

Linearly Polarized Fed Circularly Polarized DRA Reflectarray

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Abstract Two dielectric resonator antennas are discussed to generate circularly polarized waves in a reflectarray antenna. In this case, two models are discussed here, one is DRA supported on cross slot, while the second is aperture coupled DRA supported on cross strip line coupled to DRA by cross slot. The verification of reflection coefficient phase of cell is satisfied by CST microwave studio and HFSS package. A complete array of 15 x 15 fed by a circular horn tilted by 45 degree was designed and simulated at X-band by full wave package. The simulated results show that the obtained 1.5-dB gain bandwidth and 3-dB axial ratio bandwidth of the reflectarray with aperture coupled DRA can reach as large as 25% and 12.5%.

Keywords Circular Polarization, Dielectric Resonator Antenna, Aperture Coupled DRA, Reflectarray

1. Introduction

High gain antennas with light weight and compactness are desired in satellite communications and radar applications. Downsizing of antennas and associated technologies have recently become somewhat of a trend in the antenna community. Reflectarrays offer a competitive alternative to reflectors in many narrow-band pencil-beam and shaped-beam antenna applications. One way to increase the antenna gain is to construct an antenna array with hundreds or thousands of elements. However, it usually suffers from a noticeable power loss in the feeding network. In contrast, a large aperture reflector antenna that avoids the usage of a feeding network can achieve a higher efficiency and hence is widely used in many communication systems. The reflectarray works much like a traditional reflector antenna. The planar reflectarray is rapidly becoming an attractive alternative because of its advantages such as low mass and volume, ease of manufacture, and possibilities offered for beam shaping and electronic beam control[1]. The circularly polarized (CP) antenna has been widely used since the electromagnetic wave emitted from the antenna is robust against the environmental interference. Therefore, a variety of different CP reflectarrays have been proposed and implemented in the literature. In[2,3], an angular rotation technique has been applied to the elements to attain the

phase delay for the CP reflectarrays. One essential condition of this technique is that the primary source must be a CP feed antenna. In[4], a linearly polarized feeder has been used with tilted angle of 45° with variable cross slot patch reflectarray and cross strip patch reflectarray for generating circularly polarized reflected beam while in[5] both the dimensions of the patch element can be adjusted to achieve the required 90° phase difference between orthogonal field components for circular polarization. Dielectric resonator antennas have been shown to offer several advantages including wide bandwidth and high radiation efficiency. They are viable candidates for numerous applications as either individual elements or in an array environment. A reflectarray that uses a DRA as the radiating element has been developed[6-10]. Also, DRA reflectarrays using linearly polarized feed was designed to realize circular polarization[7] based on the following principle. The polarization of the feed runs parallel to the diagonal line of the square cell element, and its linearly polarized field is decomposed into two equal components along the sides of the square cell. Then, the field with necessary phase shift on each component is reradiated by the cell element to attain a CP focused beam. In this letter, we present a DRA reflectarray cell element for designing the CP reflectarray antenna with linearly polarized feed. The reflectarray is illuminated by linearly polarized wave generated from a circular horn. A circularly polarized reflectarray using crossed slot DRA elements and cross strip line aperture coupled DRA are presented. The circular polarization is generated when a 90° for RHCP or -90° for LHCP phase difference between the phase response of the two arms of the crossed slot DRA element or cross

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strip line aperture coupled DRA is achieved. The analyses are carried out using CST microwave studio[12]. The circularly polarized reflectarray is designed to operate at X-band.

2. Numerical Results

2.1. Circular Horn Feeder

A center feed structure is used with a distance to the edge of the aperture of 10.5 cm. A X-band circular polarized horn antenna with dual feeds probes shifted by 90° for right hand circular polarization at 10GHz was used as feeder with center fed as shown in Figure. 4. The outer aperture of horn is 40mm, length of 40mm while the waveguide of 20mm. The focal to reflectarray dimension is $F/D=1$ for both designs.

