Design of a 1-Bit Reconfigurable Transmitarray Element in Ku Band

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Abstract- An electronically reconfigurable transmitarray element designed in Ku band is presented. The proposed element using two orthogonally coupling slots structure with two PIN diodes, can be electronically controlled to generate two phase states with 180° phase difference and low transmission loss. The metal vias are added around the element to eliminate the transmission zeros under oblique incidence, and improve the transmission characteristics. In simulation, the insertion loss of two states are 1.5 dB at normal incidence. Full-wave simulation results show that the proposed element with vias loading achieves a stable performance under oblique incidences.

I. INTRODUCTION

As one of the high-gain antennas, transmitarray antenna (TA) [1] is a promising potential technology to be applied for satellite-based telecommunication systems. TA is combined with the favorable features of the lens antennas and the microstrip arrays. Contrary to the traditional phase array, TA has obvious advantages in low-profile, light-weight, and easy fabrication. Meanwhile, TA can eliminate the loss and parasitic effects of the constrained feed networks and can dramatically improve the radiation performance.

A fully electronic scanning performance is achieved by integrating the phase-shifting devices on the transmitarray. Reconfigurable transmitarray antennas (RTAs) overcome the scanning degradations for the phase aberration of the fixed arrays. Reconfigurable transmitarray antennas (RTAs) are integrated with tunable devices, e.g., PIN diodes [2], varactor diodes [3], MEMS [4] or tunable materials [5] instead of additional phase shifters or expensive transmit/receive (T/R) modules used in the traditional phased arrays. Hence, RTAs are regarded as a promising effective alternative for wireless communication.

Several antenna prototypes for RTAs designs have been fabricated and measured in literature. 2-bit element is designed with variable phase delays at 34.8 GHz [6]. The continuous tunable phases nearly 360° phase range are realized by loading the multiple varactor diodes between top layer and bottom layer in C Band, as shown in [7]–[9]. Two PIN diodes are integrated on the active side of each 1-bit element to change the relative direction of the receiver and the transmitter [10]. The linear polarization manipulation and the continuous controllable phases are achieved in X band [11]. 1-bit RTA produces circularly polarization from linear polarization using two PIN diodes [12]. The main challenges in RTAs design are dc biasing, packaging and assembly for active devices in finite element space or finite array space. It becomes especially restrictive for high phase quantization design. Therefore, 1-bit RTAs are more practical to reduce the system complexity and cost [13].

In the previous work [14], a 1-bit reconfigurable element with subwavelength size has been proposed. However, the design of small-size element increases the complexity of bias circuits, especially for large-aperture array antennas. Therefore, a 1-bit reconfigurable element with half-wavelength size is further designed in this paper. The rest of this work is organized as follows. Section II describes the performance of the proposed 1-bit RTA element. Section III concludes this work.

II. THE ELEMENT DESIGN AND PERFORMANCE

A. 1-Bit RTA Element Design

The geometry of the proposed 1-bit transmitarray element is shown in Fig. 1. The size of the element is 12 mm×12 mm (P = 12 mm), corresponding to 0.5λ₀×0.5λ₀ at the design frequency of 12.5 GHz. The proposed element adopts the guided-wave approach [15] to control the transmission. Two H-shape slots (W=1 mm, L=7.9 mm) are regarded as the...
receiving (Rx) and transmitting (Tx) layers, respectively. They are orthogonally placed to isolate directly coupling, and achieve the polarization transformation, as shown in Fig. 1(b) and(d). The incoming space-wave is first coupled by the receiving layer to a guided-wave. The guided-wave is then phase shifted in the U-shaped microstrip line (Ws=1 mm, Ls1=2.8 mm, and Ls2=4.2 mm), and is finally re-radiated by transmitting layer. Two PIN diodes are symmetrically integrated on the U-shaped microstrip line, as shown in Fig. 1(c). A 180° phase difference is obtained by altering the states (ON-OFF state and OFF-ON state) of two PIN diodes (PIN1-PIN2). Metal vias are employed around the element to improve the shielding between the adjacent elements and suppress surface wave modes. Two identical substrate layers (Taconic TLX-8, εr=2.55, tanδ=0.0019, thickness=0.78 mm) and three copper layers are required in the element structure.

