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Website: www.aarf.asia Email : editor@aarf.asia , editoraarf@gmail.com

IMPLEMENTATION OF MICROSTRIP PATCH ARRAY ANTENNA WITH BEAMFORMING SYSTEMS

P.Hamsagayathri (Research Scholar)
Department of ECE
Bannari Amman Institute of Technology
Sathyamangalam, Erode

P.Sampath (Professor)
Department of ECE
Bannari Amman Institute of Technology
Sathyamangalam, Erode

ABSTRACT

Breast cancer is one of most common life-threatening diseases among world's women. Early detection of Breast cancer aids in fast and effective treatment to save life. As mammogram has certain limitations, Microstrip antennas are used as alternative in growing medical application. The primary objective of the project is to design a simple and cost effective Micro strip Patch array antenna with each has dimension of 37 mm X 28 mm using FR4 substrate for operating frequency 2.45 GHz. The system of 4 -element microstrip linear array antenna along with Butler matrix is designed and analyzed to separate the desired signal with phase difference. It also combines the signals and steer the radiation in particular direction using Wilkinson power divider and passive Butler matrix. Experimental results of proposed antenna are simulated and discussed using the ADS simulation software. The proposed antenna has a bandwidth of 30 MHz covering the frequency range 2.445-2.475 GHz, the return loss below -30 dB and antenna gain of 7 dBi. The patch antenna holds good efficiency of 84%. This paper proposes design patch array antenna with beam forming system that can be applied for early Breast tumor detection in women.

Keywords— Dielectric constant, return loss,Gain, Bandwidth, Patch antenna, Mammography.

I. INTRODUCTION

Over the last few years, a significant growth of research involving the use of microwaves to image the human body and many researches are ongoing to the use of microwaves for breast cancer diagnosis. Breast cancer is one of the most life-threatening tumors among the women in the world. Early diagnosis of cancer is a key factor in providing long-term survival of breast cancer patients. The X-ray mammography is commonly used diagnostic technique for breast tumors detection in Women. However, ionization effects cause health hazard, while breast compression induce considerable discomfort in patients. Tumors located close to the chest wall or underarm result in false negatives. As per World Health Organization (WHO), Mammography has 20% False-negative and 12% False-positive rate [7]. The limitations of X-ray

Mammography has motivated to develop the microstrip patch antenna as alternate tool for breast cancer detection [4].
This technology leverages the contrast between the dielectric properties of benign and malignant tissues at microwave frequencies to identify the presence and location of significant scatters. The microwave breast imaging technique works on the principle where the signal is scattered by an object when

the object is illuminated under an electromagnetic signal [5]. The scattering parameters of the signal depend on various factors like signal strength, material properties of the object and so on. For a given signal source and the environment, the scattered signals depend on the electrical properties of the object, especially dielectric and conductivity. This technique is used to detect the tumor in the breast using microwave signals. The breast tumors have very distinct electrical properties with higher dielectric permittivity and higher conductivity, which allows them to detect by analyzing the scattered signals. Breast tumor cells scatter more signal than the normal breast tissues, which can be received by a separate antenna. The scattering properties of the transmitting antenna changes due to the scattered signals and it can be analyzed and utilized for the tumor detection [10].

II. DESIGN OF 4:1 WILKINSON POWER DIVIDER

The Power divider is especially important microwave component used to feed the array of antenna systems. It splits input power between 'n' ports with equal amplitude and phase. Though it is similar to corporate feed network, Wilkinson power divider requires less space. In 4:1 Power divider, there are one input port and four output ports.

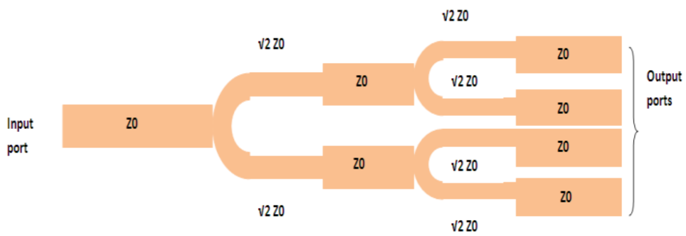

Figure 1 4:1 Wilkinson Power divider

The quarter-wavelength transmission line in the divider should have the characteristic impedance of √2 Z0 and thus length and width of transmission line are calculated and simulated in ADS.

