Design of phased array antenna for beam forming applications using 4X4 Butler matrix

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Abstract - *In this paper, the design of a microstrip antenna array with four port Butler matrix is presented. The Butler matrix is used as a beam forming network and it produces orthogonal beams that can be steered in different directions. Simulated butler matrix has 10 dB return loss bandwidth of 20%. This matrix feeds four single element micro strip antennas that can be operated from 2.412GHz to 2.484GHz. The circuit is designed by considering a single layer structure that makes it simpler. The design of wide band microwave devices such as branch-line coupler, cross-coupler and phase-shifters are also incorporated the switched beam antenna is designed for 2.4GHz band Wi-Fi (Wireless Fidelity) system.*

Key Words: **Butler matrix, beam forming network, orthogonal beams, single layer structure**

1. INTRODUCTION

Smart antennas have been characterized as one of the most prominent devices in wireless communication. Nowadays, there is a considerable work in prototype and test beds of such system .The use of "Smart antenna" can improve wireless performance .Smart antenna may contain switched-beam or fully adaptive configuration that electronically steer the pattern toward an individual user. An adaptive antenna array aims to reject automatically interference signals by modifying its radiation pattern using adaptive algorithms. This pattern modification allow to steer the main lobe in the desired signal direction and to create pattern nulls in directions of interfaces, which results in better signal to noise ratio. Implementation of this algorithm is more complex than the switched-beam system. Switched beam system produces multiple narrow beams and selects from them the appropriate beam that gives the strongest signal level. The switched beam systems are the solution in the current transition phase between the scarce and full integration of the smart antenna technology. The benefits of the switched beam antenna is that only fairly simple RF signal processing is required ,which makes it possible to apply the techniques also in existing wireless system. The draw- back of the system is that it has limited adaptability .One of the most crucial parts of a switched beam antenna system is the antenna feeding network [5]. Implementation of such a switched beam antenna is based on a Butler matrix. This paper details the realization of a 4 x 4 Butler matrix with four single patch antenna array and its constituting components. In order to minimize the space occupied by the microwave circuit and for easy circuit implementation we consider single layer micro strip structure. This configuration can be used in smart antenna system for wireless application 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 phase increment provided by the Butler matrix. Therefore, it would increase the performance of the system in terms of antenna's gain, and as a result, it would reduce the possible power usage. By doing that, the reliability and and capacity of the system can be enhanced. Generally wideband system need double/multilayered design[I],[5],[7] but here illustration of a butler matrix on a single layer structure is given, that is easy to fabricate and as well as maintained wideband operating frequency. In simulation RT/duroid 5880 *(cr=2.2)* is considered for substrate with height of 1.58mm. Least number of bends is used in transmission line for the reduction of microstrip discontinuity [10]. Also the overall dimension of the structure has kept compact. This type of matrix incorporated with antenna can be used in base stations for 2.4GHz band Wi-Fi.

2. QUADRATURE (90°) HYBRID

Quadrature hybrids are 3dB directional couplers with 90° phase difference in the outputs of the through and coupled arms. This type of hybrid is often made in Micro strip or strip line and is also known as branch-line hybrid. The basic operation of the branch-line coupler is as follows. With all ports matched, power entering port 1 is evenly divided between ports 2 and 3, with a 90° phase shift between these outputs. No power is coupled to ports 4. Thus, the [S] matrix will have the following form [6]:

$$[S] = \frac{-1}{\sqrt{2}}\begin{bmatrix} 0 & j & 1 & 0 \\ j & 0 & 0 & 1 \\ 1 & 0 & 0 & j \\ 0 & 1 & j & 0 \end{bmatrix}$$

Simulated Return loss and Phase difference of the two ports of quadrature hybrid are given in Figure 2. 3dB power division in ports 2 and 3 is obtained in operating frequency. Also perfect isolation and return loss at ports 4 and 1 is found at the designed frequency. The hybrid junction has a frequency bandwidth of 820MHz, which is about 33% of its center frequency.

