Performance of Thinned Microstrip Reflectarrays

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***Abstract*—A reflectarray uses the phasing characteristics of microstrip patches, on its aperture, to direct the main beam in a desired direction. The geometry and dimensions of the microstrip patches are used to control these phasing characteristics. Normally grid arrangement of microstrip patches on reflectarray aperture is rectangular or circular grid. In order to reduce the number of microstrip patched on reflectarray aperture, a novel thinning concept is proposed here. This thinning of reflectarray is proposed in the form of a novel windmill shaped grid setting. Parameters such as gain, SLL, beamwidth and number of elements of this reflectarray are compared with reflectarray having conventional grid settings and are presented in this paper.**

***Index Terms*—circular grid, microstrip array, thinned reflectarray, windmill shaped grid.**

I. Introduction

A microstrip reflectarray is made up of an aperture of secluded microstrip patches and a feed horn antenna. The feed horn illuminates the microstrip patches which are intended to re-radiate the incident field with a specified beam shape and direction [1]. This type of antenna combines some of the appealing features of microstrip patches and reflectors. Just like a microstrip patch array, it is a low profile and light weight antenna and at the same time it provides high gain close to that of a reflector. Also spatial feeding of the reflectarray eliminates the design intricacy linked with usual microstrip patch array. Additionally, the reflectarray can be easily redesigned for various coverage specifications whereas a reflector would require costly fabrications of new molds along with thermal and mechanical modeling for each coverage specification [2]. Because of these features, reflectarrays have quite a few attractive applications in direct broadcast satellite (DBS) services, earth remote sensing systems which require large aperture antennas [1] and in micro-spacecraft missions, where high gain antennas with small volume and low mass are needed [3].

There are several types of microstrip antennas that can be used as elementary antennas for reflectarray. These antennas can be variable-sized patches [3], microstrip patches with variable-length phase delay lines attached [4], square or cross loops [5, 6] or, for circular polarization only, identical patches but with different angular rotations [7]. For linearly polarized reflectarray with different grid settings, designed in this paper, variable-sized patches are used as elementary antennas. Variable-sized patches are chosen as they allow much more liberty in laying out an array in comparison with patches having variable length stubs. Also bandwidth can be superior as bandwidth of the stubs is no longer a factor [8]. Moreover, fabrication error is fewer for variable-sized patches in comparison with square or cross loops [5].

In this paper, reflectarray with thinned aperture is designed and presented. Impact of array spacing, aperiodicity and finiteness or aperture thinning is vigorously studied in literature for microstrip arrays [9, 10] both for fixed beam and multiple beam antennas [11]. However, in the case of reflectarray, aperture thinning is never reported. Here aperture thinning is presented with respect to reflectarray in order to improve the radiation pattern. For this, reflectarray with thinned aperture in the form of a novel grid setting and reflectarray with some conventional grid settings are designed and simulated. The effect of these grid settings on the radiation pattern of the antenna is studied and a performance comparison of these reflectarrays is presented.

II. Design, Fabrication and Measurement of 29x29 Microstrip Reflectarray

Basic geometry of a microstrip reflectarray using patches of variable size is shown in Fig. 1.

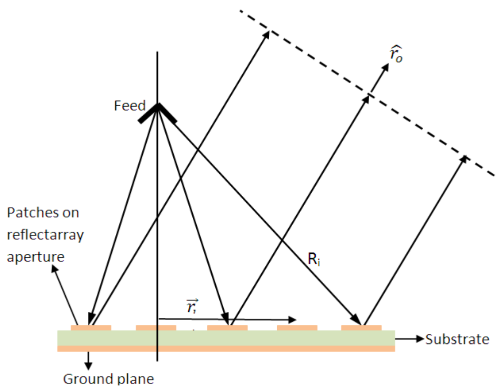

Figure 1. Basic geometry of microstrip reflectarray.

The intrinsic design principle of reflectarray requires that the phase $\varnothing_i$ of the reflected field, from the reflectarray, be selected so that the overall phase delay from the feed to a fixed aperture plane in front of the reflectarray is the same for all elements [8]. It is also acknowledged as equal phase delay condition and is specified by (1).