III. DESIGN OF 4 x 4 BUTLER MATRIX

The Butler matrix is used as the passive beam forming device that steer the antenna radiation in different directions [15]. 4 x 4 Butler matrix has 4 input ports and 4 output ports. The output from power divider is connected to input of the Butler matrix and four different arrays of antenna are connected to output of the Butler matrix to transmit in different direction. Butler matrix consists of 4 Quadrature and 1 crossover coupler which divide the input power into 4 outputs with same amplitude but with different phase angle.

Advantages

The main advantages of Butler matrix are

- Easily implemented using Hybrid couplers and phase shifters
- Narrow Beam width with high directivity
- Possible to achieve the continuous beam scanning
- Require minimum number of components

A. *Design of 90^0 Hybrid Coupler*

The 90^0 Hybrid couplers are passive device that generates the equal power division (3 dB) with 90^0phase shift at its output ports.

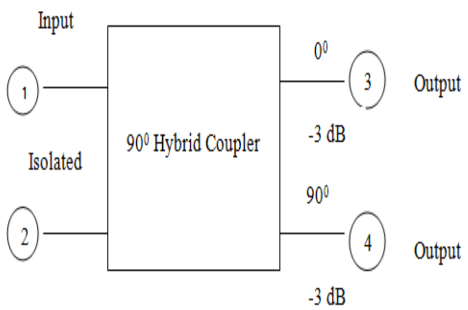

Figure 2 90^0 Hybrid Coupler

The 90^0 hybrid coupler can be designed using scattering parameters

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

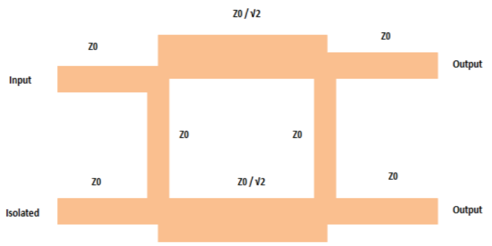

Figure 3 Design of 90^0 Hybrid Coupler

B. Design of Crossover (0 dB Coupler)

The crossover can be constructed using two 90^0 Hybrid couplers with two input ports and two output ports. In crossover, adjacent ports are isolated and it is also called as 0 dB coupler. The scattering parameters of the crossover is shown below

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

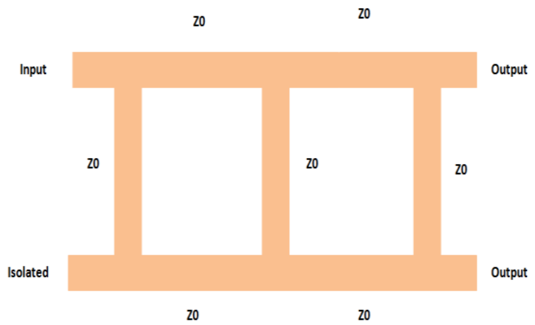

Figure 4 Design of 0 dB Crossover

The length and width of the butler matrix elements are calculated based on the characteristic impedance and simulated in ADS using below design layout.

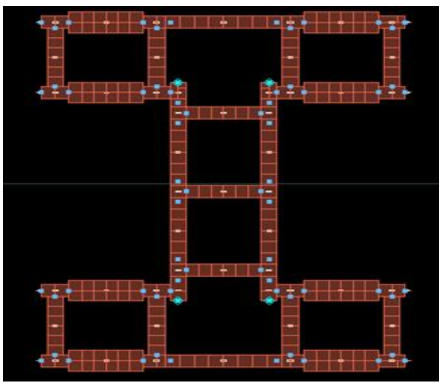

Figure 5 Design of 4 x 4 Butler Matrix

IV. RECTANGULAR PATCH ANTENNA DESIGN

The design procedure of rectangular Microstrip patch antenna has three essential parameters. They are:

Frequency of operation (f_r)

The resonant frequency of the antenna must be chosen appropriately to be use for specific application. The resonant frequency for proposed antenna design is 2.45 GHz.