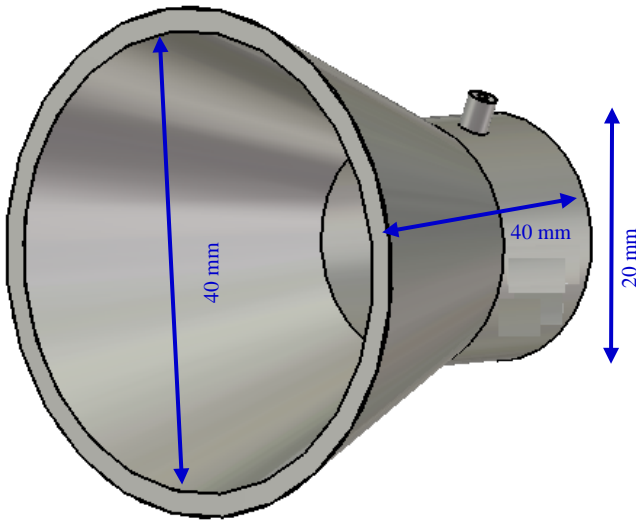


Figure 1. Circular horn structure.

Considering the array on the x-y plane illuminated by a feed horn, the required phase distribution, $\Phi(x_i, y_i)$, at each element of the array to collimate a beam in the (θ_o, ϕ_o) direction is determined as:

$$\begin{aligned} \varphi(x_i, y_i) &= k_o(d_i - \sin \theta_o(x_i \cos \phi_o + y_i \sin \phi_o)) \\ d_i &= \sqrt{(x_i - x_f)^2 + (y_i - y_f)^2 + (z_f)^2} \end{aligned} \quad (1)$$

where k_o is the propagation constant in vacuum, d_i is the distance from the feed horn to the element i of the array and (x_i, y_i) are the coordinates of the element.

2.2. DRA Supported on Variable Cross Slot Lengths

The cell consists of DRA with fixed size with substrate of same dielectric constant of DRA of 10.2, supported on ground plane with variable slot lengths L_1 and L_2 with phase differ of 90 degree to generate RHCP reflected beam as shown in Figure. 2.

The fixed size DRA with cross slot cell is designed to generate circularly polarized reflected beam at X-band. The geometry of reflectarray cell structure dimension is shown in Figure. 2. The cell size is 11mm x 11mm with dielectric

resonator of fixed thickness of 2.5mm with dielectric constant 10.2 supported on substrate with same dielectric constant with thickness of 0.5mm, ground with slot width 1.4mm, and variable length, Spacer of 2mm and ground plane. The waveguide model is used to calculate the reflected wave phase versus the slot length variation. CST microwave studio and HFSS software[11] are used to investigate the performance of the antenna for the variation of the phase of the reflection coefficient against slot length (L) with a phase range (0° - 330°) as shown in Figure. 3. Once the desired phase is calculated to compensate the different paths from feeder to reflectarray and make all reflected beams are coherently phase at the aperture plane by equation (1), L_1 is calculated and L_2 is calculated from the same Figure. 3 after add 90° to phase of L_1 .

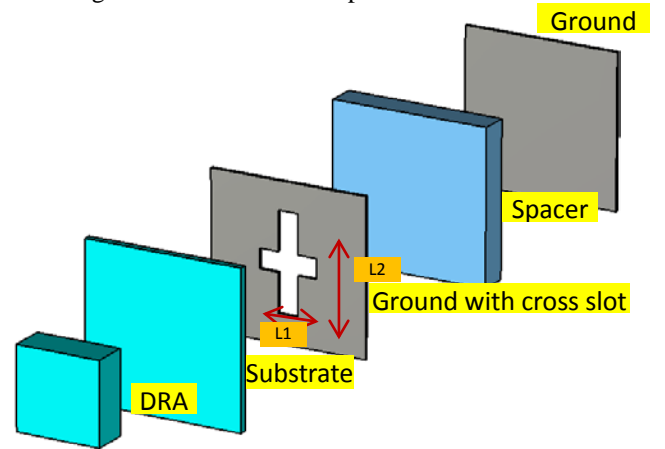


Figure 2. DRA with cross slot cell.

