# Design of Broadband Single Layer Printed Reflectarray Using Giuseppe Peano Fractal Ring

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***Abstract*** **─** In this paper, a broadband single-layer microstrip reflectarray element composed of a Giuseppe Peano fractal ring and a square ring is presented and investigated. The proposed element has been validated by comparing the simulation results with those obtained by measurement in a waveguide simulator. By using this type of cell element, a wideband single layer reflectarray is designed, fabricated, and tested. Measured results demonstrate 1 dB gain bandwidth of 17 % over the frequency range of 12.25 GHz - 14.5 GHz.

***Index Terms***- Aperture efficiency, Giuseppe Peano fractal, microstrip antenna, reflectarray, and TE and TM waves.

## I. INTRODUCTION

Microstrip reflectarray antenna has been proposed as a major alternative for parabolic reflector antenna since 1991[1]. The reflectarray idea combines certain characteristics of reflector and array antenna, respectively. The reflectarray consist of an array of patches that convert spherical waves produced by the feed into plane waves to form a main beam in a given direction. Reflectarray antennas have several advantages such as low manufacturing cost and simple mechanical design, but they suffer from narrow frequency bandwidth, which is due to differential spatial phase error in large reflectarray and narrow band operation of each array elements. To overcome these limitations, a lot of researches have been made in recent years [2-15]. In [5-7], a multilayer reflectarray composed of two or three stacked array with rectangular patches of variable size with 1 GHz bandwidth, and 400˚ phase variation has been introduced. Another example, in [8] a single-layer microstrip reflectarray element composed of a rectangular patch and a rectangular ring has been introduced. Using these elements, a prime-focus 45-element linear reflectarray operating at 10 GHz has been designed. In [9] a wideband reflectarray using artificial impedance surface with 1 dB gain bandwidth of 20 % has been proposed. The other worthwhile ideas are a broadband reflectarray design with a combination of cross and rectangular loop element [10] or a reflectarray design based on aperture coupled patches with a true time delay line [11].

In this paper, a wideband reflectarray element with a 600˚ phase variation range in 11.5 GHz - 14.5 GHz has been designed exploiting Giuseppe Peano fractal ring. Fractal structures can give rise to miniaturized wideband antenna. The proposed structure is described in section II along with the definition of parameters and demonstration of the simulation results. In order to validate the simulated results, the fractal ring element is fabricated and tested in a waveguide simulator. Measured results will be shown in section III. In section IV, using these elements, a one layer reflectarray is designed to operate at 13.5 GHz. The overall size of this antenna is 250 mm × 250 mm (11.25 $\lambda_0$ × 11.25 $\lambda_0$).

## II. THE STRUCTURE AND PHASE CHARACTERISTIC OF THE PROPOSED ELEMENT

The recursive procedure of the Giuseppe Peano fractal is shown in Fig. 1, which is applied to the edge of the square patch up to the first iteration as depicted in Fig. 2 [12].

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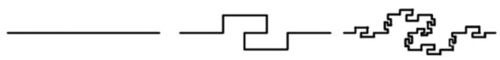


Fig. 1. Initiator and generator of the Giuseppe Peano fractal.

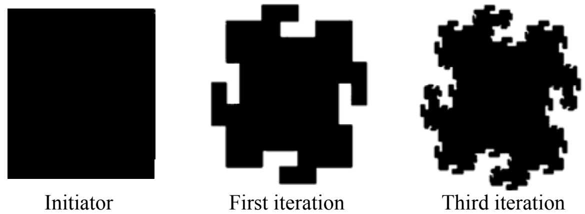



Fig. 2. Giuseppe Peano fractal as applied to the edges of the metallic patches.

Using this fractal, a fractal ring element has been designed and shown in Fig. 3. The proposed structure consists of one Giuseppe Peano fractal ring in combination of a square ring. In this layout, the fractal ring layer is etched on a 5 mil thick Rogers RT/Duroid 5880 with a dielectric constant of 2.2 and a loss tangent of 0.0009. A 3.125 mm thick layer of ECCOSTOCK PP-2 low-loss foam ($\varepsilon_r=1.03$) is stacked beneath the ring layer for bandwidth enhancement and wider phase range purposes. The configuration of the proposed fractal ring microstrip antenna is depicted in Fig. 3 with the following optimized parameters: $w_1 = w_2 = 0.2$ mm, $t_1 = 3.175$ mm, $t_2 = 0.127$ mm, $l_2 = l_1 - 1.5\, w_1$, $l_3 = 2/7\, l_1$, and $l_1$ change to produce proper phase. For the center frequency of 13.5 GHz, 12 mm (0.54 $\lambda_0$) period square unit cell is chosen in order to avoid the formation of grating lobes in the array's radiation pattern.

