Microstrip Antenna Array with Beamforming Network for WLAN Applications

Nhi T. Pham¹, Gye-An Lee², and Franco De Flaviis¹
¹Department of Electrical Engineering and Computer Science
University of California, Irvine, CA 92697, USA
²Skyworks Solutions Inc.

Abstract: A beamforming network with a multi-narrow-beam antenna array for WLAN applications is presented. The antenna array has four inputs and is excited by the Butler matrix feeding network to electronically steer the beams in desired directions. The architecture of the Butler matrix beamforming network is analyzed with the considerations of coupling effects between fundamental elements of the network and the antenna array. The prototype is fabricated on Rogers RT/duroid 5880 substrate with a relative permittivity of 2.2. Details of the simulated and measured results are investigated and analyzed.

Introduction: The topic of multi-beam smart antenna array has been receiving much attention due to its wide range of applications. Different multi-beam antenna prototypes are implemented for the applications in base stations [1], [2] to improve the quality of transmission and enhance the cellular capacity, range, and coverage [3] because the antenna array is capable of pointing to desired targets automatically in real time. Moreover, the multipath fading and interferences phenomenon in communications systems can be solved using switched beam antenna array for rejecting interference signals and increasing desired signal level [1]. The system can produce multiple narrow beams in different directions and select the strongest signal among all of the available ones. The system can distinguish the users that stand at different positions, and as a result, expand the capacity [3]. Smart antennas can be characterized into two main categories: adaptive antenna array and switched beam system [1]. Compared with adaptive antenna arrays, switched beam systems have advantages in implementation because of its simplicity in the design [1].

In this paper, we present the study of smart antenna system for WLAN applications based on switched beam system. The system can produce narrow multi-beams in different directions instead of omni-directional patterns. The beam scanning can be obtained by different feedings with the phase increment provided by the Butler matrix. Therefore, it would increase the performance of the system in terms of the antenna’s gain, and as a result, it would reduce the possible power usage. By doing that, the reliability and capacity of the system would be improved. The study is focused on the investigation of the Butler matrix as a feeding network for the antenna array. The array is formed by four single patched antennas, which provide omni-directional patterns individually. As all the radiating elements are implemented together, the system can produce narrow beams in different directions with higher gain. The microstrip printed circuit technique is used to implement the matrix as well as the antenna array on the same substrate. The investigations of the coupling effects among components of the matrix as well as between the matrix and the antenna array are taken into consideration. Details of the design of the feeding network together with the antenna array are described, and the simulated as well as experimental results are presented and discussed.

Antenna Array and Beamforming Network Configuration and Design:

Butler matrix is a \(2^n \times 2^n\) network with \(2^n\) input, \(2^n\) output, \(2^{n-1} \log_2 2^n\) hybrid junctions and some phase shifters [1]. As the single layer microstrip printed circuit technique is used for the implementation of the matrix, there are several presences of cross lines in the planar layout, several crossovers are needed to isolate the signal [1]. In this study, \(4 \times 4\) Butler matrix has been designed because four beams are needed to produce by the system. The matrix has four inputs and four outputs, and it is implemented to excite an array of four patch radiating elements to produce four beams in desired directions. Fig. 1 shows the general block structure
of a Butler matrix and radiating elements [1]. It has four inputs 1R, 2L, 2R, and 1L, and four outputs 5, 6, 7, and 8 are used as inputs for antenna elements to produce four beams.

Combine all of the elements of the Butler Matrix, 4 input-4 output Butler matrix is designed and successfully fabricated on RT/duroid 5880 substrate with a relative permittivity \( \varepsilon_r = 2.2 \), dissipation factor \( \tan \delta = 0.0002 \), and thickness of 0.787mm. The simulated results are obtained from ADS Momentum and HFSS to verify the reliability of the results.

Table I shows summary of the corresponding magnitudes and phase shifts between the inputs and the outputs of the matrix.