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$$\phi_i = k_o\left(R_i - \vec{r}_i \hat{r}_o\right) - 2\pi N \qquad (1)$$

$R_i, \vec{r}_i$ and $\hat{r}_o$ are described in Fig. 1. Complete design process of a microstrip reflectarray using patches of variable size basically consists of five steps, which includes:

- Selection of feed horn antenna
- Selection of reflectarray substrate
- Determination of unit cell required phase delay
- Determination of required dimensions of microstrip patches
- Simulation of the reflectarray

All these steps are detailed in a previous work [12]. In that work, a 29x29 reflectarray was designed at 16 GHz, fabricated and tested for radiation patterns. A linearly polarized pyramidal horn, operating in Ku band, with an edge taper of about -9 dB was used as a feed for the reflectarray. Focal length of the reflectarray was 160 mm so that, as a consequence, reflectarray lies in the far-field region of feed horn. Diameter of the designed reflectarray was 292 mm, thus an f/D ratio of 0.6 was achieved. The substrate used was FR-4 with a relative permittivity of 4.4, substrate thickness of 0.5 mm and a dielectric loss tangent of 0.02. Required phase of each unit cell of the reflectarray was determined by comparing the configuration of a parabolic reflector with a flat microstrip reflectarray [13] and is shown in Fig. 2. After finding the required phase of each unit cell in the reflectarray, length of the radiating patches according to these phases was determined using the infinite array approach [8]. Reflection

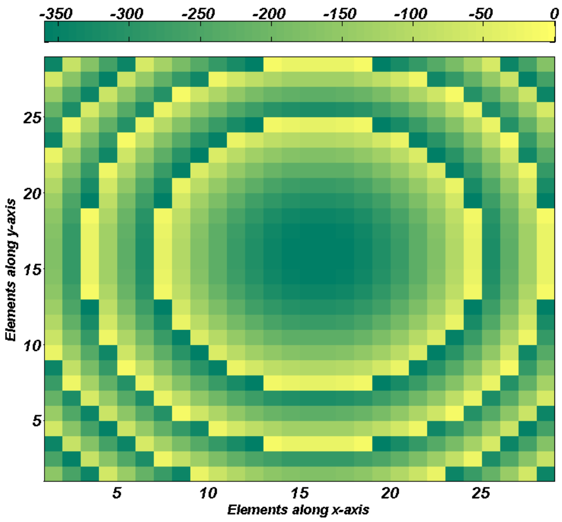


Figure 2. Required phase for each unit cell of reflectarray.

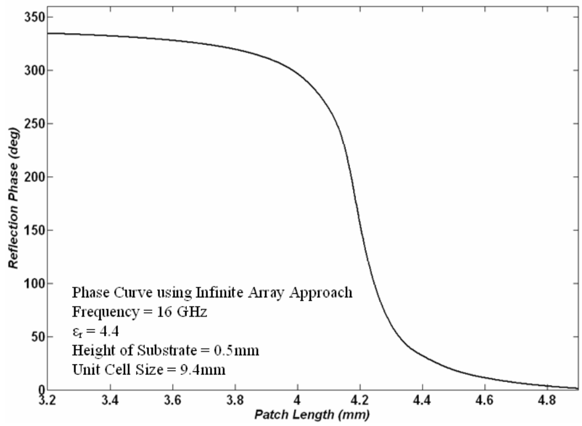


Figure 3. Phase change versus patch length for rectangular patch.

phase variation of the microstrip patch as a function of its length is shown in Fig. 3. This curve is used to determine the length of the radiating patches at the design frequency.

Designed 29x29 reflectarray along with feed horn was simulated in commercially available full wave EM simulation software while fabrication was done using chemical etching. An aluminum stand was made to support the reflectarray and also to fix the phase center of feed horn at the focal point of the reflectarray. Fabricated reflectarray along with feed horn is shown in Fig. 4 whose measured and simulated radiation patterns are compared in Fig. 5.

Simulated gain of the reflectarray was 24.7 dB and measured gain was 22.4 dB. Measured gain of the reflectarray was lower than the simulated gain which can be attributed to the errors in the positioning of phase center of the feed horn at the focal point of the reflectarray. Also the discrepancy between measured and simulated patterns is likely due to feed blockage. However, close agreement between simulated and measured gain confirmed the design process.