Dielectric constant of the substrate (εr)

The dielectric constant of substrate (εr) material plays an vital role in the patch antenna design. A substrate with a high dielectric constant reduces the size of the antenna but it also affects the antenna performance. So, there is a trade-off between dimension and performance of patch antenna where the increase in dimension of substrate decreases the antenna performance.

Height of dielectric substrate (h)

Microstrip patch antenna to be used in biomedical systems, antenna should not be bulky. The height of the substrate is chosen as 1.6 mm.

Step 1: Calculation of Width of Patch

$$W = \frac{1}{2fr\sqrt{\mu 0 \varepsilon 0}} \sqrt{\frac{2}{\varepsilon r + 1}} \qquad (1)$$

Where

εr = Relative Permittivity

fr = Resonant Frequency

Step 2: Calculation of Effective Dielectric Coefficient (ε_r)

The effective dielectric constant can be calculated as

$$\varepsilon reff = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2}\left[1 + 12\,\frac{h}{w}\right]^{-1/2} \qquad (2)$$

Where

εr = Relative Permittivity

h = Height of the substrate

w = Width of the substrate

Step 3: Calculation of Effective Length (L_{eff})

The effective length is

$$Leff = \frac{c}{2f0\sqrt{\varepsilon reff}} \quad (3)$$

Where

$\varepsilon reff$ = Effective dielectric constant

Step 4: Calculation of Length Extension (L)

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon reff+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon reff-0.258)\left(\frac{w}{h}+0.8\right)} \quad (4)$$

Step 5: Calculation of actual Length of Patch (L)

The actual length of radiating patch is obtained by

$$L = Leff - 2\Delta L \quad (5)$$

Where

$Leff$ = Effective Length

ΔL = Length Extension

Table. 1 Design specification of Patch antenna

Parameter	**Specification**
Operating Frequency	2.45 GHz
Length of the patch	27 mm
Width of the patch	38 mm
Substrate Height	1.6 mm
Patch Thickness	0.7 mil
Substrate	FR4
Dielectric constant of substrate	4.6
Loss Tangent	0.0023

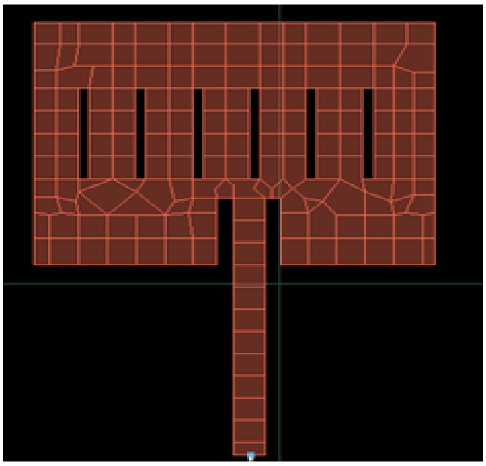

Figure 6 Design of Microstrip slotted patch antenna

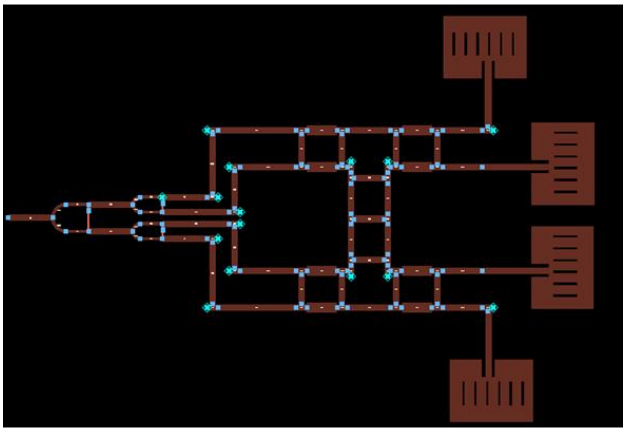

Figure 7 Microstrip slotted patch antenna with Beam forming system

V. SIMULATION RESULTS AND DISCUSSION

The proposed antenna and beam forming system is simulated through the simulation tool ADS to evaluate its performance.

