# Design of X/Ku dual-band dual-linear polarization reflectarray using double parallel dipole elements (Postprint)

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## Abstract

Two single-layer X/Ku dual-band dual-polarization reflectarray antennas of different sizes with double parallel dipole elements are presented. Elements of the two bands are set to two orthogonal linear polarizations and placed in interlaced grid. The proposed reflectarrays operate in two frequency-bands within X-band centered at 10 GHz and Ku-band centered at 13.58 GHz. The smaller size reflectarray with elements arranged in a 13 × 13 grid for X-band and in a 12 × 12 grid for Ku-band is designed and simulated first. Based on the excellent dual-band performance of the small size reflectarray, then a larger size prototype has been designed, manufactured and measured. Measured results demonstrate the maximum gain of 28.54 dB with 50.93% aperture efficiency at 10 GHz and 31.06 dB with 51.34% aperture efficiency at 13.58 GHz, which show desirable dual-band dual-polarization radiation performance.

## Full Text

## Preamble

### Design of X/Ku Dual-band Dual-linear Polarization Reflectarray Using Double Parallel Dipole Elements

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**ABSTRACT:** Two single-layer X/Ku dual-band dual-polarization reflectarray antennas of different sizes, employing double parallel dipole elements, are presented. The elements for the two bands are assigned to two orthogonal linear polarizations and arranged in an interlaced grid. The proposed reflectarrays operate in two frequency bands within X-band centered at 10 GHz and Ku-band centered at 13.58 GHz. A smaller reflectarray with elements arranged in a 13×13 grid for X-band and a 12×12 grid for Ku-band is designed and simulated first. Based on its excellent dual-band performance, a larger prototype is then designed, manufactured, and measured. Measured results demonstrate a maximum gain of 28.54 dB with 50.93% aperture efficiency at 10 GHz and 31.06 dB with 51.34% aperture efficiency at 13.58 GHz, confirming desirable dual-band dual-polarization radiation performance.

**KEY WORDS:** Reflectarray, dual-band, high efficiency.

## 1. Introduction

Parabolic reflectors and array antennas play important roles in high-gain applications, yet both suffer from distinct disadvantages. Parabolic reflectors are difficult to manufacture due to their specifically curved surfaces, particularly at higher frequencies, and they also face challenges in achieving wide-angle beam scanning. Array antennas require complex feed networks that cause high transmission loss and low efficiency. To overcome these limitations, the reflectarray antenna has emerged, offering advantages such as high gain, low profile and mass, low cost, and a flat surface. A reflectarray typically consists of an illuminating feed antenna and a flat reflecting surface composed of many microstrip elements [?].

Dual-band operation has been a subject of intense interest in microstrip reflectarray design. Over the past decades, several techniques have been proposed to achieve dual-band performance, including elements printed on a single layer [?], two-layer configurations [?], and frequency-selective surface (FSS)-backed structures [?].

A multiresonance curved double-cross element was presented in [?] to achieve dual-band dual-linear polarization performance, with simulations confirming negligible mutual coupling between elements of the two bands. In [?], a single-layer element consisting of a circular patch with slots and two phase-delay lines attached to the patch was utilized to develop a dual-band reflectarray operating in X- and K-bands. For closely separated frequencies, a single-layer element comprising a square ring and patch loaded with slots was suggested in [?], where required phase shifts in the two bands were achieved by varying element size, yielding good reflectarray performance.

For two-layer structures, a ring with gaps was used as the element to develop a dual-band circularly polarized (CP) reflectarray operating in C- and Ka-bands [?]. In another two-layer configuration, thin membranes were utilized to achieve X/Ka-dual-band CP performance with high efficiency at both bands [?]. However, two-layer configurations suffer from additional cost, manufacturing complexity, and increased weight.

Using an FSS-backed structure, a circularly polarized reflectarray operating at

L- and Ka-bands was presented in [?]. The Ka-band reflectarray employed an FSS ground-plane consisting of many concentric dual-loop elements above the L-band array, achieving excellent dual-band performance. In [?], a double square ring structure was used as the element for linear polarization in both X- and Ka-bands. A single square ring was used to construct the FSS ground-plane for Ka-band, while a solid ground-plane was defined for X-band. A dual-band FSS consisting of cross-ring elements and square-ring elements was proposed in [?], where the FSS served as a reflective ground-plane to reduce coupling between elements of the two bands. However, most of the reflectarrays mentioned above operate at widely separated frequencies. There has been limited research on single-layer, dual-band dual-polarization reflectarrays covering closely separated frequencies [?], which are needed for dual-link satellite communications.

