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Design of a Wideband Wide Scanning Phased Antenna Array with FSS Superstrates

Da-Qun Yu[1, 2, 3], Zhang-Cheng Hao[1], Lei Sun[2, 3], Kai Yan[2], Wen-Bo Zhang[2], and Yuan Jiang[2, *]

Abstract—In this paper, a planar wideband antenna array with wide scanning angle in both E- and H-planes is proposed. The dipole antenna is used as an essential element of the array. To enlarge the scanning angle of the array, two layers of frequency selective surface (FSS) superstrates are loaded on the top of the antenna elements. A conducting-patch with shorting pins is loaded under the unit patch to enlarge the bandwidth of the array. Both simulated and measured results have confirmed that the proposed antenna array can scan up to 85° and 70° in the E- and H-planes from 8 GHz to 11 GHz, respectively.

1. INTRODUCTION

Phased array antenna has been widely used in many fields due to its agile scanning, flexible beam forming, and other good properties [1]. The angle range of scanning is an important index of phased array. How to design a phased array with wide scanning angle has always been the focus of the research in recent years. Many methods have been proposed to improve scan performance of the array. In [2], an element with a reconfigurable pattern based on PIN diode is proposed. The radiation pattern of the element can be modified by tuning the operation states of the diodes. The element can scan to 60°. However, the antenna array needs to design a complex voltage-control-network to control the diode states. Tightly coupled dipole array (TCDA) is a popular choice to realize wide-angle scanning [3, 4]. With FSS superstrates loading, the TCDA can achieve 75° scanning in the E-plane [4], while the feeding network of the TCDA is complex. Artificial electromagnetic material is also a research hotspot in recent years. High impedance surfaces are utilized in the array design [5]. Although the scan angle is enlarged to 85° in E plane, this method only is adjusted to linear array. Microstrip antenna with perfectly electrically conducting (PEC) walls is proposed in [6]. The PEC walls expanded the beam width, and the array can scan to 70° is proposed in [7]. But the fabrication of the antenna is relatively complex because of the existence of the PEC walls. A simply designed antenna array in [8] with scanning range of ±58° by introducing capacitive coupling feeding is reported, whereas the bandwidth is limited.

In this paper, an antenna array with ultrawide angle scanning based on FSS superstrates and shorting pins is proposed. The FSS superstrates are utilized to compensate the inductance mismatch caused by various scanning angles. To suppress the common-mode resonance, a patch with shorting-pins is inserted under the unit patch. The simulated results show that the antenna array can scan to 85° in the E-plane and 70° in the H-plane with active VSWRs < 3.5. Moreover, a prototype of a two-dimensional array is fabricated to verify the design.

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* Corresponding author: Yuan Jiang (741303029@qq.com).
[1] School of Information Science and Engineering, Southeast University, Nanjing 210096, China. [2] Nanjing Research Institute of Electronics and Technology, Nanjing 210039, China. [3] Science and Technology on Antenna and Microwave Laboratory, Nanjing 210039, China.

2. ARRAY DESIGN

The geometry of the antenna unit is shown in Fig. 1. The antenna unit is composed of four layers of substrates. It can be divided into two parts. The first part is the basic radiating element — a dipole antenna with an unbalanced feeding structure and a conducting patch with shorting pins. These shorting pins are utilized to extend the bandwidth and scanning range by improving the impedance of the dipole antenna. The antenna ground is printed on the bottom side of the lowest substrate. The other side of the lowest substrate is the conducting patch. Shorting pins are utilized to connect the patch and ground. Above the patch, the dipole patches are printed on the top side of another substrate. One of the dipole patches is connected to the ground, and the other patch is connected to a coaxial feeding line to form the unbalanced feeding structure. Thus, the antenna unit is relatively easy to be fabricated as the feeding structure is simple. To optimize the scanning characteristics of the antenna, the FSS superstrates are loaded on the top of the antenna. They are the second part of the antenna units. The FSS superstrates contain two groups of substrates which are mirror images of each other to avoid mistaking the top and bottom for engineering consideration. Both consist of four squared patches and three metal lines. Foam is used between two layers of FSS and between antenna and FSS for support.

