IQ Modulator-based Phase Shifters Combined with Butler Matrix for Smart 2.4 GHz Antennas

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Abstract

This paper is addressed to report our study of low cost smart 2.4 GHz antenna using IQ Modulator-based phase shifters combined with Butler matrix for eliminating the RF switches. This 2.4 GHz smart antenna systems will be equipped at self deployment WLAN's or Wi-F'si access points in high interference areas for quick and simple installation by average technicians.

1. INTRODUCTION

2.4 GHz Wi-Fis can experience interference from cordless phones, microwaves, and other WLANs or Wi-Fis. The interfering signals degrade the performance of an 802.11x by periodically blocking users and access points from accessing the shared air medium. If it's not possible to reduce potential interference to an acceptable level, then consider deploying WLAN in another band spectrum, which is relatively free from interfering sources.

Wireless system designers have always had to contend with interference from both natural sources and other users of the medium. Thus, the classical wireless communication design cycle has consisted of measuring or predicting channel impairments, choosing a modulation method, signal pre conditioning at the transmitter, and processing at the receiver to reliably construct the transmitted information.

However,in contrast to classical techniques to suppress interference such as modulation, channel coding, interleaving and equalization, most of the techniques proposed for solving the problem of interference in the 2.4 GHz band focus on adaptive non signal processing control strategies including power and frequency hopping control, and MAC parameter adjustments and scheduling and deploying the smart antenna systems.

This paper is addressed to report our study of low cost smart 2.4 GHz antenna using IQ Modulator-based phase shifters combined with Butler matrix for eliminating the RF switches[1]. This 2.4 GHz smart antenna systems will be equipped at self deployment WLAN's or Wi-F'si access points in high interference areas for quick and simple installation by average technicians.

2. LOW COST 2.4 GHZ SMART ANTENNA CONFIGURATION

Figure 1 shows the basic configuration of the low cost 2.4 GHz smart antenna using IQ Modulator-based phase shifters combined with Butler matrix [1][2].

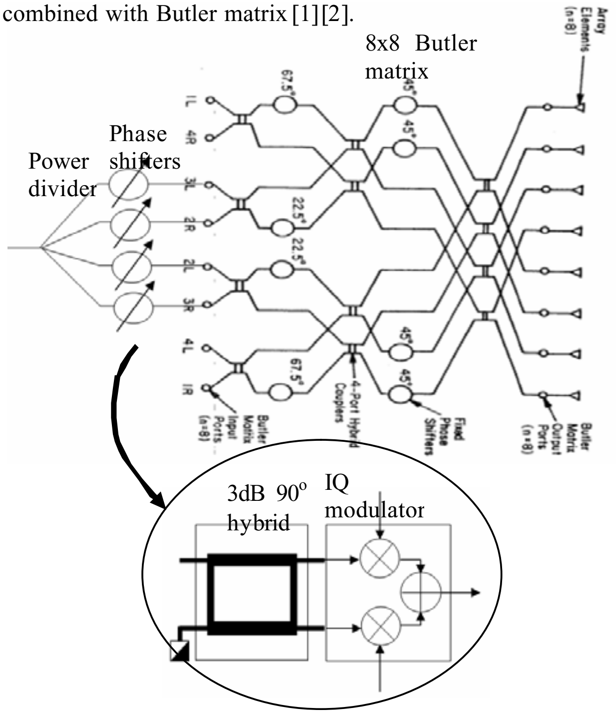


Figure 1 Low cost 2.4 GHz smart antenna configuration

RF signals from transmitter are divide by the power divider and are input to the beam port of the Butler matrix through digitally-controlled variable phase shifters. Each signal sent to a beam port is distributed and output to all antenna elements with phase differences depending on the position of the input beam port. The number of excited beam ports (four) is less than the total number beam ports (eight). The rest of the ports are terminated. The input signal distribution and the output signal disribution of the Butler matrix are related through the Fourier transform. And from the time-shifting property of the Fourier transform, the changes in position of the output signal distribution can be performed by feeding the input signals with phase differences to the multiple beam ports of the Butler matrix.

Therefore, it is possible to excite the antenna elements required without using RF switches to change the beam paths. In practical use, it is important to determine how many beam ports must be used. It is sufficient for most antenna configurations, that using half of the beam port will cover $\pm \pi/2$.

3. 2.4 GHZ ANTENNA ARRAY AND BEAMFORMER DESIGN

A. Antenna Array Design

All eight radiating elements of the antenna array are identical, and they are designed based on the rectangular patch shape with modification to achieve circular polarized as shown in figure 2 . Each antenna element of the array is operated within the frequency band of 2.4 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 CAD Ensemble® SV. 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, eight elements are simulated together with different input phase shift to study the radiation patterns. The separation distance between adjacent elements is chosen to be 73 mm. Fig. 3 shows the layout and implementation of layout and implemented array antenna. The measured VSWR of patch and its array is shown in figure 4.

