Thin Transmitarray Panel with full 360-degree Phase Shift Range

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***Abstract*-This paper presents a new design technique to reduce the thickness of the transmitarray (TA) panel while maintaining 360° phase shift range. Two types of unit cells, the receive-transmit unit cell and the frequency selective surface (FSS) unit cell, are placed in the same aperture. Comparing to the existing ultra-thin TA designs of similar panel thickness, the presented TAs do not suffer from the phase quantization loss and achieve better aperture efficiency. This study proves that it is viable to mix different types of TA unit cells to design a TA. The developed TA shows better gain than a homogeneous TA using the same elements and improved the overall efficiency by 60%. To verify the design concept, one TA with central frequency at 13.3 GHz was designed, fabricated and measured. The measured gain is 21.3 dBi and the calculated aperture efficiency of the TA is 37.9%.**

I. Introduction

Transmitarray (TA) has the advantages of moderate efficiency, lightweight, free from feed blockage, and good surface tolerances [1]. Recent years have seen many research progresses in this field, including the use of frequency selective surfaces (FSS), receive-transmit unit cells, and metamaterials [2-6]. Electronically reconfigurable TA unit cells with low bit phase quantization were reported [7-8]. Hybrid antenna configuration, which combines reflectarray and transmitarray, was proposed to design a low-profile TA [9]. The concept of tightly coupled dipole arrays was applied to the design of ultra-wideband band TA [10].

It is challenging to reduce the panel thickness of a TA while maintaining its good radiation performances. Metamaterial-based TAs with thin panels were presented in [11-12], each of which consists of three planar metallic layers printed on two bonded laminates. Regarding the TA designs using either FSS or receive-transmit unit cells, to reduce the profile of the TA panel, most of the reported ultra-thin TAs are realized by sacrificing the phase shift range of the unit cells. For example, a thin TA that uses a mixed-order elliptic filter array was reported in [13]. Although the profile of the TA is reduced to less than $0.05\lambda_0$. the achievable phase shift range is only about 163°. In [14], to obtain a planar lens with a very low profile, the unit cell only provides 2-bit phase shift.

In this paper, we present our recent research progress in the design of TA with a thin panel and 360° phase shift range. The presented design method places two different types of unit cells in the same aperture, namely FSS unit cells and receive-transmit unit cells. Each type of unit cell provides a different phase shift range, and they are used to complement each other in order to achieve the desired phase shift range. Thus, the developed TAs do not suffer from the phase quantization loss and the resulting TA panel is very thin.

This paper is organized as follows. Section II details the design concept including the configuration of the unit cells and the TA design. Section III presents the simulation and measurement results of the prototype. Section IV concludes the paper.

II. Transmitarray Design

A. *Design Concept*

The design concept is to extend the achievable phase shift range through placing the FSS and receive-transmit unit cells in the same aperture. Fig. 1 shows the present design, which mixes the receive-transmit and FSS type unit cells in the same aperture. In this study, the receive-transmit unit cell is chosen to be an insect-fed patch antenna.

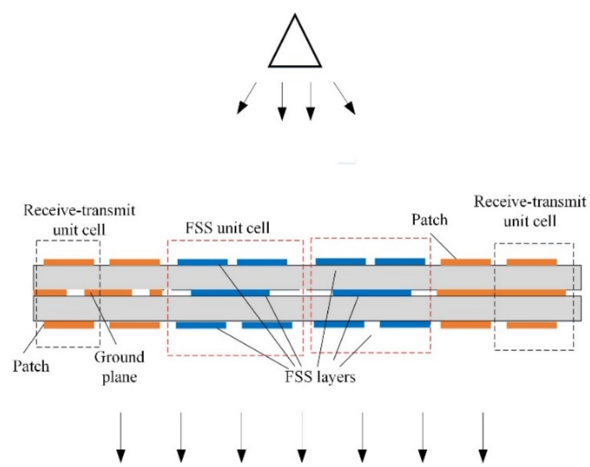

Figure 1. The concept of the presented thin TA panel design.

