Design and implementation of a wideband beamforming network for LTE and W-CDMA applications featuring a compact 16x16 Butler Matrix

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***Abstract*—This paper presents the design and implementation process of a compact wideband 16x16 Butler Matrix as a beamforming network for LTE and W-CDMA applications in the AWS and PCS 1900 MHz bands, using compact wideband branch-line hybrid couplers, Schiffman phase shifters and a novel 3-D approach of the conventional 16x16 Butler Matrix. The final operation range of the Butler Matrix is 1.62 GHz to 2.3 GHz with amplitude around -14.5 dB±1.0 dB and maximum phase imbalance of ±8.5° for phase difference between output port signals. Finally, simulations with a high gain 16-element linear patch antenna array show that the compact 16x16 Butler Matrix is able to provide adequate phase difference and uniform amplitude to the antenna array in order to perform beamforming in its operation range.**

***Index Terms*— Branch-line hybrid couplers, Butler Matrix, Phased antenna arrays, Phase shifters.**

I. INTRODUCTION

IN present wireless communication systems, there is a need for greater uplink and downlink speeds. To overcome this deficit, LTE and W-CDMA technologies have proposed the use of beamforming in base station antennas to reduce interference, increase coverage area, Signal to Noise Ratio (SNR) and provide spatial diversity [1], in order to establish higher speed links between terminals and base stations.

The Butler Matrix is a type of beamforming network that employs only passive components, provides orthogonal output signals and continuous beam scanning without any mechanical motion [2]. Nevertheless, conventional Butler Matrix design often is implemented in a 2-D structure in microstrip lines with a large layout. This work proposes a new 16x16 Butler Matrix with wideband operation and compact size.

II. BUTLER MATRIX DESIGN

In preparation for this work, a wideband 8x8 Butler Matrix using RO3003 substrates was implemented in [3]. Although, good performance was achieved, a Teflon based substrate is fragile and designs require large areas of implementation. For these reasons, FR4 substrate (εr = 4.40) was chosen due to its mechanical rigidness and higher dielectric constant. The next step was the design of the wideband couplers and phase shifters.

A. *Compact Branch-line Hybrid Coupler*

In order to achieve compact size, the method proposed in [4] was used in the design of the wideband compact couplers. After tuning, results shown in Fig. 1. were obtained.

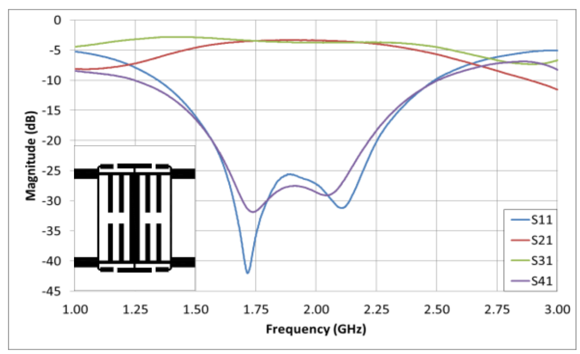

Fig. 1. Implemented compact wideband branch-line hybrid and measured S-parameters magnitude response

The coupling is -3.4±0.3dB and phase difference between output ports is 90°±0.5°. The final area of implementation of the compact coupler is 36 x 33 mm^2.

B. *Schiffman phase shifters*

For wideband operation, Schiffman type phase shifters were designed. It was noticed that, although return loss was high in the central frequency of its operation range, if designed with a central frequency of 2.4 GHz, return loss in the band of interest (1.7 GHz to 2.2 GHz) was less than -30 dB. Seven phase shifters were implemented (11.25°, 22.5°, 33.75°, 45°, 56.25°, 67.5° and 78.75°) with a maximum phase error of 2°.

III. BUTLER MATRIX IMPLEMENTATION AND PERFORMANCE

The 16x16 Butler Matrix was implemented following the schematic diagram in [5]. However, it was divided in 8 circuit boards and mounted in a novel 3-D vertical distribution as shown in Fig. 2. Coaxial cables were used to connect the elements of the Butler Matrix and eliminate the use of microstrip crossovers. Total size is 15x28x10 cm^3.

