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Design and Simulation of Phased Array Antenna for 40^{o} Beam Steering at 2.4 GHz

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Abstract-In this paper a 1x4 array patch antenna designed for (2.4 GHz) frequency. The microstrip line feed technique was used for feeding antenna and a four-way Wilkinson Power Divider designed and simulated for splitting signals to radiating elements. Phase shifter based on switched line technique applied to steer beam to 40 degree. The substrate that used in this paper as dielectric was FR4 of dielectric constant 4.6 and thickness 1.6mm. Design and simulation process were done by Advanced Design System software (ADS 2017).

Keywords- *Microstrip Patch Antenna, Array Patch Antenna, Phase Shifter, Power Splitter*

I. INTRODUCTION

Antenna has a significant role in communication systems, RADAR, biomedical instruments and many other modern applications such as automated cars. Microstrip patch antenna first introduced in 1970s. This type of antenna due to ease of fabrication, low profile and miniaturized size and volume is in demanding state. Microstrip patch antenna can be built in any shape, for instance: rectangular, circular, triangular and square [1]. Phased array antenna is designed to steer beam in a particular direction and suppress ones from undesired directions. A phased array antenna is consist of three main blocks: radiating elements, feeding network and phased shifters. Feeding networks are classified in below categories: constrained feed, space feed and semi constrained feed. Constrained types are employed in parallel or series consist of Power dividers. [2] Radiating elements can be fed by microstrip line feed, coaxial feed, aperture coupled feed, and Proximity coupled feed. [3] Phase shifters are used to obtain desired shift by employing delay lines [4]. Phase shifters usually have two main types: phase controller phase shifters and switched line phase shifters [4]. In this paper a rectangular 1x4 array patch antenna designed on ADS software at a center frequency of 2.4 GHz. The patch antennas were fed by microstrip line feeds while the feeding network was a parallel constrained network consist of a 1x4 Wilkinson power splitter. Phase shifters were designed based on switched line phase shifter to steer for 40^{o}.

II. RADIATING ELEMENT AND FEEDING TECHNIQUE

Microstrip patch antenna has a radiating patch which is made by conductive materials like copper. On the other side there is a ground plane and between two planes we have dielectric. Radiating element and feed line are photo etched on the dielectric.

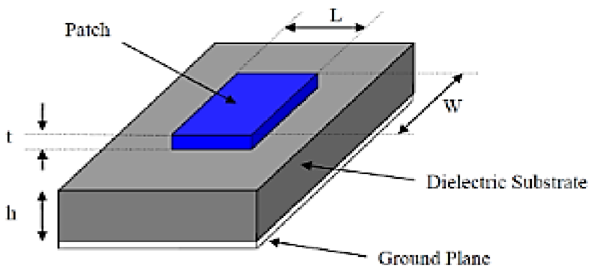

Figure 1. Structure ofmicrostrip patch antenna[1]

In this paper rectangular shape was chosen. The length of element for rectangular form should be 0.3333λ0 < L <0.5λ0, and the thickness should be very thin t<< λ0 (λ0 is the free-space-wavelength). The height of 0.003λ0 ≤ h ≤ 0.0λ0 and the dielectric constant of the substrate with the range of 2.2 ≤ εr ≤ 12 is usually chosen. [4(1to6)], [1 -38]. Radiation occurs because of fringing field between patch edge and ground plate. While low dielectric constant with thick substrate makes more efficiency in expense of larger antenna size, in the case of a compact antenna design there is a need of higher dielectric constant. [3]

In this paper FR4 (thickness=1.6mm, dielectric constant=4.6) used as the substrate. Central operating frequency was 2.4GHz and The input impedance 50 ohm. Width of rectangular patch can be achieved from equation (1).

$$w = \frac{1}{2f_r\sqrt{\mu \cdot \varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

The effective dielectric constant is important because of fringing effect and can be calculated from equation (2).This is important because some waves travel in the air and some in the substrate.

$$\varepsilon_{r_{eff}}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_\sigma-1}{2}\left[1+12\frac{h}{w}\right]^{-\frac{1}{2}} \quad (2)$$

