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Application of Butler Matrix in Switched Beam Smart Antenna

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***Abstract*—In this paper an application of the butler matrix is studied accordance of development of switched beam smart antenna. Such system also can be useful in development of the multibeam base station antenna for UMTS applications. Here smart antenna system of 4-element microstrip linear array antenna with Butler matrix beamforming network is designed, analyzed and implemented using microstrip technology. Performance of this system in analyzed as well the characteristics of the system can be studied. Beam forming patterns also studied. The antenna used in this system is microstrip slot antenna which is fed by electromagnetic coupling. The patch distribution structure used in this experiment allowed a great improvement of gain, directivity as well as the adaptation level of the studied array.**

Keywords — Butler Matrix; Adaptive Antenna; Microstrip Antenna array; Multibeams Antenna; Coupler.

I. Introduction

Study of switched beam smart antenna system has been recently become very vital in the flied of development of improved wireless network. And implementing switched beam array involves the use of butler matrix. Using butler matrix it becomes more to sophisticated do design N x N matrix. This matrix have N input ports and N out ports. That is hear N different signal can be transmitted using N different microstrip antennas.[1] Each antenna radiates in different direction.

Use of butler matrix is very advantages because of,

1. It can be implemented easily using hybrids and phase shifters.
2. The generated beam will have narrow beam with and high directivity.
3. It has minimum path lengths and number of components compared to other beam forming networks
4. This system operates with high and almost constant value of crossover level and which is independent of the frequency.
5. It is also possible to achieve continuous beam scanning using butler matrix.

Butler matrix is composed of mainly three components as, 3db quadrature couplers, crossovers, and 45^0 phase shifter. This paper presents the simulation, fabrication and measurements results of 4x4 butler matrix.

II. Beam Froming Network

Multiple beam forming network can be designed by using butler matrix. Butler network output can be connected to the microstrip antennas, and can fed with frequency 2.5 GHz.

The 4 x 4 butler matrix is as shown in following figure

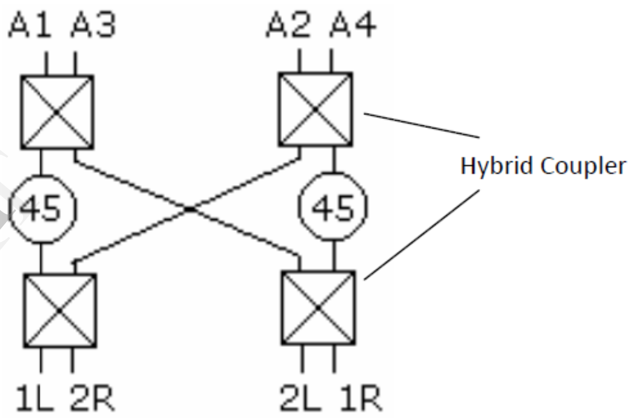


Fig. 1. 4 x 4 butler matrix

Here hybrid coupler provides the 90^0 phase shift at the output port. The crossover is done by cutting the ground plane and taking the connection from there. This works as a jumper and provides required isolation between cross points.

Design equation of the butler matrix (4 x 4) is an follow.

$$\begin{bmatrix} 2R \\ 1R \\ 1L \\ 2L \end{bmatrix} = \begin{bmatrix} 0 & -135 & 90 & -45 \\ 0 & -45 & -90 & -135 \\ 0 & 45 & 90 & 135 \\ 0 & 135 & -90 & 45 \end{bmatrix} \begin{bmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{bmatrix}$$

A 4 x 4 butler matrix creates a set of 4 orthogonal beams in space by processing the signal from the 4 antenna elements of an equi-spaced linear array. Butler matrix consists of four directional couplers, two 0 dB cross couplers, and phase shifters. Figure 2 shows the fabricated directional coupler and figure 3 shows the fabricated cross coupler.

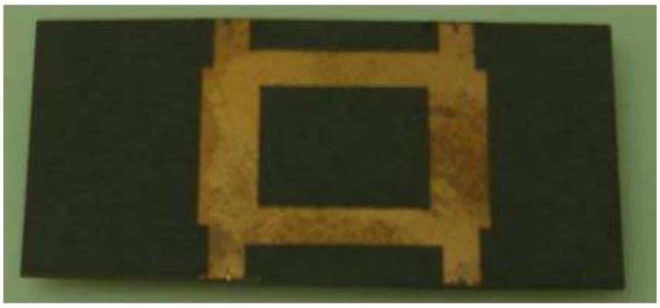
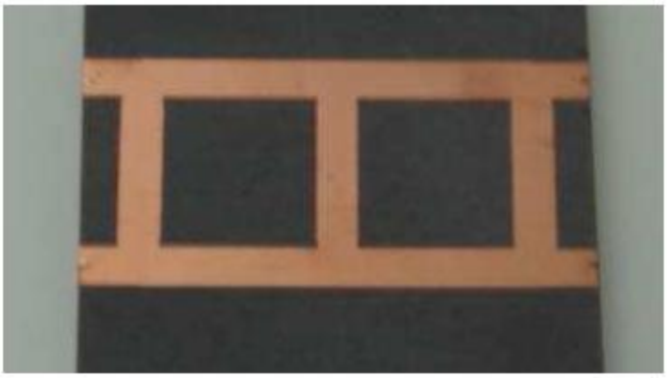


Fig 2.Fabricated directional microstrip coupler



Fib 3. Fabricated cross coupler.

