Wideband reflectarray antenna using stub-loaded inverted E elements for Ku-band applications

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***Abstract*— This paper presents the design and experimental evaluation of a wideband reflectarray antenna using stub-loaded inverted *E* elements. A reflectarray of size 200 × 200 mm^2 with 18 x 18 such elements is fabricated and measured for its radiation patterns. Through simulation-based study, two optimal gain-bandwidth performances are shown to be achievable by varying the focal distance and inter-element spacing values. In case 1, a 3-dB gain-bandwidth of 40% is observed with a peak gain and an aperture efficiency of 23.6 dBi and 28%, respectively. In case 2, a 2-dB gain-bandwidth of 32% is noted with a peak gain of 25.2 dBi and an aperture efficiency of 42%.**

Keywords—reflectarray, cross-dipole, wideband elements.

I. Introduction

Reflectarray antennas are being used in space, radar, and remote sensing applications as an alternative to the parabolic reflector [1]. In recent years, bandwidth enhancement of such antennas has been of interest to several researchers [1-5]. It is noted from open literature that the bandwidth of a reflectarray can be enhanced by employing appropriate element, such that it exhibits a linear reflection phase response along with a large dynamic phase range. On this note, several researchers have proposed various elements in the open literature to offer a smooth reflection phase performance without compromising the phase range [1], out of which, elements based on cross-dipole loaded with appropriate stubs are widely reported [1-7]. The bandwidth enhancement of a reflectarray would also be achieved by optimizing the feed position and an inter-element spacing of a reflectarray [1]. Considering these studies, bandwidth enhancement of a reflectarray is attained by employing the stub loaded inverted *E* elements and by optimizing inter-element spacing and feed position values. All simulations are done with the help of CST Microwave Studio tool 2018.

Unit cell analysis is presented in the following section. Section 3 discusses the design and analysis of the reflectarray. Section 4 presents the simulation and experimental results. Section 5 concludes the paper.

II. Stub-loaded inverted *E* loaded element design

A unit cell element of size 10.71 × 10.71 mm^2 (0.5λ×0.5λ) is designed at the frequency of 14GHz, and its configuration is shown in Fig. 1(a). This element is constructed by attaching simple dipole stubs with the cross-dipole. It is printed on the Arlon 217LX dielectric substrate (ε_r~2.2) of thickness 0.508mm as shown in Fig. 1(b). The reflection phase and magnitude characteristics of this element is estimated as a function of its geometrical length using the infinite array approach in the simulation tool at 14 GHz, and plotted in Fig. 1 (c). It is observed from this figure that smooth phase response along with a good dynamic phase range of about 440° is achieved. In order to evaluate the phase bandwidth performance of the proposed element, reflection phase values are estimated as a function of the length of element for the frequency range of 10-18 GHz in steps of 1 GHz, as shown in Fig. 1 (d). It is observed from this figure that the phase difference between the curves obtained at different frequencies is within the acceptable range of ±45° [9].

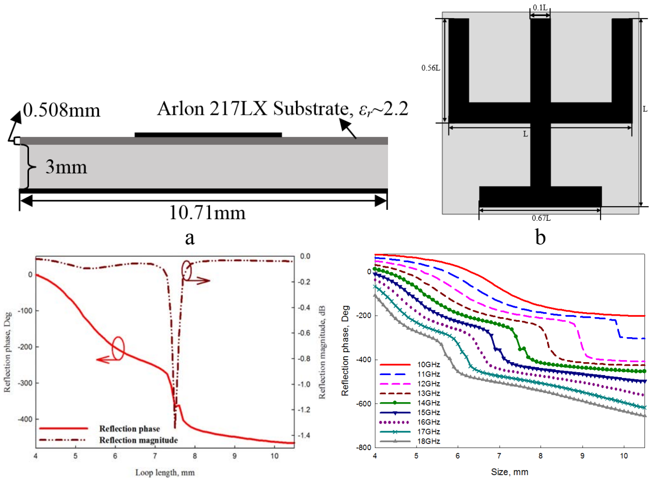

Fig. 1 Stub-loaded inverted *E* element: (a)configuration, (b) geometry, (c) reflection phase and magnitude responses at 14 GHz, and (d) reflection phase curves at various frequencies.

It is noted from Fig. 1 (c) that the maximum reflection loss is about 1.4 dB for the geometrical length corresponding to 14 GHz, which is due to the resonant effect occurring in that frequency [8]. However, this value is well below 0.2 dB for all other frequencies considered. Thus the proposed element offers an acceptable phase bandwidth and low reflection loss characteristics, and hence could be used to design a wideband reflectarray antenna.

