A 26-31 GHz Beam Reconfigurable Dual-Polarization Antenna Array

Kirill Klionovski[1], Mohammad Said Sharawi[2], Atif Shamim[1]
[1] Integrated Microwave Packaging Antennas and Circuits Technology Laboratory,
King Abdullah University of Science and Technology (KAUST), Thuwal, Kingdom of Saudi Arabia,
kirill.klionovski@kaust.edu.sa, atif.shamim@kaust.edu.sa
[2] Electrical Engineering Department, King Fahd University of Petroleum and Minerals (KFUPM),
Dhahran, Kingdom of Saudi Arabia, msharawi@kfupm.edu.sa

***Abstract*—The growing demand for higher data rates imposes special requirements for broadband, beam switching and dual-polarization mode for telecommunications antennas. In this paper, we present a design of 16-element planar patch antenna array with a Butler matrix feed network for the frequency range of 26–31.4 GHz. The antenna array operates with two linear orthogonal polarizations and provides ±42º beam switching. The Butler matrix is based on a novel combination of wideband planar couplers, crossovers and phase shifters. The design is fabricated on a low-cost multi-layer board. Experimental measurements of return loss, mutual coupling and radiation patterns confirm the wideband operational mode and wide-angle beam switching.**

***Index Terms*—Millimeter-wave antenna array, wideband antenna array, Butler matrix.**

I. INTRODUCTION

The future wireless telecommunication standards (such as 5G) are expected to address the increasing demand in higher data transfer rates. This requirement can be achieved by employing wideband front-ends, in particular, through wide-band antenna arrays that work in the millimeter-wave (mm-wave) frequency band with wide-angle beam switching and dual-polarization operational mode. The wide-angle beam switching of an antenna array is required to create a user-centric environment. The dual orthogonal polarization mode can enhance the channel capacity and the spectral efficiency of telecommunication links.

One of the ways to achieve beam switching is to use a beamforming network (BFN) such as Blass matrix, Butler matrix, Rotman lens, Nolen matrix, etc. Among these BFN, Butler matrix is the most commonly used one [1]. Many papers have previously been published on the topic of antenna arrays with Butler matrix BFN, however most of those papers present multilayer designs of BFN to increase the bandwidth. In this work, one of the target is to make a low-cost antenna array that can be manufactured easily. Due to these reasons, we are interested in a single layer planar design of Butler matrix BFN.

Some designs of millimeter-wave antenna arrays based on single layer Butler matrix BFN have been reported recently in [2-10]. The BFN designs from [2-6, 10] are based on microstrip components with the highest bandwidth of 13.5% from [5]. The BFN from [7-9] have been implemented in substrate integrated waveguide (SIW) technology with the highest bandwidth of 13.3% from [9]. As the maximum bandwidths for microstrip and SIW implementations of BFN are the same order, then the microstrip one is more preferable for us due to it can be fabricated on a low-cost laminate board.

In this paper, we present a novel 16 elements (4 x 4 arrangement) switched-beam planar patch antenna array with dual linear polarization. The beam switching is achieved through the use of a wideband Butler matrix in the microstrip implementation. The wide bandwidth of 26-31.4 GHz is achieved by using a novel combination of wideband crossovers, couplers and phase shifters along with dual-fed superstrate loaded radiating patches. Good agreement is achieved between the simulated and measured results. The antenna array demonstrates beam switching for angles of ±42º with a maximum gain of 12 dBi and 19% bandwidth.

II. ELEMENTS OF THE ANTENNA ARRAY

A typical scheme of a 4-beam Butler matrix contains four 3-dB quadrature directional couplers, two crossovers, two 45º and two 0º phase shifters. To design a single layer BFN, we use the following planar microstrip wideband components: an elliptic-patch quadrature-hybrid 3-dB coupler (see Fig. 1 (a)) [11]; a square patch crossover with circular slots (see Fig. 1 (b)) [12]; a phase shifter (see Fig. 1 (c)) based on two open-short stub phase shifters [13] and a Shiffman phase shifter [14]. These components are based on the use of a Rogers Ultralam 3850 laminate, which has a permittivity of 2.9, loss tangent of 0.0025, and a thickness of 0.1 mm.