To realize such a hybrid design, the period of the FSS and the patch must be the same, and both the FSS and patch must be designed on the same substrates. In this study, the central frequency of the TA is chosen to be 13.5 GHz.

B. *Unit Cells*

Fig.2 shows the configuration of the Receive-transmit unit cells. Two inset-fed square patches have a back-to-back configuration sharing one ground plane. The two microstrip feed lines are electromagnetically coupled by aperture coupling, where the aperture is etched on the shared ground plane. The phase shift is obtained by simultaneously varying the length of the phase delay lines that are attached to the patches.

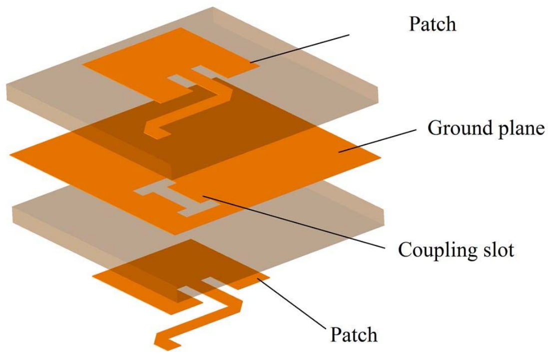

Figure 2. Configuration of the transmit-receive unit cell.

Fig.3 shows the configuration of the bandpass FSS unit cell. As shown, Layer 1 and 3 are two capacitive layers and Layer 2 is one inductive layer are used. This type of configuration is used for the purpose of increasing the bandwidth of the FSS. The FSS unit cell can be regarded as a subarray that consists of 2×2 sub-wavelength square patches. This approach can alleviate the unwanted effects of the finite size array and let the FSS unit cell maintain good bandpass filter characteristics even in a small size array. The phase shift is controlled by simultaneously changing the widths of the square patches printed on Layers 1 and 3.

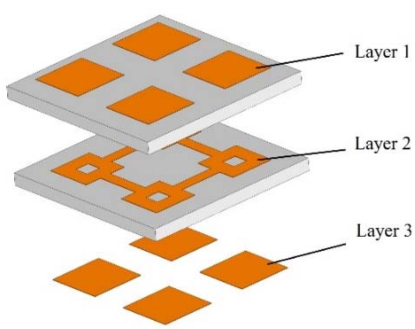

Figure 3. Configuration of the wideband FSS unit cell.

For both types of unit cells, the period is chosen to be 12 mm, which is approximately $0.5\lambda_0$ at 13.5 GHz. The three layers are printed on two 0.8mm thick RO4003C (εr=3.55, tanδ=0.0027) substrate so the total thickness of the unit cell is 1.6mm ($0.07\lambda_0$).

C. *TA Design*

The concept of hybrid TA design is to place different types of unit cells that have different phase shift range in the same aperture. These unit cells complement each other and provide the desired 360o phase shift. During the TA design, it is important to maintain the local periodicity of each type of unit cells in order to alleviate the effect of non-periodic condition. Fig. 4 shows the layouts of the designed transmitarrays using the developed unit cells. It has a square aperture with 100 unit cells (10×10). A linearly polarized corrugated circular horn antenna with gain about 13.5 dBi is used as the feed antenna and the f/D ratio is chosen to be 0.75 (representing a focal distance of 90mm), where f is the focal distance and D is the width of the TA panel.

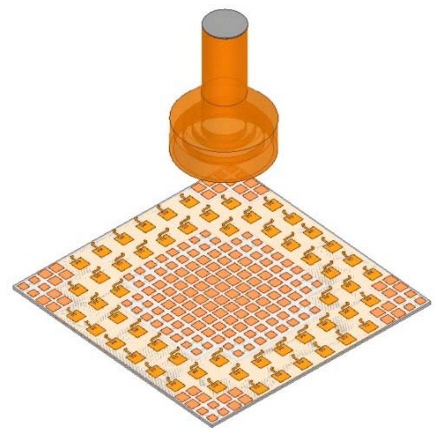

Figure 4. Configuration of the developed TA.

