# Beamforming Networks Using Cascaded Butler Matrices

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*Abstract* — This paper describes a smart antenna system, which employs the advantages of cascaded Butler Matrices in wireless communication system. By using the narrow beams available from the first Butler Matrix, it is possible for a receiver to increase the gain in the desired signal directions and reduce the gain in interference directions. Hence, high-gain narrow beam signals for long-range application are produced. A technique is introduced which uses a second Butler Matrix, acting as a mirror of the first Butler Matrix, reconstructing the antenna patterns of the individual radiating elements. The resulting outputs have broad beam width that can be used for short-range communication. This beamforming network using Butler Matrices provides a method, which could be applicable in wireless communication system applications.

*Keywords: Butler Matrix, Cascaded Butler Matrices, Narrow beam width and Broad beam width*

## I. INTRODUCTION

The implementation of smart antenna system in future wireless application is expected to have significant impact in term of optimisation of service quality and efficient use of spectrum. Hence, there is a need for beamforming antennas networks with multiple beams.

The radiation pattern of a single element antenna is generally wide and provides a low value of directivity or gain. In some applications, it is necessary to achieve very high directivity or gain in order to meet long distance communication applications. Higher directivity can be achieved by increasing the dimensions of a single antenna. A common way to increase the effective dimensions of the antenna without increasing the size of each individual element is by forming an array of identical antenna elements. This is referred to as an array antenna [1].

The elements of the array interfere constructively in the desired directions and interfere destructively in the other directions. Normally, for an array of identical elements, there are four factors that can be used to shape the overall pattern of an array antenna namely: the geometrical configuration of the overall array; the relative displacement between elements; the excitation amplitude of individual elements; and the excitation phase of individual elements.

A phased array is a group of identical antennas excited with known phase relationship with equal amplitude. The radiation pattern of the antenna is the product of the individual radiation pattern and an array factor that depends upon the phases and amplitudes of the antennas. Usually, the array factor is the dominant factor on the antenna when many antenna elements exist.

For $N$ identical elements in an array antenna as shown in Figure 1, the total field is calculated by multiplying the array factor with the electrical field of a single element. Once the array factor is defined, the total field of actual array is obtained as:

$$E(Total) = E(SingleElementatreference)x(ArrayFactor) \quad (1)$$

Smart Antennas with RF beamforming capability such as the Butler Matrix can be used for multibeam antennas. Several studies have been conducted related to the Butler Matrix. Zak, Piovano and Angelluci introduced cascaded Butler Matrices in Multi-Port Amplifiers (MPAs) [2-4]. A signal entering one port of the Butler Matrix is divided into equal parts before the signal is amplified by all the amplifiers and then recombined by the combining Butler Matrix at the output port that corresponds to the particular input port. One advantage of the system is that the failure of one of the amplifiers will not cause total loss of a beam or carrier. In addition, Suarez also used Butler Matrix in his research [5]. He reported a uniform narrow beam switched array antenna system of up to eight beams, produced by means of cascaded passive Butler Matrices.

In this paper, the advantages of having cascaded Butler Matrices have been investigated. The objective is to produce high-gain narrow beam and broad beam antenna systems that could provide multi-channel operation for diversity purposes for wireless applications.

## II. MEASUREMENT CONFIGURATION

Figure 2 shows the block diagram of the RF front-end beamforming network that consists of array antennas with 0.5λ spacing, Low Noise Amplifiers (LNAs), Wilkinson Power Divider, and cascaded Butler Matrices. The antenna beamforming network was designed to operate at 2.45GHz. In this experiment, we use a Butler Matrix as a beamforming network to provide four inputs to the diversity process, each related to a different beam. The Low Noise amplifiers are used to increase the gain of the signal and lower the noise figure of the system. The advantage of having Low Noise Amplifiers at each input port of the Butler Matrix is that the effect of the loss of the Butler Matrix on the system noise figure is reduced [6].

## III. RESULTS AND DISCUSSIONS

The radiation pattern measurements were conducted to illustrate the high gain narrow beam and broad beam properties of the proposed receiver system. Figure 3 and Figure 4 illustrate the simulated array factor as well as the measured beam pattern from the output ports of the first Butler Matrix (Port 9 to Port 12) and second Butler Matrices (Port 2) respectively. The input data for the simulated results were abstracted from measured S-Parameter measurement. Referring to the figures, beamforming patterns with peaks around ± 15° and ± 45° are generated from the output ports of the first Butler Matrix. Alternatively, broad beam patterns are generated from the second Butler Matrix. Referring to the figures, the measured radiation pattern results agree with the simulated array factor values in terms of the direction of the main beam. Generally, the measured main beams are more than 10dB greater than the side lobes.

