

## Single layer dual-band reflectarray antenna with two independent radiation patterns post-print

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### Abstract

This paper presents a design for single-layer X/Ku dual-band reflectarray antennas featuring two independent radiation patterns for the X and Ku bands. In the design, a novel dual-resonance structure is employed as the unit cell for both X and Ku bands to achieve dual-band performance using a new approach. A  $10 \times 10$  center-fed reflectarray operating at 9 GHz and 13.5 GHz with scattering angles of  $12^\circ$  and  $-30^\circ$ , respectively, is designed, and the simulated results are presented to validate the approach.

### Full Text

## Single Layer Dual-Band Reflectarray Antenna with Two Independent Radiation Patterns

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### Abstract

This paper presents a design for X/Ku dual-band reflectarray antennas using a single layer that achieves two independent radiation patterns for the X and Ku bands. The design employs a novel dual-resonance structure as the unit cell for both frequency bands, representing a new approach to dual-band performance. A  $10 \times 10$  center-fed reflectarray operating at 9 GHz and 13.5 GHz with scattering angles of  $12^\circ$  and  $-30^\circ$ , respectively, is designed and simulated to validate the proposed approach.

## 1 Introduction

Microstrip reflectarray technology has attracted widespread attention in communication and radar applications due to its numerous advantages [1]. In many applications, dual-band antenna systems are highly desirable for radar systems operating at two different frequency bands. Several techniques have been proposed in recent decades, including single-layer dual-resonance elements [2], stacked patches with double-layer structures [3, 4], and FSS-backed structures [5, 6].

Although most dual-band reflectarray antennas are designed to realize coincident main beam boresight, some applications require two completely different radiation patterns for the two bands. In [7], J. Shaker proposed a combination of FSS-backed reflectarray and conventional reflector that can operate independently in Ka/Ku bands. In this design, the reflectarray is transparent in the operating band of the conventional reflector placed beneath the reflectarray slab, while reflecting energy in the operating band of the reflectarray antenna. In [8], the conventional reflector was replaced with a ground-plane-backed reflectarray to simplify the structure, reducing surface profile and antenna mass.

For simpler designs with significantly reduced antenna mass and cost, single-layer reflectarray antennas are desirable. However, the design techniques of [7] and [8] are not well-suited for single-layer structures.

This paper proposes an approach to design a dual-band reflectarray antenna with a single layer that produces two distinct radiation patterns in the X and Ku bands. A novel dual-resonance structure is selected as the unit cell for both X and Ku bands [9]. While [9] presented a single-layer dual-band reflectarray with radiation patterns sharing the same beam direction, here we utilize four degrees of freedom of the unit cell to control the reflection phase at the two design frequencies, thereby achieving two independent radiation patterns.

### 2.1 Design Principle

Generally, due to mutual coupling, the reflection phase of a double-resonance structure with a single layer cannot be tuned independently at two different frequencies, making it difficult to achieve two different radiation patterns in the two bands. We present an approach to solve this problem.

First, we select a double-resonance structure with four degrees of freedom as the unit cell. By varying these four parameters, the reflection phase can be changed simultaneously at both center frequencies.

Second, we sweep the four parameters—that is, we change them step by step at the two designed center frequencies. This yields reflection phase data for all possible configurations (all combinations of the four parameters). During parameter sweeping, we ensure that each reflection phase at the upper frequency corresponds to a wide range of reflection phases at the lower frequency.

Third, we design the reflectarray with two independent radiation patterns by selecting appropriate configurations from the second step to simultaneously achieve the two desired radiation patterns at the design frequencies.

Through this approach, we can design a dual-band reflectarray antenna with two distinct radiation patterns.

[Figure 1: see original paper]

## 2.2 Unit Cell Design

The unit cell structure with a single layer is shown in Figure 1, which consists of an outer circular ring structure and an inner I-shaped dipole structure [9]. The unit cell size is set to  $L = 10$  mm. The outer radius of the circular ring is fixed at  $R = 4.2$  mm for all reflectarray elements. The patch is etched on a Duroid5880 substrate with a thickness of 1.524 mm and a relative permittivity of 2.2.

There are four degrees of freedom to control the reflection phase of the unit cell at 9 GHz and 13.5 GHz: (1) the inner radius of the circular ring  $R$ , which is the main parameter for controlling the reflection phase; (2) the gap between the circular ring and the I-shaped dipole  $W$ ; (3) the width of the inner I-shaped dipole  $W_B$ , where  $W_B = 2M \times (R - W)$ ; and (4) the gap inside the I-shaped dipole  $W_G$ , where  $W_G = 2N \times (R - W)$ .

To calculate the phase response, an infinite array is simulated using HFSS with master-slave boundaries and Floquet port excitation. Figure 2 shows the simulation results, indicating that the reflection phase curves change significantly with different values of  $M$ , while the reflection phase varies primarily as the value of  $R$  changes. The phase difference between the two frequencies ranges from  $200^\circ$  to  $300^\circ$ .