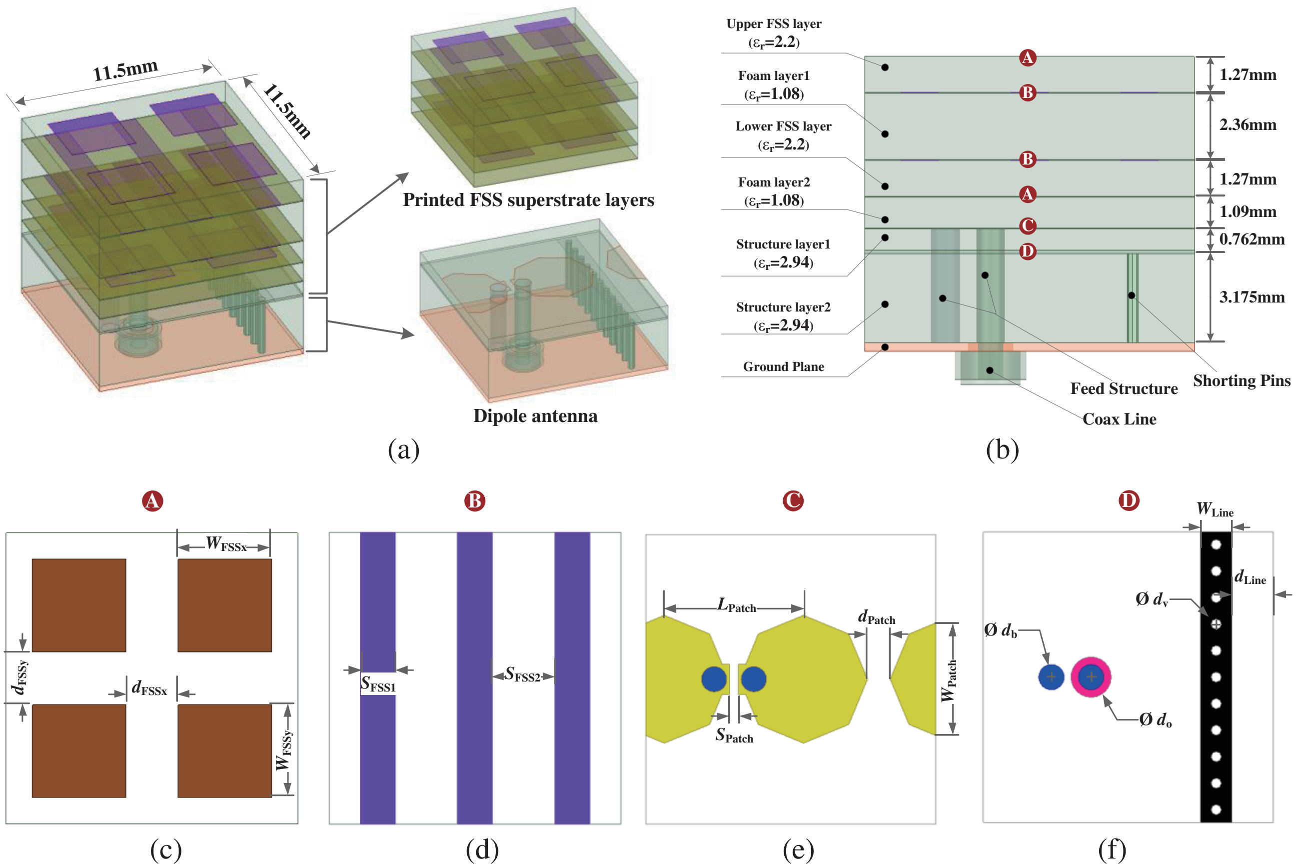
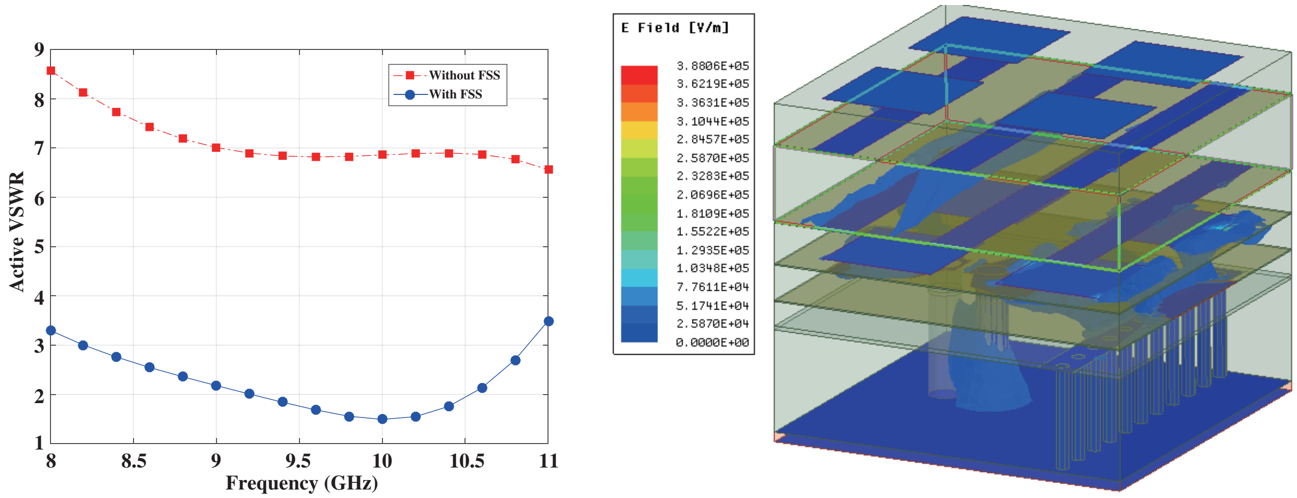


