and 18 GHz. This is evident that the dual frequency operation is possible for a simple design of one layer substrate reflectarray antenna element.

However, there is one distinct disadvantage associated with the reflectarray antenna which is its inherent characteristic of narrow bandwidth, which generally cannot exceed much beyond 10% depending on its element design, aperture size, focal length, etc [4]. For a printed microstrip reflectarray, its bandwidth is primarily limited by two factors which are the microstrip patch elements on the reflectarray surface and the differential spatial phase delay. This paper discussed the new concept of element to overcome the narrow bandwidth of the reflectarray antenna element.

II. ANTENNA STRUCTURE AND DESIGN

The element introduced in this paper namely concentric split ring square element is the combination of split ring and split square ring elements. RF35 is used as the substrate material with the dielectric constant of 3.54 and the loss tangent of 0.0018 at 1.9 GHz, while copper metal was used to simulate the designed element and the ground plane. The unit cell size is 10 mm x 10 mm. CST Microstripes software is used as the tool to analyze the phase variation graph. In CST Microstripes model, 0° phase reflection is used to define the resonance, whereas for a perfect conductor this is 180° relative to the incident wave.

In Fig. 2, *R* is the square ring element radius, *O* is the outer ring radius, *I* is the square length while *g* is the gap size for the split of the element. The nominal inner radius of the outer split ring element is 3.56 mm with the ring width is 0.4 mm and the radius of the split square ring is 3.06 mm which gives the ratio of *R/O* value equals to 0.86. The value of *R* and *I* is fixed at the same value to give the ratio of *I/R* equals to 1. Ideally the gap size should be smaller [8, 9] so that the resonant frequency is not increased but in this work, the gap size is limited to 0.28 mm due to the fabrication tolerances.

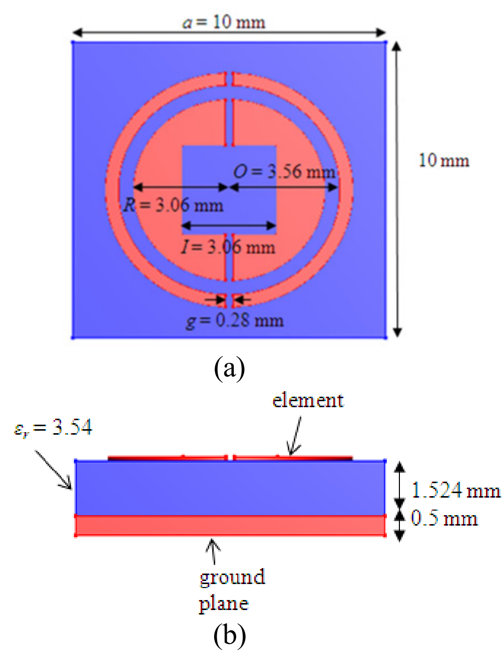

Fig. 2. The view of concentric split ring square reflectarray element (a) top-view (b) side-view.

The methodology used to establish a suitable design for the concentric split ring square reflectarray element is shown in Fig. 3. The first step of validation is to familiarize with the software and confirm the design procedure. Then, the basic annul of conventional ring element is replaced by the new potential concept of square hole. The combination of this new element with ring is to observe the operation of dual frequency resonance which is to reduce the cost of development two antennas for dual frequency operation.

From studies in [8, 9, and 10], the introduction of gap into a structure can affect the frequency response performance. In this work, the gap (or split) introduction into the elements then been analysed for bandwidth enhancement. Once the nominal size of element is determined, phase curve graph is plotted to observe its phase slope and phase range performance. As a final step of checking performance of the proposed reflectarray element, a unit cell was manufactured, and tested using the waveguide approach [4]. The side walls of the equivalent TEM waveguide are formed by a perfect magnetic conductor, while its bottom and top walls are composed of a perfect electric conductor using metal guides. Using the equivalent unit cell waveguide approach, phase of the reflected wave was calculated for the loaded waveguide.

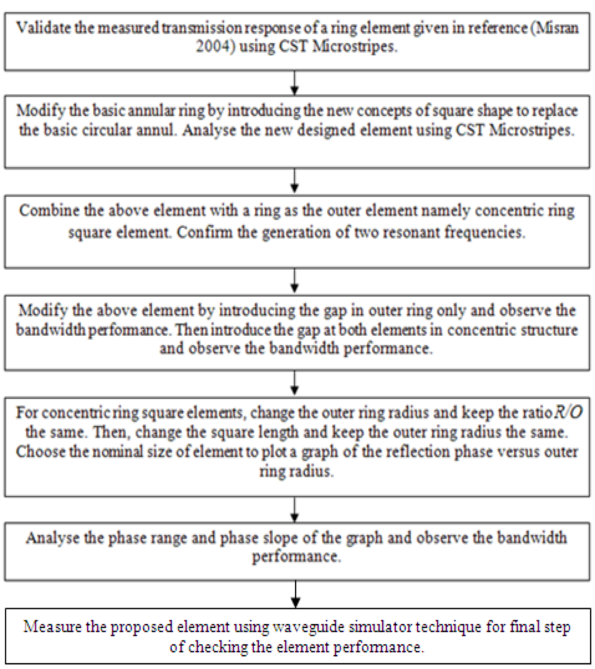

Fig. 3. Design methodology for concentric split ring square element.

