A Broadband Single-Layer Reflectarray Antenna Based on Tightly Coupled Dipole

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***Abstract*-A novel broadband single-layer reflectarray antenna based on tightly coupled dipole is proposed in this paper. Each element consists of a tightly coupled dipole and a slot line. The phase compensation is realized by adjusting the length of the slot lines. Due to the strong coupling among neighboring elements, the unit cell is able to provide a linear phase response with sufficient phase variation range over a wide frequency range. Based on the proposed element, a reflectarray with 210 elements operating at 12-22 GHz is designed. The element distance is 3.2 mm, which is approximately 0.13λ of the lowest operating frequency. Within the designed frequency band, the radiation pattern of the reflectarray antenna is stable and the shape of main beam is not distorted or split. The simulated results show that the maximum gain at 21.5 GHz is about 21.3 dB and the maximum aperture efficiency at 21 GHz is about 46%. The cross-pol levels of the reflectarray are below -32 and -20 dB in the E- and H- planes, respectively.**

***Index Terms*-Broadband antenna array, reflectarray antenna, tightly coupled dipole.**

I. INTRODUCTION

Reflectarray antennas combine the advantages of conventional parabolic antennas and phased array antennas [1]. Compared to conventional parabolic antennas, reflectarray antennas have planar apertures and are easy to be manufactured. Moreover, the feed networks of reflectarray antennas are simpler than that of the phased array antennas. Due to the advantages of low profile, light weight and low cost, reflectarray antennas are widely used for various applications. However, the most significant drawback of the reflectarrays is their narrow bandwidth [2]. There are two main factors resulting this: the inherent narrowband characteristics of the microstrip elements and the phase compensation error of the spatial delay for different elements [1].

There are several ways to increase the bandwidth of the reflectarray antennas, such as increasing the thickness of the substrate [3], using multi-resonant element [4], adopting true-time delay lines [5], and employing the sub-wavelength technique [2]. Although these method are effective in improving the bandwidth of relectarrays, some of them are implemented at the price of increased manufacturing cost, profile and weight [3], [4]. To keep the fascinating feature of the reflectarray antenna, it is demanded that the array aperture can be printed on a single-layer substrate. For this purpose, a broadband reflectarray antenna using single-layer rectangular patches embedded with inverted L-shaped slots was proposed in [6]. In [7], triple-gapped rings with attached phase-delay lines were used as the unit cell to broaden the bandwidth of a reflectarray antenna. In [8], a single-layer high-efficiency wideband reflectarray using hybrid design approach was proposed. To further enhance the bandwidth performance, tightly coupled dipoles were used to achieve ultra-wide-band reflectarray antenna in [9]. However, it is also noticed that the bandwidth improvement of this design is attained at the expense of increased manufacturing complexity.

In this paper, a novel broadband single-layer reflectarray antenna based on tightly coupled dipole is proposed. The design combines the advantages of tightly coupled arrays and conventional reflectarray antennas. The proposed element consists of a tightly coupled dipole and a slot line. The distance between adjacent elements is only 3.2 mm, which is approximately 0.13λ of the lowest operating frequency. The reflection phase curves versus the lengths of delay lines are rather linear within the operating frequency band. Based on the proposed element, a reflectarray with 210 elements is designed. Within the operating band, the radiation pattern of the reflectarray antenna is very stable and the cross-pol levels are lower than -32 and -20 dB in the E- and H- planes, respectively.

II. UNIT CELL DESIGN AND ANALYSIS

Fig. 1 shows the geometry of the proposed unit cell. As shown in Fig. 1, the unit cell is composed of a tightly coupled dipole and a slot line connected to the dipole directly. The dipole and slot line are printed on a Rogers RO4003C substrate with a thickness of 0.813 mm (the relative permittivity and loss tangent are 3.55 and 0.0027, respectively). The size of all dipoles is identical in the reflectarray. The reflection phase compensation of the reflectarray unit cell is achieved by adjusting the length of the slot lines. In order to obtain more linear phase response, an air layer is applied between the substrate and the ground. The value of h2 is also optimized for wide operating bandwidth. The minimum distance between adjacent elements is 3.2 mm, which is equivalent to 0.13λ at 12 GHz. As the distance between two neighboring elements is very small, the coupling between them is very strong and a wide impedance bandwidth is obtained [10].