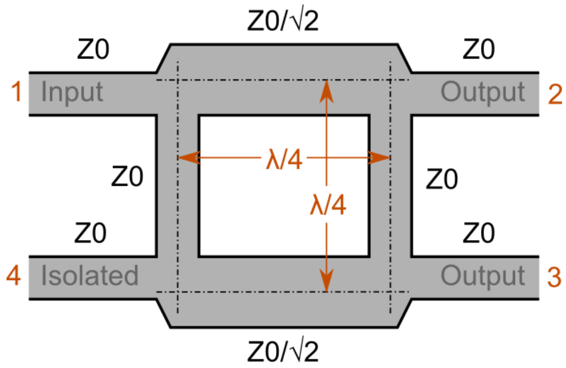
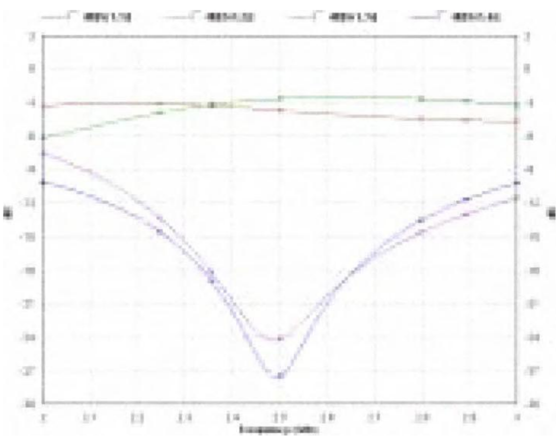
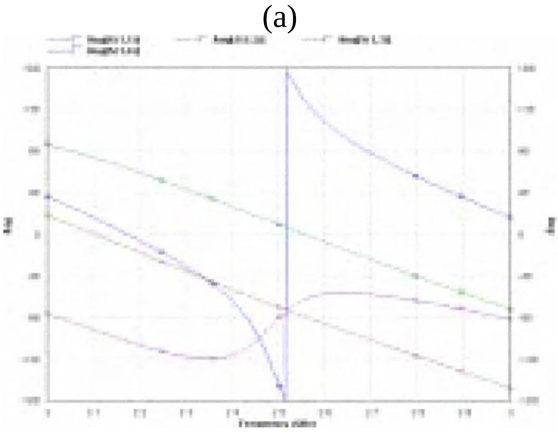


Fig -1: Hybrid coupler



(a)



(b)

Fig -2: (a) S parameter versus frequency for the branch-line coupler and (b) Phase Angle.

3. CROSS-COUPLER

These devices, also known as 0 dB couplers, are an efficient means of crossing two transmission lines with a minimal coupling between them [7]. It is possible to make a cross-coupler by connecting two 90 degrees hybrids. But more advanced and area efficient is when two parallel arms with 50 Ohm in the middle of the structure is replaced by a single 25 Ohm. The *[S]* matrix of cross-coupler will have the following form:

$$[S] = \begin{bmatrix} 0 & 0 & j & 0 \\ 0 & 0 & 0 & j \\ j & 0 & 0 & 0 \\ 0 & j & 0 & 0 \end{bmatrix}$$

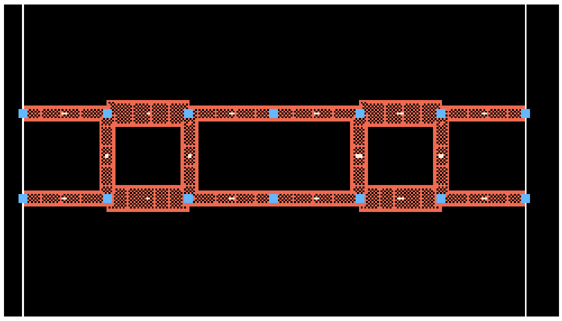


Fig -3: Cross-coupler or OdBcoupler

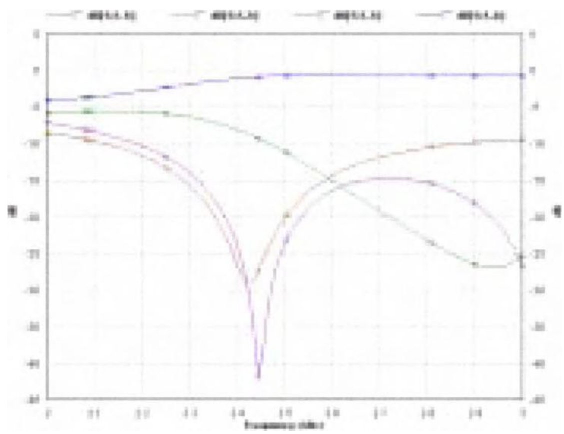


Fig -4: shows the simulated return loss of the cross coupler. The cross-coupler has a frequency bandwidth of 810MHz which is about 33% of its center frequency.