Table 1 shows that the measured and simulated results of the quadrature and cross couplers. Here four beam smart antenna generates four orthogonal beams to cover 120^0 area [1].

	Quadrature 3 dB Coupler		0 dB Cross Coupler	
	Simulated	Measured	Simulated	Measured
Return Loss (S_{11}) [dB]	−30.904	−19	−24.956	−10.7
Isolation (S_{41}) [dB]	−31.425	−18	−38.036	−23.7
S_{21}, S_{43} [dB]	−3.005	−3.5	−24.942	−28.9
S_{31}, S_{42} [dB]	−3.086	−3.8	−0.085	0.6

Table 1. simulated vs measured results of quadrature coupler and cross coupler

	P5	P6	P7	P8	β
P1	62.718	16.935	−28.747	−72.850	45
P2	−28.478	107.768	−117.055	16.946	−135
P3	16.951	−117.045	107.760	−28.456	135
P4	−72.832	−28.739	16.925	62.717	−45

Table 2. phase shift results between different ports of the butler matrix

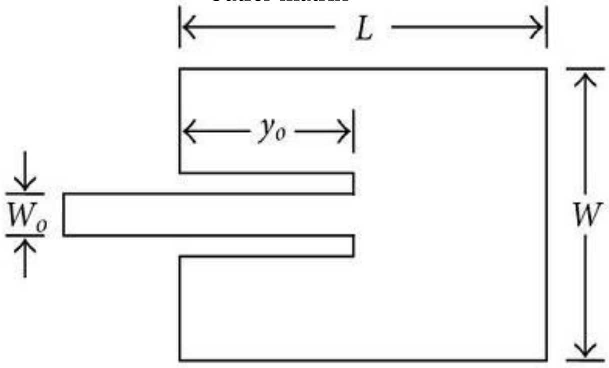


Fig 4. Microstrip patch antenna[1]

Fig 5 fabricates microstrip patch antenna

III. MICROSTRIP ANTENNA ARRAY

4 x 4 beam forming antenna array is formed of two parts. One is beam forming network which is nothing but butler matrix and second one is the array of microstrip antenna. Here 4 microstrip slot antennas are used to form a array of antenna. These antennas are connected to the 4 output ports of the butler matrix. Following fig 4 shows the microstrip slot antenna.

Figure 6. shows the results of the microstrip patch antennas. Here this results can be simulated using 3D modeling tool name HFSS[1].

With the help of design parameters, it can specified that the patch size is 48.4 mm in width and 40.025 in length. The fabricates patch antenna is as shown in fig. 5

Figure 6. shows that the measured and simulated results of the microstrip path antenna.

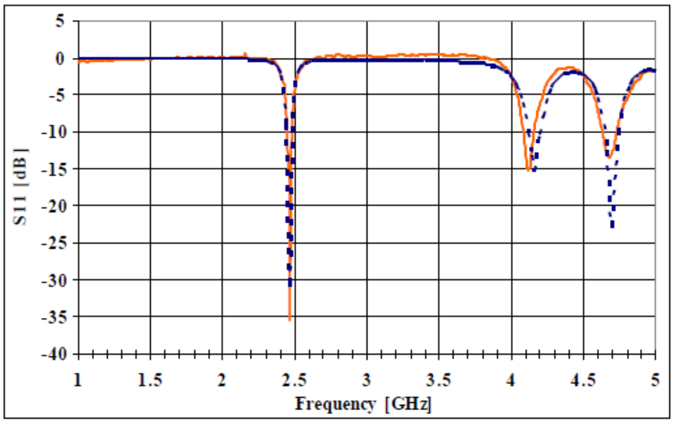


Fig. 6. Measure S- parameters (continues) vs simulated results (dotted)

	Bandwidth [GHz]	Directivity [dB]	Efficiency [%]	Gain [dB]	Beam Width
Required specs.	2.4 : 2.48	12	> 90	> 10 dB	30°
Achieved single patch specs.	2.443 : 2.475	7.5422	90	7.0244	99.1°
Achieved array specs.	2.35 : 2.55	11.389	92	11.0452	25.2°

Table 3: Achieved single patch and linear array parameters compared to required specifications.

Then a 4-element linear array is designed with an initial inter-element spacing of 0.5¸ and variable phase between elements based on the butler matrix outputs, using PCAAD software. The optimum inter-element spacing is found to be 0.45¸. The linear array is realized using microstrip technology and optimized using ADS/Momentum simulation, which is based on the method of moments. Table 1 summarizes the results obtained from the implemented single patch and the array compared to required specifications. Thus, it is clear from these results that the 4-element antenna array fulfills most of required specifications. Some other specifications such as beam steering in one of four directions and beam coverage will be achieved after the design of Butler matrix beam forming network.

