A tiled dual-polarized transmitarray with 1-bit quantization

A tiled dual-polarized transmitarray with 1-bit quantization

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Abstract. An original approach of a transmitarray which consists of the tiled unit cells placed in a plastic holder is considered. Each unit cell represents a passive receiver-transmitter structure with integrated phase-shifter, which can take either of two coding states corresponding 180° phase difference between the states. The transmitarray design supports two orthogonal linear polarizations. An example of a 10x10 element 1-bit beam steering transmitarray operated in C-band is presented. The results of radiation pattern measurements with single and multifeed excitation are shown. The proposed structure represents a cost-efficient solution for scalable transmitarrays.

1. Introduction

Nowadays, the rising the data throughput creates new challenges to wireless system design. Potentially the increasing of data throughput can be achieved by shifting the operational frequencies up to mm-waves. However, for overcoming path losses high gain antenna systems are required. There are different approaches to design high gain antennas. It can be large scale traditional antenna arrays suffering from complexity and high-power consumption due to large number of the phase shifters. Also, the dielectric lenses can be used, but it has volumetric implementation and can't provide reconfigurability. It becomes popular to design the planar beamforming network such as a transmitarray and a reflectarray. The transmitarray antenna is typically formed by half-wavelength unit cells and a source placed at a focal distance *F*. The unit cells generate a phase distribution across the array and form a plane wave front. The beamforming can be provided by changing the feed position or incorporating the tunability in side of unit cell of such systems. There are the different types of a realization of the reconfigurable transmitarray, for instance, by using varactor diodes and PIN-diodes [1-2]. Using 1-bit phase quantization in transmitarrays allows reducing the complexity and insertion loss of the unit-cell and the whole transmitarray [3].

In this paper, we present the design, simulations and measurements of a 1-bit C-band transmitarray. It supports two orthogonal polarizations. The array is assembled manually from the identical building blocks (tiles) by arranging them in the prescribed pattern to steer the beam in the desired direction.

2. The tiled transmitarray: structure and experimental results

2.1. The structure of the transmitarray

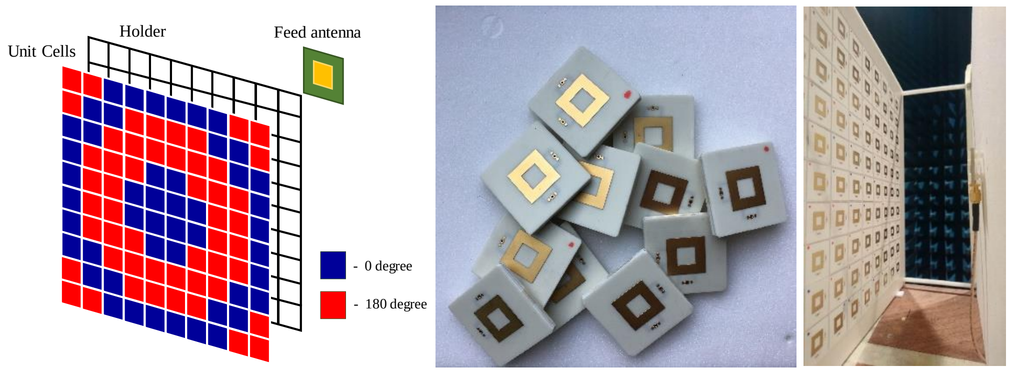
In the considered transmitarray, the ideal continuous phase distribution is discretized due to quantization of the unit cell phase shift, according to the following recipe:

$$\arg\left(T_{nm}^{d}\right)=\begin{cases}0^\circ & \forall\left|\arg\left(T_{nm}^{c}\right)\right|\le 90^\circ \\ 180^\circ & otherwise\end{cases}, \quad (1)$$

where $n = 1, 2,\ldots, N$ and $m = 1, 2,\ldots, M$ are the row and column indexes of the array which determine the position of each unit cell with respect to the reference one, T_{nm} the unit cell transmission coefficients and $\arg\left(T_{nm}^{c}\right)$ is the wrapped continuous phase shift of each unit cell required to implement the ideal phase distribution at the outward side of the transmitarray.

