A Novel Reconfigurable Millimeter-Wave Beamsteering Antenna Array Using a 3-Bit Phase Shifter

Md Nazim Uddin* (1), Elias A. Alwan (1),
(1) Florida International University, Miami, FL, USA, e-mail: muddi027@fiu.edu; ealwan@fiu.edu

Millimeter-wave (mmWave) antennas have been widely explored for fifth-generation (5G) communication because of higher data rates and capacity [1]. The prime frequency band for mmWave 5G applications is 28 GHz which has been allocated as an experimental band in different countries for the last few years. 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 array. 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. Recently, a 2-bit, a 3-bit, and a 4-bit phase-shifting mechanisms have gained attention for beamsteering with wide spatial coverages in the mmWave band. In this paper, we present a novel 3-bit corporate-fed antenna array that has a steady steering angle within the operational frequency band. A 3-bit phase shifter can be realized with phases of 0º, 45º,90º,135º,180º,225º,270º, and 315º without using additional phase delay lines. To steer the beam in a specific direction θ, the required progressive phase distribution, Φ_s, for n number of elements can be written as follows:

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

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. To test the 3-bit phase shifter topology, an aperture coupled patch antenna with a feed network was designed and implemented, as illustrated in Fig. 1(a). The design includes two tightly stacked substrate layers (RT5800 and RO4003). 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 bottom layer of the upper substrate was etched completely. 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-fed 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.1c. This floating branch is connected with the extended edge of the microstrip line by binary switches or PIN diode. Thus, the eight extended lines, separated by λ/8, represent the phases equivalent to a 3-bit phase shifter. The antenna was fabricated and shown in Fig.1d.

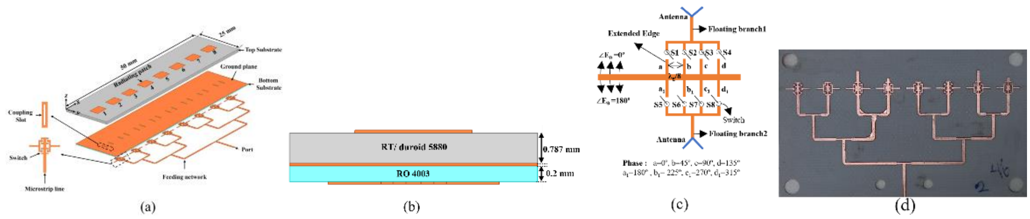

Figure 1. a) Structure of the antenna array b) Side view) 3-bit phase shifter d) Fabricated antenna

Our fabricated antenna array can steer the beam from -50º to +50º (100º). The measured prototype demonstrated a 13.44 dBi broadside gain with a ~10 dBi gain threshold within the scanning range. Concurrently, this antenna has a wider bandwidth from 26 GHz to 29 GHz (S_{11} < -10 dB). In conclusion, this antenna will serve as low cost and low-profile beamsteering solution with high gain and wide bandwidth and thus can be an excellent candidate for future mmWave application.

1. Rappaport,T.S.;Sun,S.;Mayzus,R.;Zhao,H.;Azar, Y.;Wang, K.;Wong,G.N.; Schulz,J.K.;Samimi, M.;Gutierrez, F. Millimeter wave mobile communications for 5G cellular: It will work! IEEE Access 2013, 1,335–349.