Switchable Beamsteering Antenna Array Using 3-bit Phase Quantization at 28 GHz

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***Abstract*— A novel beam-steerable 3-bit antenna array is presented for millimeter-wave application. The design operates at 28GHz and consists of a tightly stacked aperture feeding antenna with eight reconfigurable quantized phases which can effectively steer the beam from +50º to -50º. Three different configurations were fabricated and tested. The measured antenna is in good agreement with the simulation result. The measured broadside gain was 13.44 dBi with the gain threshold of 10dBi within the steering range (*viz.* 100º).**

I. Introduction

The prime frequency band for millimeter-wave (mmWave) 5G applications is 28 GHz which has been allocated as an experimental band in different countries for the last few years [1]. However, due to the excessive path loss and atmospheric absorption of mmWave frequencies, a high gain antenna array is necessary for both the transmitter and receiver systems to compensate for such losses. Concurrently, beamsteering is paramount to realize the potential of theses arrays. As such, antenna elements must be fed by progressive phases to steer the beam to a specific orientation. Traditional beamsteering techniques require external complex circuitry with multiple sources which makes the system bulky and cost prohibitive. To circumvent this complexity, different techniques have been implemented using a feeding network with delay lines [2].

Recently, a 2-bit and 3-bit phase-shifting mechanisms have gained attention to steer the beam for wide spatial coverages in the mmWave band [3]. For instance, in [4], a 2-bit phase shifter is used for the beam steering using a travelling wave antenna; nevertheless, since the antennas need an attenuator on the open end of the structure, the system suffers from power loss. In addition, the multiple reflections from each element lead to a low realized antenna gain. Another drawback is that the steering angle of the traveling wave antenna varies with the operational frequency. In this paper, we present a novel 3-bit corporate-fed antenna array that 1) eliminates the need for an attenuator and 2) has a steady steering angle within the operational frequency band. A prototype was fabricated and tested showing high realized gain and a large steering range with a gain threshold of 10 dBi.

II. Beam Steering Antenna Design

In Fig. 1a and 1b, we show the 3-D exploded view and side view of the antenna array, respectively. The antenna consists of two tightly stacked substrate layers. The upper substrate is RT/duroid 5880 (ε_r = 2.2 and tanδ = 0.009), with a thickness of

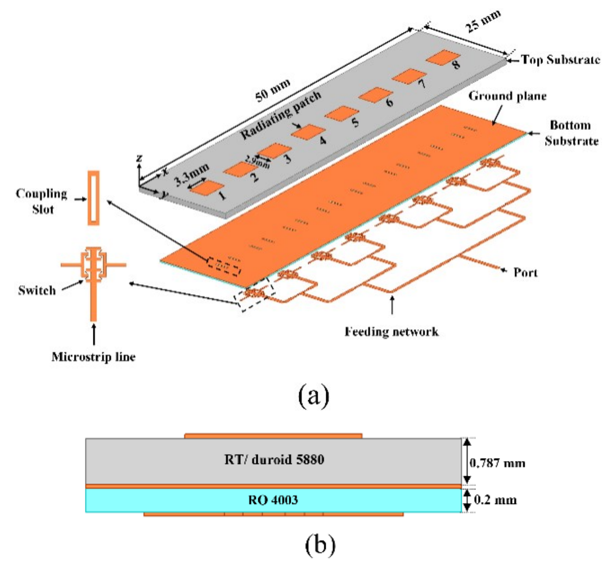

Figure 1. a) 3-D exploded view of 3-bit corporate-fed antenna array operating at 28GHz; b) Side view of the overall stack-up.

0.79 mm. The lower substrate is RO4003 (ε_r = 3.55 and tanδ = 0.0027), with a thickness of 0.2 mm. The overall stack consists of three metal layers, as depicted in Fig. 1 (b). The top layer of the upper substrate consists of the radiating element, which is a uniform patch array of 8 elements. The ground plane is in the middle of the two substrates; hence, it is on the top layer of the bottom substrate and consists of symmetrically etched slots for antenna feed coupling. The corporate-feed network is on the bottom layer of the lower substrate and consists of a one-to-eight-way uniform power divider. Each branch of the power divider consists of 8 extended branches from the two sides of the microstrip line and two floating branches, as detailed in Fig.2a. This floating branch is connected with the extended edge of the microstrip line using binary switches or PIN diode. Overall, the design consists of 8 elements array, where each element consists of a patch antenna in the top layer, two slots in the ground layer, and a 3-bit phase shifter on the bottom. The top patches and feeding network are isolated by ground plane, forming an aperture coupled antenna. Eight switches were used to control the connection of the phase shifter. Fig. 2a represents a typical 3-bit phase shifter topology using transmission lines. The 3-bit phase shifter can be realized by 8 extended edges in sides of the transmission line. Four edges can be extended in