The transmitarray consists of tiled unit cells, which are placed in a plastic holder. The proposed unit cell is formed by two patches with square defects. Each defected patch is capacitively loaded by two U-shaped half wavelength resonators [4]. The pairs of U-shaped resonators are placed in orthogonal planes. In the proposed unit cell, a 180° phase shift can be realized by changing the feed point of the U-shaped resonator on the receiving side of the transmitarray from one end of the resonator to the other. The structure can be excited by plane wave with linear polarization (TE or TM) or circular polarization. The size of the tiled unit cell is 23 x 23 mm^2.

The structure has been manufactured to ensure the capability of a tiled transmitarray. At this stage the reconfigurability has been ensured with different types of tiles with fixed state of the phase delay. The difference between two states is 180°. A sample tile distribution for broadside radiation pattern and focal distance 90 mm is shown in Fig. 1 (a).



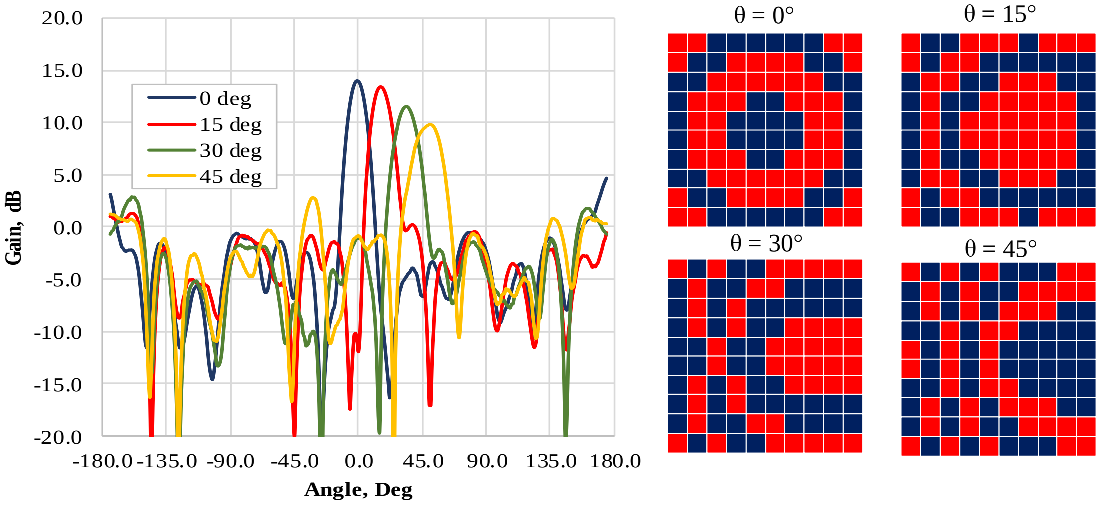
(a) (b) (c)

Figure 1. Proposed 1-bit tiled transmitarray architecture (a) and manufactured transmitarray: separate phase shifting tiles(b), inside view of the transmitarray with patch antenna as a feed (c).

2.2. Single feed excitation

The array feed was designed as a linear-polarized slot-fed rectangular patch antenna with the simulated gain of 6-dBi at 5.8 GHz and a half-power beamwidth of 90° and it was fabricated in the multi-layer PCB technology. The type of polarization of the proposed transmitarray is defined by the polarization of the feed, because the unit cell is invariant to polarization.

The transmitarray has been fed with different excitation configurations. First, various tile distributions have been tested with a single patch antenna designed to illuminate the structure at 5.75GHz. The patch antenna feed was positioned at a distance of 90 mm corresponding to the optimal efficiency. The antenna measurements were carried out in the far-field anechoic chamber using the transmitarray as the receive antenna and a standard dual-polarization horn as the transmit antenna. The measured H-plane radiation patterns for four beam-scan angles (0°, 15°, 30° and 45°) at 5.75 GHz are shown in Fig. 2(a). The corresponding phase distributions obtained using (1) are shown in Fig. 2(b). The measured results agree with full wave electromagnetic simulations. A gain loss of about 4 dB has been measured between the broadside and 45° patterns at 5.75 GHz. The gain loss is expected due to beam steering and 1-bit phase approximation.