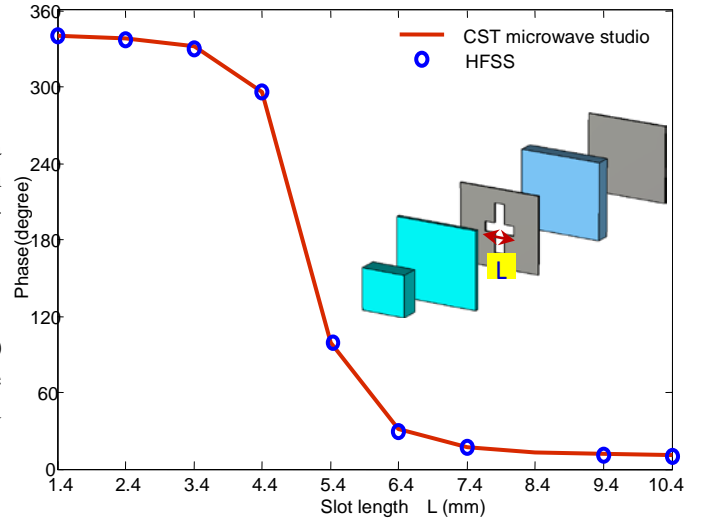


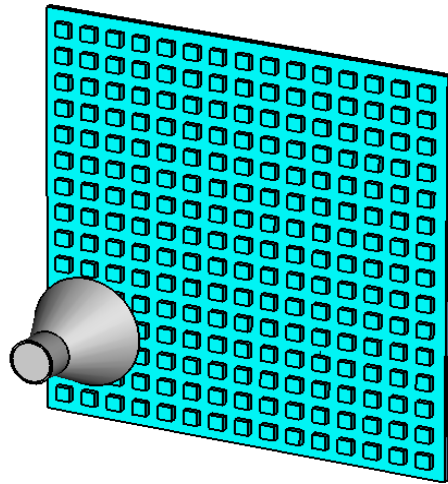
Figure 3. Phase versus slot length.

The complete array structure is shown in Figure. 4, with layers of cross slot of variable lengths. It is subdivided into 225 elements of equal size of 11mm x 11mm arranged in a lattice of 15 x 15 elements as shown in Figure. 4. Simulated XZ plane (H plane) and YZ plane (E plane) are shown in Figure. 5 and 6 respectively. The reflected beam is broadside. As designed, the RHCP pattern is dominant and it achieves a maximum directivity of 24dB at 10.5GHz, the

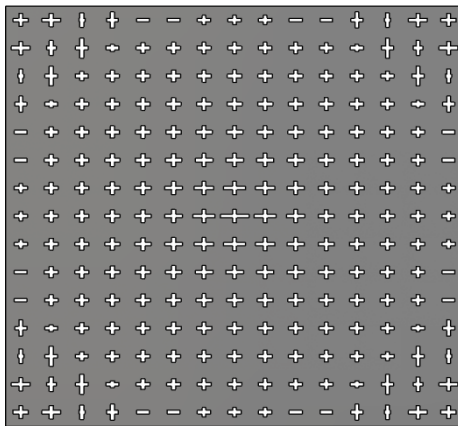
axial ratio at the desired frequency 10GHz was 2dB with gain of 23.5dB. The 1.5dB gain bandwidth of reflectarray is about 14% from 9.6GHz to 11GHz with aperture efficiency of 59% at 10 GHz according to equation :

$$G_o = \frac{4 \times \pi \times \eta_{ap} A_{phy}}{\lambda_o^2} \quad (2)$$

Where G_o is the gain, A_{phy} is the physical area (18cm x 18cm), While the 3dB axial ratio bandwidth is from 9.8GHz to 10.9GHz, about 11% as shown in Figure. 7 and 8 respectively.



(a)



(b)

Figure 4. Array geometry a) 3 D view b) Cross slot layer.

