A 4×4 Digitally Reconfigurable Transmitarray: Measurement of Radiation Patterns

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Abstract In this letter, measured radiation patterns of a 4×4 digitally reconfigurable transmitarray are presented. It is possible to get beam steering and polarization conversion operation using the 4×4 digitally reconfigurable transmitarray. There is a total of four PIN diodes in each unit cell of the transmitarray. The polarization conversion operation is realized using the upper two PIN diodes and the beam steering operation is realized using the lower two PIN diodes. “State1” and “State2” are the biasing conditions of the upper two PIN diodes. These states can be represented as “0” and “1”. By arranging “0” and “1” on the top and bottom layer of the transmitarray, beam steering, and polarization conversion operations can be obtained digitally. This type of transmitarray is useful for radars, satellites, and other types of communications applications.

key words: Transmitarray, near-field, beam steering, PIN diode.
Classification: Microwave and millimeter wave devices, circuits, and hardware

1. Introduction

“Digital Electromagnetics” is an area of study where electromagnetic waves are digitized without using conventional phase shifters for different applications [1]. Digitally reconfigurable transmitarray proposed in [1], is an ideal example in the area of “Digital Electromagnetics”. It is possible to control electromagnetic waves in real-time and get different functionalities in a programmable way using digitally control transmitarray. In the literature, first, a passive type transmitarray was proposed connecting the upper patch and lower patch in [2]. There are some active analog-type transmitarray in the literature, where varactor diode based phase shifters were used [3-11]. There are some transmitarray and some reflectarray whose phases were discretized into using PIN diodes without using conventional phase shifter [12-31]. Digitally reconfigurable transmitarray is promising compared to phased array antennas because of very low losses, low cost. Beam scanning and dual-polarization are now promising operations for future communication systems. A scanned beam can point a beam in the desired direction. Hence, it can improve energy efficiency significantly. Dual-polarization can increase the channel capacity two times. Both scanned beam and the dual-polarized beam can significantly improve the data rate for future communication systems.

In this letter, we have presented measured radiation patterns for our proposed 4×4 transmitarray for different bias states [1]. We measured the radiations patterns in an anechoic chamber. Initially, near-field data was measured in an anechoic chamber. After that, using transformation, the far-field radiation patterns were obtained from the near-field data.

2. Configuration of unit cells and 4×4 transmitarray

Fig. 1 (a) Side view of the unit cell (b) upper patch (c) lower patch.

The side view of the unit cell is shown in Fig.1 (a). The
upper patch and lower patch are shown in Fig. 1 (b) and Fig. 1 (c), respectively. The unit cell was designed with two Taconic substrates which were sandwiched together with a bonding film. Each Taconic substrate with a permittivity of 3.5, loss tangent of 0.0018, and a height of 1.52 mm had a total area of 15×15 mm² (0.47λ₀×0.47λ₀). The upper side of the unit cell had two PIN diodes (MA4GP907, MACON, Lowell, MA, USA). A centralized via with a diameter of 0.4 mm connected the upper patch and lower patch. The same type of two PIN diodes was on the lower side of the unit cell. A 4×4 transmitarray was presented and the transmission and reflection coefficient of the 4×4 transmitarray were verified in [1].

3. Fabricated transmitarray and measurement setup

The fabricated 4×4 transmitarray is shown in Fig. 2. There was an X-band miniaturized horn antenna that was used to spatially feed the 4×4 transmitarray.

![Fabricated 4×4 transmitarray.](image1)

A D-sub connector was used for biasing the PIN diodes of the 4×4 transmitarray. As we had fabricated a very small array for initial verifications of the reflection and transmission coefficients, there was spill-over leakage from the transmitarray. To overcome this issue, we had placed some absorbers around the transmitarray as shown in Fig. 2. The measurement setup for the 4×4 transmitarray is shown in Fig. 3.

![Radiation patterns measurement setup for the 4×4 transmitarray.](image2)

The procedure to measure the radiation patterns is as follows:
1. Calibration by using standard horn antenna (horn-probing antenna)
2. Measurement of near-field data (S-parameter, magnitude, and phase) at each different polarization (scanning under the V-pol. and H-pol. condition)
3. After finishing the scanning, the radiation pattern was calculated by transformation (FFT) S/W.

In the “State1” condition, polarization conversion and phase-shifting operations of the unit cell were in an “Off State”. Fig. 4 and Fig. 5 show measured and simulated E-plane and H-plane radiation patterns for the “State1”, respectively. In the “State3”, the polarization conversion was “On State” and the phase-shifting operation was “Off State”. Fig. 6 and Fig. 7 show simulated and measured E-plane and H-plane radiation patterns for the “State3”, a polarization converted state. The antenna can scan the beam at a certain angle while the phase distributions of the lower layers of the unit cells are arranged in a particular pattern. Fig. 8 shows E-plane simulated and measured radiation pattern for the radiation patterns while the States of unit cells were arranged for the right-side scanned beam. A measured peak gain of the transmitarray was observed at θ=22° for the right-side scanned beam. Fig. 9 shows E-plane simulated and measured radiation pattern for the radiation patterns while the States of unit cells were arranged for the left-side scanned beam. A measured peak gain of the transmitarray was observed at θ=-14° for the left-side scanned beam. The maximum simulated gain of the proposed array for the “State1” was 12.2 dBi. The measured gain patterns were different for different states because of the fabrication error of the proposed array. The frequency of all measured radiation patterns was at 9.35 GHz.
**Fig. 4** E-plane simulated and measured radiation patterns of the 4×4 transmitarray for the “State1”.

**Fig. 5** H-plane simulated and measured radiation patterns of the 4×4 transmitarray for the “State1”.

**Fig. 6** E-plane simulated and measured radiation patterns of the 4×4 transmitarray for the “State3”.

**Fig. 7** H-plane simulated and measured radiation patterns of the 4×4 transmitarray for the “State3”.

**Fig. 8** Simulated and measured radiation patterns of the 4×4 transmitarray with peak gain at $\theta=22^\circ$ (Measurement).

**Fig. 9** Simulated and measured radiation patterns of the 4×4 transmitarray with peak gain at $\theta=-14^\circ$ (Measurement).
5. Conclusion

In this letter, we have verified the radiation patterns of our recently proposed digitally reconfigurable transmitarray. A 4×4 transmitarray had beam steering and polarization conversion capabilities. We have measured the radiation patterns of our proposed 4×4 transmitarray. The antenna is a promising antenna for radars and other communication applications where each unit cell can be programmed according to the desired functions. An 8×8 or 16×16 transmitarray can be fabricated for real-time applications.

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