3. PHASE SHIFTER

For designing a 4 x 4 butler matrix we need two phase shifter, this thing can be easily made by micro strip transmission lines. Changing the length of transmission line desired phase shift can be found. Two 45° phase shifter is required. Simple calculations are needed to design these things.

$$\phi = \beta l = \sqrt{\varepsilon_e} k_0 l$$

Here $k0 = 2\pi f / c$, l is length of the transmission line, P is the propagation constant.

5. BUTLER BEAM-FORMING ARRAY OR BUTLER MATRIX

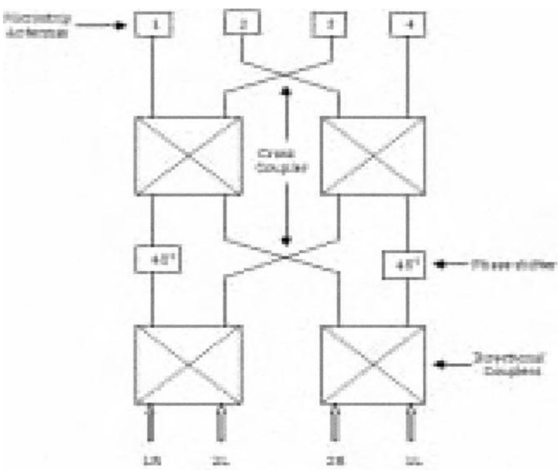
Butler matrix is an analog RF beam-forming network. It consists of 3-dB directional couplers (hybrid junctions) and fixed phase shifter to form *N* contagious beams with an N-element linear array. The number *N* is an integer expressed as some power of 2, that is *N* = 2P [8] .The 3-dB coupler is a four-port junction, as we discussed in the previous sections. The block diagram of 4 x 4 butler beam forming matrix is given in Figure 5. The Butler matrix is a four-element array that produces four independent beams. It utilizes four directional couplers and two fixed phase shifters. Butler matrix has 2P input and 2P outputs. The number of hybrid junctions/directional couplers required for *N* element array is equal to *(N* /2) log; *N,* number of fixed phase shifts is *(N* /2)(10gz(N) -1). The Butler matrix is theoretically lossless in that no power is intentionally dissipated in terminations. There will always be, however, a finite insertion loss due to inherent losses in directional couplers, phase shifters and in transmission lines that make up the network. The low cross-over level of a butler matrix is one of its disadvantages [8]. Using the universal variable u = *(d/*A)(sin***P***- sin***Pi)***, where *d/A* is the element spacing in wavelength and *8i* is the axis ofthe ith beam measured from broadside, the Butler beam patterns are as follows: (a) (b) Fig. 5.(a)Block diagram of four-element Butler beam forming matrix and (b) layout. The phase shift between the inputs and corresponding outputs that are given in Table 1(simulation results). Some phase errors have been found but these are tolerable.

$\sin \theta_i = i\,\lambda/2Nd$, i=l, 2, 3... , (N-l) (5)

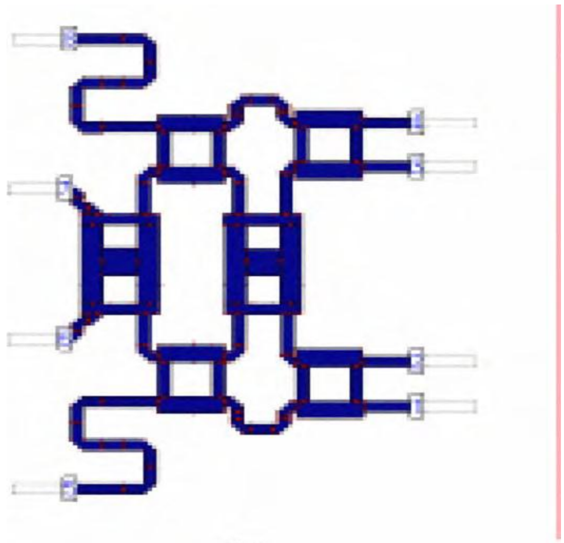
The corresponding inter-element phase shift with spacing $d = \lambda/2$ is

$$\alpha_i = \beta d \sin \theta_i = i \frac{\pi}{N}$$

where $\beta = \frac{2\pi}{\lambda}$ is the wave number [9]