<table>
<thead>
<tr>
<th>Port</th>
<th>1R</th>
<th>2L</th>
<th>2R</th>
<th>1L</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mag</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.524</td>
<td>0.506</td>
<td>0.472</td>
<td>0.480</td>
</tr>
<tr>
<td>Phase</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>129.4</td>
<td>90.83</td>
<td>47.98</td>
<td>-1.45</td>
</tr>
<tr>
<td>Mag</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0.481</td>
<td>0.496</td>
<td>0.507</td>
<td>0.497</td>
</tr>
<tr>
<td>Phase</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>44.94</td>
<td>175.3</td>
<td>-54.4</td>
<td>88.75</td>
</tr>
<tr>
<td>Mag</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0.497</td>
<td>0.507</td>
<td>0.496</td>
<td>0.481</td>
</tr>
<tr>
<td>Phase</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>88.75</td>
<td>-54.4</td>
<td>175.3</td>
<td>44.94</td>
</tr>
<tr>
<td>Mag</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0.480</td>
<td>0.472</td>
<td>0.506</td>
<td>0.524</td>
</tr>
<tr>
<td>Phase</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-1.45</td>
<td>47.98</td>
<td>90.83</td>
<td>129.4</td>
</tr>
</tbody>
</table>

All four radiating elements of the antenna array are identical, and they are designed based on the rectangular patch shape. Each antenna element of the array is operated within the frequency band of 5.25 GHz with microstrip line feeding method. The output ports of the Butler matrix are used as the microstrip feeding lines for the antenna elements. The effective length and width of the patch antennas are calculated using the theory of microstrip patch antenna, and these dimension are then optimized by using the simulation software Ansoft HFSS. Notice that inset feedings, recessed some distance from the patch antenna are used to achieve good impedance matching at the inputs of the radiating elements. It is shown that good impedance matching is obtained at the operating frequency. Then, four elements are simulated together with different input phase shift to study the radiation patterns. The separation distance between adjacent elements is chosen to be half-wavelength. Fig. 2 shows the layout and implementation of the Butler matrix together with the antenna array. All elements are fed with the same signal magnitude, but the phases are varied to produce different beams. The radiation characteristics of the antenna array are studied. The array exhibits four narrow beams in desired directions as it is fed by different phase at the ports.

**Analysis and Experimental Results:**

Fig. 3 a)-h) show the isolations, return losses, and couplings of the 4 x 4 Butler matrix in the operation frequency band of about 5.25 GHz. The simulated results are obtained from ADS Momentum and HFSS to verify the reliability of the results. It can be seen that the isolations from fours input ports are greater than 20dB. The couplings show almost constant magnitude at the output ports. However, there are still some mismatches occur inside the matrix and cause the small differences in the magnitude at the output ports.

The radiation characteristics of the beams are measured using far-field method in the anechoic chamber. Fig. 4 illustrates radiation patterns of 1L, 2R, 2L, and 1R beams respectively. From the radiation patterns, it is shown that the angles of the four beams associated with different inputs are 16°, -39°, 38°, and -15°. For the beams at -15° and 16°, the side lobe levels (SSL) are lower than −10dB. However, the SSL of the 2L and 2R beams, corresponding to the beams at 38° and -39°, are greater than −10dB. This is due to the mutual coupling effects between the radiating elements as well as the slightly mismatches between the feeding network and the antennas.
Conclusion: The Butler matrix with four inputs and four outputs has been designed to excite a phased antenna array to steer the beams in different directions. All components of the Butler matrix have been investigated and studied. The Butler matrix is also fabricated together with the patch antenna array to study about the radiation patterns over the frequency band of WLAN 5.25 GHz. Reasonable isolations, return losses, and couplings are obtained among the basic elements of the Butler matrix, and radiation characteristics of the antenna array are confirmed between the theoretical and measured results. This prototype is suitable for the applications of WLAN to minimize the consumed power.

References:

Fig. 1. Topology of the 4 x 4 Butler matrix and antenna array

Fig. 2. Layout and implementation of the Butler matrix and antenna array
Fig. 3. a)-h) Isolations, return losses, and couplings of the matrix when different ports are fed.

Fig. 4. Measured beam patterns at 5.25 GHz when a. port 1R is fed, b. port 2L is fed, c. port 2R is fed, and d. port 1L is fed.