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# *CMA-based Low-Profile Broadband Meta-surface Antenna*

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***Keywords:*** CMA, low-profile, broadband, meta-surface antenna.

***Abstract:*** A broadband low-profile meta-surface antenna based on characteristic mode analysis（CMA）is proposed in this paper. The antenna consists of three layers of metal and two layers of dielectric. The three metal layers are meta-surface, GND with cross slot and microstrip feeder from top to bottom. This paper first analyzes the meta-surface antenna by using CMA and then designs the proposed antenna. Simulation verification shows that the frequency range of $|S_{11}| \leq -10dB$ includes 4.48GHz-6.52GHz, and the relative bandwidth is 37%. The radiation direction is +z in all working frequency bands with the gain above 7.1dB. The results show low-profile broadband antenna is realized.

## 1. Introduction

Modern society is developing rapidly, and there are increasing requirements of antennas for wireless communication systems. In order to meet the higher demand for antennas in wireless communication systems, various miniaturized, multi-band, wide-band, and circularly polarized antennas are continually being proposed[1-3]. Then traditional antennas always have various defects, and they must be exchanged for a certain performance improvement at the expense of other performance. Under the circumstances that the traditional antennas cannot meet the communication needs, the proposal of the meta-surface structure makes up for the shortcomings of the traditional one. It provides a new technical means for designing antennas, so that more novel antennas can better serve wireless communication systems.

Though microstrip patch antenna is the most common forms of low-profile antennas in traditional antenna designs, they have the problem of narrow bandwidth. To solve this problem, previous researchers have used methods such as capacitive coupling feed, stacking patches, and increasing the air band. However, these methods not only increase the complexity of the antennas but also increase the costs of designing antennas. After a series of studies, it is proposed that the meta-surface structure is a two-dimensional meta-material, which meets the performance requirements of some communication systems without increasing the complexity of the antenna and the design cost. Meta-surface provides new ideas for antenna designers.

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In recent years, pieces of literature on using meta-surface structures to implement low-profile wideband antennas were published[4-8]. In 2015, a literature proposed a using meta-surface structure to realize a low profile antenna. This antenna relies on the horizontal slot radiation of a $4 \times 4$ square meta-surface and simultaneously excites two adjacent modes to achieve a full frequency band[8]. In 2017, an essay proposed a low-profile broadband meta-surface antenna, which is excited by a microstrip feed through a slot of two adjacent modes of the meta-surface to achieve broadband performance[7]. In 2019, a writing proposed a CPW-fed broadband meta-surface antenna, which uses the inconsistency of the size of the meta-surface unit to achieve broadband performance[4]; a literature has designed a circularly polarized wide-beam meta-surface antenna, which is fed by a microstrip to excite the meta-surface through four cross slots to achieve circularly polarized wide-beam performance[6]; another literature proposed a broadband dual-polarized meta-surface antenna[5]. The antenna makes broadband performance through $4 \times 4$ meta-surfaces with unequal cell sizes, and produces dual-polarization through the double feed, increasing the complexity of the antenna structure.

This paper uses characteristic mode theory to design a low-profile broadband meta-surface antenna. The purpose is to realize the broadband by analyzing the characteristic mode of the meta-surface and selecting the corresponding feeding method to activate the target mode. The theory analyzation of characteristic mode on meta-surface antenna was illustrated in Section II. Section III explains the antenna design procedure. Finally, the conclusion is presented in Section IV.

## 2. Meta-surface Design and CMA

### 2.1. Theory of Characteristic Mode

Method of characteristic mode was proposed in 1965. It was used to study the relationship between the surface current of the perfect conductor (PEC) and the tangential electric field in 1971. Then it was promoted to be used in the medium in 1972, and it was used to study the N-port network in 1973. Inagaki et al. proposed that the characteristic field of the characteristic mode was orthogonal in any area in 1982. D. Liu et al. derived the generalized characteristic module theory in 1990. Marta et al. Further perfected the characteristic mode theory in 2004. Now, it is widely used in antenna design.

Theory of characteristic mode defines a series of mutually orthogonal modes for conductors of any shape. The Eigen equations are as follows

$$X\vec{J}_n = \lambda_n R\vec{J}_n \tag{1}$$

$$\vec{J} = \sum_{n=1}^{N} \alpha_n \vec{J}_n \tag{2}$$

$$Z = R + jX \tag{3}$$

In (1), $\vec{J}_n$ is the characteristic current, $\lambda_n$ is the characteristic value, R is the real part of the Hamiltonian operator, X is the imaginary part of the Hamiltonian operator. A conductor current expansion formula , which is based on the characteristic current as of the basis function, is shown in (2). J is the total current and $\alpha_n$ is the mode weighting coefficient. The Hamiltonian operator is given in (3).

$$MS = \frac{1}{|1 + j\lambda_n|} \tag{4}$$

The MS value shown in (4), is used to judge the validity of the model. If $\lambda_n = 0$ and $MS = 1$, then the mode is considered to be a resonance mode. Generally, the frequency band of $MS \geq 0.707$ is defined as the effective frequency band of the mode.