To demonstrate the performance of the reflectarray unit cell, the magnitudes of the reflection for different delay line lengths

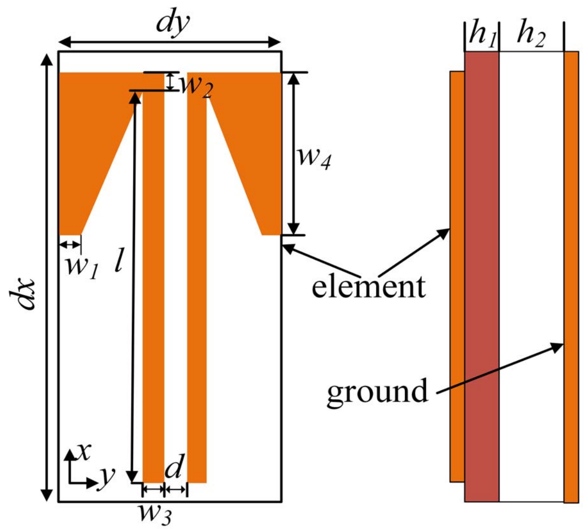

Fig. 1. Geometry of the proposed unit cell.

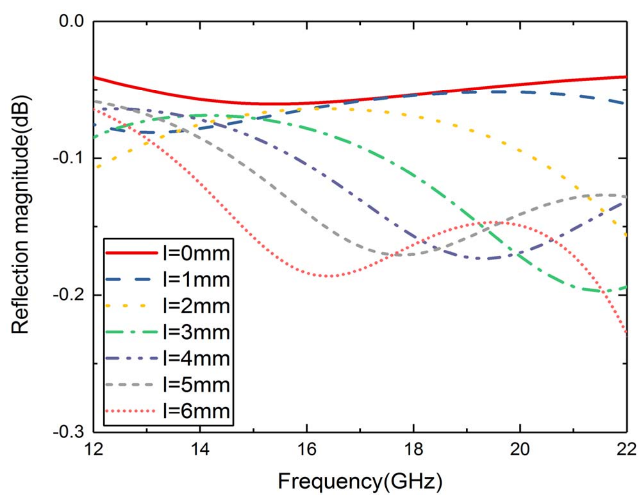

Fig. 2. Magnitudes of the reflections for different delay line lengths *l*.

l are plotted in Fig. 2. It can be seen that the maximum loss is only about 0.23 dB within the bandwidth of 12-22 GHz. The reflection phase curves versus different delay line length *l* at different frequencies are shown in Fig. 3. It is observed that the phase curves are rather linear within the operating bandwidth. Over 360° phase variation is realized at 18 GHz, which is sufficient to compensate the spatial phase difference. In summary, good reflection performance is obtained by the proposed unit cell within a wide bandwidth.

III. Reflectarray Design and Results

As shown in Fig. 4, a reflectarray with 210 elements is designed. A primary-fed reflectarray configuration is chosen in the design and a feed horn with 25^{o} beamwidth at the center frequency is utilized. The distance from the feed antenna to the reflecting surface is 50 mm. The f/D ratio is chosen to be 0.74 to provide a proper illumination while maximize the aperture efficiency.

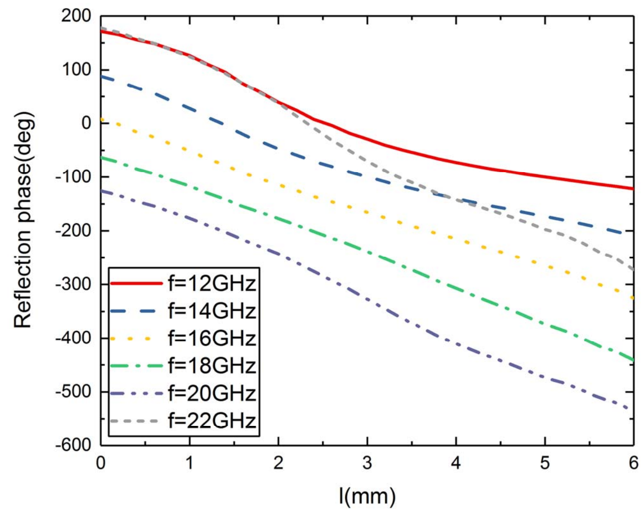

Fig. 3. Reflection phase curves versus different delay line lengths *l*.

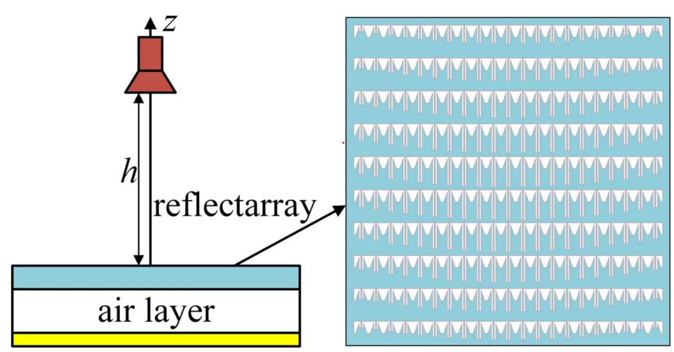

Fig. 4. Geometry of the proposed reflectarray.