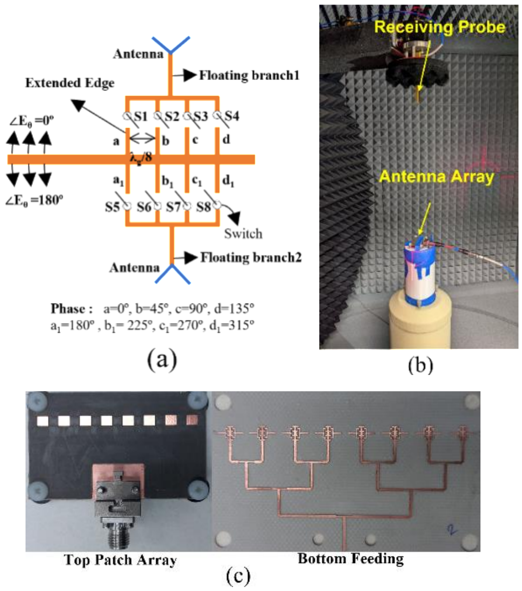

Figure 2. a) Typical 3-bit phase shifter; b) Measurement setup c) Top patch and bottom feeding of fabricated antenna

one direction and four edges will be extended from the opposite direction, forming eight extended edges in two sides of the transmission line. The physical distance between the adjacent two edges is equivalent to λ_g /8, which corresponds to the electrical phase difference of 45º.Thus eight extended branch represent 360º phases. This periodic phase can be mapped from 0-360º by using eight extended edges. These edges can be connected to the antenna by using 8 binary switches or PIN diodes. The ON state represents the corresponding phase of the antenna, and while one switch is ON, seven other switches are OFF. The signal flows from the transmission line to the floating branches when the corresponding switch is ON. Thus, eight binary switches can represent 3-bit phase shifter since a reconfigurable n-bit phase shifter can be built by 2^n switches. As such, the energy in the floating branch will couple to the corresponding coupling slot in the ground above the transmission line and excite the aperture. A beam-steering antenna can be built using a 3-bit phase shifter. To steer the beam in a specific direction θ, the required progressive phase distribution φ_s, for n number (n=8) of elements can be written as follows

$$\Phi_s = -n \times k_0 \times d \times \sin(\theta); \quad n = 1 \ldots\ldots 8 \qquad (1)$$

Here, *d* is the distance between the antenna elements, k_0 is the wavenumber, and θ is the steering angle. First, the progressive phase Φ_s needs to be quantized and mapped from 0º to 360º in eight different states using the 3-bit phase shifter.

Our designed antenna array can steer the beam from -50º to +50º. To verify this, three prototypes (0º, +26º, and +43º) were fabricated as shown in Fig. 2c. The radiation measurement was done using a mmWave anechoic chamber as shown in Fig. 2b. Fig. 3 and 4 represents the realized gain and S_{11} for different scanning array respectively. The measured prototype demonstrated a 13.44 dBi broadside gain with a ~10 dBi gain threshold within the scanning range. Concurrently, this antenna

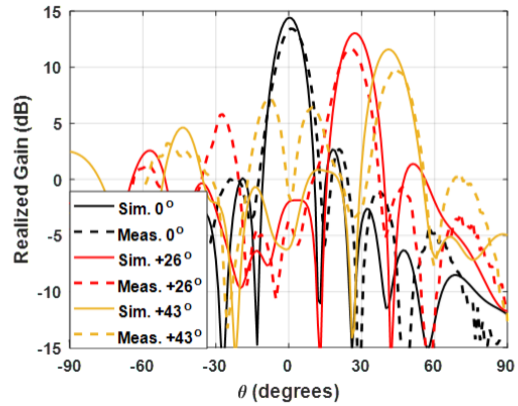

Figure 3. Simulated and measured gain for different scanning array

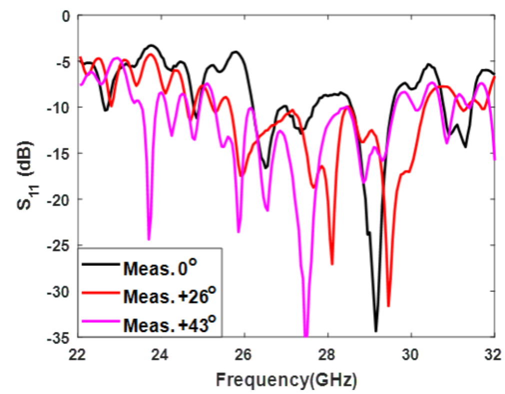

Figure 4. Measured S_{11} for different scanning antenna array

has a wider bandwidth from 26 GHz to 29 GHz (S_{11} < -10 dB), as depicted in Fig 4.

III. Conclusion

In this paper, a 3-bit phase-shifting mechanism was realized by a microstrip transmission line for a fabrication-friendly design and implementation ease of the beam steering system. Our fabricated antenna array demonstrated a 13.44 dBi broadside gain with a ~10 dBi gain threshold within the scanning range. As such our antenna is a leading candidate for millimeter-wave and next generation communications systems.

Acknowledgment

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