The PIN diode selected for this reconfigurable transmitarray element is MACOM MADP-000907-14020. For ON or OFF state, the PIN diode is modeled as a series of lumped RLC elements: R=7.8 ohm and L=30 nH for ON-state diode. And C=25 fF and L=30 nH for OFF-state diode.

### B. Simulated Element Performance

The element is illuminated by two Floquet ports in HFSS. Periodic boundary conditions are applied on four of the boundaries to mimic an infinite array environment. The parameters of the two H-shaped slots are optimized to ensure good matching to the coupling transmission line, as well as a stable element performance under various oblique incidences. The S-parameters of the proposed reconfigurable transmittarray element illuminated by a y-polarized wave is shown in Fig. 2. Table I lists the S-parameters of the simulated results at 12.5 GHz with two states. For ON-OFF state, it is seen that the y-polarized wave passes through the element and is converted into the x-polarized wave at 12.5 GHz, where the reflection magnitude is less than -10 dB and the minimum insertion loss is about -1.5 dB. The similar results are obtained for OFF-ON state. The transmission phase curves for two states are parallel. Thus, the phase difference between the two states is 180° independent with frequency, indicating a good element-bandwidth performance.

The performance of the proposed element for different incident angle are also analyzed. The elevation angle of

| Table 1: The Simulated Results of the Designed Element |
|-----------------|-----------------|-----------------|
| State | Magnitude (dB) | Phase (°) | PIN1-PIN2 |
|-----------------|-----------------|-----------------|
| 1 | -1.5 | -5 | ON-OFF |
| 2 | -1.5 | 175 | OFF-ON |

Fig. 2. Simulated magnitude and phase responses of the proposed element under normal incident angles: (a) magnitude, (b) phase.

Fig. 3. Simulated magnitude and phase responses of the proposed element under oblique incident angles: (a) magnitude, (b) phase.
0°–30° are investigated. The simulation magnitude and phase of element are plotted in Fig. 3. Under oblique incidence angle, the magnitude response curve and phase response curves are basically coincident.

C. Floquet-Mode Analysis

It is worth mentioning that the proposed element without vias loading is very sensitive to the angle of incidence and quickly deteriorates for oblique incidence. The geometry of the proposed element without vias loading is shown in Fig. 4. The simulation results for ON-OFF state without metal vias are shown in Fig. 5. It is observed that incidence by 30° drastically distorts the frequency response and the transmission magnitude is close to -50 dB at 12.5 GHz.

In the Floquet’s theory [16], it explains the reasons of the deterioration of the frequency response for oblique incidence. In multilayer structures, two metallic sheets are regarded as a parallel plate waveguide where the guided modes are excited. A transmission zero occurs when one of the Floquet modes coincides with a guided mode of the structure. The lowest order resonance frequency ($f_{0l}$) of the guided modes satisfies:

$$f_{0l} = c/p(\sqrt{\varepsilon_r \sin \theta_{inc}})$$  \hspace{1cm} (1)

where $c$ is the speed of light, $p$ is the periodicity, $\varepsilon_r$ is the relative permittivity of the substrate, and $\theta_{inc}$ is the incidence angle. Equation (1) shows that the lowest order mode can be excited at 12.5 GHz under 30° incidences. It is obvious that the sensitivity of incident angle is reduced and the bandwidth is increased, by loading metal vias around the half-wavelength element.

III. Conclusion

In this paper, a 1-bit reconfigurable transmittarray element is proposed. Half-wavelength is selected as element size to reduce the system complexity and cost. To eliminate the transmission zeros under oblique incidence, the metal vias are introduced around the element to obtain stable performance. Finally, simulation results verify the good performance of the proposed element in this paper.

REFERENCES