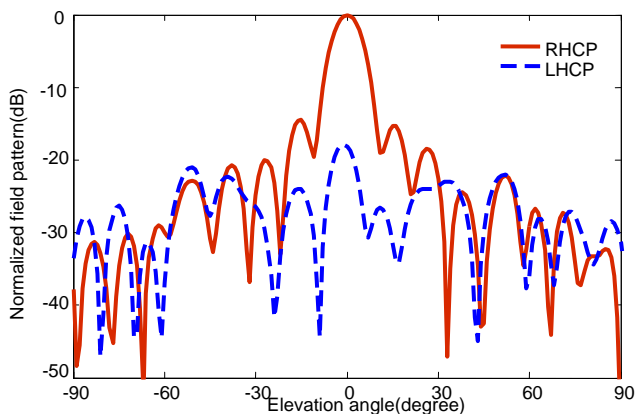


Figure 5. XZ plane normalized field pattern at 10GHz.

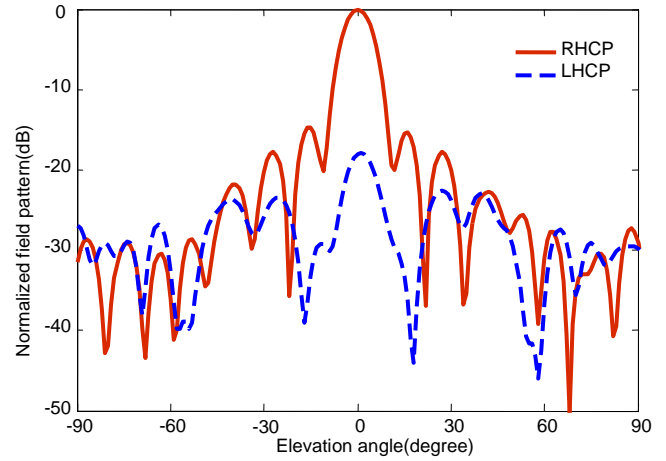


Figure 6. YZ plane normalized field pattern at 10GHz.

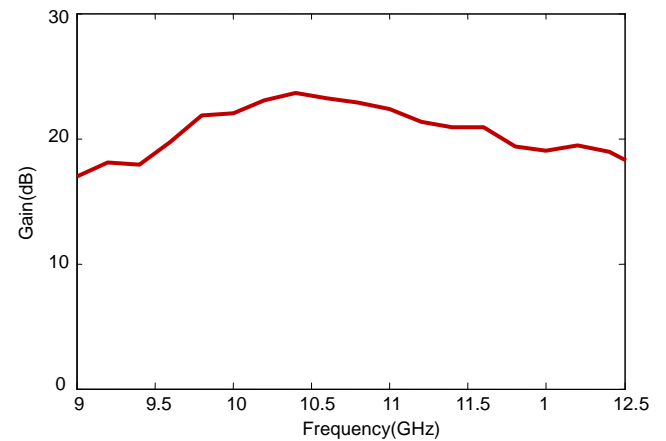


Figure 7. Gain versus frequency.

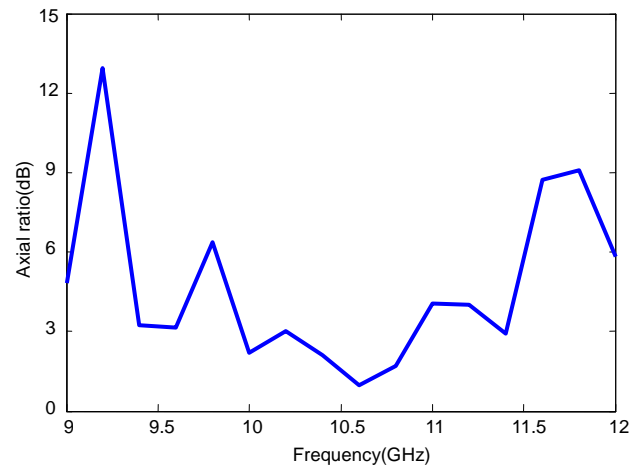


Figure 8. Axial ratio versus frequency.

