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Research Article

Millimeter-Wave Single-Layer Dual-Frequency Reflectarray Antenna

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To fulfill the dual-frequency requirements, elements are needed to resonate at two different, independently adjustably frequencies. A low weight, low cost, and easy to fabricate single-layer dual-frequency reflectarray is designed, fabricated, and measured, with gain values of 27 and 29.2 dBi at 20 and 30 GHz, respectively.

1. Introduction

Printed planar reflectarrays [1–4] have gained increasing interest due to their low weight, design flexibility, or ease of fabrication. Some microwave systems use different frequencies simultaneously, for example, VSAT links with downlink and uplink in the 20 and 30 GHz frequency ranges, respectively. Dual-frequency reflectarrays have already been realized based on multilayer structures [5–8] by arranging separate elements side by side [9] or by using elements operating at different frequencies in the two polarizations. In [10], composed split-ring reflector elements are investigated but only operate in one linear polarization, and no antenna is demonstrated. Finally, in [11], the reflector elements are switched between operating frequencies by p-i-n diodes. Recently, two methods of single-layer dual-frequency reflectarray antennas have been presented [12, 13].

In this paper, to fulfill the low weight, low cost, design flexibility, and ease of fabrication requirements, a novel single-layer dual-frequency reflectarray is presented. This antenna needs an offset feed in front of the reflectors. The applied principle is similar to that used in [12, 13]. As example frequencies, 20 and 30 GHz have been selected [14].

2. Single-Layer Dual-Frequency Elements

In this paper, elements are needed to resonate at two different, independently adjustably frequencies to fulfill the dual-frequency requirements. This principle is the basis of [12, 13], and a number of alternative elements for single polarization have already been described in [15]. This principle has to be extended for a dual-frequency antenna and adjust the array elements independently for the two frequencies, for example, 20 and 30 GHz. The double-frequency resonance is used to provide more wideband and flatter response for a single frequency band; and, simultaneously, the two resonances may be selected farther away from each other, resulting in two phase angle sections effectively usable for two different frequencies.

An element from [15] was selected here, as shown in Figure 1. The element is printed on an RT Duroid 5880 substrate (ε_r = 2.22, substrate thickness 0.508 mm) with backside metallization.

With the typical approach, the behavior of the reflectarray elements is investigated using a periodic array of elements and a normally incident wave. A simulation is conducted with CST Microwave Studio [16]. The solver is the

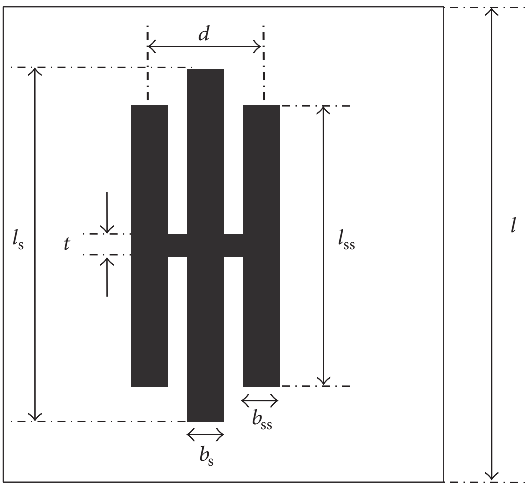

Figure 1: Reflector element for the dual-frequency reflectarray (l = 6.8 mm, d = 1.6 mm, t = 0.3 mm, and $b_s = b_{ss}$ = 0.5 mm).

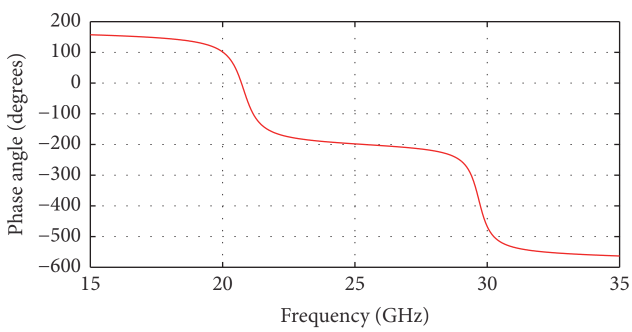

Figure 2: Phase angle curve of the element in Figure 1 for l_s = 5 mm and l_{ss} = 3.5 mm.

frequency-domain solver. The polarization is parallel to the vertical strips.

In Figure 1, the unit cell is a square, and the length l is 6.8 mm. In the middle of the structure, there is a central metal strip parallel to the polarization of the incident wave with a width b_s = 0.5 mm and a length l_s. Another metal patch with a width t = 0.3 mm crossing the central strip is added. Two shorter strips with a different resonant length l_{ss} can be seen at the sides of the central metal strip. They are symmetric, and the distance between the two strips d is 1.6 mm. The width of the shorter strips (b_{ss}) is also 0.5 mm. The coupled structure provides two resonances.