Figure 4 shows the frequency response for concentric split ring square element with gaps and concentric solid ring square element without the gaps. The reflection phase shown in this figure are for vertical polarization where for the proposed element structure, vertical polarization will result in different reflection phase due to the introduction of vertical splits.

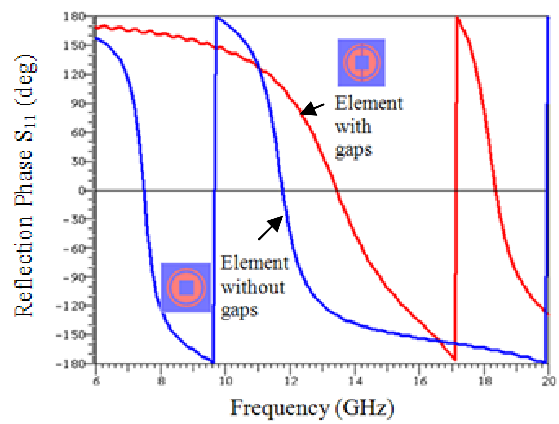

Fig. 4. Frequency response for two designed element.

The slope of the phase versus length curve is a measure of the bandwidth of the reflectarray, as a curve with a smaller slope will lead to less phase error when the electrical size of the elements change with frequency [1].

From Fig. 4, it is clearly shown that, for the first resonance, the gradient of the curve is largely decreased when gap is introduced in the design. This entails the bandwidth enhancement from 26.9% to 67.6%. While for the second resonance, the bandwidth is slightly improved from 19.8% to 20.3%.

The concentric ring square element produces two frequencies operation which covers Ku-band at 13.44 GHz and 18.36 GHz as shown in Fig. 5.

It is observed from Fig. 5 that at the first resonant frequency, the first element of splitted ring is strongly excited while at the second resonant frequency, the second element of splitted square is strongly excited. This evident that the outer ring is determining the first resonance, while the inner square ring determining the second resonance. From Fig. 5, it is also clearly shown that only quarter of element is simulated since we are using the concept of symmetry that is available for the waveguide approach.

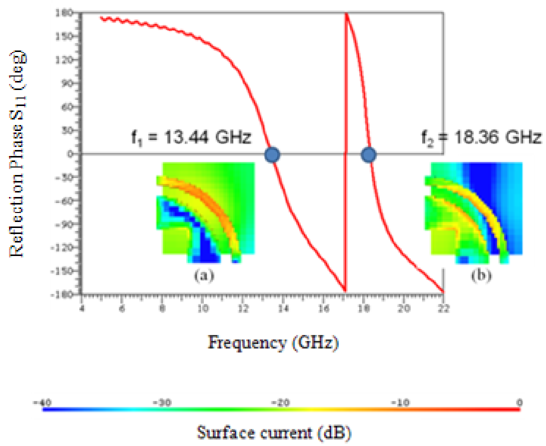

Fig. 5. Surface current distribution (a) at 13.44 GHz and (b) at 18.36 GHz for a grounded concentric split ring square reflectarray element.

For the experimental validation of the element analysis, the element is designed in an array environment for compromising TE_{10} mode of waveguide simulator. The elements were inserted in the waveguide, where the ground plane with the apertures are in contact with the waveguide flange. Figure 6 shows the fabricated element with the developed waveguide simulator and the full set-up of measurement process.

From Fig. 6, it is shown that a waveguide simulator is used to measure the performance of the developed element. This waveguide is needed to be designed to compromise with the analysed resonant frequency of the designed element. The single port is used to get the scattering parameter, S_{11}.

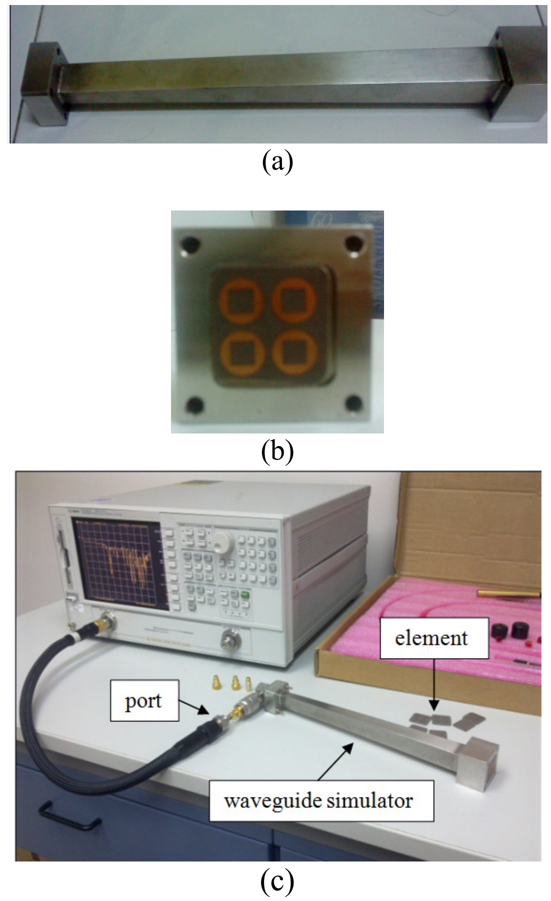

Fig. 6. Measurement stage (a) waveguide simulator and (b) fabricated element inserted into the waveguide aperture (c) full set-up of measurement process.