The patch length has greater effect on resonance frequency rather than the width and can be obtained from equation (3).

$$L=\frac{1}{2fr\sqrt{\varepsilon_{r_e}ff}\sqrt{\mu_0\varepsilon_\sigma}}-2\Delta L \quad (3)$$

The additional line length because of fringing effect can be achieved from equation (4) (W/h>1).

$$\frac{\Delta L}{h}=0\cdot412\frac{(\varepsilon_{reff}+0\cdot3)(\frac{w}{n}+0\cdot264)}{(\varepsilon_{r_{eff}}-3.258)(\frac{w}{h}+3\cdot8)} \quad (4)$$

The effective patch length can be obtained from equation (5).

$$L_e=L+2\Delta L \quad (5)$$

Base on the information gotten above, the effective patch length of 29.5mm and the width of 36.9mm were calculated.

Among usual feeding techniques micristrip line feed was used. In this method a strip line connects to the edge of patch with smaller width than patch. The inset cut reduces the need of impedance matching. Increasing dielectric thickness causes increasing spurious feed radiation and also surface waves that makes undesired cross polarized radiation and deficiency in desired bandwidth. [3]

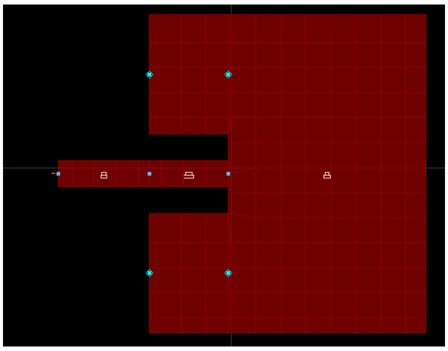

Figure 2. Designed Inset fed Microstrip patch antenna

III. FEEDING NETWORK

For more desired operations such as synthesize required pattern, increase directivity and scanning beam antenna can be built in arrays. Feeding network and phased shifters. Feeding networks are classified in below categories: constrained feed, space feed and semi constrained feed. Constrained types are employed in parallel or series consist of Power dividers.

In this paper parallel feeding network applied to the radiating elements based on 1x2 way Wilkinson Power Dividers designed in [5] and [6].

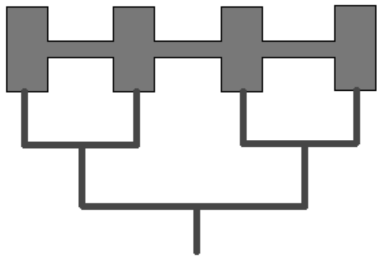

Figure 3. Parallel array network[2]

Fig. 4 illustrates a conventional 2-way Wilkinson Power Divider. Power division ratio (K^2) of the output ports is up to the particular application that is going to be designed. In this case this proportion was 1:1 so (S_{21}=S_{12}). Ports are isolated so [S] matrix of the device is reciprocal (S_{ij}=S_{ji}).

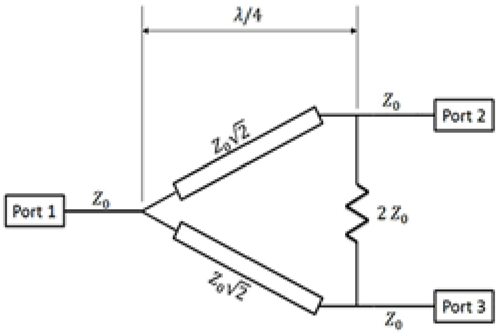

Figure 4. Wilkinson Power Divider [power2, 4]

All ports are matched (S_{11}=S_{22}=S_{33}=0). Terminals are isolated so we have S_{23}=S_{32}=0. Since the power is split equally the insertion loss between port 1to2 and also between ports 3 to1 is same. ($|S_{12}| = |S_{13}| = 1/\sqrt{2}$).