The scattering matrix of the structure has been obtained using high-frequency structure simulator software (HFSS) [13] and a unit-cell approach with the master-slave boundary to emulate an infinite periodic structure as shown in Fig. 4. The reflection phase and reflection amplitude of the fractal ring element on the top surface of the patch for different fractal side are shown in Figs. 5 and 6, respectively. As shown in both figures, a 600˚ phase variation range and a maximum of 0.8 dB loss can be achieved with the change in the fractal length from 3.5 mm to 9.1 mm. As the phase variation range increases, a higher efficiency can be attained. Furthermore, a parallel phase variation in the whole band has been achieved for this particular combination for the fractal and the square ring, using a cell size of 12 mm .

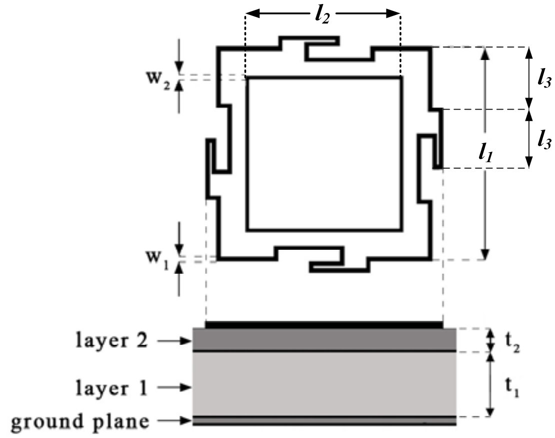



Fig. 3. Periodic unit cell of the proposed element.

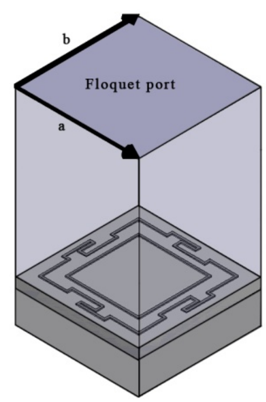



Fig. 4. Rectangular unit cell of HFSS simulation using floquet port.

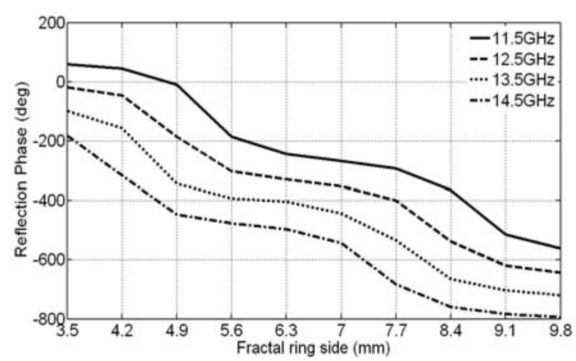



Fig. 5. The reflection phase at normal incidence for a periodic array of fractal ring on a grounded substrate versus the fractal ring side at four frequencies on the top surface of the patch.

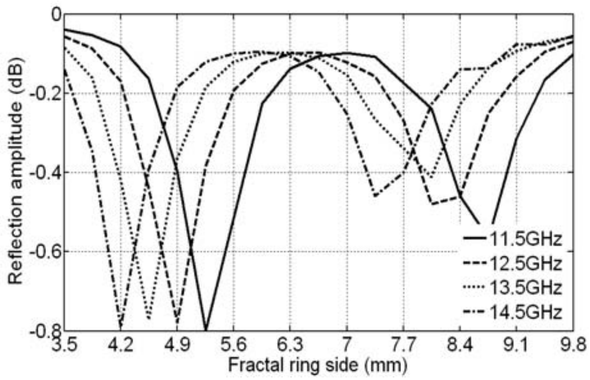



Fig. 6. The reflection amplitude at normal incidence for a periodic array of fractal ring on a grounded substrate versus the fractal ring side at four frequencies on the top surface of the patch.

Figure 7 shows the phase of the reflected wave versus the fractal ring side of a radiating element when a plane wave impinges with different angles of incidence. This structure was simulated using HFSS with floquet port and master slave boundary. As shown in Fig. 7, there is a small variation as the incident angle changes. Thus, the effect of the incident angle in designing of the reflectarray is negligible.

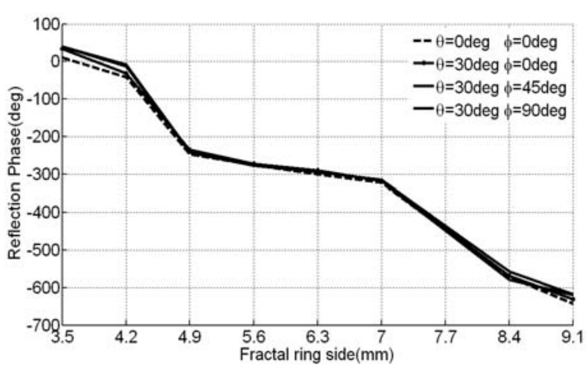
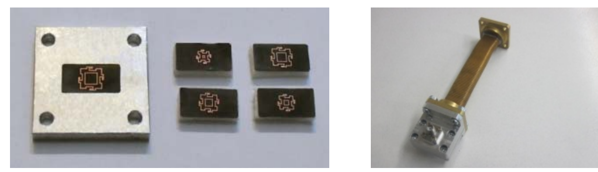



Fig. 7. Phase of the reflected wave versus fractal ring side for plane wave excitation with different incident angle at a center frequency of 13.5 GHz.