(a)



(b)

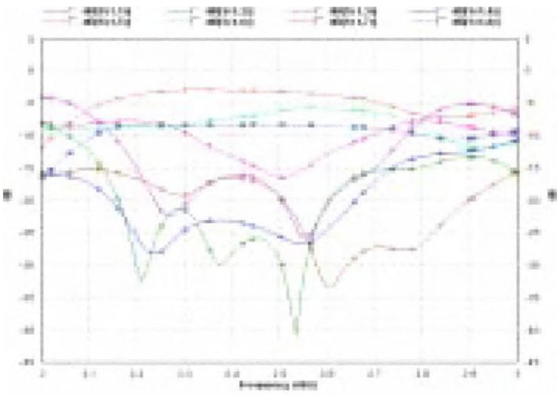
Fig -5:(a)Block diagram of four-element Butler beamforming
Matrix and (b) layout

The phase shift between the inputs and corresponding outputs that are given in Table 1(simulation results).Some phase errors have been found but these are tolerable.

Table -1: Input-Output Phase Shift (degrees) of Butler Matrix at 2.45 GHZ

Ports	Ant.1	Ant.2	Ant.3	Ant.4
1R	130.04	88.25	40.20	-3
2L	43.75	-178.20	-41.35	88.75
2R	88.12	-43.18	177.96	43.78
1L	-1.10	46.50	92.05	133.25

Figure 6 given below gives the detailed S-parameters of the matrix. In almost all cases the return loss is -10dB or below except for some cases where return losses are deviated from the desired value. Operating frequency range for different ports is between 2.15-3.0GHz. So about 500MHz operating frequency is obtained in different ports and it is 20% of the center frequency.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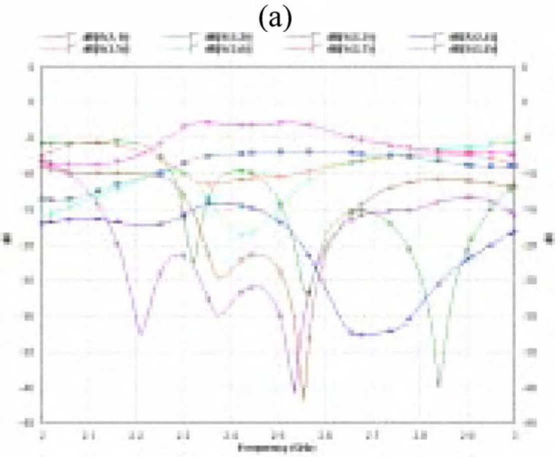
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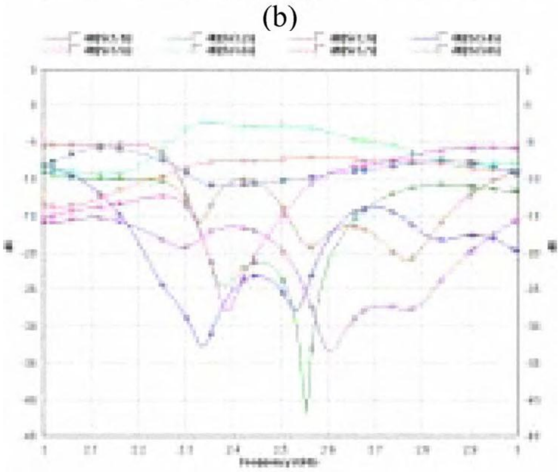
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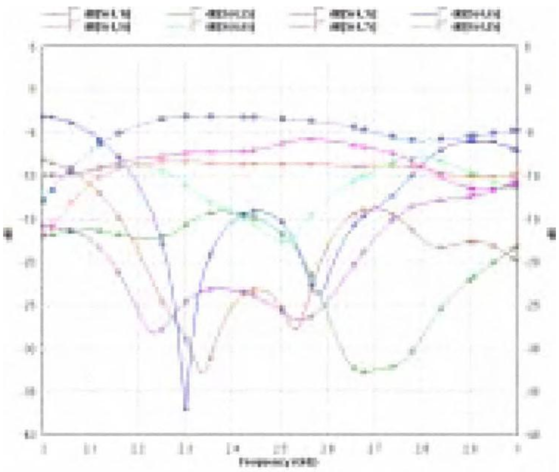
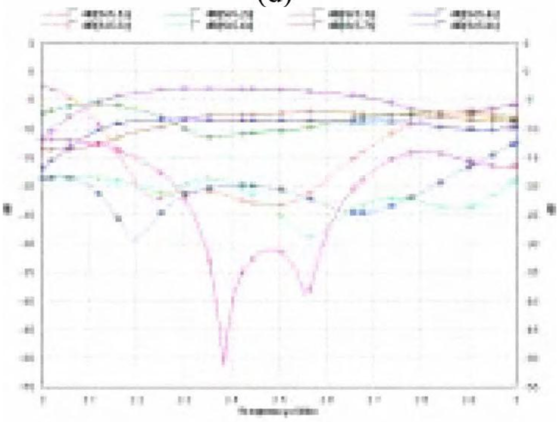