S-parameters matrix based on the information above can be written for Wilkinson Power divider as equation (6).

$$[s]=\frac{-j}{\sqrt{2}}\begin{bmatrix}0&1&1\\1&0&0\\1&0&0\end{bmatrix} \quad (6)$$

The parametric values of Wilkinson Power Divider are calculated from bottom formulas.

$$z_{03}=Z_0\sqrt{\frac{1+k^2}{k^3}} \quad (7)$$

$$z_{o_2}=z_{03}k^2 \quad (8)$$

$$R=Z_0\left(k+{}^1/_k\right) \quad (9)$$

$$R_2=Z_0K \quad (10)$$

$$R_3=\frac{Z_0}{K} \quad (11)$$

Since Z_0 was chosen to be 50 ohm, $Z_0 \sqrt{2}$ will be equal to 70.71 ohm and R will be equal to 100 ohm. Line width and length of for 50 ohm was chosen 4.87mm and 18.17mm respectively, for 70.71 ohm width was chosen to be 2.7mm and length 18.5mm. Layout of 2-way Wilkinson Power Divider is shown in Fig.5

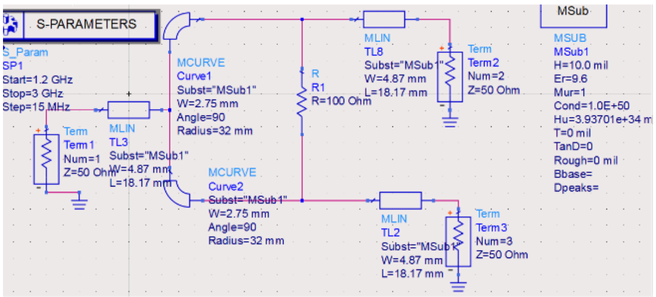

Figure 5. 2-way Wilkinson Power Divider

Since the objective of this paper was to design an antenna array with four radiating elements, there was a need of a 4-way power splitter which was designed based on connected 2-way power splitters.

Using 4-element array antenna caused an increase in return loss to -35db from 23db for a single element. (Fig. 9)

IV. PHASE SHIFTER

In transmission, when beam from a particular direction is desired, antenna is rotated to that direction. But in modern transmission systems beam steering can be done by phased array antenna. Despite limited bandwidth this type of antenna can steer main beam of radiation by phase shifters and reduce the effect of side lobes [4]. Phase shifters are categorized as Mechanical phase

Shifters, ferrite phase shifters, semiconductor device phase shifters and transmission line phase shifters [7]. The phased delay in the feed network can be obtained from [4],

$$\Delta L = \frac{\beta_0}{2\pi f \sqrt{\varepsilon_{eff}}} \qquad (12)$$

Where β is propagation constant, ε_{eff} is effective dielectric constant and c is speed of light.

Based on equation (12) the final design was done by adding phase shifters to feed lines to steer beam for admired direction of 40 degree.

V. RESULTS

The Final Designed Phased Array Antenna for 40^{o} Beam Steering at 2.4 GHz in this article was illustrated in figure 6. All blocks, consist of: a 4-way power divider, phase shifters and patch antenna substrates according to the desired details were individually examined, then, combined to the final design.

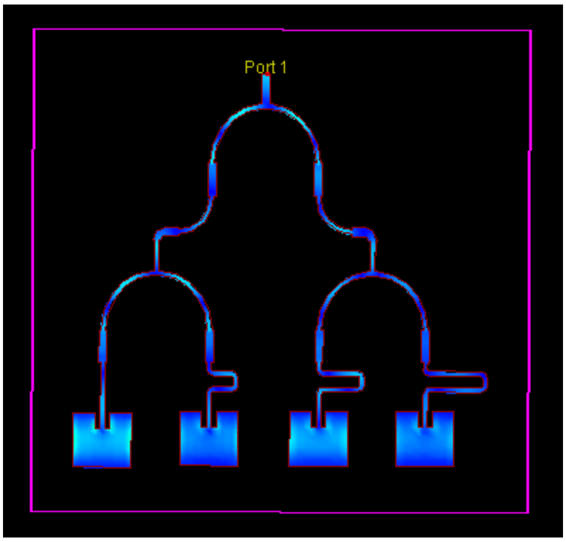

Figure 6. Final designed antenna array

Return loss from the designed single patch antenna substrate, 2-way Wilkinson power divider, and 4-way Wilkinson power divider and in the end, final designed 4-element array antenna illustrated here. 3D radiation pattern of final array antenna is shown in figure 10. Gain, Directivity and Gain-Phase proportion is inhibited in figure 11. All the results were obtained by ADS (2017) software.