## III. VALIDATION IN WAVEGUIDE SIMULATOR

To validate the simulation result, five elements has been fabricated and tested using waveguide simulator technique [14]. In this technique, the radiating elements were inserted into a waveguide section, and the reflection is measured in the excitation port. The simulations were obtained by defining the corresponding geometry in HFSS. The measurement setup for Ku band is shown in Fig. 8. In this approach, the cell size is 15.8 mm × 7.9 mm equal to WR62 dimensions. The length of the fractal ring is changed from 3.5 mm to 6.3 mm, as shown in Figs. 9 and 10, respectively. As can be seen, the agreement between the simulation and the measurement result is good. The reason of a small discrepancy between results is due to the tolerance in the manufacturing process and also due to the difference between the real losses of the material and the nominal value.



(a) (b)

Fig. 8. Waveguide simulator (a) five fabricated unit cells and (b) WR62 waveguide.

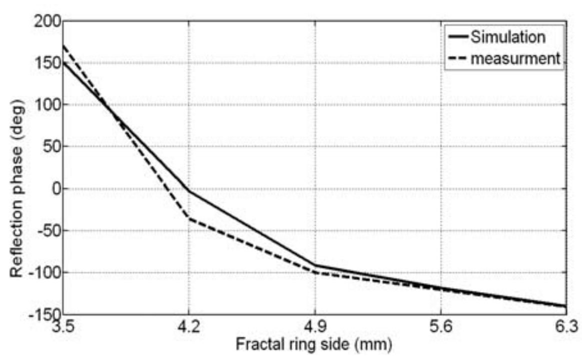



Fig. 9. Simulated and measured reflection phase for varying fractal ring side at a center frequency of 13.5 GHz and $44.68^0$ incidence angle.

## IV. REFLECTARRAY ANTENNA DESIGN AND PERFORMANCE

First step to design a reflectarray is determining the phase pattern on the reflectarray surface. The required phase delay at element $n$ to achieve a reflected beam in a given direction ($\theta_0$, $\phi_0$) is

$$\phi_l = K_0[d_l - sin\theta_0(x_l cos\varphi_0 + y_l sin\varphi_0)], \quad (1)$$

where ($x_l, y_l$ ) are the coordinate of element *n*, $K_0$ is the wave number, $d_l$ is the distance from the phase center of the feed to the element $n$, and ($\theta_0$, $\phi_0$) is the main beam direction. For example, for a reflectarray with 441 elements arranged in a square grid of 21 × 21 elements and $f/D$ ratio equal 1, the phase distribution required for each element to generate a pencil beam at boresight is shown in Fig. 11. The required phase range is $600^0$, which is achievable using the proposed cell.

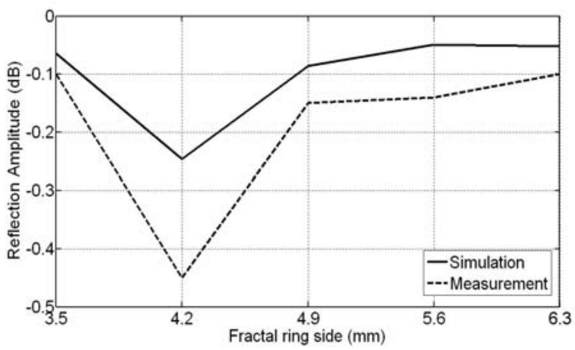



Fig. 10. Simulated and measured reflection amplitude for varying fractal ring side at a center frequency of 13.5 GHz and $44.68^0$ incidence angle.

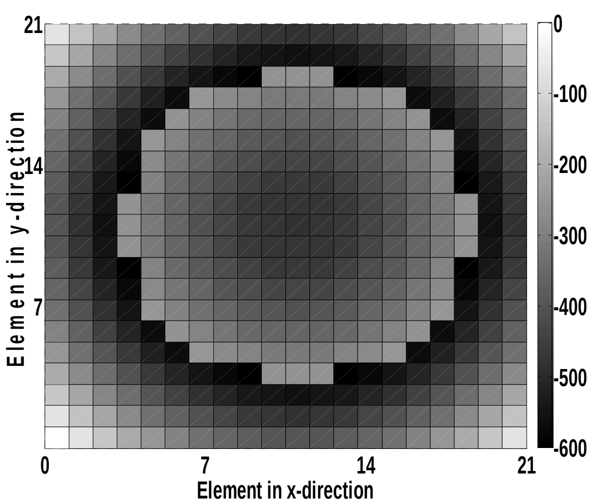



Fig. 11. Required phase distribution on the reflectarray surface to generate a pencil beam pointing on boresight.