2.3. Aperture Coupled Reflectarray with Cross Strip Lines

The cell is designed to operate at X-band with a phase range that covers 360 degree. The geometry of an aperture coupled DRA reflectarray cell structure dimensions is shown in Figure. 9.

The cell size is 12mm x 12mm with dielectric resonator of fixed thickness of 6mm with dielectric constant 10.2, ground with slot of dimension 5mm x 0.6mm, transmission

line strip width of 0.8mm with variable length was supported on lower substrate of dielectric constant 10.2, Spacer of 2.5mm and ground plane. Also, the waveguide model is used to calculate the reflected wave phase versus the dielectric resonator sizes variation. CST microwave studio and HFSS software are used to investigate the performance of the antenna for the variation of the phase of the reflection coefficient against transmission line length (L) with a complete phase period (0° - 360°) as shown in Figure. 10.

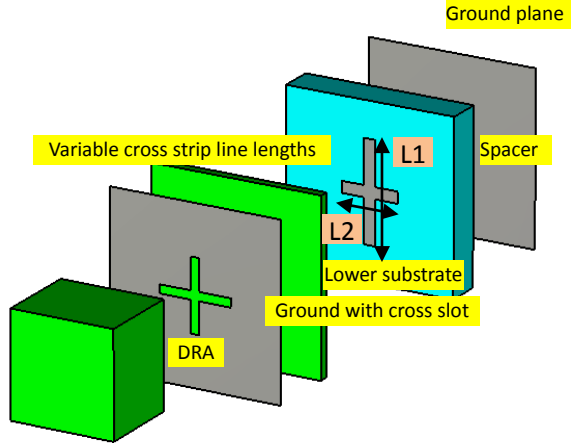


Figure 9. Aperture coupled DRA cell.

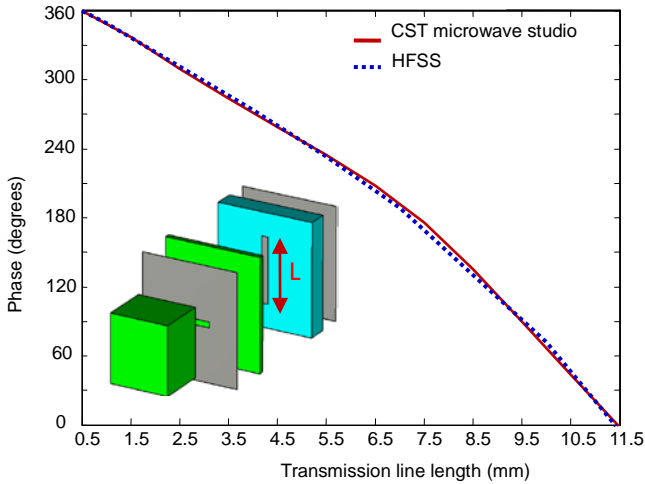


Figure 10. Phase versus DRA length.

The array is subdivided into 225 elements of equal size of 12mm x 12mm arranged in a lattice of 15 x 15 elements. Simulated XZ plane(H plane) and YZ plane(E plane) are shown in Figure. 11 and 12 respectively. Also as designed, the RHCP pattern is dominant and it achieves a maximum directivity of 23.5dB at 10.5GHz, the axial ratio at the desired frequency 10GHz was 1dB with gain of 23dB. The 1.5dB gain bandwidth of reflectarray is about 25% from 9.5GHz to 12GHz while the 3dB axial ratio is from 9GHz to 10.4GHz or about 14% with aperture efficiency of 44% at 10GHz as shown in Figure. 13 and Figure. 14, respectively. Also, as the desired cell phase is calculated to compensate the different paths from feeder to reflectarray and make all reflected beams are coherently phase at the aperture plane by equation (1), L_1 is calculated and L_2 is

calculated from the same Figure. 10 after add 90° to phase of L_1 .