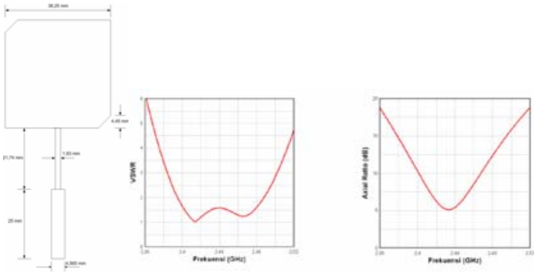


Figure 2 Layout of design pacth and its VSWR and axial ratio

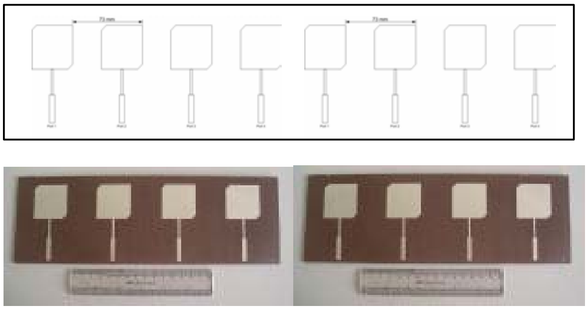


Figure 3 Layout and implemented 2.4 GHz array antenna

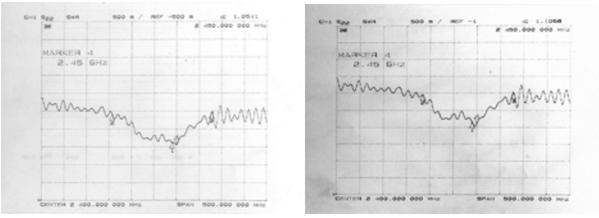


Figure 4 Measured VSWR of single patch and array antenna

B. Butler Matix Design

Butler matrix is a 2^n x 2^n network with 2^n input, 2^n output, $2^{n-1} \log_2 2^n$ hybrid junctions and some phase shifters . 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 . In this study, 8 x 8 Butler matrix has been designed because eight beams are needed to produce by the system. The matrix has eight inputs and eight outputs, and it is implemented to excite an array of eight patch radiating elements to produce eight beams in desired directions.

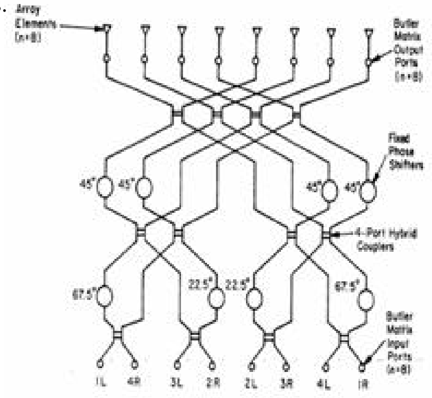


Figure 5 general block of 8x8 Butler matrix [2]

Fig. 5 shows the general block structure of a 8 x 8 Butler matrix and radiating elements [2]. It has eight inputs 1L, 4R, 3L, 2R, 2L, 3R, 4L and 1R, and eight outputs are used as inputs for antenna elements to produce eight beams. Combine all of the elements of the Butler Matrix, 8 input-8 output Butler matrix is designed and successfully fabricated on Arlon Diclad 527 substrate with a relative permittivity er = 2.5 and thickness of 1.57 mm. Figure 6 and 7 presented the hybrid and crossover layouts and their S-parameters.

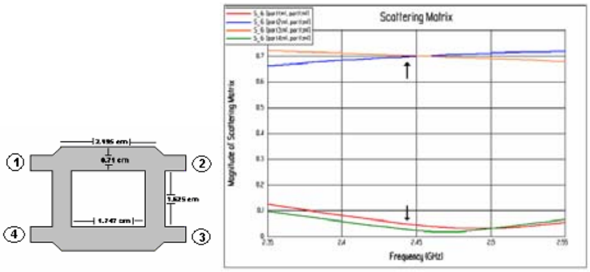


Figure 6. Hybrid 90° layout and its simulated S-parameters

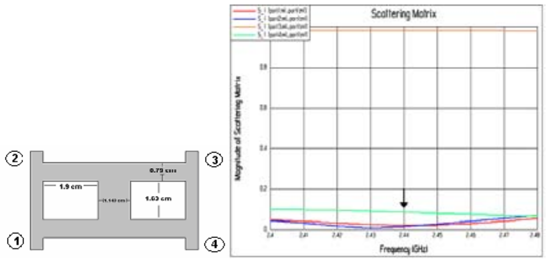


Figure7. Cross over layout and its simulated S-parameters

C. Power Divider Design

For distributing the RF signals from transmitter to phase shifters, an one input port and four output ports power divider is designed with output port length a half wavelength, 42.6 mm.

