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Investigations into a Circular Ring with Variable Length Arc Element for Phasing Wideband Reflectarray

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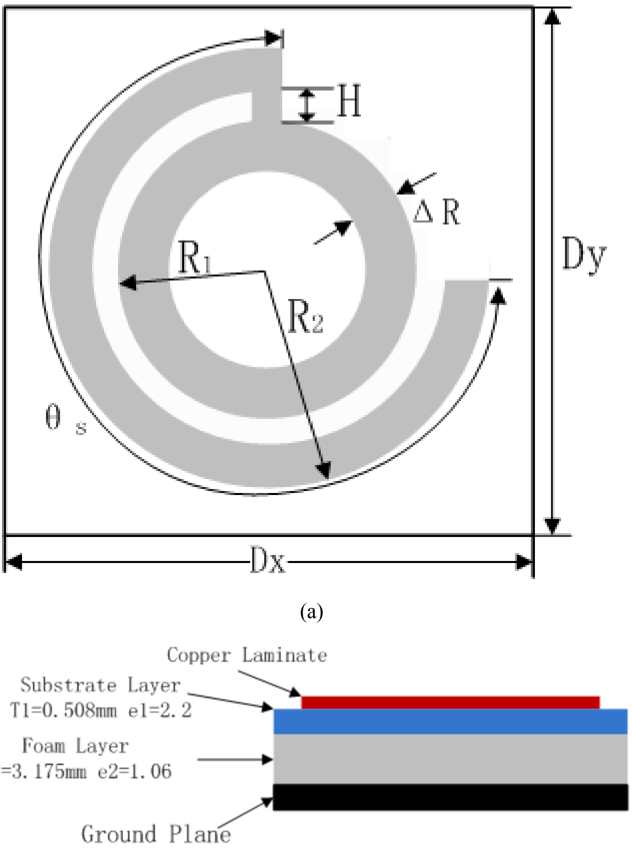
***Abstract* — A new phasing element for use in a wideband microstrip reflectarray is described. It is formed by a variable length arc attached to a fixed size circular ring. It is shown that the new phasing element offers a double resonance with an increased phasing range that is welcome in the reflectarray phase compensation procedure. The extended phase range enables the use of a thicker substrate to obtain a slower phase slope and thus an increased operational bandwidth of the reflectarrray. In the proposed approach, an increased reflectarray thickness is achieved using a foam layer placed underneath the substrate laminate carrying the phasing elements pattern. The usefulness of the newly proposed phasing element is demonstrated in the design of a 13x13 element reflectarray. Full wave EM simulations carried out with CST Microwave Studio confirm a wideband operation of the designed reflectarray.**

***Index Terms* — Reflectarray, wideband, single layer, printed antenna.**

I. INTRODUCTION

A microstrip reflectarray is considered as a viable alternative to a traditional parabolic reflector [1]. It uses a planar reflector formed microstrip antenna elements with a suitable phasing mechanism which enables conversion of a spherical wavefront produced by a feed into a planar wavefront. Due to the use of microstrip antenna technology, the reflectarray offers good tradeoff between a phased array and a conventional parabolic reflector. Its advantage over the traditional parabolic reflector is that a large number of microstrip patch elements offer a considerable freedom to beam shaping at a much reduced cost compared to phased arrays [2]-[4]. For its proper operation the reflectarray requires at least 360° phasing range of its elements at a given frequency of operation. This requirement is usually not met by typical microstrip phasing elements such as variable size patches developed on a single substrate. In this case, an insufficient phasing range (around 300°) and a sharp phasing slope of variable size microstrip patches lead to narrow operational bandwidth of the reflectarray. To overcome this shortfall, multi-layer variable square patch structures have been proposed to offer an increased phasing range which exceeds the required 360°. These multi-layer structures also offer a reduced phasing slope when developed on thick substrates enabling an increased operational bandwidth with smaller manufacturing errors [5]-[6]. However, the inconvenience of this approach is that each layer of the multi-layer reflectarray has to be manufactured separately. In turn, the assembly should take care of eliminating air gaps. As a result, the manufacturing process becomes elaborate and expensive. To counter this problem, single-layer double-ring structures offering multi-resonance operation with an increased phasing range (of more than 360°) and low phasing slopes have been investigated as viable alternatives to multi-layer counterparts [7]-[8].