Using the above equation, a 250 mm square center-fed reflectarray using the aforementioned cell elements was designed and fabricated as shown in Fig. 12.

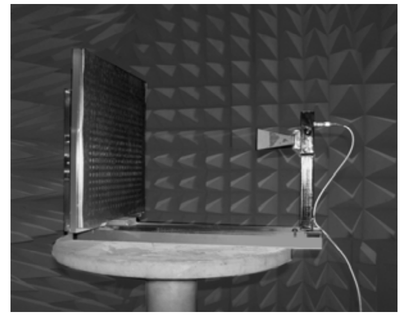


Fig. 12. Photographs of the one layer proposed reflectarray.

In order to illuminate the reflectarray, a standard linear polarity ATM horn 62-441-6 was selected. The measured gain for this horn at 13.5 GHz is 15 dB. The co- and cross-polarized radiation patterns at the center frequency of 13.5 GHz are shown in Figs. 13 and 14, respectively. As shown in these figures, the isolation between the co- and cross-polarized in the E- and H-Planes is better than 25 dB in the boresight direction and the side lobe level is around 13 dB.

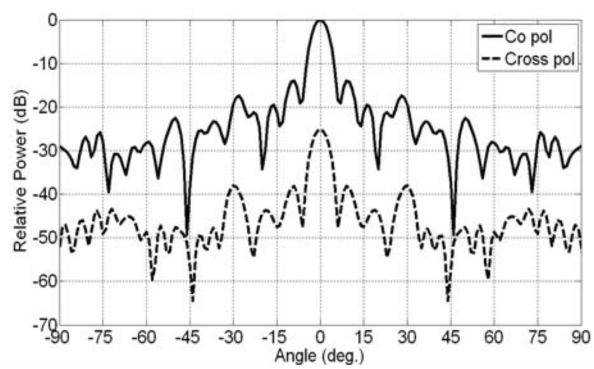



Fig. 13. Simulated vertical E-plane radiation pattern of a reflectarray at 13.5 GHz.

The measured gain over the frequency range from 11 GHz to 16 GHz is shown in Fig. 15, which demonstrates a 1 dB gain bandwidth close to 17 %. This is considered an excellent result. The aperture efficiency was computed as the ratio of measured gain to the maximum directivity [15]. The efficiency of this reflectarray is about 50 %. To attain higher efficiency one should reduce the blockage attributed to the feed antenna, the spillover effect due to the feed illuminating areas outside of the reflectarray, the feed's non-uniform illumination across the reflectarray's aperture, and the diffracted fields from the edges.

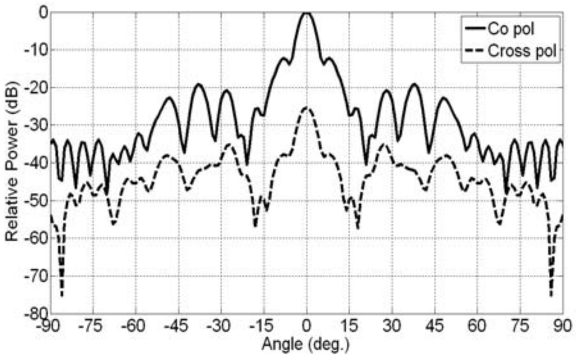



Fig. 14. Simulated horizontal H-plane radiation pattern of a reflectarray at 13.5 GHz.

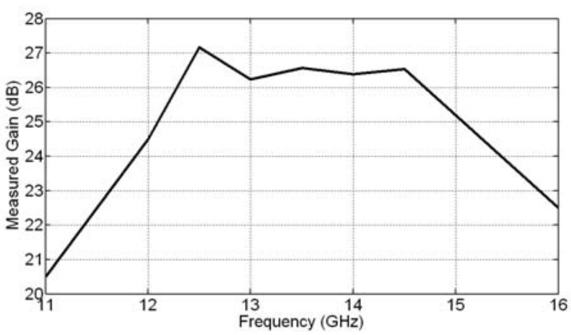



Fig. 15. Measured gain of the prototype reflectarray versus the frequency range.

## V. CONCLUSION

A single layer microstrip reflectarray element with fractal and square ring elements has been designed and analyzed. Compared with other reflectarray elements, this element can produce a phase variation range exceeding $600^0$. By using these elements a 441 element reflectarray operating at 13.5 GHz with 1 dB gain bandwidth of 17 % has been designed and tested. Good agreement between the simulation and measured result has been observed.

## ACKNOWLEDGMENT

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