III. Design and analysis of a wideband reflectarray antenna

The compensation phase required at each location of a plane reflector of size 200 × 200 mm^2 is estimated using matlab code at the design frequency of 14 GHz, for a feed location of (0, 0, and 140 mm) and a beam direction of (θ_b=0° and ϕ_b=0°). The simulation model thus made is shown in Fig. 2 (a). Interpolating this phase distribution and the elements' reflection phase curve shown in Fig. 1 (c), the reflectarray is constructed with 18×18 elements using a simulation software. It is then analyzed with a center-fed pyramidal horn for various focal distance and inter-element spacing values to attain the optimal radiation pattern and gain characteristics. From this study, the optimum gain-bandwidth performances are observed for a focal distance (*f*) of 139.5 mm and an inter-element spacing (*d*) of 9.2mm (case 1) in the Ku band and for *f*=134.5mm and *d*=10.6mm, (case 2) in the X-Ku band. A reflectarray with the specifications pertaining to case 1 is fabricated. This prototype along with a mounting structure is in Fig. 2 (b). The simulation and experimental analyses for both cases are presented in the next section.

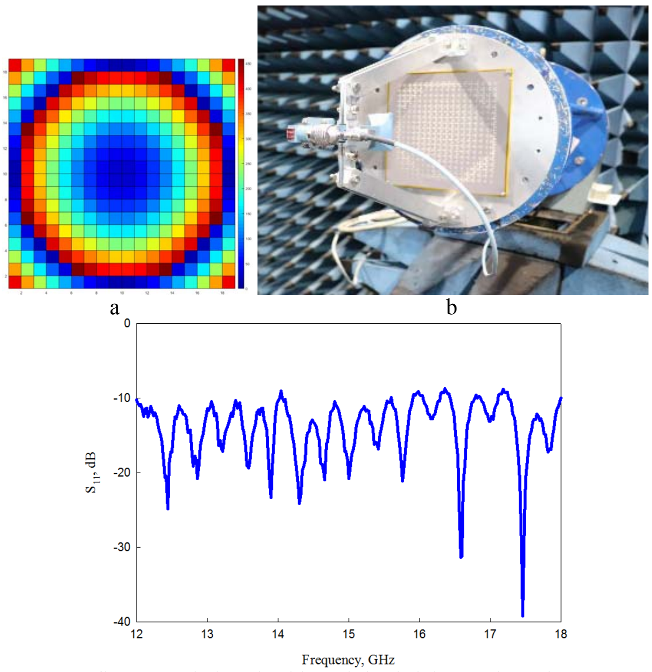

Fig. 2 Reflectarray designed with stub-loaded inverted *E* elements: (a) estimated phase distribution, (b) fabricated prototype, and (c) reflection coefficient (S_{11}) plot.

IV. Simulation and Measurement Results

Initially, the impedance matching (S_{11}) performance of reflectarray system is measured using a network analyzer, where the feed was positioned at 139.5 mm. It is then plotted as a function of Ku band frequencies, as shown in Fig. 2 (c). From the figure, it is observed that a good matching is noted with the S_{11} values being about -10 dB or below at the considered frequencies. The radiation patterns were measured at the anechoic chamber measurement facility at the Satellite Application Center, ISRO, Ahmedabad, and the results are described below.

A. Radiation pattern

(i) Case 1

The simulated and measured Co- and X-pol radiation patterns of the proposed reflectarray are plotted in the H-plane at 12 GHz and in the E-plane at 15 GHz in Figs. 3 (a) & (b), respectively. The main lobes of both the patterns exhibit a good match, and some discrepancies are noted between their side-lobes, especially beyond second side-lobe. While comparing simulated and measured cross-polarization patterns, a significant deviation is observed. However, the measured one is well below -32 dB with respect to the main lobe peak value, as shown in Figs. 3 (a) and (b). The above deviations could be caused by the alignment of feed horn, diffractions caused by the mounting structure, and fabrication tolerance [9, 11]. From these figures, a 3-dB beam-width of about 7.1° is noted at both frequencies. Further, the side-lobe levels are observed to be about -9 dB and -12 dB at 12 GHz and 15 GHz, respectively.

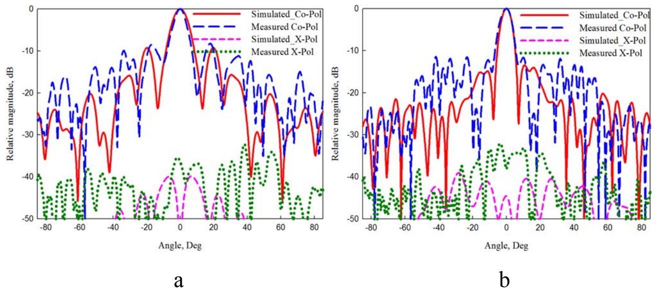

Fig. 3 Simulated and measured Co- and X-pol radiation patterns of the proposed reflectarray (case 1) in the (a) H-plane at 12 GHz and (b) E-plane at 15 GHz.

(ii) Case 2

The radiation patterns of the reflectarray (case 2) are estimated only by employing the array theory and the simulation tool, as this model was not fabricated. The estimated Co- and X-Pol patterns in both H- and E- planes are presented at 12 GHz in Fig.4 (a) & (b), respectively. The 3-dB beam widths of about 7.5° and 7° are achieved in H- and E- planes, respectively. It is observed from Fig. 4 (a) and (b) that the side lobe level and cross-polarization values are well below -15 dB and -40 dB, respectively. The gain and aperture efficiency performances that are obtained for both cases are presented in the following section.