We then sweep the four parameters at 9 GHz and 13.5 GHz, respectively. The infinite array model is used to carry out the parameter sweep in HFSS by tuning  $R$ ,  $W$ ,  $M$ , and  $N$  as specified in Table 1.

**Table 1. Parameter Sweeping Ranges**

Parameters	$R$ (mm)	$W$ (mm)	$M$	$N$
Range	1.5-3.6	0.1-0.3	0.1-0.6	0.2-0.8
Step	0.1	0.1	0.1	0.1

We thus obtain reflection phase data for all configurations ( $R$ ,  $W$ ,  $M$ ,  $N$ ). Figure 3 shows the available reflection phases at 9 GHz and 13.5 GHz based on this data.

[Figure 2: see original paper]

[Figure 3: see original paper]

In Figure 3, each point  $(p, p)$  in the blue area represents a unit cell with one of all possible configurations. The blue area occupies 70% of the entire region (i.e.,  $-180^\circ$  to  $+180^\circ$  for both axes). Our results indicate that 70% coverage is sufficient for realizing two completely different radiation patterns.

### 3 Reflectarray Design

In this section, a  $10 \times 10$ -element center-fed reflectarray operating at 9 GHz and 13.5 GHz is successfully designed, and simulation results are presented to demonstrate the effectiveness of the proposed approach.

In the first step, the required phase shift for each unit cell is calculated at 9 GHz and 13.5 GHz, respectively, according to the equation below:

$$\phi_{R_i} = k_0 d_i - k_0 (x_i \cos \phi_0 + y_i \sin \phi_0) \sin \theta_0$$

where  $k$  is the propagation constant in vacuum,  $d$  is the distance from the phase center of the feed to the center of the  $i$ th unit cell in the reflectarray, and  $(\phi_0, \theta_0)$  is the designed main beam radiation angle of the reflectarray. The phase shifts are designed to compensate for the spatial delay between the feed and unit cells. Here, the phase shifts are calculated for  $(12^\circ, 0^\circ)$  at 9 GHz and  $(30^\circ, 180^\circ)$  at 13.5 GHz.

In the second step, a pyramid horn feed is selected and positioned. The feed horn can operate at both 9 GHz and 13.5 GHz with its phase center located at the aperture surface center for 9 GHz and 3 mm inside the aperture surface for 13.5 GHz. The horn is positioned 90.5 mm above the reflectarray plane, and the side view of the reflectarray geometry is shown in Figure 5.

The required reflection phases for both frequencies are shown in Figure 4, where the red star points indicate the calculated phase shifts for all unit cells. Only 50 points are shown in Figure 4, corresponding to half of the total elements due to symmetry about the x-axis as illustrated in Figure 5.

We can see from Figure 4 that although approximately 26% of points lie outside the blue area, the design approach still works effectively as demonstrated below.

After completing these two steps, the final center-fed reflectarray is simulated using CST Microwave Studio software according to the layout shown in Figure 6, with an aperture size of 100 mm and 100 elements. The configuration of each unit cell in the layout is determined by the red points in Figure 4.

The simulated E-plane normalized radiation patterns at 9 GHz and 13.5 GHz are shown in Figure 7. The main beam direction is exactly  $(12^\circ, 0^\circ)$  at 9 GHz and  $(30^\circ, 180^\circ)$  at 13.5 GHz, precisely as designed. Thus, our goal is achieved.

[Figure 4: see original paper]

[Figure 5: see original paper]

[Figure 6: see original paper]

[Figure 7: see original paper]

The maximum gains of the designed dual-band reflectarray are 13 dBi at 9 GHz and 19.1 dBi at 13.5 GHz, with corresponding side lobe levels (SLL) of -8 dB and -12 dB, respectively. The SLL at 9 GHz is relatively higher than that at 13.5 GHz due to phase errors introduced by the outer-area points in Figure 4, which affect the performance of the dual-band reflectarray. To address this issue, we can design an improved unit cell that occupies the entire region of the reflection phase distribution for both bands. Currently, dual-resonance and multi-resonance structures with better performance are under investigation for use as unit cells in dual-band reflectarrays with two distinct radiation patterns.

The simulated efficiency of the dual-band reflectarray is 20% at 9 GHz and 32% at 13.5 GHz.

#### 4 Conclusions

This paper presents a design for a single-layer dual-band reflectarray antenna with two independent radiation patterns at 9 GHz and 13.5 GHz. As an example, a  $10 \times 10$ -element dual-band reflectarray antenna was designed with two independent main beam radiation angles:  $(12^\circ, 0^\circ)$  at 9 GHz and  $(30^\circ, 180^\circ)$  at 13.5 GHz.

Simulation results show maximum gains of 13 dBi at 9 GHz and 19.1 dBi at 13.5 GHz, along with side lobe levels of -8 dB at 9 GHz and -12 dB at 13.5 GHz. The realized main beam radiation directions for both 9 GHz and 13.5 GHz are exactly as designed. We also demonstrate that phase error plays a major role in the design, which is primarily determined by the element characteristics.

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