(a)

(b)

Fig. 1b Configuration of the proposed phasing element (a) Top View, (b) Side View

However, the use of double-ring phasing elements faces some manufacturing problems because of a narrow gap between rings. As a result, manufacturing errors can result in phase errors leading to a deficient reflectarray.

This paper elevates this problem by proposing a new phasing element for use in a single layer microstrip reflectarray. The new phasing element is formed by a variable length circular arc which is attached to a fixed size circular ring. In this arrangement, the phase is controlled by the arc length. The new element is easy to manufacture compared to the double ring structure described in [7]. Parameters of the new phasing structure are carefully chosen to offer both the required phasing range and slow phasing slope for bandwidth enhancement. Its phasing properties are investigated by simulating its behavior in a unit cell with periodic boundaries. Finally, using this new phasing element a 13×13 element reflectarray is designed. Full wave EM simulations of the array are carried out with CST Microwave Suite. The reflectarray performance is assessed in terms of its radiation pattern and gain. The CST MS generated results are confirmed using alternative computation formulas in [1].

II. UNIT CELL CONFIGURATION AND DESIGN

Investigations focus on a single layer reflectarray operating in X band with the center frequency of 11.5GHz. The newly proposed microstrip phasing element is shown in Fig.1a and Fig.1b. The planar array assumes a square lattice of periodicity of $D_x=D_y=15$mm, which is equivalent to 0.58 wavelength at the design frequency. The proposed phasing element is composed of a circular ring of width ΔR and radius R_1 with a circular arc of radius R_2 attached to the ring using a notch of height H. The electrical length of the arc is $_s$. This parameter is the main parameter responsible for controlling the phase of reflection coefficient of a unit cell. it The element is supported by a thin substrate of thickness $T_1=0.508$ mm and relative permittivity $_1=2.2$. A thick foam of thickness $T_2=3.175$ and relative permittivity $_2=1.06$ is placed under the substrate to reduce the slope of the reflection phase characteristic so that the operational bandwidth is increased and manufacturing errors are minimized.

The phase characteristics of the element are obtained by performing full-wave electromagnetic simulations of a unit cell [4]. Simulations utilize the Unit Cell boundary conditions available in the Frequency Solver of CST Microwave Studio 2010. The assumed unit cell represents a TEM waveguide structure when a wave is normally incident on a infinite periodic array of identical elements, as illustrated in Fig.2.

III. PHASE RESPONSE RESULTS AND PARAMETRIC STUDY

In simulations, the radius of the circular ring element (R_1) is fixed at 4.6 mm. The width of the phasing arc is the same as that of the circular ring and is given as 0.1* R_1. The notch height H is chosen as 0.2* R_1. In order to investigate the performance of the proposed structure, two parametric studies are conducted. These include the effect of foam thickness T and the notch height H.

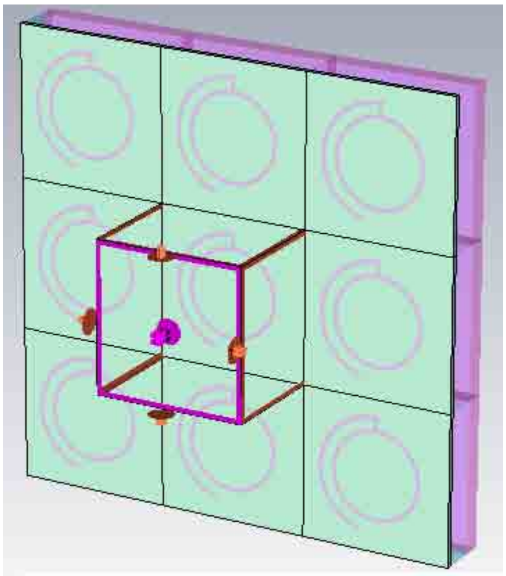


Fig. 2 Configuration of phasing element's unit cell.

In the first investigation, three different foam thicknesses are considered as ruled by their availability: $T_2=3.175$ mm, $T_2=6.35$mm and $T_2=9.525$mm.