## 2.2. Antenna Geometry

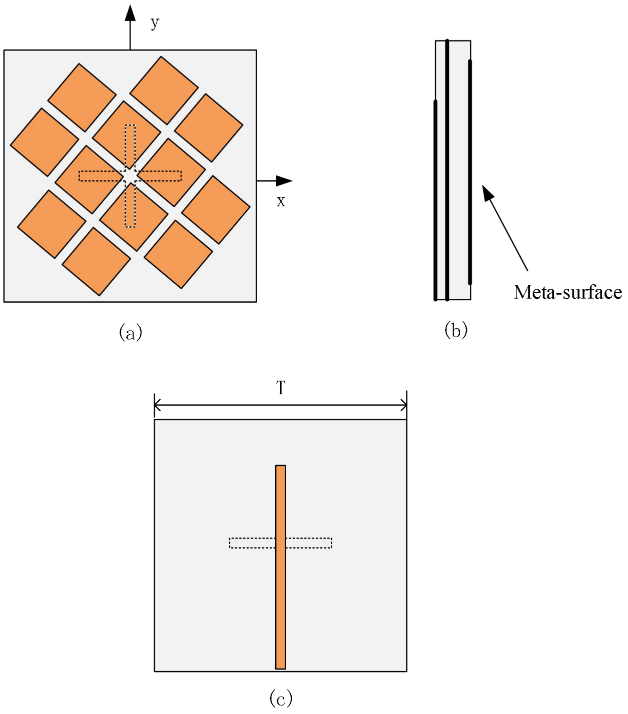


Figure 1: Structure of the proposed antenna. (a) Top view. (b) Side view. (c) Bottom view.

As shown in Figure 1, the antenna consists of two layers of dielectric and three metal layers. The top of the upper dielectric board is the meta-surface, and the bottom is the ground plane (GND) with cross slot, the bottom of the lower dielectric board is a microstrip feeder. The meta-surface is composed of the same square elements with the side length of $a = 8.8\text{mm}$ and the distance of $b = 1\text{mm}$ between the cells. The cross slot is constructed of two identical rectangle slot, and slot length on GND is $S_l = 17\text{mm}$, and its width is $S_w = 1.6\text{mm}$. The length of the bottom microstrip feeder is $f_l = 31.3\text{mm}$, and its width is $f_w = 1\text{mm}$. The heights of the upper dielectric substrate of the antenna $h_1 = 3\text{mm}$, the heights of the lower dielectric substrate $h_2 = 0.8\text{mm}$. The overall size is equal to $\text{T} \times \text{T} = 55\text{mm} \times 55\text{mm}$. The dielectric substrate is Rogers RO4003C and its dielectric constant of 3.55, the loss tangent of 0.0027.

## 2.3. CMA of Meta-surface Antenna

The simulation model in commercial simulation software CST MWS is shown in Figure 2. There is only one layer of dielectric board (no slot on the GND) in Figure 2 (a), the z - direction of the structure is an electric boundary condition $(E_t = 0)$. The model In Figure 2 (b) has two layers of dielectric plates (cross slots on the GND), the z - direction of the structure is in an open boundary condition (add space). The remaining boundaries are open boundary conditions, that is, the x- and y-directions present infinite GND.

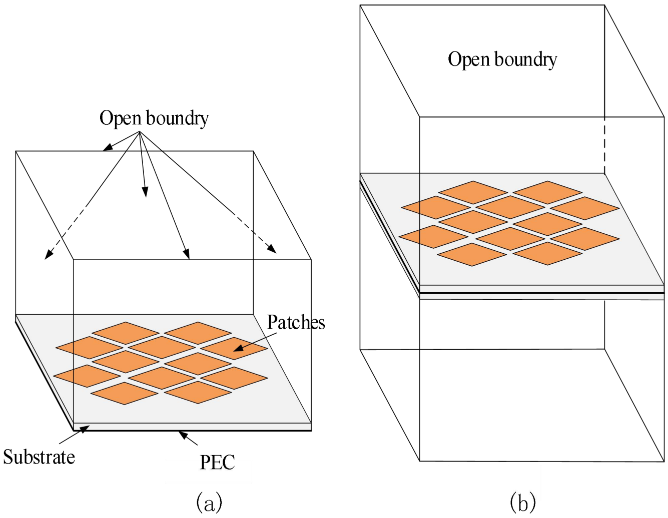


Figure 2: CST simulation model diagram. (a) only the upper substrate. (b) Two-layer substrate.