For this particular design, we use a wideband square patch antenna element with semi-circular cut-outs and a superstrate loading (see Fig. 1 (d)) [15] that can support two

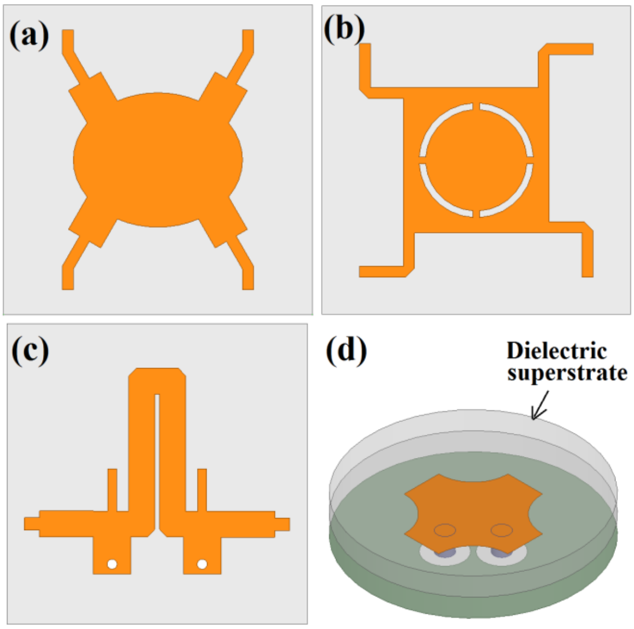

Fig. 1. (a) the quadrature 3-dB directional coupler; (b) the crossover; (c) the phase shifter; (d) the radiating patch element.

orthogonal linear polarizations. The radiating element and the superstrate are implemented on a Rogers RO4533 laminate, which has a permittivity of 3.3, loss tangent of 0.0025, and a thickness of 0.76 mm.

III. The Antenna Array Design

A prototype of the dual-polarized antenna array that is based on two independent Butler matrix BFNs has been fabricated and measured in an ORBIT FR chamber (Fig. 2). The prototype has 8 ports to create 8 independent beams: 4 ports of the first Butler matrix BFN operate with a vertical

Fig. 2. Measurements of the antenna array inside the chamber.

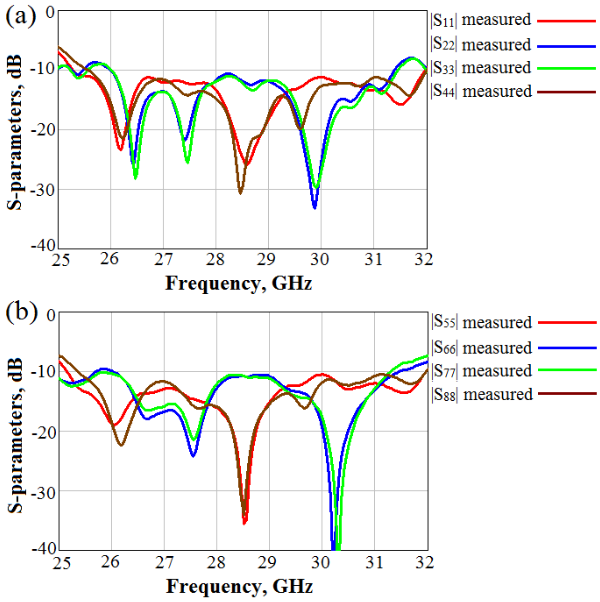

Fig. 3. The measured reflection coefficients: (a) for ports 1-4, (b) for ports 5-8.

polarization. The other 4 ports of the second Butler matrix BFN operate with a horizontal polarization.

Measured S-parameters show that the reflection coefficients (Fig. 3) for all ports are less than -10 dB for the frequencies of 26-31.4 GHz (the bandwidth is 19%). The isolations between the all ports are more than 15 dB for the working frequency band. Fig. 4 shows the measured radiation patterns of the antenna array in the plane perpendicular to the long edge of the array at the frequency

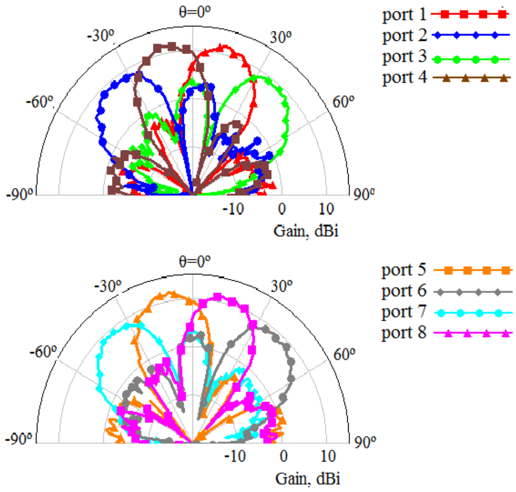

Fig. 4. Measured radiation patterns of the antenna at 28 GHz.

of 28 GHz when different ports are excited. The angle θ in the figure is measured from the normal to the aperture of the array. From Fig. 3 we can see that the directions of the beams are ±13° and ±42°. Maximum gain is 12 and 9 dBi for the beams with ±13° and ±42° main directions, respectively. The side lobe level is -10 and -8 dB for the beams with ±13° and ±42° main directions, respectively.

IV. CONCLUSIONS

We propose the design of a 16-elements antenna array operated with two orthogonal linear polarizations at the frequency range of 26-31.4 GHz. The antenna array provides ±42º pencil beam switching and it is based on planar Butler matrix feed network and wideband patch radiating elements.

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