Fig. 3 shows the phase response as a function of the electrical length of the phasing arc ($_s$). From results shown in Fig.3 it can be seen that the reflection phase slope becomes slower as the foam thickness is increased. At the same time, the phasing range is the same for the three different thickness cases. Therefore, increasing the foam thickness offers reduction in the phasing slope without sacrificing the phasing range. This property helps to increase the operational bandwidth of the reflectarray.

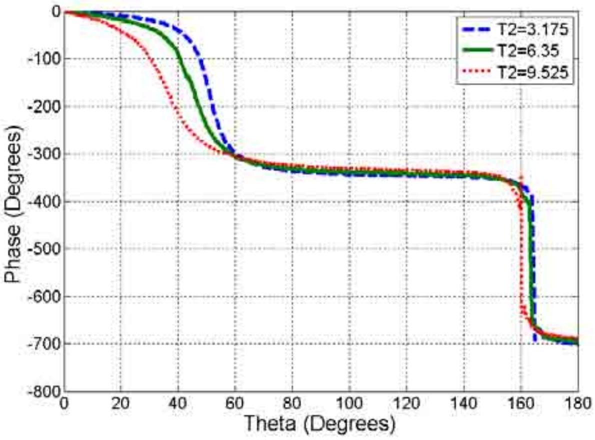


Fig. 3 Phase characteristic of phasing element for foam thickness of 3.175mm, 6.35mm and 9.525mm

Another parametric study focuses on the coupling effect between the phasing arc and the circular ring. For comparison, two cases of notch height H; 0.2*R_1 and 0.4*R_1 are considered when the foam thickness is set to 3.175mm. Fig.4 shows the phase characteristic results for the two investigated cases. As observed from results in Fig.4, the phasing slopes are similar and the phasing range remains unchanged, as the distance between the circular ring and the phasing arc is increased. The only different behavior brought out by the increase of H is the location of resonances which are shifted to the lower values of $_s$.

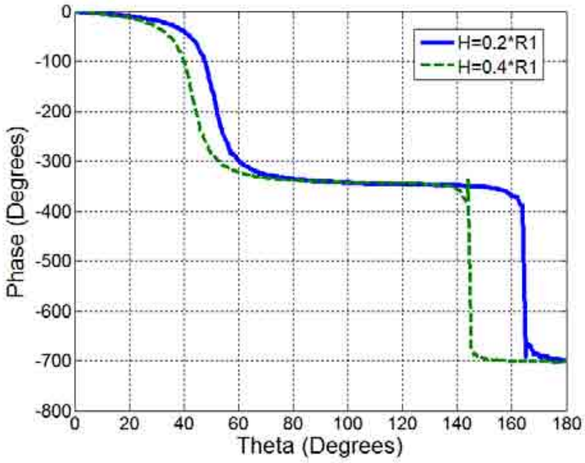


Fig. 4 Phase characteristic of phasing element for notch height H of 0.2* R1 and 0.4* R1

As observed from both Fig.3 and 4, there are two resonances which govern the phase characteristic. The main resonance, being in the lower range of $_s$, offers a gentler phasing slope. This is of importance in achieving a wideband performance of the unit cell and the reflectarray. By changing $_s$ from 0° to 62°, the phase range of 400° with a slow slope is obtained. It is apparent that that the proposed phasing element offers the required 360° phase range with a gentle slope.

IV. SIMULATION OF REFLECTARRAY

In order to demonstrate the advantage of the proposed phasing element, a reflectarray formed by 169 elements (13×13) is designed using the phase characteristics obtained in the earlier analysis. In the design, the spacing between elements is fixed at 15mm (0.58 wavelength at 11.5GHz). A conical horn with aperture radius of 21.5mm, presented in [8], is selected as the primary focus feed. This feed is optimized to achieve a flat gain in the 11.0GHz to 12.0GHz band. In order to minimize sidelobes of the array, the focal length F is chosen to be equal to the reflectarray aperture size D=195mm. The required compensation phase at each unit cell is computed by using the following formula from [2]:

$$\phi_{m,n} = k_0(d_i - (x_i \cos\varphi_b + y_i \sin\varphi_b)\times\sin\theta_b) \qquad (1)$$

In this equation, x_i and y_i are the coordinates of each element in X and Y directions, and d_i is the distance of each element to the phase centre of feed.