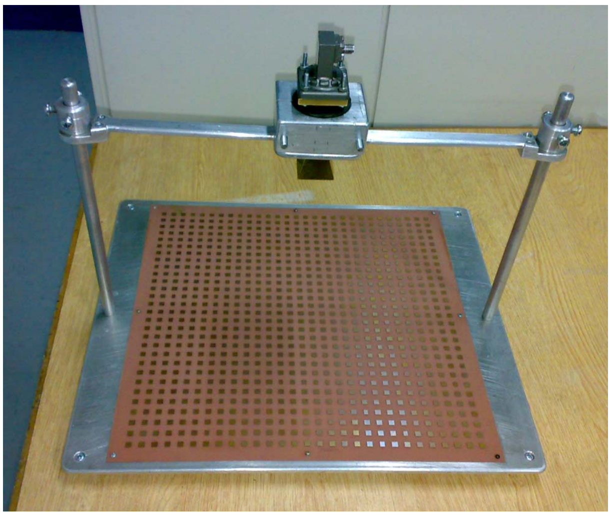
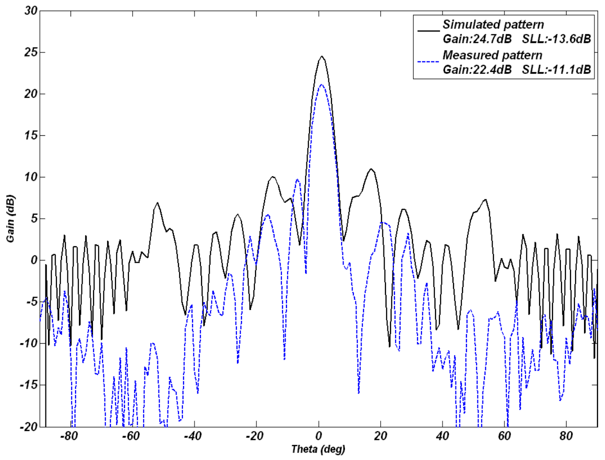
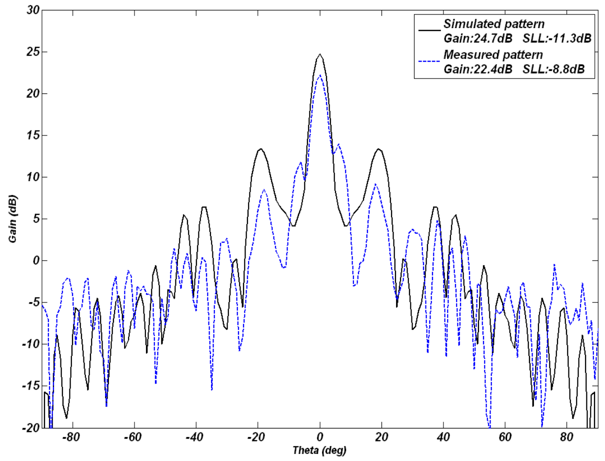


Figure 4. Fabricated 29x29 reflectarray and feed horn along with aluminum stand.



(a)



(b)

Figure 5. Measured and simulated radiation patterns in (a) E-plane and (b) H-plane.

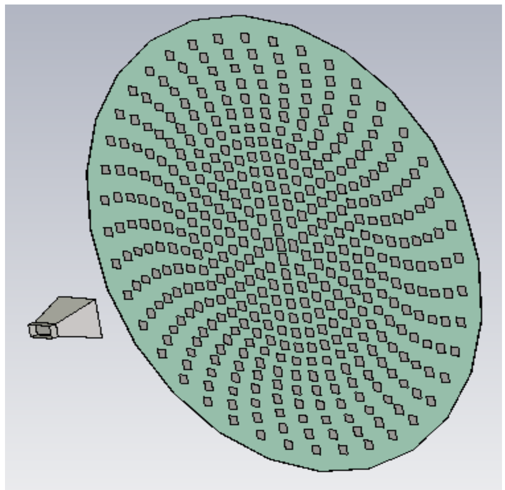


Figure 6. Simulation setup for the reflectarray with thinned aperture.