(d)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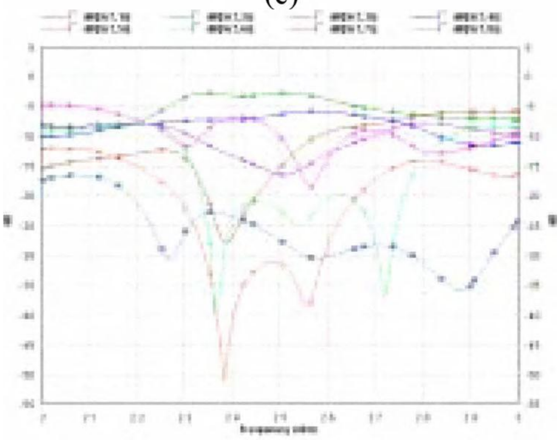
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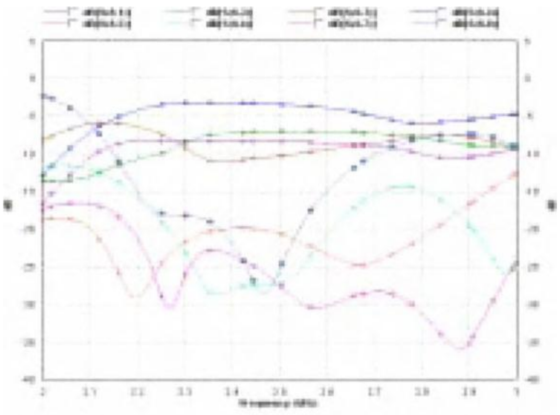


(h)

Fig -6: (a) to (h) illustrates the simulated S-parameters of the 8 different ports

6. MICROSTRIP ARRAY ANTENNA WITH BEAM FORMING NETWORK

Single element micro strip antenna of operating frequency 2.45GHz is considered for array element. Inset-feeding techniques are used for better impedance matching at the inputs of the radiating elements. Four single element patch antenna are inserted into the four port of the butler matrix, this configuration gives a switched beam antenna system. Fig. 7 shows the layout of the simulated antenna. Total dimension of the structure is 244mmx195mm. Dimensional parameters of the antenna are given in Table 2. Fig. 8 shows the detailed s-parameters of the butler matrix with antenna at different ports. All cases the return loss is -10dB or below at resonance frequency but in port IL this condition is not maintained, which is somewhat shifted. In Fig. 9 four different beam patterns of the butler matrix are shown, a little amount of phase errors have been found. Theoretically the angle of four beams when feeding in port IR ,2L ,2R and IL are found 15°,45°,-45° and -15° respectively but after simulation 16°,41^0,-42° and -19.5° have been found in different ports. It is acceptable as the phase error is within 10°. From the beam pattern curves, we also see that for ports 2R, 1Land 2L side lobe levels (SSL) is lower than 13.32dB than main lobe. But for port IR side lobe level is 9dB lower than the main lobe. 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. Gain of the antenna varies from 8.73085dB to 11.I075dB when feeding at different ports.