By varying probe feed length, feed position, ground plane, width of the slot and length of the slot, the s-parameter variation is studied. The gain and bandwidth is enhanced for the Rectangular shaped microstrip patch with minimized return loss. The length and width of the transmission line is optimized and parameters are simulated and analyzed

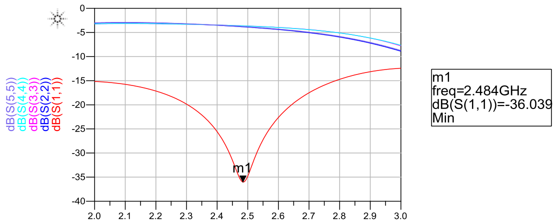

Figure 8 S- Parameters of 4:1 Power divider

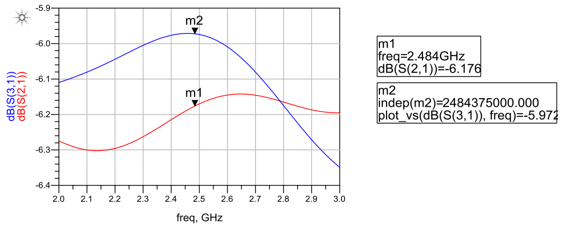

Figure 9 Insertion loss of port 2 and 3

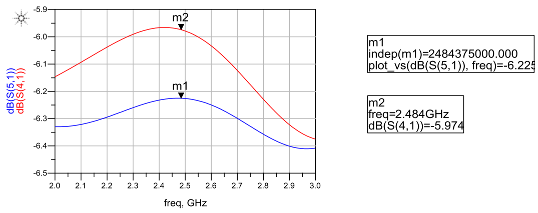

Figure 10 Insertion loss of port 4 and 5

From the Figure 8, 9 and 10, S-parameters of 4:1 power divider are analyzed and inferred that it has the return loss of -36 dB and insertion loss (S21, S31, S41 and S51) of 6 dB.