This paper presents two single-layer dual-band dual-polarization reflectarray antennas of different sizes operating in X-band centered at 10 GHz and Ku-band centered at 13.58 GHz. Two orthogonal sets of double parallel dipoles, each dedicated to one band, serve as the unit cell element. The smaller reflectarray comprises 13×13 elements for X-band and 12×12 elements for Ku-band. Simulated results show excellent dual-band dual-polarization performance. Subsequently, a larger reflectarray is designed, manufactured, and tested. A single broadband pyramidal horn antenna serves as the feed for both bands in a fixed position with two orthogonal polarization directions. Measured results show maximum gains of 28.54 dB at 10 GHz and 31.06 dB at 13.58 GHz, with efficiencies exceeding 50% at both frequency bands.

## 2. Element Design and Phase Characteristics

The proposed reflectarrays consist of two orthogonal sets of double parallel dipole elements, whose configuration and arrangement are illustrated in Fig. 1 [Figure 1: see original paper]. The double parallel dipoles for both bands are interlaced on top of a single-layer substrate with a uniform periodicity of $L$. The periodicity $L$ is set to 14 mm, which corresponds to 0.47 wavelengths at 10 GHz and 0.63 wavelengths at 13.58 GHz. The substrate is F4B laminate with a relative permittivity of 2.25 and thickness $h = 1.5$ mm. The length of the short dipole $b$ is proportional to the length of the long dipole $a$ with ratio $k$ (i.e., $b = k \times a$). The gap between the two dipoles is $d$, and the widths of both dipoles are $w$.

To analyze the reflection phase characteristics of the element, simulations were performed using HFSS with master-slave boundaries and Floquet ports to model the periodic structures.

Figures 2 [Figure 2: see original paper] through 4 [Figure 4: see original paper] show the influence of element parameters on reflection phase and magnitude curves at the two bands. From these results, the optimal parameter values for achieving desired reflection phase and magnitude curves at both bands are determined to be: $d = 1.4$ mm, $w = 1.5$ mm, and $k = 0.75$. The reflection phase and magnitude at different oblique incidence angles are depicted in Fig. 5 [Figure 5: see original paper], showing that incidence angles have minimal influence on both phase and magnitude. Figure 6 [Figure 6: see original paper] shows the phase and magnitude response of the element for different frequencies at X- and Ku-bands. By varying the length of the long dipole $a$ from 4.2 mm to 13.8 mm, a reflection phase range of 650° at 10 GHz and 680° at 13.58 GHz is obtained, which substantially exceeds the minimum required range of 360°.

Figure 7 [Figure 7: see original paper] shows the reflection magnitude versus frequency for both polarizations. *E*_{//} represents the polarization of the incident wave parallel to the length direction of the double parallel dipoles, while *E*_{ } represents the polarization perpendicular to the dipoles. The reflection magnitude is better than -0.45 dB for different values of $a$ in both cases (*E*_{//} and *E*_{ }). Figure 8 [Figure 8: see original paper] shows the coupling between the double parallel dipoles in the two orthogonal directions at 10 GHz. The incident wave polarization is set perpendicular to the length direction of the double parallel dipoles, and the reflection phase is calculated with respect to the dipole length. The results show that the reflection phase changes negligibly when the incident wave polarization is perpendicular to the dipole length direction. Similar results are obtained at 13.58 GHz, indicating low coupling levels between the double parallel dipoles in the two orthogonal directions.

The mutual coupling between dipoles of the two bands is also investigated. To evaluate the effect of dipoles in one band on those in the other band, the unit cells shown in Fig. 9 [Figure 9: see original paper] are used to analyze mutual coupling. The coupling between elements of the two bands is shown in Fig. 10 [Figure 10: see original paper], demonstrating that Ku-band dipoles have minimal effect on the reflection phase and magnitude of X-band dipoles and vice versa, indicating low mutual coupling levels between the two bands. Figure 11 [Figure 11: see original paper] shows the electric current vector on the surface of the dipole element (see Fig. 9) when excited by a $y$-polarized plane wave. Most of the current is $y$-directed with almost no $x$-directed current, which would be responsible for cross-polarization. Similar results are obtained at 13.58 GHz. Figure 12 [Figure 12: see original paper] shows the cross-polarized reflection magnitude of the dipoles, which is much smaller than the co-polarized reflection magnitude shown in Fig. 10, indicating a substantial reduction in antenna cross-polarization level. Figures 10–12 collectively demonstrate that low mutual coupling and cross-polarization levels are achieved.

The very low mutual coupling levels between the two bands indicate that coupling has negligible effect on reflectarray performance, including cross-polarization, efficiency, and gain.