With the polarization parallel to the vertical strips, the lengths l_s and l_{ss} are adjusted for the reflection phase angle of the lower and upper frequency bands, respectively. Some interdependence of the angles is due to coupling of the strips. A typical reflection phase angle curve is plotted in Figure 2.

The resulting data for the two frequencies are plotted; the graph of 20 GHz is shown in Figure 3, and that of 30 GHz is shown in Figure 4.

The reflectarray antenna is designed as an offset antenna. According to this, the power of the horn antenna is incident not vertical to the reflector but obliquely from below. This

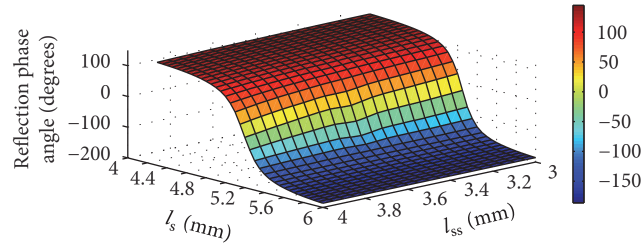

Figure 3: Phase angle behavior of the coupled structure (see Figure 1) at 20 GHz.

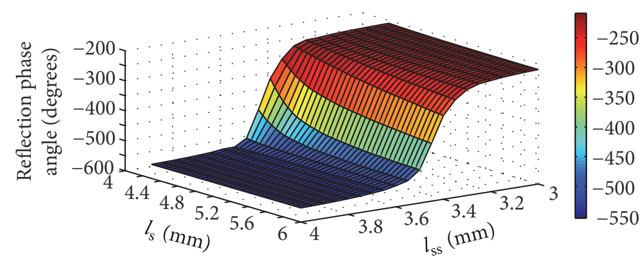

Figure 4: Phase angle behavior of the coupled structure (see Figure 1) at 30 GHz.

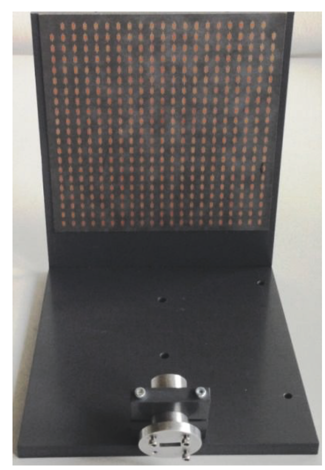

Figure 5: A photo of the dual-frequency coupled structure antenna.

design has the advantage that the shading of the antenna reflector by the feed is kept low. The reflector itself has a square shape with a size of 150 mm × 150 mm. The support for the reflector and horn is a holder made of PVC, and the distance between the reflector and feed horn is 164 mm. The antenna picture is shown in Figure 5.

3. Experimental Results

The transmission between the transmit antenna and the antenna being tested was recorded as a function of frequency. These values were then compared to those of pyramidal horns at K-band and Ka-band with approximately 20 dB of gain each. The respective results are plotted in Figure 6.

Table 1: Summary of the single-layer dual-frequency reflectarray antenna results.

	$\Phi_{3\,\text{dB}}$	$\Theta_{3\,\text{dB}}$	$G_{\max}$	η	SLL_E	SLL_H
20 GHz	6.2°	6°	27 dBi	39.9%	15 dB	15 dB
30 GHz	4.2°	4°	29.2 dBi	29.4%	17 dB	16.5 dB

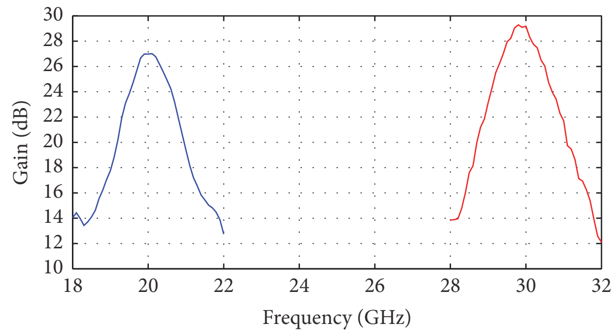

Figure 6: Measured gain values of the single-layer dual-frequency reflectarray.