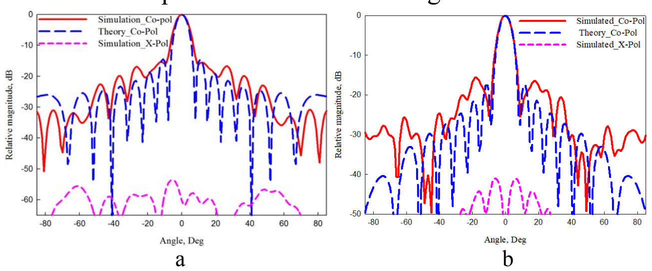

Fig. 4 Theoretical and simulated Co- and X-Pol radiation patterns of the reflectarray at 12 GHz for case 2 in (a) H-plane and (b) E plane.

B. Simulated gain and aperture efficiency performances

The gains of the reflectarrays are estimated through simulation. Optimal gain performances are achieved at two focal distances and inter-element spacing values as discussed above. Subsequently, they are plotted as a function of frequency in Fig. 5. The gain-bandwidth performances are achieved in these two cases with an operating frequency range in the X-Ku and Ku bands. It is observed from Fig. 5 that when an inter-element spacing is reduced to 9.2mm against the designated one of 10.71mm, and with a minor variation of focal distance, i.e., 139.5mm, the reflectarray operates in the entire Ku band frequency range of 12-18 GHz. Another optimal gain performance is achieved for an inter-element spacing of 10.6 mm and the focal distance of 134.5 mm in the frequency range of 10-13.8 GHz. It is noted from this study that the inter-element spacing can be varied to control the operating frequency range for a given reflectarray with a minimal optimization of a focal distance.

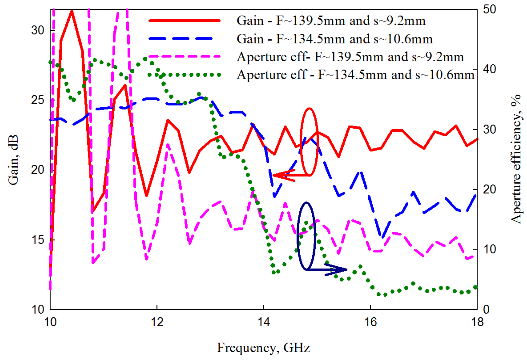

Fig. 5 Simulated gain and aperture efficiency values as a function of frequency for two optimal focal distance and inter-element spacing values.

The aperture efficiency values are estimated from the simulated gains and then plotted as a function of frequency in Fig. 5. The gain, aperture efficiency, and bandwidth performances that are achieved for the above-mentioned cases are listed in Table I. It is noted from this table that a 3-dB gain-bandwidth of 40% is achieved with the peak gain and aperture efficiency of 23.6 dBi and 28% for case 1. And for case 2, a typical 1-dB and 2-dB gain bandwidth of about 20% and 32% is achieved, respectively. The peak gain and aperture efficiency values are noted to be about 25.2 dBi and 42%, respectively, as shown in Fig. 5 and Table I. This study demonstrates that the focal distance and inter-element spacing modifies the operating bandwidth, irrespective of the element configuration being used, which is consistent with a study carried out in [10]. Furthermore, the reflectarray realized with stub-loaded inverted *E* elements offers wider gain-bandwidth for case 1, with a maximum gain of 23.6 dBi, which is lesser than the gain obtained for case 2. This could be due to the reduction in an effective reflecting aperture [9, 11-12]. Therefore, the reflectarray parameters should be chosen in such a way that they result in wider gain-bandwidth without compromising its gain performance to a large extent [13-14].

TABLE I. SIMULATED GAIN-BANDWIDTH PERFORMANCES OF THE REFLECTARRAY

Case #	Focal d/t, mm	Inter-element spacing, mm	Gain-bandwidth		Operating frequency range, GHz	Peak gain, dBi	Peak aperture efficiency, %
			Ref.	%			
1	139.5	9.2	3-dB	40	12-18	23.6	28
2	134.5	10.6	1-dB	20	10.8-13.2	25.2	42
			2-dB	32	10-13.8		

Owing to better radiation pattern and bandwidth performances along with moderate gains, the reflectarray realized with stub-loaded inverted *E* elements could be used in satellite, remote sensing, and DBS applications.

V. Conclusion

The simulation and experimental analyses of a linearly polarized wideband reflectarray with simple stub-loaded inverted *E* elements were presented. By simulation-based study, two gain-bandwidth performances were achieved for two different reflectarray configurations. The typical gain-bandwidths of about 40% (3-dB reference) and 32% (2-dB reference) were noted for case 1 and case 2, respectively.

Acknowledgment

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