IV. 4 X 4 BUTLER MATRIX MICROSTRIP PATCH SMART ANTENNA SYSTEM

The figure 7. Shows the 4x4 butler matrix microstrip patch smart antenna system. Here patch antennas are connected to the output ports of the butler matrix. Beamforming characteristics can be analyzed of 4x4 butler matrix microstrip patch smart antenna system by uniform amplitude distribution.

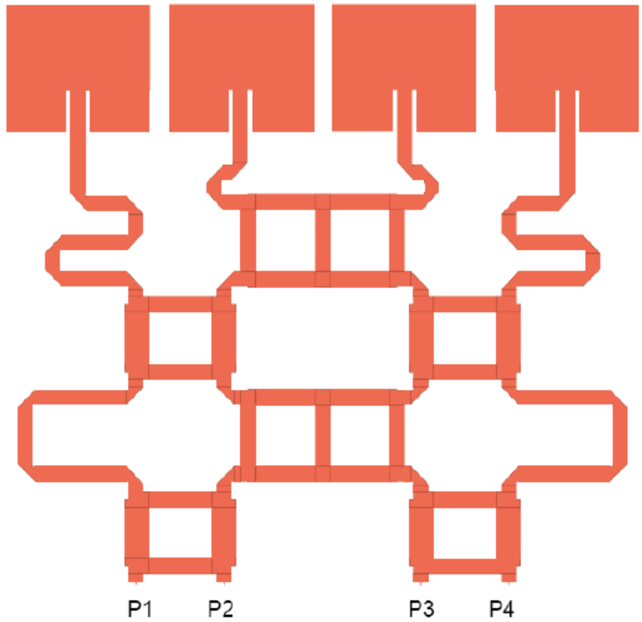


Fig. 7. 4x4 butler matrix microstrip patch smart antenna

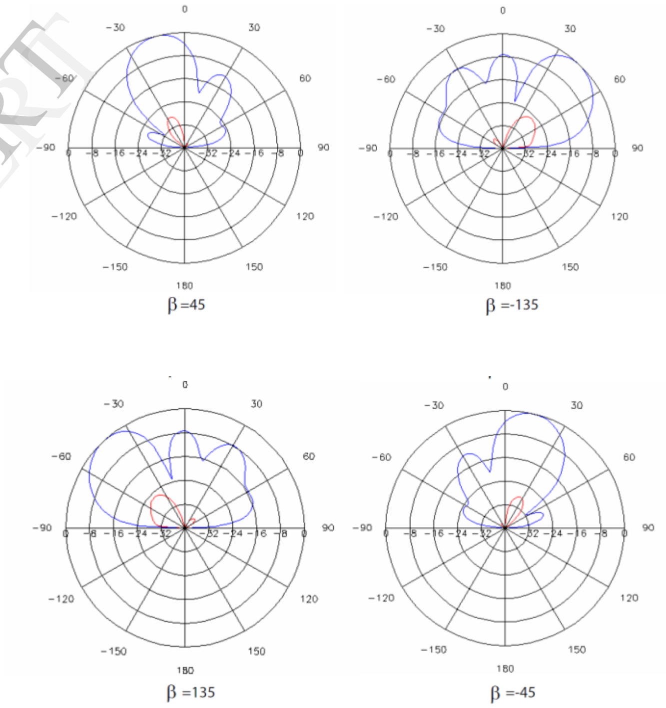


Fig. 8 simulated E-theta(in) and E-phi(out) beam patterns of 4x4 butler matrix microstrip patch smart antenna at different β Using FHSS.

Furthermore, smart antenna efficiency and directivity are improved, while minimizing its size to cope with the required constraints. Finally, the implemented antenna is also compared to similar recent published implementation in Table 4[1]. This comparison proves that this work enhances many parameters which shows an outstanding performance of the proposed antenna due to design and optimization efforts.

Features	Other antenna	Butler matrix antenna	Enhancements
Centre Frequency	2.4GHz	2.45Ghz	---
Physical size cm x cm	24.2 x 18.5	21.3 x18.6	11.5%
Microstrip subrate	ε_r=3.38, h= .051mm tan δ = 0.0027	ε_r=2.2 h= 1.57mm tan δ = 0.0009	----
Radiator element	S_{11}= -23 db@f_0 BW=0.54%;(13MHz)	S_{11}= -33 db@f_0 BW=1.31%;(32MHz)	43.4% 146%
Amplitude taper	Uniform	Uniform	-----
Antenna gain	------	11.0452	-------
Antenna directivity	------	11.389	-----
Spatial scan coverage	84^0	97.4^0	15.9%
Maximum scan range @ β = ±45^0 @ β = ±135^0	± 12^0 ± 42^0	± 14.3^0 ± 47.8^0	19.2% 13.5 %
SLL : @ β = ±45^0 @ β = ±135^0	-14dB -8dB	-14dB -8dB	------

Table 4

V. CONCLUSION

Through modeling and simulation procedures the element of the butler matrix like patch antenna, directional coupler, cross coupler can be designed and measured. Also simulated and measured resulted can be compared. And finally using this information butler matrix beam forming smart antenna is studied and analyzed. Smart antenna parameters like efficiency, directivity and maximum scan angel are improved while physical size of the antenna is minimized.

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