(a) (b)

Figure 2. Measured radiation patterns of the tiled 1-bit transmitarray for several scan angles: $\theta_0 = 0°, 15°, 30°, 45°$ at $f = 5.75$GHz (a) and the corresponding phase distribution (b).

2.3. Multiple feed excitation

In order to demonstrate multiple feed properties of the antenna under test, the transmitarray with broadside beam tile distribution has been excited with 3x1 patch antenna array with periodicity of 32.5 mm. The patches were fed separately, and the measured radiation pattern is presented in Fig. 3. As a result the radiation patterns are three beams separated by 15 degrees. Each of the side beams exhibit 1 to 2 dB gain deterioration, which is commensurable with gain drop demonstrated for single feed tile distribution $\theta_0 = 15°$in Fig. 2. Effect of mutual coupling between feeding antennas is almost negligible for such separation distance. The simulated isolation is below -20 dB that is in a good agreement with a theoretical assessment [5]. Thus, the considered configuration makes possible the use of the transmitarray for MIMO applications.

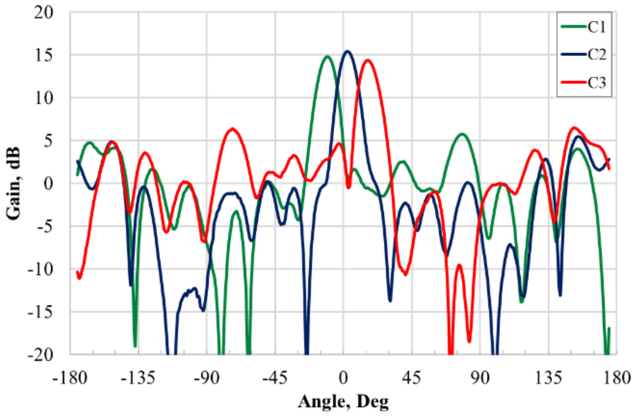


Figure 3. Measured radiation patterns of the tiled 1-bit transmitarray for three separate feed coordinates: $C_1 = -32.5$ mm, $C_2 = 0$mm, $C_3 = +32.5$ mm.

3. Conclusion

In this paper the tiled design of the 1-bit C-band transmitarray with dual polarization was proposed. The simulated and measured results of the beam steering for the scan angles up to 45° was demonstrated. It was been shown that the proposed structure can achieve better than 15 dBi gain and lower than 7 dB sidelobe level for the scan within the 2.5% operating bandwidth.

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References

[1] Huang, Cheng, et al. "Using reconfigurable transmitarray to achieve beam-steering and polarization manipulation applications." *IEEE Transactions on Antennas and Propagation* **63.11** (2015): 4801-4810.

[2] Frank, Martin, Robert Weigel, and Alexander Koelpin. "Design of a 24 GHz reconfigurable transmitarray element with continuous phase range." *Antennas and Propagation (EUCAP), 2017 11th European Conference on. IEEE*, 2017.

[3] A. Clemente, L. Dussopt, R. Sauleau, et al., "Wideband 400-element electronically reconfigurable transmitarray in X band," *IEEE Trans. Antennas Propag*., **61.10** (2013): 5017–5026.

[4] I. V. Munina, V. V. Kirillov, A. P. Verevkin and P. A. Turalchuk, "Unit cell for 1-bit reconfigurable transmitarray with circular polarization," *Journal of Physics: Conf. Series*, **1092** (2018).

[5] O. G. Vendik and D. S. Kozlov, "A Novel Method for the Mutual Coupling Calculation Between Antenna Array Radiators: Analysis of the radiation pattern of a single radiator in the antenna array.," in *IEEE Antennas and Propagation Magazine*, **57.6** (2015): 16-21.