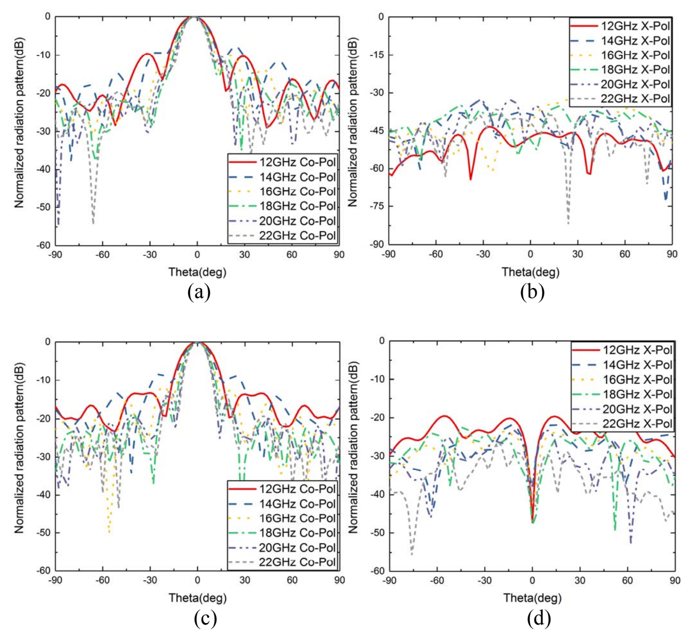

Fig. 5. Simulated E- and H-plane patterns of the proposed reflectarray at various frequencies. (a) E-plane co-pol patterns. (b) E-plane cross-pol patterns. (c) H-plane co-pol patterns. (d) H-plane cross-pol patterns.

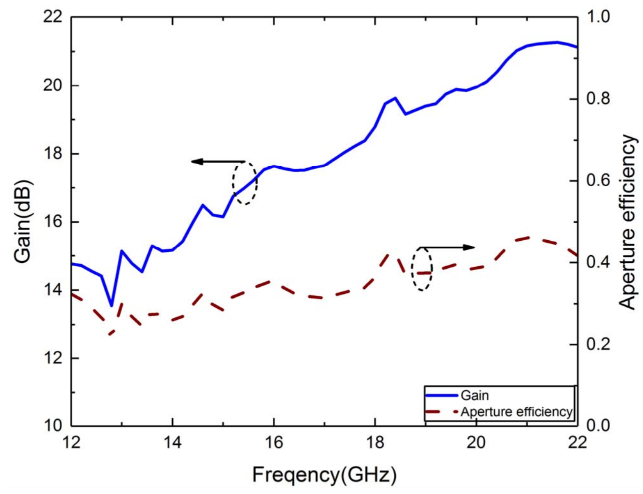

Fig. 6. Simulated gain and aperture efficiency of the proposed reflectarray.

The simulated radiation patterns in the two principal planes at different frequencies are shown in Fig. 5. It can be seen that a well-defined pencil beam in broadside direction is obtained and the radiation pattern keeps stable across the whole band. The shape of the main beam is not distorted when the frequency varies from 12 to 22 GHz. The simulated sidelobe levels are below -10 dB in both principle planes. It is also noted that in the region around the main beam, the simulated cross-pol levels are below -32 and -20 dB in the E- and H-planes, respectively. In general, a reasonable performance has been achieved in terms of the main beam shape, sidelobe level, and cross-pol levels.

The simulated gain and aperture efficiency of the proposed reflectarray are shown in Fig. 6. The simulated gain varies from 13.6 to 21.3 dB in the working band and peaks at 21.5 GHz. The simulated aperture efficiency of the proposed reflectarray varies from 22% to 46% within the bandwidth and peaks at 21GHz.

IV. Conclusion

A novel broadband single-layer reflectarray antenna based on tightly coupled dipole is proposed in this paper. The element consists of a tightly coupled dipole and a slot line. The element distance is 3.2 mm, which is approximately 0.13λ of the lowest operating frequency. The element is optimized to provide a linear phase response with good reflection magnitude. Based on the proposed element, a broadband reflectarray antenna is designed. The antenna has stable radiation patterns from 12 to 22 GHz. Within 1.8:1 frequency range, the shape of main beam is not distorted or split Moreover, the proposed reflectarray antenna features reasonable gain and aperture efficiency as well as low cross-pol levels. The presented reflectarray antenna is a good candidate for various applications such as the high-date-rate satellite communications.

□. Acknowledgment

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