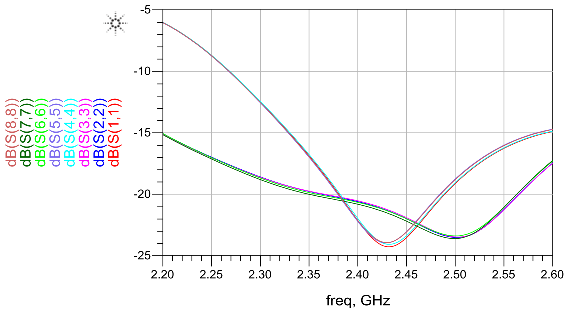

Figure 11 S- Parameters of Butler Matrix

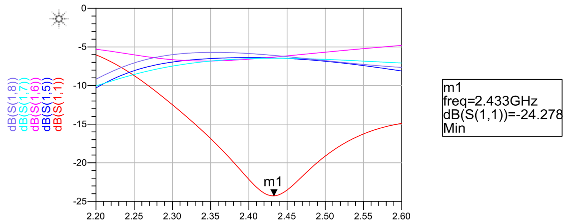

Figure 12 S-Parameters of Butler matrix with Port 1 excitation

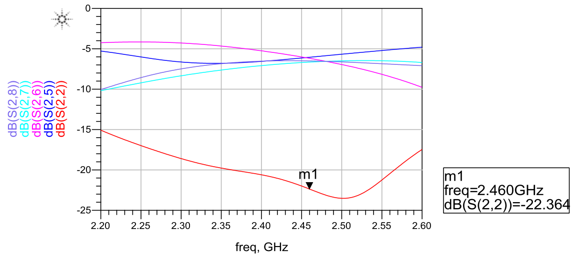

Figure 13 S-Parameters of Butler matrix with Port 2 excitation

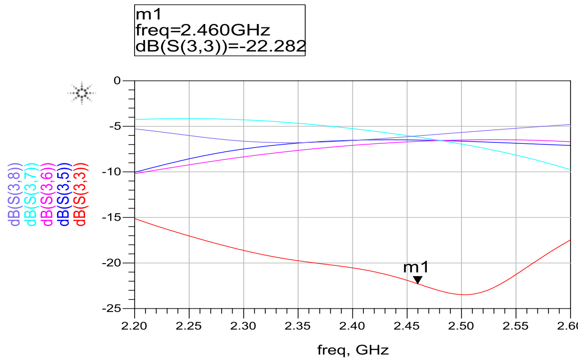

Figure 14 S-Parameters of Butler matrix with Port 3 excitation

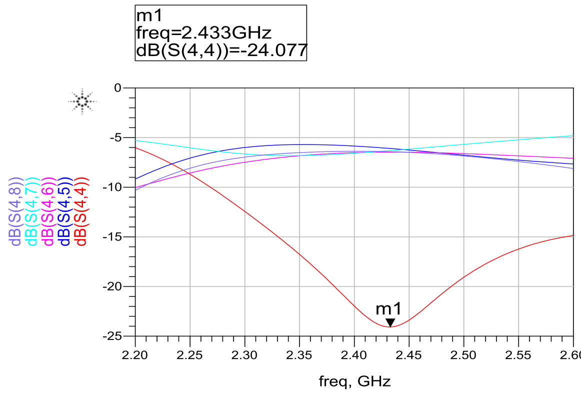

Figure 15 S-Parameters of Butler matrix with Port 4 excitation

The main goal of 90^0 hybrid coupler is to provide excellent return loss and the phase shift of 90^0 between the output ports. The length and width of the transmission lines are optimized and obtained the return loss of -24 dB. The S- Parameter magnitude response is shown in Figure 11,12, 13, 14, and 15 for different port excitation and phase plots are shown below

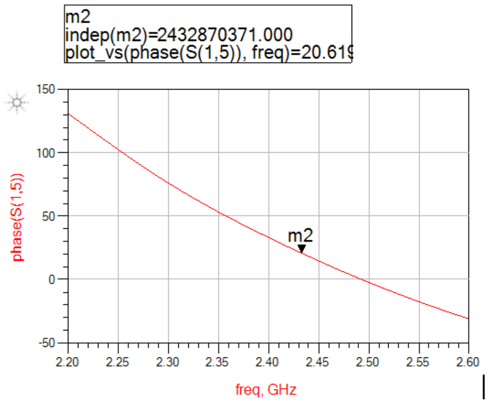

Figure 16 Phase difference between port 1 and 5

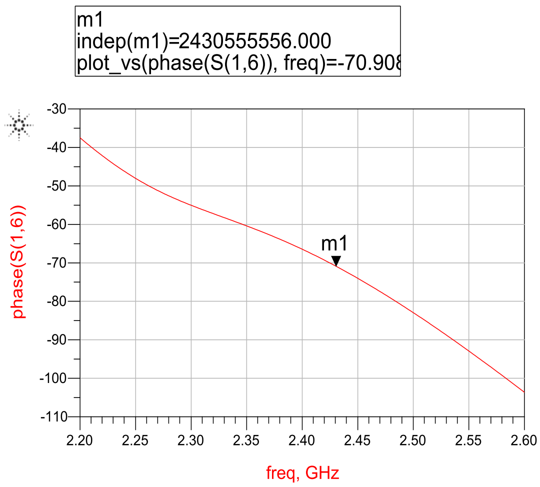

Figure 17 Phase difference between port 1 and 6

Figure 16 and 17 depicts the phase difference between ports 5 and 6 with respect to port 1.From the analysis, it is observed that, it has the phase difference of 20 and -70 degrees respectively