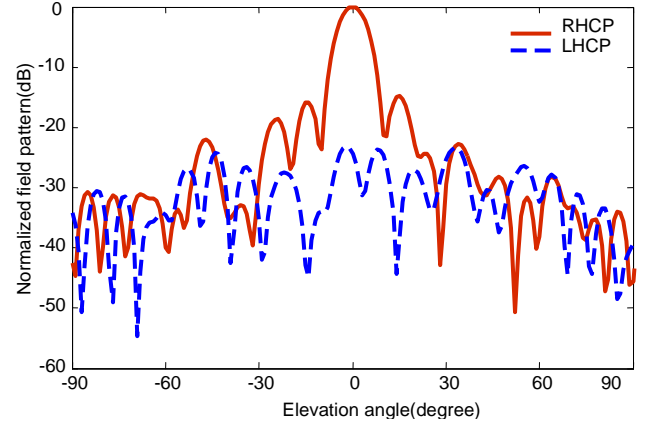


Figure 11. YZ plane normalized pattern at 10GHz

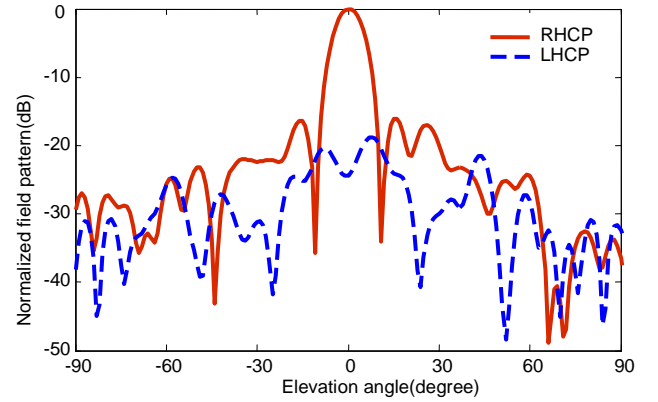


Figure 12. XZ plane normalized pattern at 10GHz.

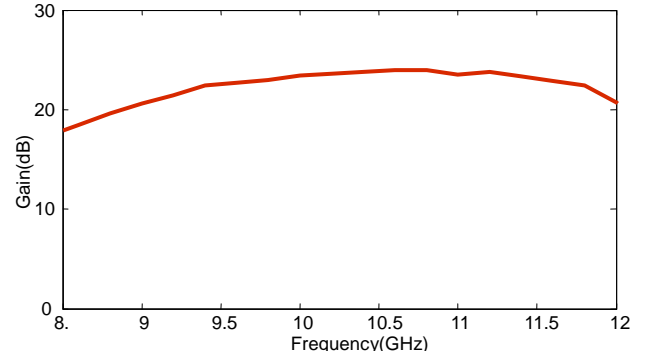


Figure 13. Gain versus frequency.

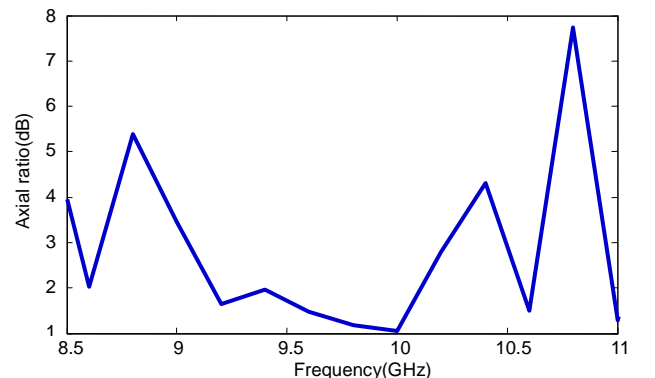


Figure 14. Axial ratio versus frequency.

3. Conclusions

New types of designing circularly polarized reflectarray antenna was presented in this paper. DRA with cross slot of variable slot lengths is presented with suitable gain of 23.5dB at 1GHz and 3dB axial ratio of 11% at X-band. The second model was aperture coupled DRA with cross strip line and cross slot are presented with gain of 23dB at 10GHz and 3dB axial ratio of 14% at X-band. The phase figure was verified using CST and HFSS with good agreement between them.

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