## 3. Reflectarray Design and Performance

Using the double parallel dipoles described in Section 2, two single-layer dual-band dual-polarization prime-focus reflectarray antennas of different sizes are designed. The double parallel dipoles for both bands are interlaced on top of a substrate with uniform periodicity $L = 14$ mm. By varying $a$ from 8.4 mm to 12.3 mm for X-band and from 5.8 mm to 8.25 mm for Ku-band, the required phase shift can be satisfied at both bands. The smaller reflectarray, with elements arranged in a 13×13 grid for X-band (centered at 10 GHz) and a 12×12 grid for Ku-band (centered at 13.58 GHz), is printed on a 1.5-mm F4B substrate ( _r = 2.25). The geometry of the small reflectarray is shown in Fig. 13 [Figure 13: see original paper]. The X-band reflectarray is designed to operate in $y$-polarization, while the Ku-band reflectarray operates in $x$-polarization.

The focal distances $F$ (distance between the reflectarray and the feed) for both bands are set to the same value of 134.4 mm. Figure 14 [Figure 14: see original paper] shows the simulated radiation patterns of the small reflectarray at 10 GHz and 13.58 GHz. The side lobe levels are -16.3 dB in the E-plane and -18 dB in the H-plane relative to the peak gain at 10 GHz. At 13.58 GHz, the side lobe levels are -17.4 dB in the E-plane and -17.1 dB in the H-plane. The simulated results demonstrate excellent dual-band dual-polarization radiation performance.

Based on the good performance of the small reflectarray, a larger reflectarray with elements arranged in a 25×25 grid for X-band (centered at 10 GHz) and a 24×24 grid for Ku-band (centered at 13.58 GHz) is designed, manufactured, and tested. Figure 15 [Figure 15: see original paper] shows the geometry of the reflectarray. The larger reflectarray has an octagonal aperture with size $D =$ 350 mm. The focal distances of the large reflectarray for both bands are set to the same value of 268.8 mm. The $F/D$ ratio is 0.768 at X-band and 0.8 at Ku-band. A single broadband pyramidal horn antenna serves as the feed for both bands in a fixed position with two orthogonal polarization directions. The simulated radiation patterns of the feed pyramidal horn antenna at 10 GHz and 13.58 GHz are shown in Fig. 16 [Figure 16: see original paper].

The measured radiation patterns of the large reflectarray at 10 GHz and 13.58 GHz are shown in Fig. 17 [Figure 17: see original paper]. The measured peak gain is 28.54 dB at 10 GHz with side lobe levels of -25 dB in the E-plane and -22 dB in the H-plane. The maximum cross-polarization levels are -26 dB in the E-plane and -22 dB in the H-plane. At 13.58 GHz, the measured peak gain is 31.06 dB with side lobe levels of -20 dB in the E-plane and -22 dB in the H-plane. The maximum cross-polarization levels are -26 dB in the E-plane and -25.5 dB in the H-plane.

The measured aperture efficiency  is calculated using  = G_m/D_ideal, where G_m is the measured gain, D_ideal is the ideal directivity, and A is the aperture area of the reflectarray. The ideal directivity is calculated as D_ideal = 4 A/ ². After calculation, D_ideal is 31.47 dB at 10 GHz and 33.95 dB at 13.58 GHz. The NSI planar near-field system is used to measure the performance of the fabricated prototype. First, the directivity of the reflectarray is measured, yielding 30.12 dB at 10 GHz and 32.7 dB at 13.58 GHz. After calibration with a standard gain horn, the measured gain of the reflectarray is 28.54 dB at 10

GHz and 31.06 dB at 13.58 GHz. Using the formulas above, aperture efficiencies of 50.93% at 10 GHz and 51.34% at 13.58 GHz are achieved. Measured gain and efficiency of the large reflectarray versus frequency for X- and Ku-band are shown in Fig. 18 [Figure 18: see original paper]. The results show 1-dB gain bandwidths of 5.5% for X-band and 2.9% for Ku-band. The narrow bandwidth performance could be improved by increasing substrate thickness or inserting an air layer between the substrate and ground plane. The aperture efficiency is 50.93% at 10 GHz and 51.34% at 13.58 GHz, demonstrating high efficiency in both bands.

Table I compares the performance of the proposed reflectarray with previously published works. The proposed design offers advantages of high efficiency and low side lobe level compared to the designs in [**?**], [**?**], [**?**], [**?**].

## 4. Conclusion

Two single-layer X/Ku dual-band dual-polarization prime-focus reflectarray antennas of different sizes have been designed in this paper. The proposed reflectarrays operate in two closely separated frequency bands with orthogonal polarization directions. Double parallel dipoles serve as the reflectarray elements for both bands and are placed in an interlaced grid. Based on the good performance of the smaller reflectarray, a larger prototype was fabricated and measured. The measured results demonstrate good radiation performance with high efficiency in both bands.

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*Note: Figure translations are in progress. See original paper for figures.*