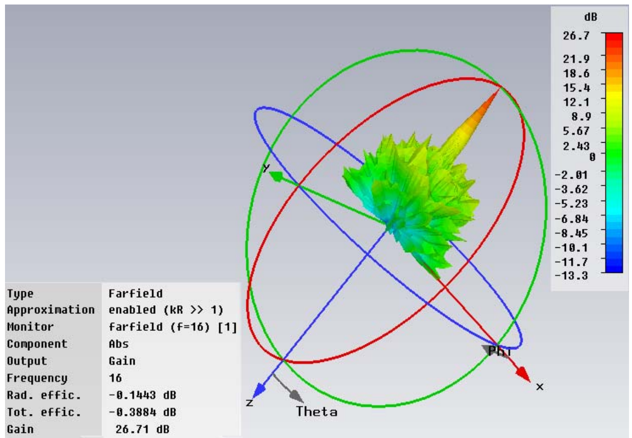


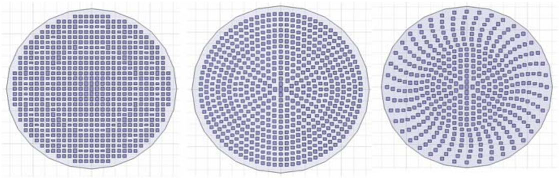
Figure 7. Simulated radiation pattern for the reflectarray with thinned aperture.

III. Reflectarray with Thinned Aperture

In order to make the aperture of the reflectarray thin, a novel grid setting for elementary antennas on reflectarray aperture is designed. This grid setting is named windmill shaped grid setting. Thus the reflectarray with thinned aperture will be cited as reflectarray having windmill shaped grid throughout this paper. This reflectarray is designed using the same design process as detailed in section II. In that section, reflectarray was designed and fabricated using FR-4. Due to higher losses attributed to FR-4, the overall gain of the reflectarray using FR-4 as substrate was inferior. However the gain of a reflectarray can be enhanced by using a substrate having a lower value of relative permittivity and a low loss tangent [8]. Thus, here Rogers RT5870 (having a relative permittivity of 2.33 and a loss tangent of 0.0012) with a thickness of 0.508mm is used as a substrate for the designed reflectarray. Due to unavailability of Rogers RT5870, only simulated radiation patterns have been presented. Simulation of reflectarray along with feed horn is carried out in commercially available EM software. Simulation model of this reflectarray is given in Fig. 6 while its radiation pattern is shown in Fig. 7.

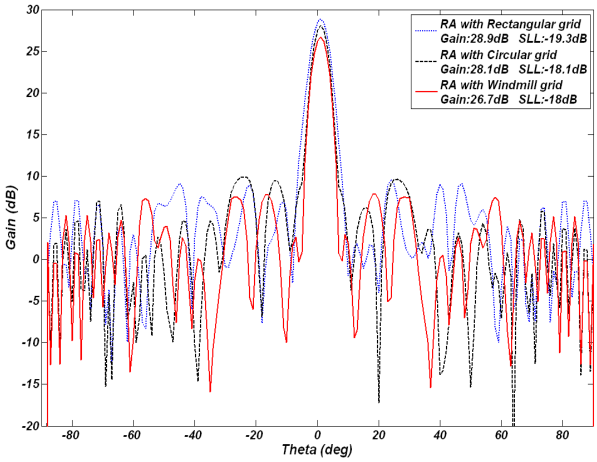
IV. Comparison of Reflectarray having Different Grid Settings

In order to carry out a comparison of reflectarray having windmill shaped grid setting with reflectarray having rectangular and circular grid setting, reflectarray with all three grid settings are designed and simulated. Patterns for rectangular grid, circular grid and windmill shaped grid are shown in Fig. 8. For rectangular grid, grid points are obtained by simply placing points at 90 degree to each other both in horizontal and vertical directions. Distance between these grid points is fixed at 0.5λ. For circular grid, grid points are arranged in concentric rings where rings are 0.5λ apart. On each ring, grid points are placed along the ring with distance between any two adjacent points equal to 0.5λ. For windmill shaped grid, grid points are arranged in concentric rings originating from the center up to the middle of the reflectarray aperture just as for circular grid. From middle of the reflectarray aperture, grid points are arranged in the form of arcs extending outwards. Distance between two adjacent grid points along the arc is fixed at 0.5λ. Simulated radiation patterns of reflectarray having rectangular grid, circular grid and windmill grid are shown in Fig. 9.