The required physical length of each element is obtained from the characteristics shown in Fig.3 assuming the foam thickness of 3.175mm. Next, the entire reflectarray is simulated in CST. In order to reduce the computing time, the conical horn's radiation pattern is saved first, and then the proposed array is illuminated by the feed in CST Microwave Studio's I-solver, in which the surface mesh is used to cover the patch elements only. Compared to the volume mesh of Transient Solver, the surface mesh in Integral Solver greatly reduces the number of mesh cells and hence the computation load. The full wave simulation took one and a half hour on a computer server of 8 cores and 16G RAM. In order to confirm the CST results, the radiation pattern was also generated using the formula described in [1].

Fig.5. shows the radiation pattern results at the center frequency of 11.5GHz obtained using CST and the method given in [1].

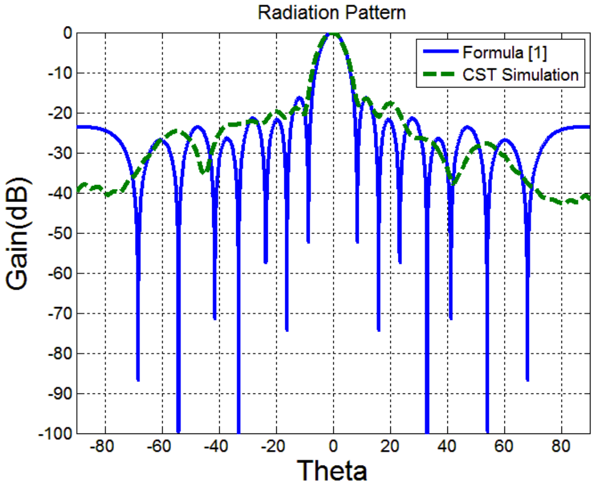


Fig. 5 Radiation patterns obtained from CST and formula given in [1].

A good agreement between the two sets of results is observed. The main beam overlaps well in both patterns with the beamwidth of approximately 8° and the first side lobes at about -16dB in the two cases. In addition, there is an agreement in location of the second side lobes. Due to the small number of elements in the proposed reflectarray, the 3rd and higher order sidelobes level are not well predicted by the formula given in [1] because the side elements do not behave as in an infinite array.

Fig.6 shows the radiation patterns at the center frequency (11.5GHz), as well as at the lower (11.0GHz) and upper portion (11.7GHz) of the investigated frequency band. It is apparent that the radiation pattern of the proposed reflectarray remains approximately constant across the whole desired operating frequency band except for some side lobes' variation. The first and second side lobes become a little higher at lower and higher edges of the band.

Fig.7 shows the reflectarray's gain as a function of frequency as obtained from CST simulations. In the simulation, the same horn radiation pattern is assigned for all the frequency points. Note that if the varying horn gain is included, only a small change in the reflectarray gain of a small fraction of dB is experienced.

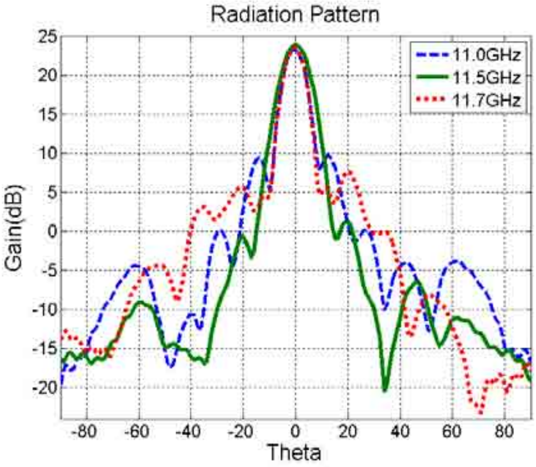


Fig. 6 Radiation Pattern at the centre, upper and lower parts of the 11.0-12.0 GHz band.