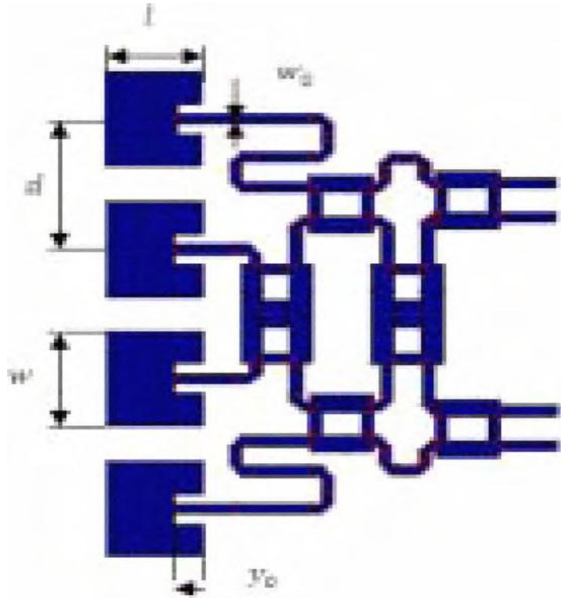
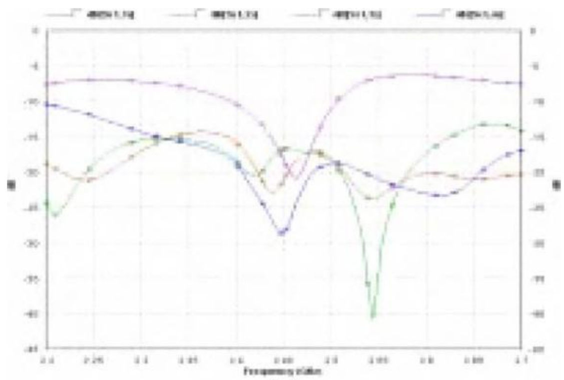


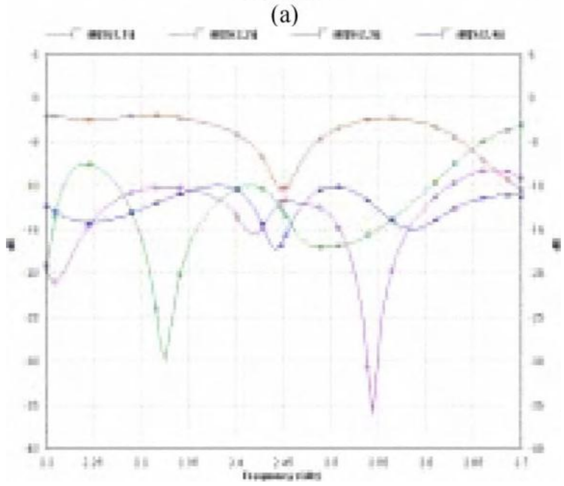
Fig -7: The proposed Microstrip antenna array with Butler Matrix Layout.

Table -2: Dimensional Parameters of single patch

w	l	d	W0	Y0
48.4mm	40.49mm	65mm	5.02mm	14.2mm



(a)



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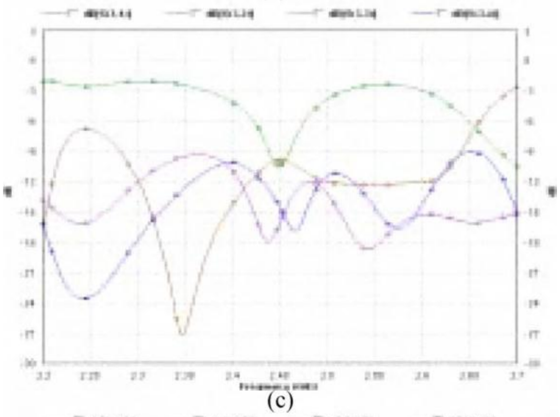