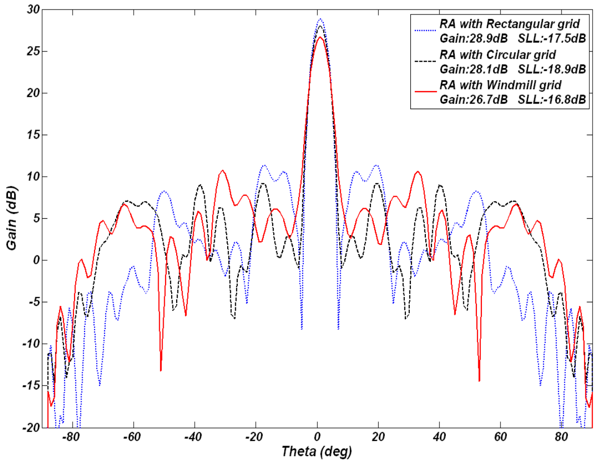


(a) (b) (c)

Figure 8. Reflectarray with (a) rectangular grid, (b) circular grid and (c) windmill grid.



(a)



(b)

Figure 9. Simulated radiation patterns for reflectarray with different grid settings in (a) E-plane and (b) H-plane.

A comparison of different parameters of reflectarray with all three grid settings discussed in this paper is given in Table I. A loss in gain of about 2.2 dB has been observed for reflectarray with windmill grid as compared to reflectarray with rectangular grid. However a loss in gain of about 1.4 dB has been observed for reflectarray with windmill grid as compared to reflectarray with circular grid. It can also be observed from Fig. 9 and Table I that the side lobe level of reflectarray with windmill grid is comparable with the side lobe level of reflectarray with rectangular or circular grid. The loss in gain for reflectarray with windmill grid is due to the fact that the number of elements for reflectarray with windmill grid is less than the number of elements for reflectarray with rectangular or circular grid. For reflectarray with windmill grid, the loss in gain is also due to the fact that the power coming from the feed is not fully intercepted by the reflectarray aperture. The power coming from the feed and not intercepted by the microstrip patches (between the wings of windmill) is essentially reflected. It is therefore not used constructively and contributes to increase the general level of spurious radiation. This is not the case in the thinned direct radiating array where all the input power is radiated (and phased) by the elements. Thus a thinned microstrip reflectarray shows radiation performance which is inferior to that of a reflectarray with rectangular or circular grid in terms of gain but is comparable in terms of side lobe level.

TABLE I. COMPARISON OF REFLECTARRAY WITH DIFFERENT GRID SETTINGS

		Reflectarray with		
		Rectangular grid	***Circular grid***	***Windmill shaped grid***
Total number of elements		665	617	435
Total Gain		28.9 dB	28.1 dB	26.7 dB
Side lobe level	E-plane	-19.3 dB	-18.1 dB	-18 dB
	H-plane	-17.5 dB	-18.9 dB	-16.8 dB
Half-Power Beamwidth	E-plane	5.2 deg	4.6 deg	5.3 deg
	H-plane	4.5 deg	4.5 deg	4.9 deg

V. CONCLUSION

In this paper, a thinned microstrip reflectarray is designed in the form of a novel grid setting of elementary antennas on its aperture. This grid setting is named windmill grid setting. When radiation patterns of this reflectarray are compared with the radiation patterns of reflectarray with conventional rectangular or circular grid, a loss in gain of about 2.2dB is observed while side lobe level remains almost the same. The loss in gain is due to the fact that the number of elements is reduced and the elements do not reradiate the full input power. As a result, it can be said that the thinned reflectarray has reasonable gain and side lobe level however it exhibits no advantage in performance over reflectarray with conventional rectangular or circular grid setting.

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