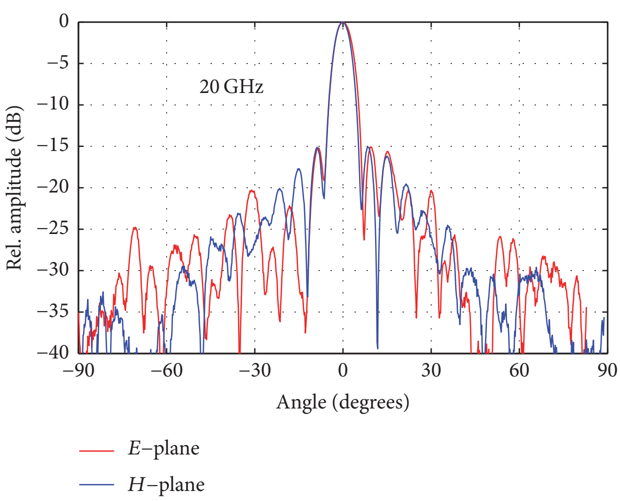

Figure 7: E-plane and H-plane diagram of the single-layer dual-frequency reflectarray at 20 GHz.

The maximum antenna gain at 20 GHz is 27 dB, and that at 30 GHz is 29.2 dB. The 3 dB bandwidth is in the range of 1.1 GHz at the lower frequency range, and that is in the range of 1.2 GHz at the higher frequency range.

The radiation diagrams of the single-layer dual-frequency reflectarray antenna are measured at different frequencies. The normalized radiation patterns of the single-layer dual-frequency reflectarray antenna at 20 GHz are plotted in Figure 7. The sidelobe level in the E-plane is −15 dB, and that in the H-plane is −15 dB. The 3 dB beamwidths corresponding to the E-plane and H-plane are 6.2° and 6°. The normalized radiation patterns of the single-layer dual-frequency reflectarray antenna at 30 GHz are plotted in Figure 8. The sidelobe level in the E-plane is −17 dB, and that in the H-plane is −16.5 dB. The 3 dB beamwidths corresponding to the E-plane and H-plane are 4.2° and 4°.

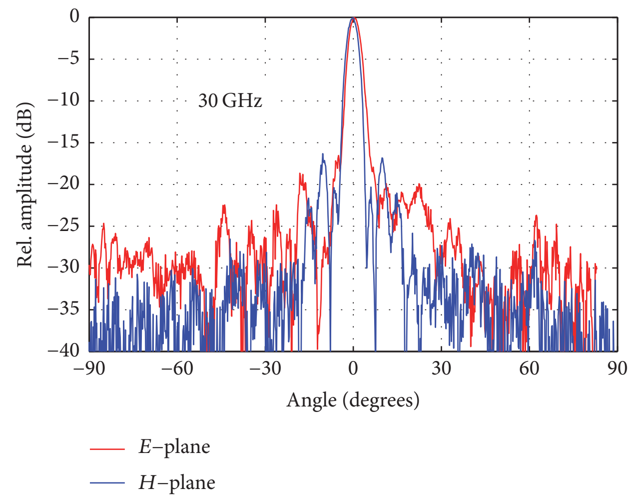

Figure 8: E-plane and H-plane diagram of the single-layer dual-frequency reflectarray at 30 GHz.

The radiation diagrams that are very similar to those in Figure 7 are maintained within a 1.1 GHz bandwidth at approximately 20 GHz, and the radiation diagrams that are very similar to those in Figure 8 are maintained within a 1.2 GHz bandwidth at approximately 30 GHz.

4. Conclusion

A summary of the single-layer dual-frequency reflectarray antenna performance is given in Table 1. $\Phi_{3\,\text{dB}}$ and $\Theta_{3\,\text{dB}}$ are the 3 dB beamwidths corresponding to the E-plane and H-plane, $G_{\max}$ is the maximum antenna gain, SLLE and SLLH are the maximum sidelobe levels in the E-plane and H-plane, and η is the aperture efficiency of the single-layer dual-frequency reflectarray antenna, which is calculated with formula (1).

$$\eta = G\frac{\lambda^2}{4\pi A}. \tag{1}$$

A is the antenna opening surface (diameter) geometric area and equals $150^2\ \text{mm}^2$.

This contribution has shown the feasibility of a very simple structure for a dual-frequency, single-layer reflectarrays which can be operated at arbitrary polarizations. Some slight asymmetries in radiation diagrams are due to the uneven antenna surface which is glued to the carrier plate.

For the single-layer dual-frequency reflectarray antenna in this paper, a major drawback is the small bandwidth. The improvements would be investigating modifications of the element dimensions to improve bandwidth or selecting a smaller unit cell size which is expected to reduce the specular reflections away from the center frequency and potentially to increase bandwidth as well. A dual-layer substrate with wide rectangular elements may also give a substantial improvement and may exhibit results closer to those of [7]. This method, however, would be taken at the expense of a more complicated fabrication process and higher cost for the material.

Conflicts of Interest

Jinjing Ren and Wolfgang Menzel declare that there are no conflicts of interest regarding the publication of this paper.

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