Figure 1. The geometry of the antenna element. (a) Whole model, (b) layers, (c)–(f) dimension of layer A, B, C, D ($W_{\text{FSSx}} = 3.67\,\text{mm}$, $d_{\text{FSSx}} = 2.08\,\text{mm}$, $W_{\text{FSSy}} = 3.67\,\text{mm}$, $d_{\text{FSSy}} = 2.08\,\text{mm}$, $S_{\text{FSS1}} = 1.37\,\text{mm}$, $S_{\text{FSS2}} = 2.46\,\text{mm}$, $L_{\text{Patch}} = 5.52\,\text{mm}$, $S_{\text{Patch}} = 0.37\,\text{mm}$, $d_{\text{Patch}} = 0.90\,\text{mm}$, $W_{\text{Patch}} = 4.47\,\text{mm}$, $W_{\text{Line}} = 1.22\,\text{mm}$, $d_{\text{Line}} = 1.66\,\text{mm}$, $d_v = 0.4\,\text{mm}$, $d_o = 1.6\,\text{mm}$, $d_b = 1.0\,\text{mm}$).

The simulations of the antenna element have been carried out with periodic boundary condition in High Frequency Structure Simulator (HFSS). Driven Modal solver is selected for the simulations. To ensure the accuracy of the simulations, the option of Maximum Delta S is set to 0.02 and option of



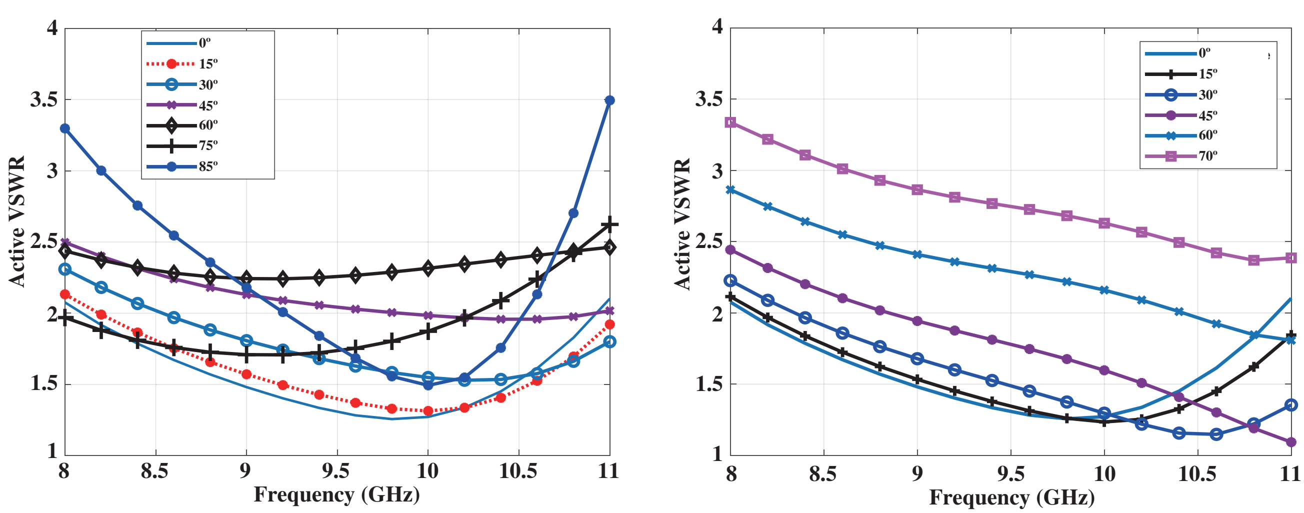
(a) (b)

Figure 2. (a) The active VSWRs of the antenna element with/without FSS. (b) Electric field distribution.