III. SIMULATION AND MEASUREMENT RESULTS

The designed TA was fabricated and measured in the anechoic chamber. It is found that the maximum gain of the TA is not at the designed central frequency, 13.5GHz. Instead, the central frequency of TA slightly shifts to a lower frequency, 13.3GHz. This is caused by the effect of finite array size. Fig.5 shows the simulated S11 of the feed horn with and without the transmitarray panel. As shown, at the operation frequency range of the transmitarray, the incident wave is transmitted. Fig. 6 (a) and (b) compare the simulated and measured radiation pattern of the TA at 13.3 GHz in E-and H-planes. There is good agreement between the simulation and measurement results except for small discrepancies in sidelobe levels. The measured gain is about 21.3 dBi and the calculated aperture efficiency of the TA is 37.9%. EM simulations were performed to find out how the radiation performance of the developed TA is improved compared to the case that TA designs only employing the FSS or the patch antenna as the unit cell. During this study, the patch and the FSS have the same configurations as the ones used in the presented TA design. It was found that when only FSS elements are used, in the central frequency, the TA has a gain of 16.7 dBi, while the gain of patch-only TA is 19.2 dBi.

Using the developed technique to design the TA, the gain is improved by 2.1 dB.

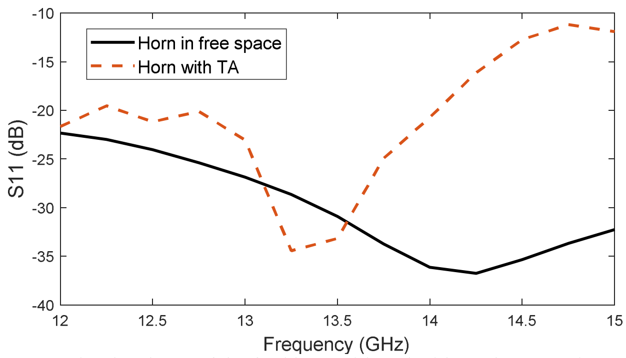

Figure 5. Simulated S11 of the feed horn with and without the transmitarray panel.

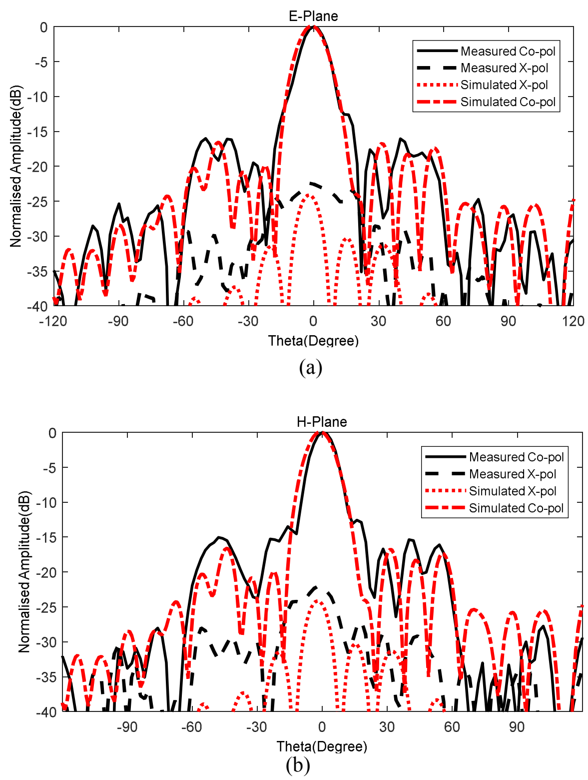

Figure 6. Comparison of the measured and simulated radiation patterns of the fabricated TA prototype I at 13.3 GHz. (a) In Phi=0-degree plane (E-plane). (b) In Phi=90-degree plane (H-plane).

IV. CONCLUSION

A new design concept is presented to design a thin panel transmitarrays. The approach places the FSS and patch antenna elements in the same aperture. This avoids the phase quantization errors suffered from many reported ultra-thin designs and maintains the good radiation performance. Compared to other reported lowprofile designs of similar aperture size, the developed ultrathin transmitarray is one of the thinnest but with higher gain and comparable 1-dB gain bandwidth.

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