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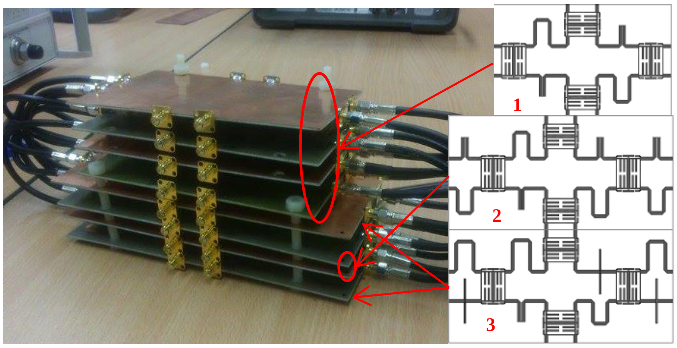
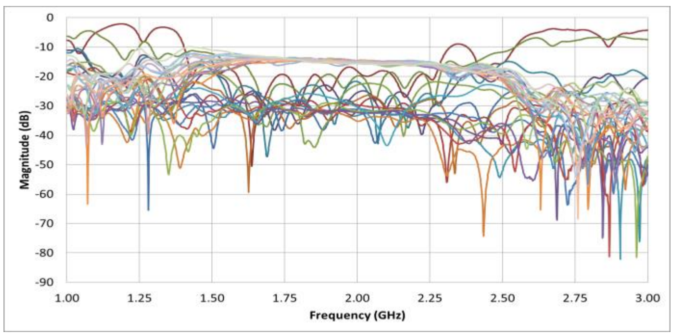
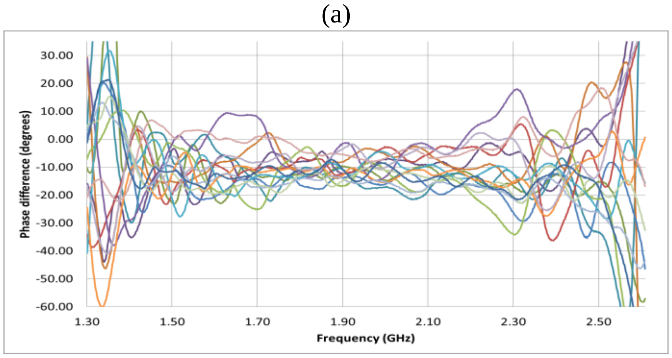


Fig. 2. 3-D compact 16x16 Butler Matrix and its three types of circuit boards used in its implementation

The final operation range of the Butler Matrix is 1.62 GHz to 2.3 GHz with amplitude of the output signals at -14.5 dB±1.0 dB and error in phase difference between output ports of ±8.5° for every input port. Results are shown in Fig. 3.



(a)



(b)

Fig. 3. (a) Measured S-parameters magnitude response for input port 1, (b) measured phase difference between output ports for input port1

Next, the high gain 16-element patch antenna array based on [6], shown in Fig. 4, was introduced to verify the beamforming functionality. However, there was not an adequate environment at university facilities to measure an antenna array of 1.5 meters long at far field distance. For that reason, radiation patterns, shown in Fig. 5, were simulated with Keysight EMPro using the measured amplitude and phase of the output signals of the Butler Matrix. With this, beamforming using the compact 16x16 Butler Matrix was proved. The chosen frequency of simulation is 1.9325 GHz.

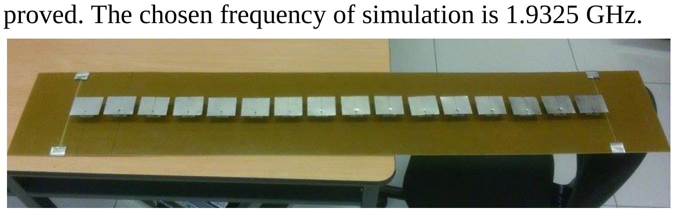


Fig. 4. Implemented high gain 16-element patch antenna array.

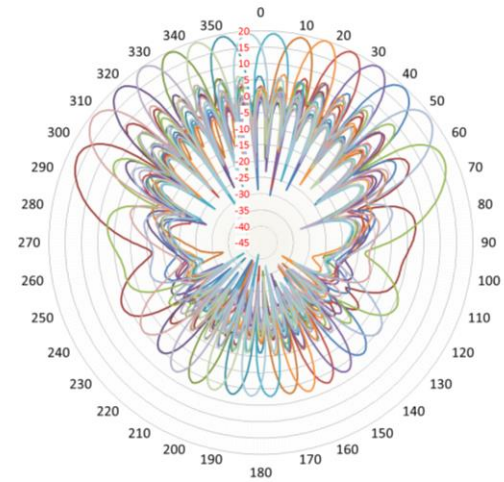


Fig. 4. Simulated radiation patterns at 1.9325 GHz

IV. Conclusion

Design and implementation of a compact wideband 16x16 Butler Matrix for the AWS and PCS 1900 MHz bands is presented. It possesses an operation range from 1.62 GHz to 2.3 GHz with amplitude at -14.5 dB±1.0 dB and error in phase difference between output port signals of ±8.5°. Simulated radiation patterns of a high gain 16-element antenna array driven by the 16x16 Butler Matrix prove its beamforming functionality as uniform amplitude and adequate phase difference of the signals are provided to the antenna array.

V. MTT-S Scholarship Experience and Future Plans

The MTT-S Scholarship has been a great motivation for my career as Telecommunications Engineer. I appreciate and thoroughly enjoyed all the time I spent on this work. Also, it allowed me to travel to IWS 2015 and IMS 2015, where I met many professors, industry professionals and other students looking for the same bright future in microwaves ad RF.

Regarding my plans, I desire to start postgraduate studies to obtain knowledge of beamforming in mm-Wave bands, a subject that has impressed me in the two conferences I attended, continue researching and obtain an industry position as antenna and microwave circuits designer.

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