Minimum Converged Passes set to 2 in the solution setup. The effect of the FSS as the array scanning to 85° in the E-plane is shown in Fig. 2(a). As expected, the active voltage standing wave ratio (VSWR) of the proposed antenna array has been significantly improved when the FSS is utilized, implicating that the FSS can be employed to enlarge the scanning angle.

When the proposed antenna array scans to 85° in the E-plane, the electric field strength reaches its peak, as shown in Fig. 2(b), in the feasible scanning range. As can been seen, when the feeding power is 20 W, the electric field strength is lower than 3.88×10^5 V/m which is about 10 times less than the air breakdown field strength of 3×10^6 V/m. Hence, the maximum power of each port is more than 20 W.

The presence of FSS superstrates can reduce the reactance change caused by various scanning angles. After loading the FSS superstrates, the bandwidth of the antenna array is very narrow when scanning to 85°. By adding the patch with shorting pins under the dipole, the working bandwidth of the antenna is expanded. The simulated active VSWRs with various scanning angles are illustrated in Fig. 3. As illustrated, the active VSWRs are below 3.5 from 8 to 11 GHz when scanning up to 70° and

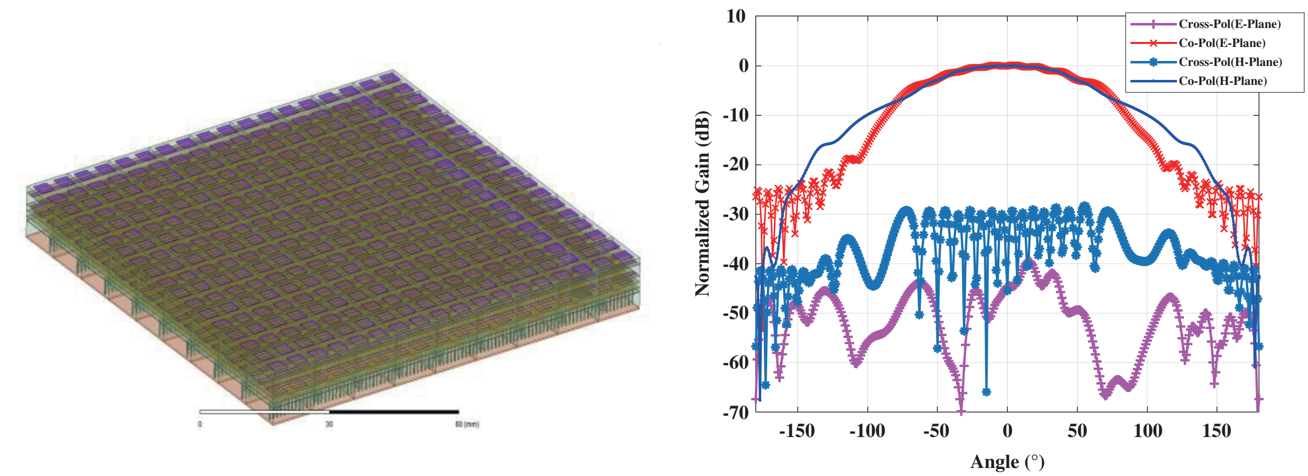


(a) (b)

Figure 3. The active VSWRs of the antenna with FSS structure. (a) E-plane, (b) H-plane.

85° in the H- and E-planes, respectively.

In order to obtain the radiation patterns of the antenna unit, a 9 × 9 antenna array is simulated. The radiation patterns of the center antenna unit in both E- and H-planes are shown in Fig. 4. The half-power beam width (HPBW) is 122° in the E-plane and 112° in the H-plane at 9.5 GHz.

