W-band Dual-Large-Reflectarray Antenna with Low Sensitivity and Broad bandwidth Characteristic

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Abstract

The dual-large-reflectarray antenna with low sensitivity and broad bandwidth characteristics is presented. The proposed unit cell is composed of a simple multi-resonant element which is a patch and a square loop. Then, the low sensitivity and broad bandwidth can be achieved through the stepwise variation strategy rather than the conventional variation method of the unit cell. With this multi-resonant element, the total range of 430° and the average sensitivity of 15.9°/0.1mm can be achieved. A 6072-element large reflectarray antenna is designed, simulated. Finally, the simulated results show that the peak gain is 35.9 dBi and the 1-dB gain bandwidth is 12GHz in W-band.

1. Introduction

The Microstrip reflectarray antenna is a technique of converting the curved conductor reflector antenna to the planar reflect-array antenna through appropriate phase adjustment of the unit cell element. It has advantages such as low cost, low profile, easy manufacturing, and versatile radiation performance compared to the curved conductor reflector antenna [1]. This technology has attracted wide attention in many applications, such as communication, radar, and millimeter-wave system [2]. In general, the size of the unit cell is about λ/2 in order to avoid the grating lobe. In the case of the target frequency at 94GHz, the size of the unit cell is 1.6mm. Therefore, the phase shift of the unit cell can be extreme in accordance with the fabrication tolerance. If the reflectarray is designed in the millimeter-wave, the sensitivity of the unit cell which is the change rate of the reflection phase according to element variation is a very important factor. To achieve low sensitivity, multilayer structure [3] and multi-resonant [4] design technology are widely used. However, in the case of a multilayer structure, the manufacturing process is complicated and the process error can be increased in the millimeter wave. Besides, in the case of multi-resonant elements, as the number of resonant element increases, the complexity also increases. Even though the phase range can be wide with multi-resonant element, it has a disadvantage of high sensitivity in a resonant section.

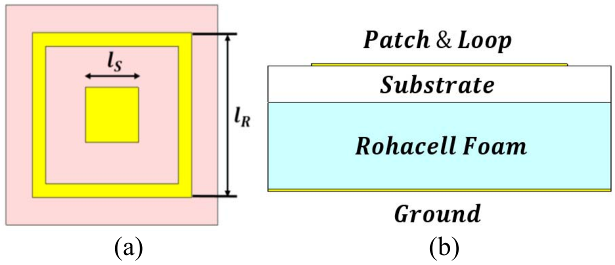

Fig. 1. Proposed unit cell element configuration. (a) Top view, (b) Side view

In this paper, the unit cell composed of a relatively simple type of multi-resonant element is used, and the resonant element is not changed at the same time, but it is individually changed. In addition, the element variation method is subdivided to satisfy the low sensitivity in all section rather than the specific section (non-resonant section). Then, the phase ranges become not the S-curve which is general characteristic of the conventional unit cell. The low sensitivity and broad gain bandwidth is satisfied through the subdivided variation strategy of multi-resonant element.

2. Reflectarray Element and Design

A schematic view of the proposed unit cell is depicted in Fig.1. The center frequency of W-band is around 94GHz. The proposed unit cell consists of multiple resonant elements which are loop and patch together with a rohacell foam. Due to its symmetric geometry, it is suitable for dual linear polarizations. The unit cell periodicity is 1.6mm (≈1/2λ at 94GHz) in both directions. The unit cell is assumed to be fabricated on a dielectric substrate with thickness 0.254 mm, relative permittivity ε_r=2.2, and loss tangent tanδ=0.0009 (Rogers RT 5880). A rohacell foam of height h=0.7mm is added beneath the dielectric substrate. In general, a conventional variation method of the multi-resonant element is simultaneously changing all element. If all multi-resonant elements are changed at the same time, the achievable phase range is increased but the sensitivity (slope) of phase curve is also

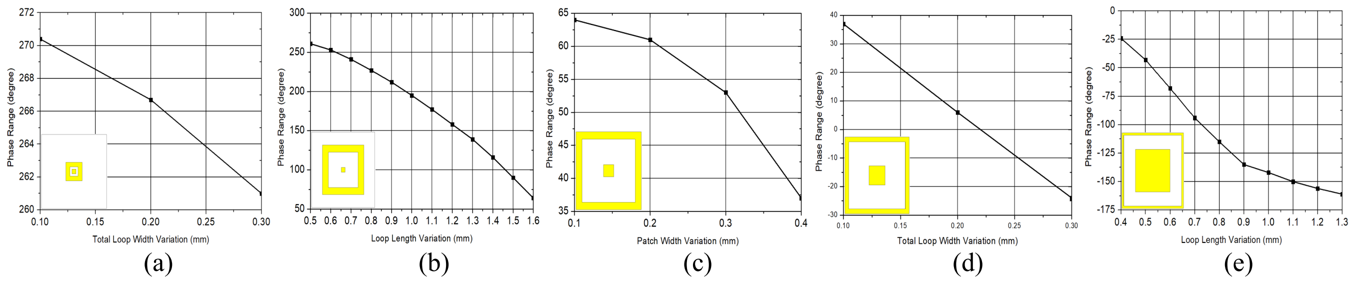

Fig. 2. Procedure of simulated reflection coefficient phase. (a) Procedure □ (the variation of a total loop width), (b) Procedure □ (the variation of a loop length), (c) Procedure □ (the variation of a patch width), (d) Procedure □ (the variation of a total loop width), (e) Procedure □ (the variation of a loop length)

