Novel Element for Bandwidth Improvement of the Reflect-array Antenna

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Abstract— **In this paper novel reflect-array antenna elements are proposed using aperture-coupled dielectric resonator antenna structures. Using these new structures, wide phase range and wide frequency bandwidth (up to 28.5%) with parallel and linear phase curves are obtained. In each case, an array consisting of 289 elements was simulated using the finite integration technique (FIT). The arrays exhibit 3-dB gain bandwidth and radiation efficiency up to 28% and 56%, respectively. The results are validated using transmission line method (TLM).**

Keywords: **Reflect-array antenna, aperture-coupled dielectric resonator antenna, phase curves.**

I. Introduction

Reflectarray antenna as a combination of reflector antenna and array antenna, with its features such as easy installation and construction, eliminating the complexity problems and losses of the microstrip feed lines by using the space feed, and the capability of scanning the beam by placing phase shifters in the elements, is a viable alternative high gain antenna. The reflect-array antenna is composed of many elements with proper phase shifts that are located on a flat surface and illuminated by a feed antenna that can convert the incident wave to a planar phase front in the far-field region of the antenna [1]. This phase shift can be obtained by altering any of the geometrical parameters of the elements.

The concept of reflect-array was introduced in 1963 by Berry [2] for the first time. Despite all the benefits of the reflect-array antenna, narrow bandwidth is a main drawback of it. A lot of works has been done to increase the bandwidth of the reflect-array antenna. Use of certain shapes for the element [3] and use of true time delay lines [4] are from these works. Although the phase range of 360 degrees is sufficient for the reflect-array antenna design, but as shown in [5], using more phase shifts results in a better performance. Also as expressed in [6], linear and parallel phase curves represent the better performance of the antenna in terms of bandwidth.

The aperture coupled structure due to these two mentioned advantages is a good choice as a reflect-array antenna element. Using a special form of slot in the aperture coupled structure is one of the works that has been done to increase the bandwidth of the reflect-array antenna. In [7] by using an hourglass shape for the slot in the aperture coupled patch structure, a 24% gain bandwidth is obtained. In this work, the side lobe level is only about 10 dB less than the main lobe and the efficiency in the central frequency is equal to 27 %.

In recent years, the dielectric resonator antenna is used as a reflect-array antenna element. From the features of this antenna: more bandwidth than the patch antenna, low loss and high radiation efficiency can be noted [8]. In the year 2000, Keller used DRA with variable dimensions as a reflect-array antenna [9]. DRA loading with variable slot and strip were studied in [10] and [11], respectively. In [12] by using DRA in the aperture coupled structure, an 18% gain bandwidth is obtained.

In this paper, using the bow tie shape for the slot, we have increased the gain bandwidth and radiation efficiency. The proposed element is composed of rectangular DRA that is coupled to the stub through the bow tie slot in the ground plane. Line can be changed symmetrically on both sides of the slot. On the other hand, line can have a fixed and a variable part, namely asymmetrical changes. Both cases in this paper have been examined. Another new design that we have examined here is creating a curvature on the both sides or one side of the microstrip line. After obtaining phase curves and array design for each of these four modes, eventually the obtained results are compared with previous works. Comparison of the results shows the better performance of the proposed elements in terms of gain bandwidth, cross polarization level and antenna radiation efficiency. For calculation of gain and pattern, finite integration technique (FIT) in CST microwave studio software is used. Finally, to confirm the results, calculations are carried out with transmission line method (TLM) in CST MS software.

II. Analysis of the Proposed Unit cell

The proposed element is composed of a rectangular dielectric resonator antenna with ε_r=10.2 that is placed on a dielectric substrate with ε_r=10.2 and thicknesses of 1.5 mm. On one side of the substrate there is a ground plane with a bow tie slot. DRA is coupled to the microstrip line through this plane that is placed on the other side of the substrate. Phase shift is obtained with change in the length of the stub. As noted in the previous section, four cases are examined. In the first and second cases, line is a rectangle and it can change symmetrically or asymmetrically around the slot. In the third case one side of the line has curvature. In the fourth case both sides of the line have curvature.

A) *First case*

The element is shown in Fig. 1 and microstrip line changes are asymmetrical around the slot. The microstrip line is shown in Fig. 2. After checking different values for the parameters of the structure, optimal values have been determined in Table 1. Figure 3 show phase curves based on

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asymmetrical changes in the length of the stub at three different frequencies. For drawing the phase curves, values obtained in Table 1 were used with Lm=3.1 mm. A phase range more than 400 degrees is obtained. Phase curves are linear and parallel in the 22.5 % frequency bandwidth.

B) Second case

The element investigated in this section is as shown in Fig. 1 but with symmetrical change around slot. The optimal values are defined in Table 1. Figure 4 show phase curves based on symmetrical changes in the length of the stub at three different frequencies. For drawing the phase curves values obtained in Table 1, were used. A phase range more than 400 degrees is obtained. Phase curves are linear and parallel in the 27 % frequency bandwidth.