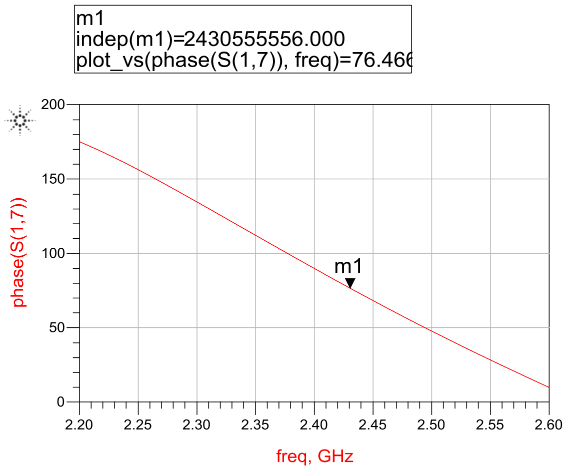

Figure 18 Phase difference between port 1 and 7

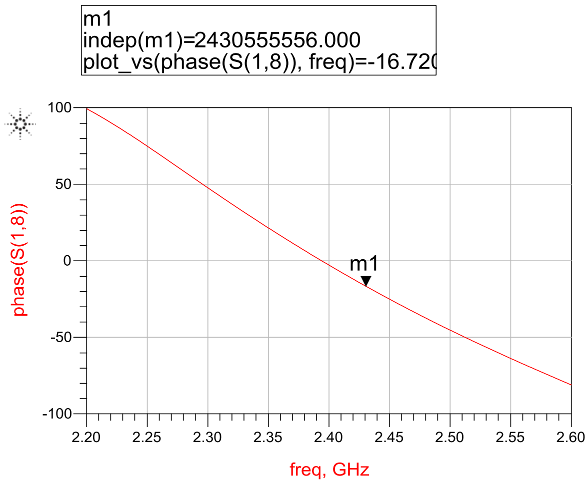

Figure 19 Phase difference between port 1 and 8

From above Figure 18 and 19, it is clear that phase differences between output ports 7 and 8 are shown. When port 1 is excited, the phase difference between output ports are tabulated below

Table. 2 Phase difference between the output ports

Input Port	**Output Port**	**Phase Difference**
Port 1	Port 5	20
Port 1	Port 6	-70
Port 1	Port 7	76
Port 1	Port 8	-16