TABLE I
THE MAXIMUM, MINIMUM AND AVERAGE SENSITIVITY OF PROPOSED UNIT CELL

	Phase Range (°)	Maximum Sensitivity (°/0.1mm)	Minimum Sensitivity (°/0.1mm)
Procedure □	10	5	4
Procedure □	197	26	8
Procedure □	27	16	8
Procedure □	59	31	31
Procedure □	141	26	5
Total Procedure	430	15.9 (Average)	

increased. Due to sudden change in the vicinity of the resonance, the phase curve is shown as S-curve instead of straight line. The conventional variation method of the multi-resonant element usually has high sensitivity at the resonant section. This results can lead to large phase error in the case of fabrication inaccuracy and deteriorate the performance of reflectarray antenna. However, it is possible to satisfy the low sensitivity of phase curve by changing the multi-resonant elements in a stepwise strategy instead of a conventional variation method [5]. Considering the manufacturing tolerances, the simulation resolution of the element variation is 0.01 mm. Fig.2 depicts the phase curve versus size of patch, size and width of loop through stepwise strategy. The variation method of the resonant element are sub-divided into five steps. The phase range and the sensitivity value according to each step are shown in Table 1. The phase curve of each step depicts almost straight line in contrast to S-curve. The total phase range of all step is 430° and the maximum and total average of sensitivity are 31°/0.1mm, 15.9°/0.1mm, respectively. This results are quite low sensitivity of phase curve compared to the conventional multi-resonant elements.

3. Broadband Characteristic of Reflectarray Element

The main drawback of reflectarray performance is the narrow bandwidth, generally lower than 5 percent and even less for large reflectarray due to the narrow band of

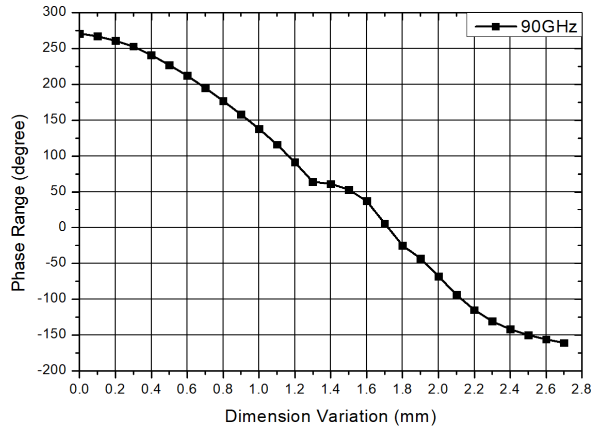

Fig. 3. Phase reflection coefficient versus dimension variation for five step

the unit cell and the differential spatial phase delay. Generally, the moderate size reflectarray is mainly affected by first factor and the large reflectarray is mainly affected by the second factor as well as first factor [6]. Reflectarray size can be classified as the moderate and large size based on the below size and the above size of 20λ, respectively. In this paper, the size of the main reflectarray is 100mm. It belongs to a large reflectarray over 31λ. Fig.3 shows the reflection phase curve of unit cell of the center frequency. It is the results of added five step versus the dimension variation of resonant elements. Note that the reflect-ion phase varies almost linearly in contrast to the conventional S-curve. Such a parallel linear line can lead to the low phase dispersion ($= d\phi/df$) according to the frequency variation which is characteristic of the broad bandwidth [7].

4. Chaasegrain Reflectarray Performance

Figure 4 shows the geometry of a cassgrain structure and proposed reflectaaray antenna which consists of the pyramidal feed horn, the sub-reflector of a hyperbola, the rohacell strut which support the sub-reflector and the planar main reflectarray. The sub-reflector is a curved conductor reflector rather than a planar reflectarray. This is because, in the proposed geometry, the conductor sub-reflector is a nearly flat reflector with almost no curvature,

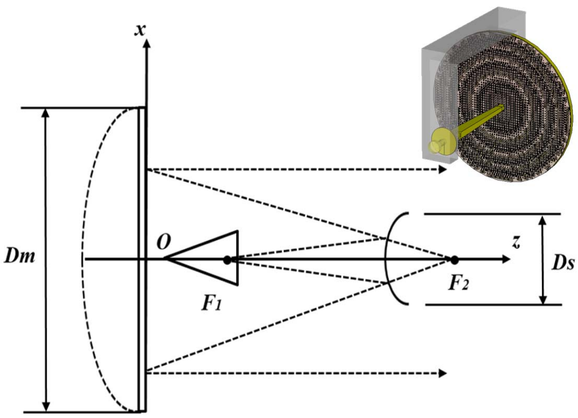

Fig. 4. Cassegrain geometry and proposed reflectarray antenna schematic view.