III. RESULTS AND DISCUSSION

With the designed structure dimension given in Section 2, the simulated reflection phase versus outer ring radius is plotted and shown in Fig. 7 and Fig. 8 for first and second resonant frequency respectively. For Fig. 7 and 8, the ratio of R/O = 0.86, I/R = 1 and g = 0.28 mm is fixed for the phase studies.

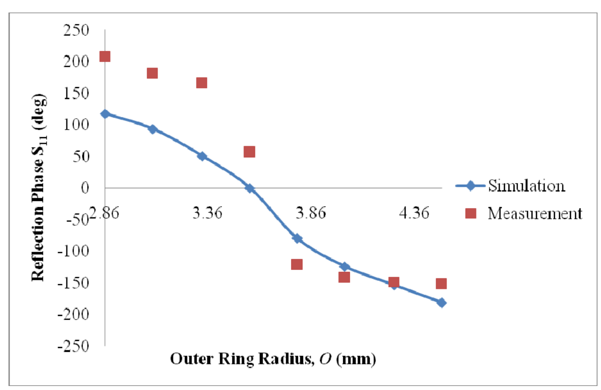

Fig. 7. Phase curve of concentric split ring square element at f_1 = 13.44 GHz.

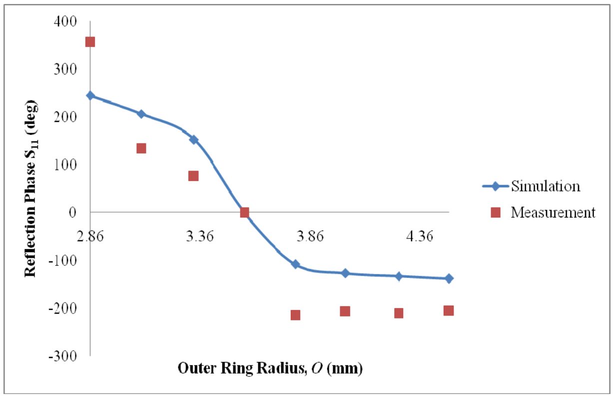

Fig. 8. Phase curve of concentric split ring square element at f_2 = 18.36 GHz.

The linear phase range simulated at the first resonance is 320° with the gradient of 0.15°/µm and the phase range at the second resonance is 464° with the gradient of 0.33°/µm.

The bandwidth performance is 67.6% and 20.3% at the first and second resonance, respectively. The concentric element concept is used to achieve a dual frequency operation compared to the single element concept which gives only one resonant frequency.

Both simulation and measurement results show good agreement with slight differences due to minor fabrication error and some noise from signal reflected inside the waveguide simulator.

In the concentric element design, the critical feature of mutual coupling should be taken care of because the design which consist two elements using copper metal material can easily caused a short circuit. In this work, the gap between the first and second resonance element is fixed at 0.5 mm.

Table 1 shows the summary of comparison between concentric solid ring square element and concentric split ring square element. The introduction of split on the structure significantly affects the frequency response performance and improves the narrow bandwidth of the antenna element.

IV. CONCLUSION

A new design of reflectarray elements for the broadband dual frequency Ku-band application is proposed in this work which is the concentric split ring square element. By modifying the current distribution of the physical geometry of the basic concentric ring square element leads to a better phase variation and bandwidth. This new design gives the good performance in bandwidth which is up to 67.6% and 20.3% in dual frequency operations. The phase range for the element is also in a good practical region which gives the value of 320° and 464° at both resonant frequencies respectively. The reflectarray antenna is easy to fabricate and low cost. These features are very useful for worldwide portability of communication applications.

Table 1: Comparison of two studied element shapes performance

Element / Parameter	Concentric Solid Ring Square	Concentric Split Ring Square
Resonant Frequency (GHz)	f_1 = 7.48 f_2 = 11.78	f_1 = 13.44 f_2 = 18.36
Phase Range (°)	at f_1 = 249 at f_2 = 230	at f_1 = 320 at f_2 = 464
Phase Slope (°/µm)	at f_1 = 0.54 at f_2 = 0.50	at f_1 = 0.15 at f_2 = 0.33
Bandwidth Performance (%)	at f_1 = 26.9 at f_2 = 19.8	at f_1 = 67.6 at f_2 = 20.3

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