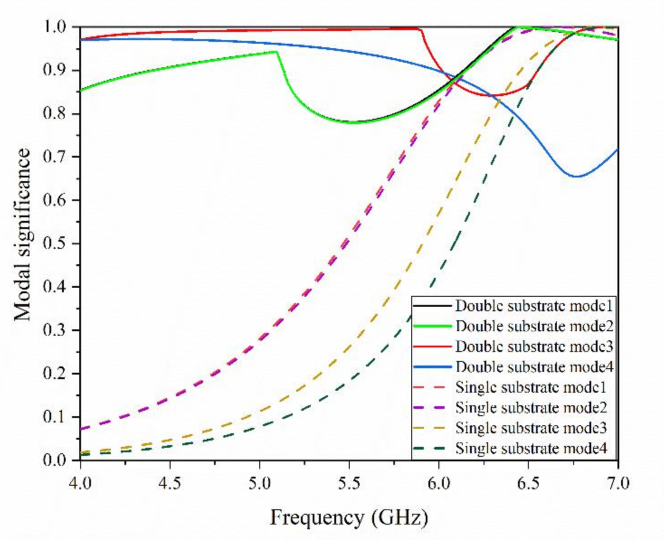
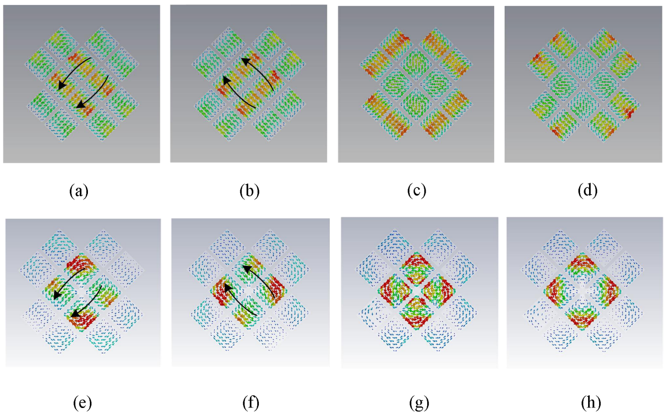
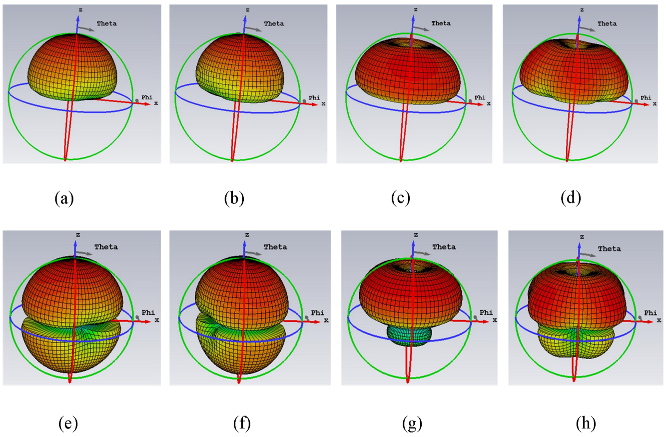


Figure 3: Modal significance of mode1 – mode4.


(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 4: Modal current of mode1-mode4. (a)-(d) Only upper substrate mode 1-mode 4. (e)-(h) Two-layer substrate mode 1-mode 4.



(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 5: Modal radiation patterns of mode 1-mode 4. (a)-(d) Only upper substrate mode 1-mode 4. (e)-(h) Two-layer substrate mode 1-mode 4.

Figure 3 shows the MS curves obtained from the first four characteristic modes analyzed in two cases. It can be seen that the MS value of the first model is of little help in designing broadband antennas. But the MS of the second model has a more full adequate bandwidth, and broadband performance can be easily achieved. Figure 4 is the current distribution obtained from the analysis of the characteristic patterns in the first four modes of the two cases. It is not difficult to see from the comparison, The current distribution of the first two modes is not affected by the slot and the dielectric of the feed layer. The current distribution of The last two modes is different. But by comparing the radiation pattern of the first four modes given in Figure 5. Its radiation patterns will not be affected whether the mode contains a feeding layer or not. However, due to the cross slot in the ground, the simulation results show the radiation back lobe. In other words, the increasing presence of the feed layer can positively increase the sufficient bandwidth without seriously degrading other performances of the antenna.