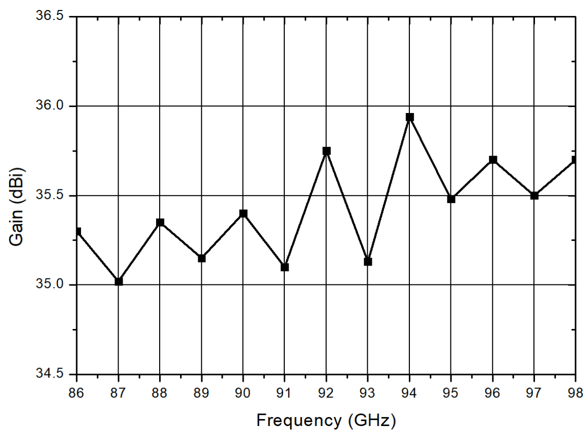

Fig. 5. Simulated gain characteristic of proposed dual cassegrain reflectarray.

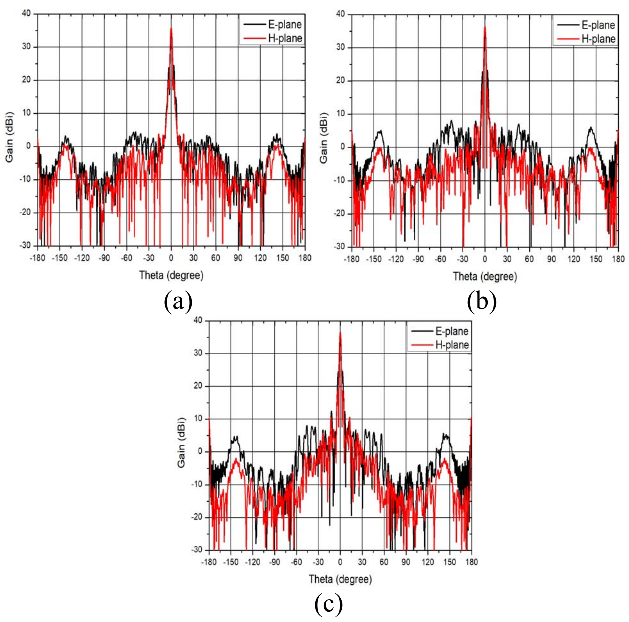

Fig. 6. Simulated gain patterns of E and H-plane. (a) 86GHz, (b) 92GHz, (c) 98GHz.

so there is no need to convert to a planar sub-reflectarray.

The required reflection phase of the elements arranged on the main reflectarray to compensate the phase of the incident field from the phase center of the pyramidal feed horn is calculated as follow: [1]

$$\phi_R = k_0(d_i - (x_i cos\phi + y_i sin\phi)sin\theta) \qquad (1).$$

Where, ϕ_R is the phase of the reflection coefficient for element i, k_0 is the propagation constant in vacuum, d_i is the distance between the element and the phase center of feed horn. The diameters of a main reflectarray and a sub-reflector are *Dm* and *Ds*, respectively. Two foci of the hyperbola are marked as *F1* and *F2*. The dimensions of the dual cassegrain reflectarray are as follows: *Dm*= 100mm (31.3λ at *f*=94GHz), *Ds*=19mm, *OF2*=83mm, *F/D*=0.922. Fig.5 shows the simulated peak gain curve for the proposed reflectarray according to frequencies. In simulation, it can achieves peak gain is 35.9dBi at 94GHz, aperture efficiency is 40%, and 1-dB gain bandwidth is 12GHz, from 86 to 98GHz. As mentioned in Section Ⅲ, these results are achieved by low sensitivity and small dispersion according to frequency variation. The *E* and *H*-plane gain patterns at 86, 92, 98 GHz of reflectarray antenna are shown in Fig. 6(a), (b), and (c), respectively.

5. Conclusion

In this paper, we proposed the w-band dual cassegrain large reflectarray with low sensitivity and broad bandwidth characteristics. In consideration of millimeter wave antenna characteristics which is very sensitive to the phase shift of the unit cell due to the manufacturing tolerance, the phase range is derived by individually subdividing variation strategy of the multi-resonant element. As a result, low sensitivity and small dispersion characteristics are achieved and these results can lead to high gain and broad bandwidth even though the reflectarray antenna has a very large size.

6. References

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