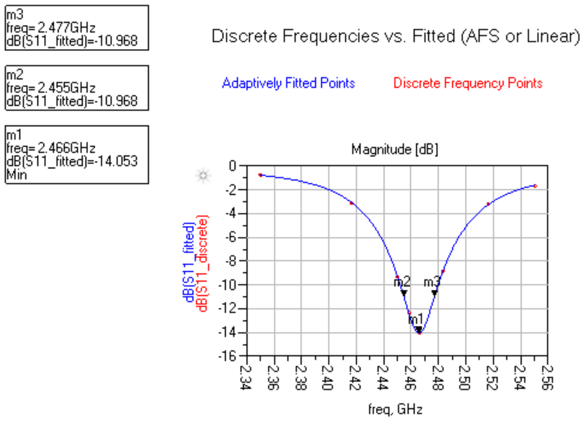

Figure 20 S-Parameters of slotted patch antenna

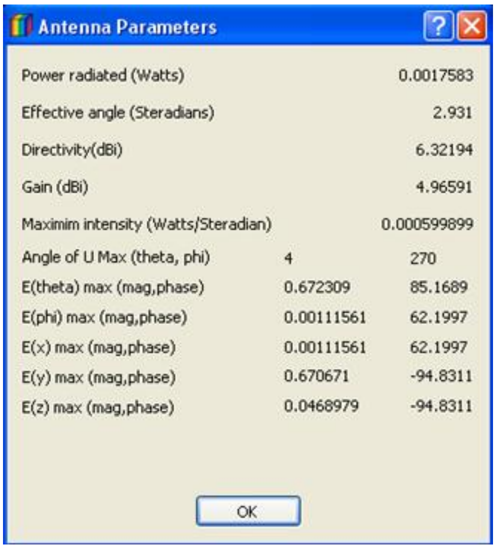

Figure 21 Antenna parameters of slotted patch antenna

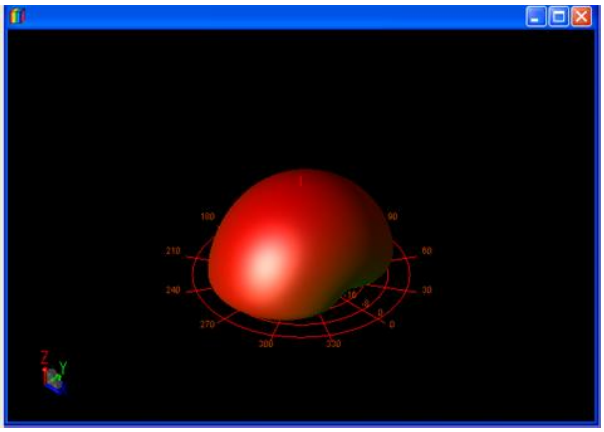

Figure 22 Radiation pattern of slotted patch antenna

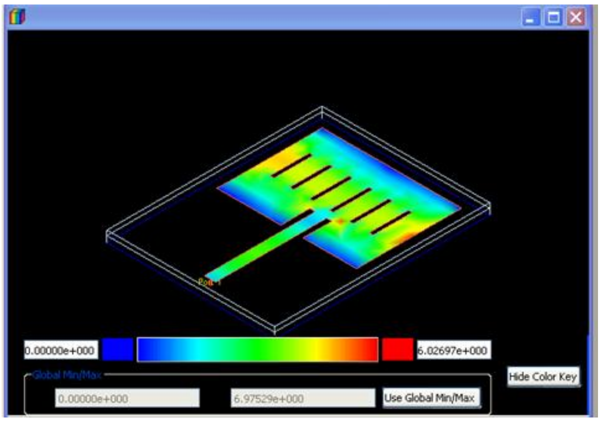

Figure 23 Current distribution of slotted patch antenna

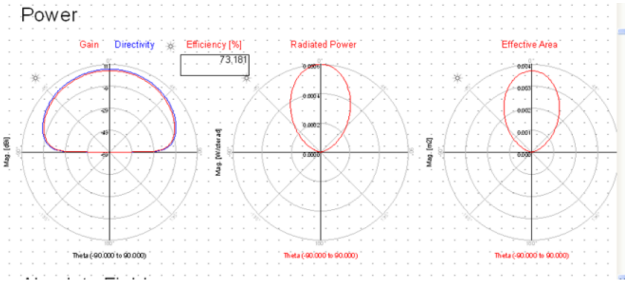

Figure 24 Efficiency of slotted patch antenna

Figure 20 and 22 shows that the radiation pattern of the single patch antenna has single main lobe with return loss of -14 dB resonating at 2.45 GHz. Figure 22 depicts that it has the gain of 4 dBi and directivity of 6 dBi and efficiency is captured in Figure 24. As it has sharp edge slots, the current distribution is plotted in the Figure 23.