C) Third Case

In this section one side of the microstrip line has curvature as shown in figure 5. The final values obtained for impedance matching and linear and parallel phase curves are shown in Table 2. Figure 7 shows phase curves based on changes in the length of the stub at three different frequencies. For drawing the phase curves, values obtained in Table 2 were used. A phase range more than 400 degrees is obtained. Phase curves are linear and parallel in the 21.5 percent frequency bandwidth.

D) Fourth case

In the final structure, both sides of the line have curvature. The element is as shown in Fig. 1. The microstrip line is shown in Fig. 6. The optimal values are shown in Table 2 and the radius is equal to 0.7 mm. Figure 8 shows phase curves based on changes in the length of the stub at three different frequencies. Values obtained in Table 2, were used for drawing the phase curves. A phase range more than 400 degrees is obtained. Phase curves are linear and parallel in 28.5 % frequency bandwidth.

As a result, phase curves obtained in four cases are linear in comparison with [10] and [11]. Also, the phase range and frequency bandwidth with parallel and linear phase curves are greater. These conditions show better performance of the investigated structures compared to the previous works.

III. Reflect-array Antenna Design

After designing the element and obtaining the phase curves, an array should be designed to obtain the antenna far-field characteristics. The array is illuminated by a pyramidal horn with an aperture size of 4.94 cm × 7.32 cm.

A) First Case

The center frequency for this element is 10.7 GHz. Figure 9 shows the array structure without DRA. 289 elements are considered that are placed in an area of 28.9×28.9 cm^2. The optimal value for the focal length is obtained equal to 36.71 cm. Figure 10 show co-pol and cross-pol patterns for the E-plane and H-plane at the frequency of 10.7 GHz. As it is apparent, the cross-polarization level is less than -100 dB and the side-lobe level is less than -15 dB. To confirm the results, calculations have been performed using transmission line method. In Fig. 11 co-pol patterns for the E-plane and H-plane are plotted using FIT and TLM. Figure 12 shows gain versus frequency using the two methods. According to this figure, a gain bandwidth equal to 27 % is obtained. The gain at the frequency of 10.7 GHz is 26.8 dB, that is corresponding to 47.83 % radiation efficiency.

B) Second case

The center frequency for this element is 10.4 GHz. The number of elements and focal length is as previous case. Figure 13 shows co-pol and cross-pol patterns in E-plane and H-plane at the frequency of 10.4 GHz. As it is apparent, the cross-polarization level is less than -100 dB. To confirm the results, calculations have been performed using the transmission line method. In Fig. 14, the co-pol patterns in E-plane and H-plane are plotted using FIT and TLM. Figure 15 shows gain versus frequency using the two methods. According to this figure, a gain bandwidth equal to 22 % is obtained. The gain at the frequency of 10.4 GHz is 28 dB, that is corresponding to 56.4% radiation efficiency.

C) Third case

The center frequency for this element is 10.65 GHz. 256 elements are considered that are placed in an area of 27.2 cm × 27.2 cm. The optimal value for the focal length is obtained equal to 34.55 cm. Figure 16 show co-pol and cross-pol patterns in E-plane and H-plane at frequency of 10.65 GHz. As it is apparent, cross-polarization level is less than -120 dB and side-lobe level is less than -14 dB. To confirm the results, calculations have been performed using transmission line method. In Fig. 17 co-pol patterns in E-plane and H-plane are plotted using FIT and TLM. Figure 18 shows gain versus frequency using the two methods. According to this figure, a gain bandwidth equal to 10 % is obtained. The gain at the frequency of 10 GHz is 27.3 dB, that is corresponding to a 43.77 % radiation efficiency.

D) Fourth Case

Figure 19 show co-pol and cross-pol patterns in E-plane and H-plane at the frequency of 10.5 GHz. As it is apparent, cross-polarization level is less than -120 dB and the side lobe level is less than -15 dB. To confirm the results, calculations have been performed using transmission line method.

In Fig. 20 co-pol patterns in E-plane and H-plane are plotted using FIT and TLM. Figure 21 shows gain versus frequency using the two methods. According to this figure a gain bandwidth equal to 27.6% is obtained. The radiation efficiency at the frequency of 10.5 GHz is 33 %.

IV. Discussion

In Table 3 the results of these four cases are compared. As it is clear, the best performance in terms of gain bandwidth is related to the third element. Cross polarization level is very low in all elements and side lobe level performance is acceptable and better than [7]. In all cases, higher radiation efficiency than [7] is obtained. Although the radiation efficiency in [12] is very high but the gain bandwidth for all cases studied in this paper is more than the gain bandwidth obtained in [12].

V. CONCLUSION

In this paper, we have studied a new element for reflect-array antenna. It consists of a DRA aperture-coupled structure with bow tie slot. Four elements have been studied, which include the following cases: symmetric change in the line, asymmetric change in the line, creating curvature in one side of the line, and creating curvature in both sides of the line. In all cases, the obtained phase curves are linear and parallel in a wider frequency bandwidth than the previous works and phase range is more than 400 degrees. For design of the array, 289 elements in three cases and 256 elements in one case are considered that are illuminated with a pyramidal horn antenna. Comparing the performance of these four elements with previous works show better performance in terms of gain bandwidth, cross polarization level and radiation efficiency.

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