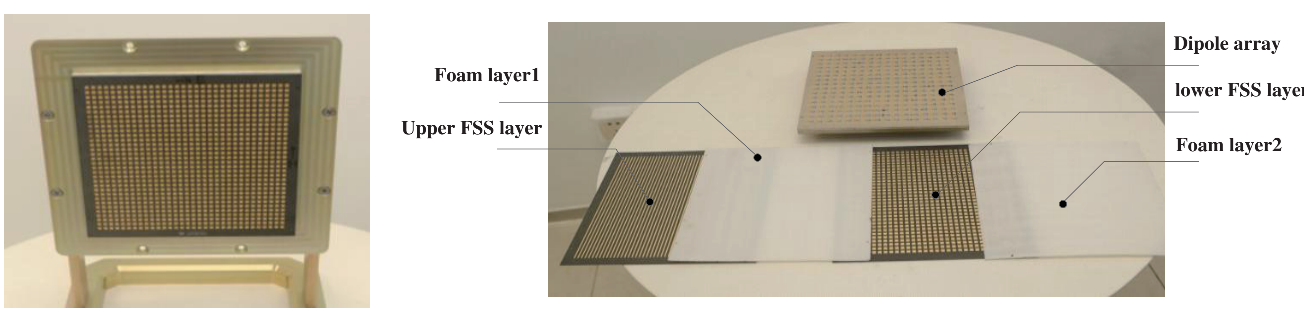


(a) (b)

Figure 4. The simulation model and results of central element patterns (a) array model, (b) central element patterns at 9.5 GHz.

3. EXPERIMENTAL RESULTS AND DISCUSSION

A prototype with 16 × 16 units is fabricated using printed circuit board (PCB) technology to validate the performance of the designed antenna array. This scale is larger than 9 × 9 for element pattern simulation because the scanning angle can reach up to 85°. In this case, the scale of the prototype should be big enough to acquire accurate active VSWRs. The photo of the prototype is shown in Fig. 5. The dipole antenna and PEC-shoring-pins structure are fabricated by the laminate and low-loss prepreg. The FSS superstrates are fabricated separately. The distances between these three parts of the prototype are maintained by foams. Finally, the foam layers and other parts of the antenna array are glued together.



(a) (b)

Figure 5. The photo of the fabricated antenna array (16 × 16).

The active VSWRs are measured using vector network analyzer (VNA). The measured results are shown in Fig. 6. As shown, the proposed antenna array can scan to 85° and 70° with active VSWRs less than 3.5 from 8 to 11 GHz in the E- and H-planes, respectively. The embedded element patterns dictate the array's gain variation with scan and the relative co- and cross-polarization levels. To perform this

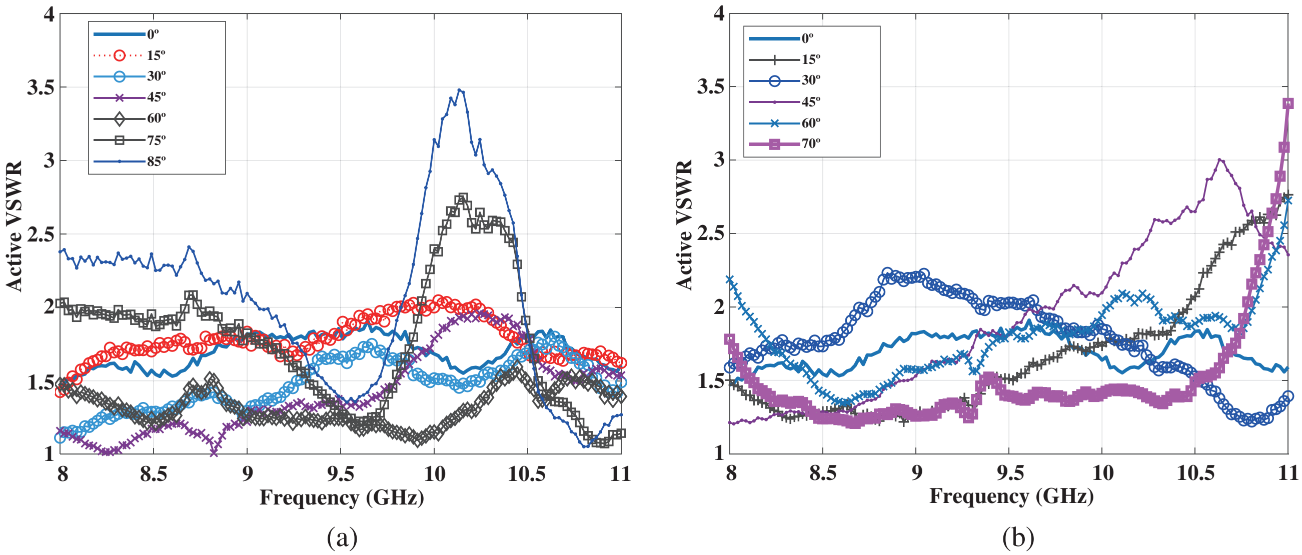


Figure 6. The measured active VSWRs (a) E-plane, (b) H-plane.