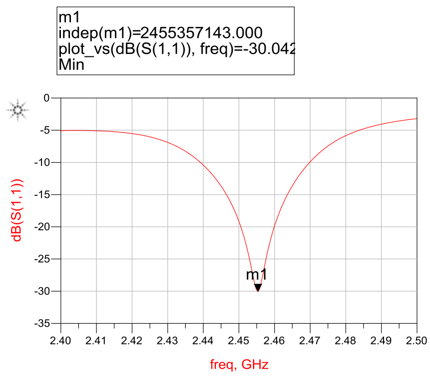

Figure 25 S-Parameters of slotted patch antenna with

beam forming system

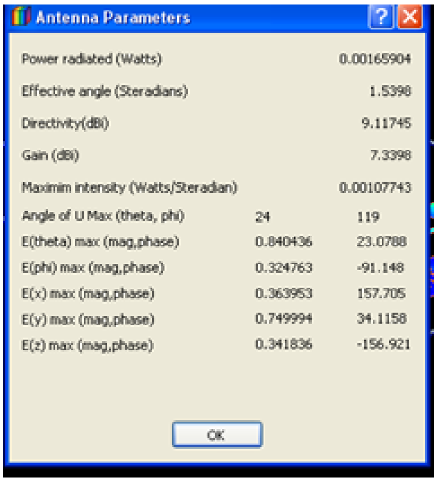

Figure 26 Antenna parameters of slotted patch antenna with beam forming system

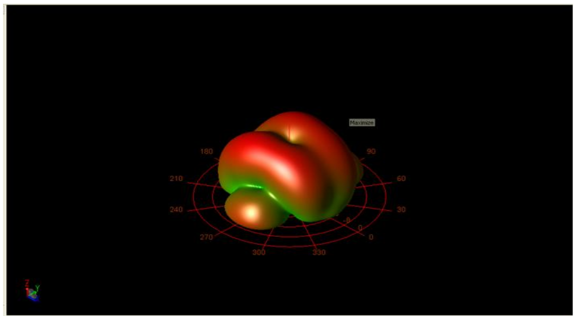

Figure 27 Radiation pattern of slotted patch antenna with beam forming system

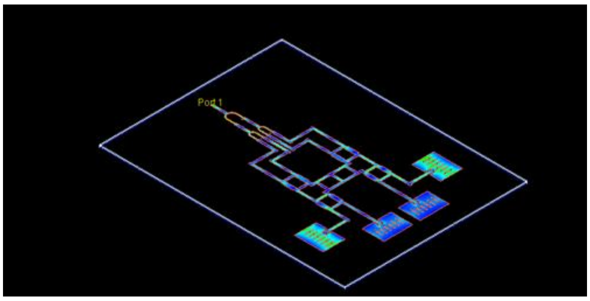

Figure 28 Current distribution of slotted patch antenna with beam forming system

The output from Butler matrix is connected to the input of the array of antennas and simulated using ADS and antenna parameters are analyzed. Figure 25, 26 shows that combined beam forming network has return loss of -30 dB with gain of 7 dBi and directivity of 11dBi. Directive lobes are shown in the radiation pattern and current distribution of the beam forming network is capture in Figure 27 and 28.

VI. FABRICATION AND TESTING

The proposed antenna and beamforming system has been fabricated and tested using Agilent Technologies - Vector Network Analyzer (VNA).The testing setup was performed for single patch antenna, beam forming circuit and then combined circuit of beam forming system with array of antennas. In Figure 29, single patch antenna input port is connected to port 1 of VNA using cables.

Figure 29 Measurement of S11 for single patch antenna

The scattering parameters (-21.46 dB) and resonant frequency are measured as 2.45 GHz as shown in Figure 29. The antenna parameters are compared for simulated and fabricated results in the below Table.3.

Table .3 Comparison of patch antenna parameters for simulated and fabricated results

Antenna Parameters	Simulation Results	Fabrication results
Resonant Frequency	2.46 GHz	2.45 GHz
Return loss	-14 dB	-21 dB

The testing setup was performed for beam forming circuit where port1 of the VNA is connected to input port of the power divider and output port is connected to port 2 of the VNA.

Figure 30 Measurement of S_{11} for Beam forming circuit with array of antennas

The magnitude response of S_{11} parameters is observed as -14.12 dB at resonant frequency of 2.46 GHz as shown in Figure 30.The corresponding phase response at 2.46 GHz is measured as 23^0 and it is clearly depicted in Figure 31.

Figure 31 Phase response for Beam forming circuit with array of antennas

Table .4 Comparison of patch antenna parameters for simulated and fabricated results

Antenna Parameters	Simulation results	Fabrication results
Resonant Frequency	2.45 GHz	2.46 GHz
Return loss	-30 dB	-14 dB

VII. CONCLUSION

In this paper, power divider, elements of Butler matrix and array of patch antenna characteristics are investigated using ADS software. From the analysis, it is observed that the four patch microstrip antenna with beam forming system is more efficient which gives higher gain of 7 dBi and better return loss of -30 dB at the desired frequency range centered at 2.45 GHz. Antenna parameters like efficiency, directivity , gain and return loss are improved for patch antenna along with butler matrix.

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