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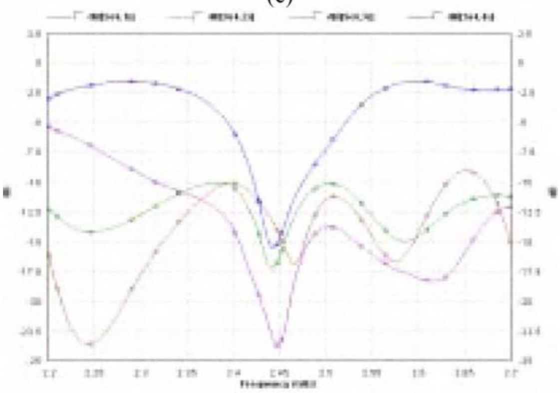
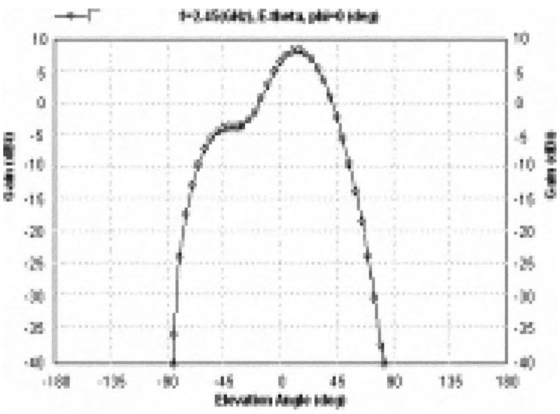
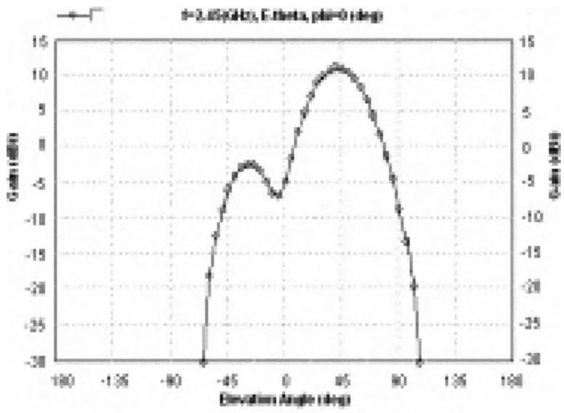


(d)

Fig -8: (a) to (d) illustrates simulated S-parameters of four different ports.



(a)



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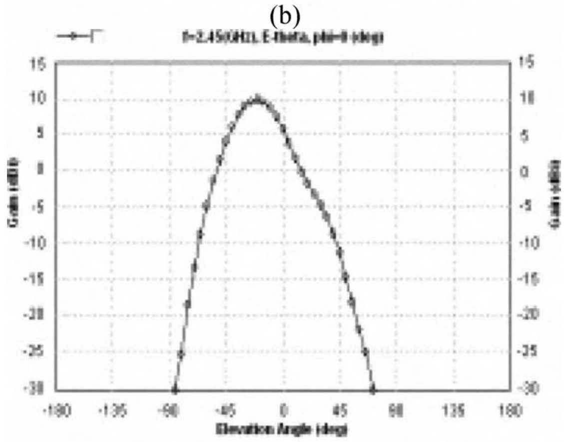

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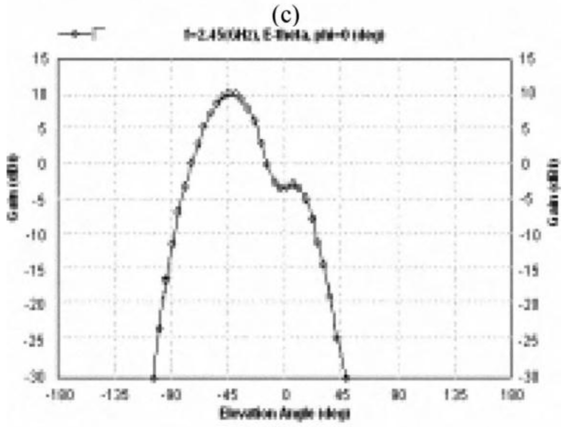

(d)

Fig -9: Beam patterns at four different ports (a) 1R, (b) 2L, (c) 1L and (d)2R.

7. CONCLUSION

Wide band 4 x 4 Butler matrix has been designed for the excitation of micro strip array antenna to steer the beams in different desired directions. Most important thing about the simulated structure is that it can be easily implemented current photolithographic technology with minimum cost and it requires simple materials for construction. The simulated butler matrix has wideband operating frequency range from 2.15GHz to 3.0GHz. At last simulation has been done by incorporating butler matrix and four micro strip antennas. This structure gives operating frequency range from 2.412GHz to 2.484GHz.

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