## VII. CONCLUSION

In this paper, the measurement results and analysis of the cascaded Butler Matrices system are illustrated. The RF front-end architecture generates high-gain narrow beam and broad beam signals when the Butler Matrix are cascaded. This provides multi-channel operation for diversity purposes for wireless applications such as vehicle communication system.

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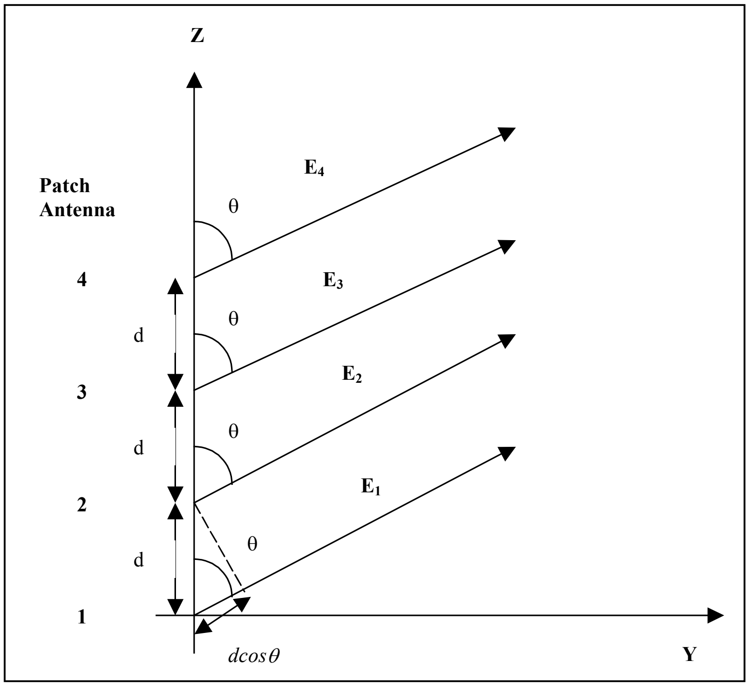