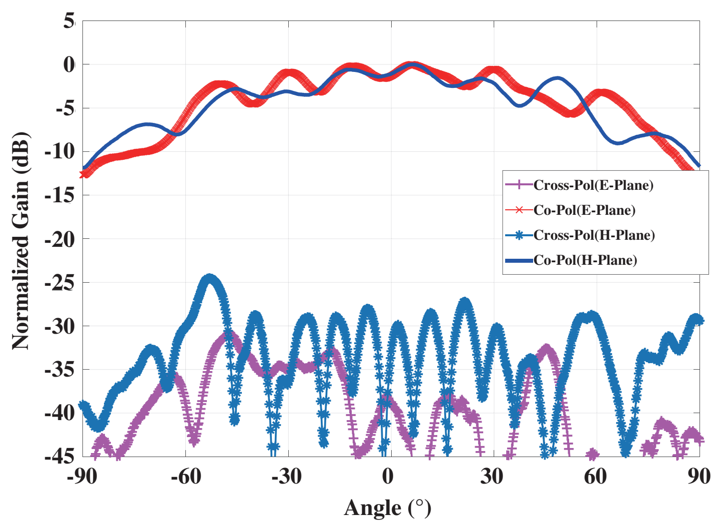


Figure 7. The measured central element patterns.

measurement, the array was mounted on an azimuth positioner in a far-field chamber. The embedded element patterns are found by exciting a central element and measuring the resultant radiation pattern, with all other elements terminated. Measured results are shown in Fig. 7.

Generally, the measured active VSWRs and element patterns are in line with expectations and verify the good performance of the proposed antenna array. The measured active VSWRs show a peak less than 3.5 at around 10.2 GHz when scanning to more than 70°. This is caused by that several parts of the antenna array are not glued well. It can be settled by improved gluing technology.

To better show the advantages of the proposed wideband wide scanning phased array, comparisons with various previous antenna designs are presented in Table 1. Clearly, compared with other previous works [2–7], the proposed design has a wider two-dimensional scanning angle while achieving a wide operating bandwidth.

Table 1. Comparison of the proposed antenna with previous ones.

Ref.	Operating Frequency	Bandwidth	Beam scanning range	Technology
[2]	5.8 GHz	Narrowband	Linear, H-plane: $\pm 60°$	Reconfigurable Elements
[3]	$0.68 \sim 5$ GHz	152.1%	Two-dimensional, H-plane: $\pm 45°$ E-plane: $\pm 45°$	TCDA + Integrated Balun
[4]	$0.5 \sim 3.1$ GHz	144.4%	Two-dimensional, H-plane: $\pm 60°$ E-plane: $\pm 75°$	TCDA + FSS
[5]	2.7 GHz	Narrowband	Linear, H-plane: $\pm 85°$	High Impedance Surfaces
[6]	$4.8 \sim 6.0$ GHz	22.2%	Two-dimensional: H-plane: $\pm 60°$ E-plane: $\pm 60°$	Metasurface
[7]	$3.7 \sim 4.3$ GHz	15.0%	Linear, E-plane: $\pm 85°$	Wide Beam Elements
[8]	$9.5 \sim 10.5$ GHz	10.0%	Two-dimensional: H-plane: $\pm 58°$ E-plane: $\pm 58°$	capacitive coupling feeding
This work	**$8 \sim 11$ GHz**	**31.6%**	**Two-dimensional, H-plane: $\pm 70°$ E-plane: $\pm 85°$**	**FSS**

4. CONCLUSIONS

A novel antenna array loaded with FSS superstrates and shorting pins is proposed. The existence of these two structures expands the scanning angle of the array to 85° in the E-plane and 70° in the H-plane, respectively. Within the frequency band of $8 \sim 11$ GHz, the antenna array has good active VSWRs properties for various scanning angles. The obtained results have confirmed that the proposed antenna array has potential applications for phased array radars.

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