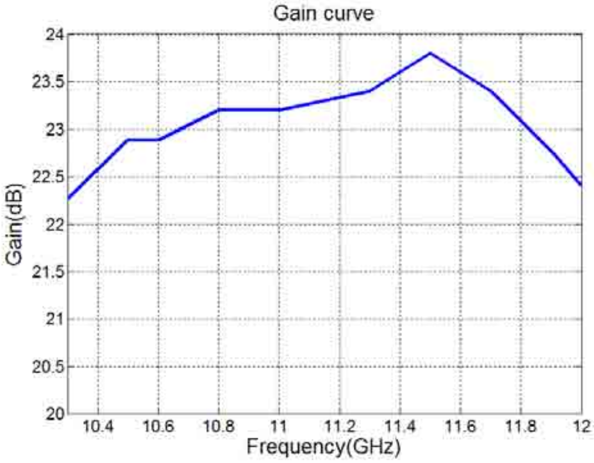


Fig. 7 Gain variation of the proposed array across the frequency band.

As can be seen in Fig. 7, the reflectarray has a maximum gain of 23.8dB at the centre frequency of 11.5GHz and then the gain degrades slowly as frequency varies. The 1 dB gain variation occurs across the 10.45GHz to 11.87GHz band. Therefore, the proposed reflectarray exhibits a 1dB gain bandwidth of around 12.3%.

VI. CONCLUSION

A novel element in the form of a circular ring accompanied by a variable length circular arc for phasing a single layer microstrip reflectarray has been described. The new element offers a multi resonance operation which leads to an extended phase range required for a reflectarray with an increased operational bandwidth. To achieve a slower phase slope as a function of the arc length, a foam layer is applied under the substrate laminate carrying the phase element pattern. The phasing behavior of the newly proposed element has been thoroughly investigated using a full-wave EM simulation tool CST Microwave Studio. The obtained results have shown that the proposed phasing structure offers both sufficient phasing range and a slow phasing slope to fulfill the requirement of wideband operation of the reflectarray. The usefulness of the new phasing element has been demonstrated in the design example of a primary fed 169 element reflectarray operating at X-band. The full wave simulation of the array has been performed in CST Microwave Studio showing a 12.3% 1dB bandwidth of this antenna.

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REFERENCES

[1] J. Huang, "Microstrip reflectarray", Proc. 1991 *IEEE Antenna Propagat. Symp*., pp. 612–615, June 1991.

[2] D. M. Pozar, S. D. Targonski, and H. D. Syrigos, "Design of millimeter wave microstrip reflectarrays", *IEEE Trans. Antennas and Propagation*, Vol. 45, No. 2, pp. 287–296, Feb. 1997

[3] J. A Zornoza and M. E. Bialkowski," Australia and New Zealand satellite coverage using a microstrip patch reflectarray", *Microwave and Optical Technology Letters*, vol. 37, No. 5, pp. 321-325, June 2003

[4] F.-C. E. Tsai and M. E. Bialkowski, "Designing a 161-element Ku-band microstrip reflectarray of variable size patches using an equivalent unit cell waveguide approach", *IEEE Trans. Antennas and Prop*. vol. 51, No. 10, pp. 2953-2962, Oct. 2003.

[5] J.A. Encinar, "Design of two-layer printed reflectarrays for bandwidth enhancement", Proc. 1999 *IEEE AP-S Symp*., pp. 1164–1167, 1999..

[6] J.A. Encinar, "Broadband design of three-layer printed reflectarrays", *IEEE Trans. Antennas and Propagation*, Vol. 51, No. 7, pp. 1662–1664, July 2003..

[7] M.E. Bialkowski and K.H. Sayidmarie, "Investigations into phase characteristics of a single-layer reflectarray employing patch or ring elements of variable size" *IEEE Trans. Antennas and Prop*., Volume 56, No. 11, pp3366 – 3372, Nov. 2008.

[8] Yuezhou Li, M.E. Bialkowski, K.H. Sayidmarie and N.V. Shuley "Microstrip reflectarray formed by double elliptical ring elements," Proc. *4th European Conference on Antennas & Propagation (EuCAP),* pp. 1-4, Barcelona, Spain, 12-16 April, 2010.