**Figure 1:Array Antenna Geometry**

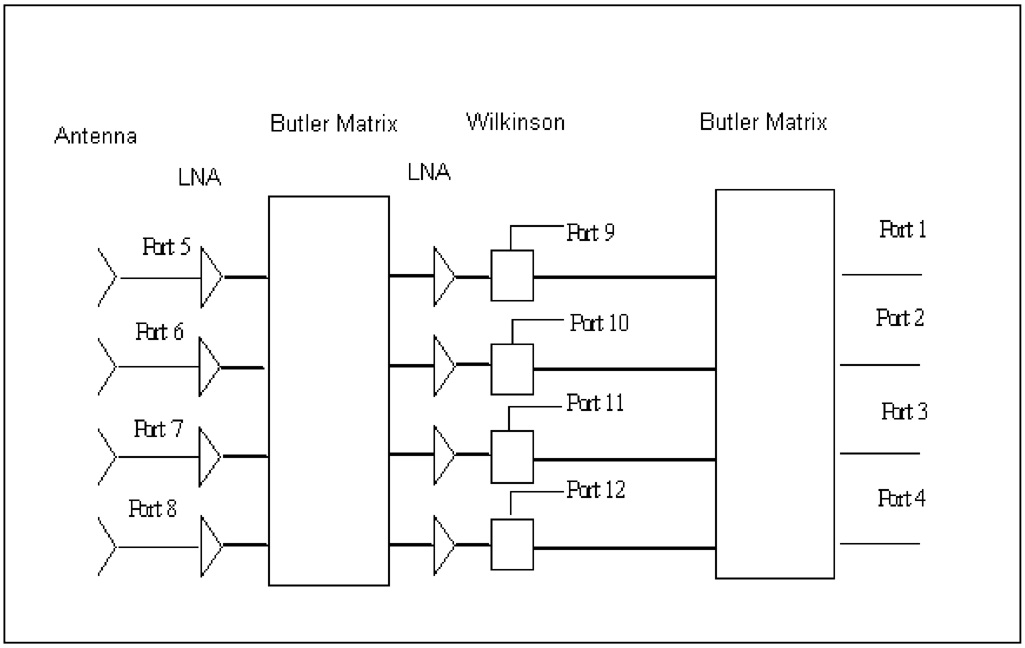

**Figure 2: Block Diagram of the RF Beamforming Network**

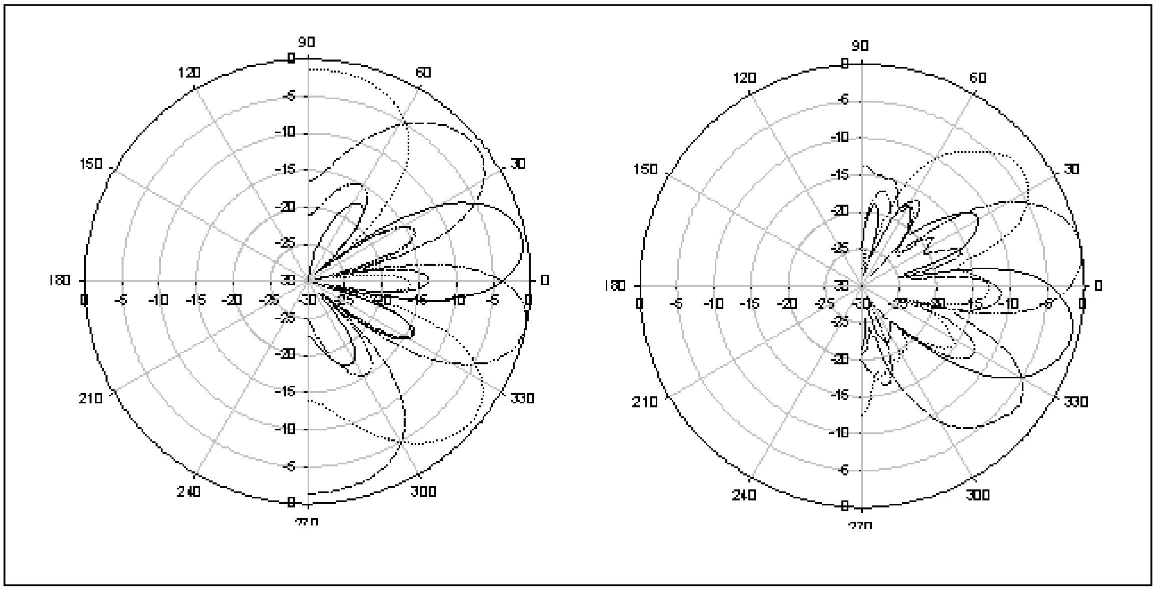

**Figure 3: Simulated Array Factor and Measured Radiation Pattern of Narrow beam**

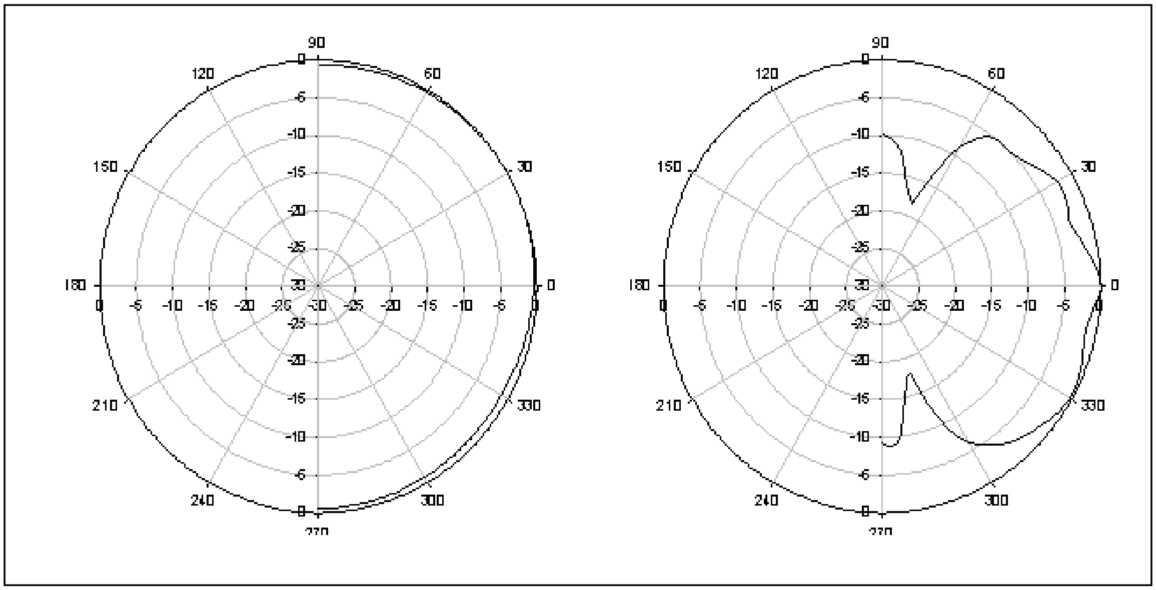

**Figure 4: Simulated Array Factor and Measured Radiation Pattern of Broad beam**