## 3. Antenna Design

The proposed antenna is simulated and optimized in ANSYS HFSS, and the simulation results are given. From the $|S_{11}|$ curve of Figure 6 that the frequency range of $|S_{11}| \leq -10dB$ is 4.48GHz-6.52GHz, and the relative bandwidth reaches 37%, which realizes the broadband performance of the antenna. From the gain curve of Figure 6, the minimum gain in the operating frequency band is 7.1dB. Figure 7 is the radiation pattern simulation results of the antenna, Figure 7 (a) shows the XOZ plane, Figure 7 (b) shows the YOZ plane, at the frequency points 4.7GHz, 5.55GHz, and 6.35GHz, respectively. The Z-axis radiation is the maximum radiation in the working frequency band. The results show low-profile wideband broadside antenna is realized.

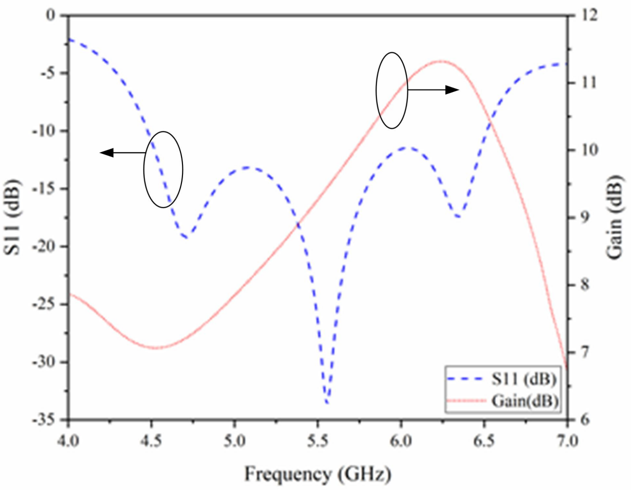
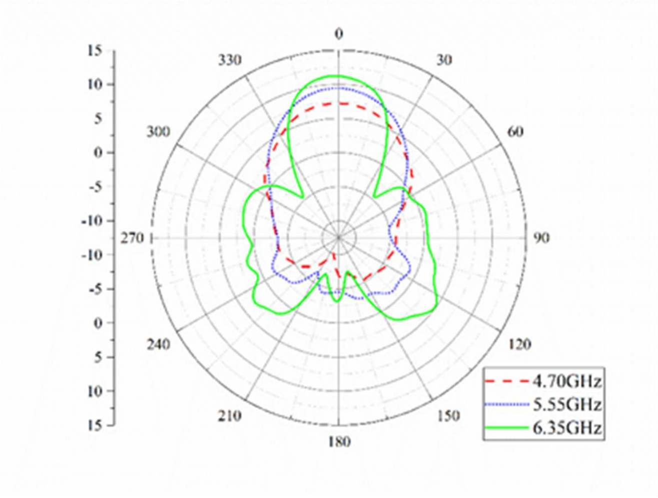
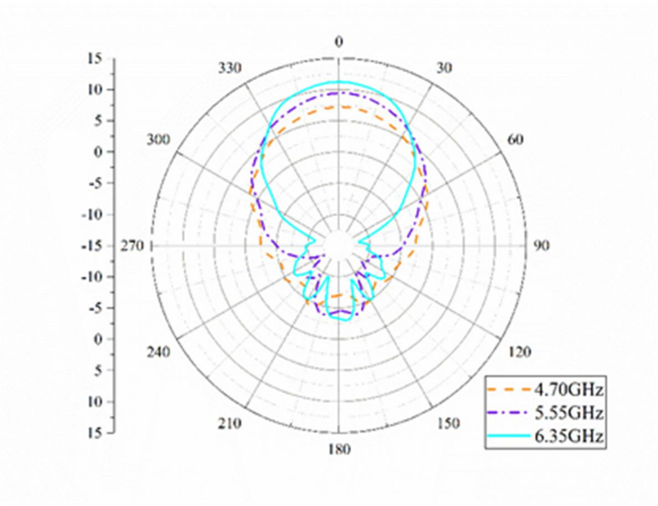


Figure 6: Simulated $|S_{11}|$ and Gain of the proposed meta-surface antenna.



(a)



(b)

Figure 7: Radiation pattern of the proposed meta-surface antenna. (a) XOZ plane. (b) YOZ plane.

## 4. Conclusions

A CMA-based low-profile broadband meta-surface antenna is proposed in this paper. The CST software is used to perform CMA on the meta-surface antenna, and the proposed meta-surface antenna is simulated in HFSS. Simulation results show that the frequency range of $|S_{11}| \leq -10dB$ includes 4.48GHz-6.52GHz, and the relative bandwidth is 37%. The radiation direction is +z in all working frequency bands with the gain above 7.1dB. The results show low-profile wideband broadside antenna is realized.

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