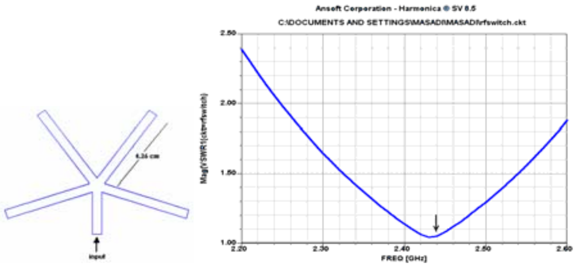


Figure 8. Layout design of power divider and its simulated VSWR .

D. Digitally Controlled Phase Shifter

The signal from each power divider arms is applied to the IQ modulator based phase shifters[3]. The head of this subsystem consists of four identical 3-dB 90^{o} hybrid and silicon monolithic IC MAX2721 from MAXIM [4] as shown in figure 9. The IC MAX2721 is a quadrature phase shift keying (QPSK) modulator which consists of two double balanced mixers, an adding circuit to combine the outputs. It is key element of this design and the other key element is control board, which is specially designed for this application, through which it is possible to do a sensitive control of the dc signals for channel I and Q using software which installed on the PC.

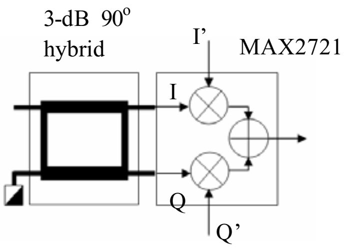


Figure 9 Block diagram of digitally controlled phase shifter

4. Simulated and Measured Beam Patterns

When used with a linear array, such array of above eight square patchs, the 8x8 Butler matrix produces eight beams that overlap at about 3.9 dB below the beam maxima. An 8x8 Butler matrix-fed array can cover a sector of up to 120° . In traditional approach, each beam can be selected using an RF switch. A Butler matrix can also be used to steer the beam of a circular array by exciting the Butler matrix beam ports with amplitude and phase weighted inputs followed by a variable uniform phase taper. The simulated eight beams of 8x8 Butler matrix is shown as in figure 10.

And for making comparison with the IQ modulator-based phase shiftre combined with Butler matrix, the figure 11 below displays the measurements results of 4 input ports which is connected to IQ modulator phase shifters with phase differences 0^{o}, -30^{o}, 10^{o}and -20^{o} .The radiation characteristics of the beams are measured using far-field method in the anechoic chamber.

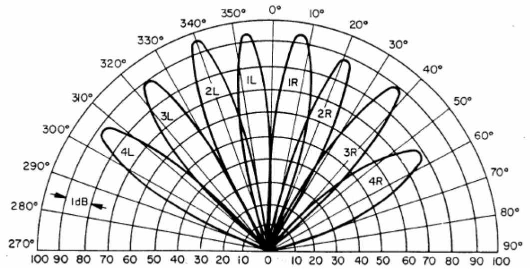
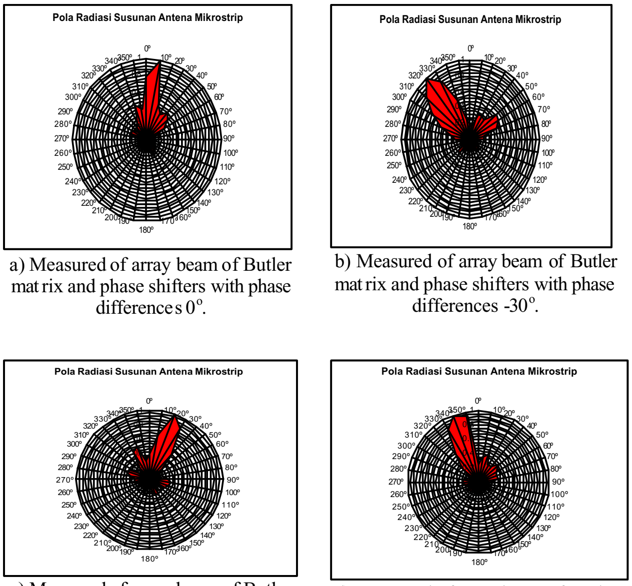


Figure 10 Simulated eight beams of Butler matrix only



a) Measured of array beam of Butler matrix and phase shifters with phase differences 0^{o}.

b) Measured of array beam of Butler matrix and phase shifters with phase differences -30^{o}.

c) Measured of array beam of Butler matrix and phase shifters with phase differences 10^{o}.

d) Measured of array beam of Butler matrix and phase shifters with phase differences -20^{o}.

Figure 11 Measured beam patterns of Low cost 2.4 GHz smart antenna

5. CONCLUSIONS

The proposed low cost 2.4 GHz smart antenna has been presented in this paper. The combination of IQ modulator-based phase shifter and Butler matrix also has been demonstrated and from the measurement results we can see that the beam steering is able to be controlled by feeding the signals with phase differences to the multiple beam ports of the Butler matrix without using the RF switches .

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