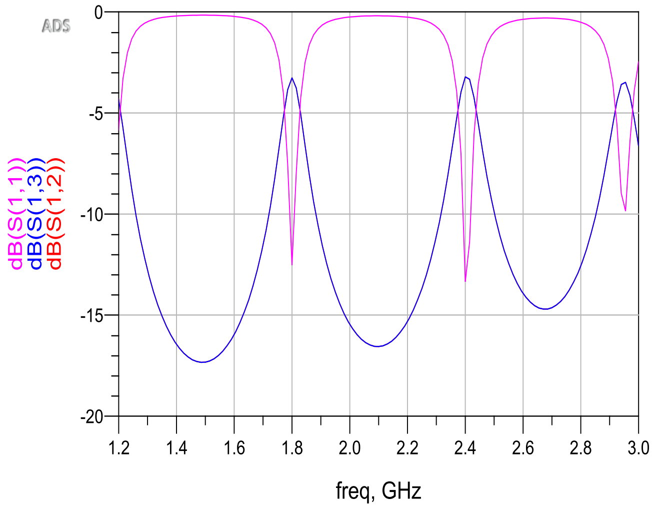

Figure 7. Results of designed 4-way Wilkinson Power Divider

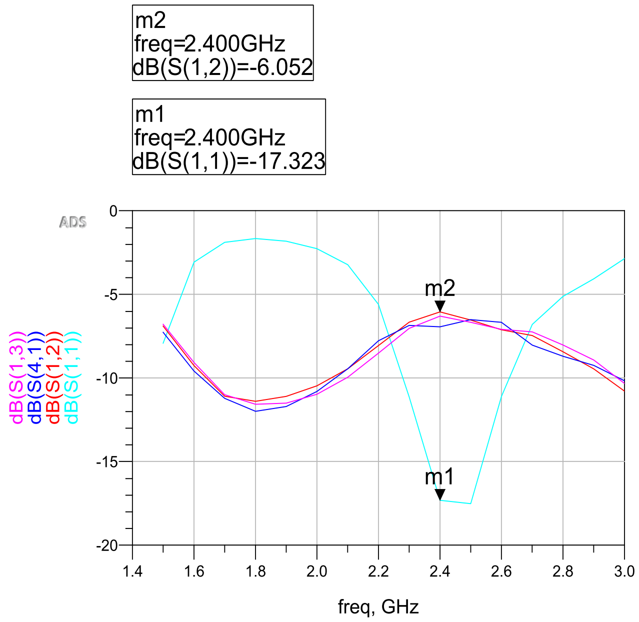

Figure 8. Results of designed 2-way Wilkinson Power Divider

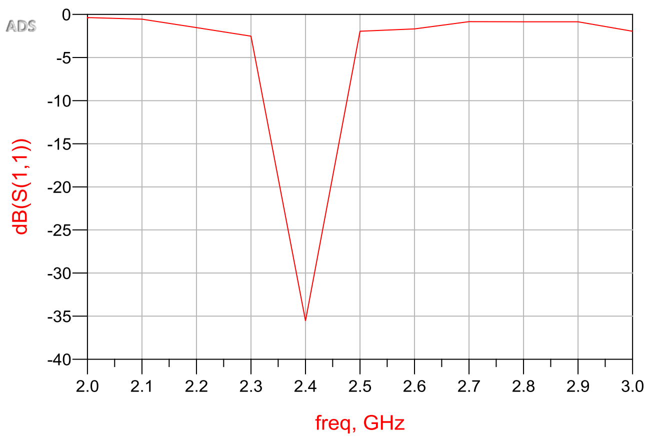

Figure 9. Return loss for 4-elemant array antenna

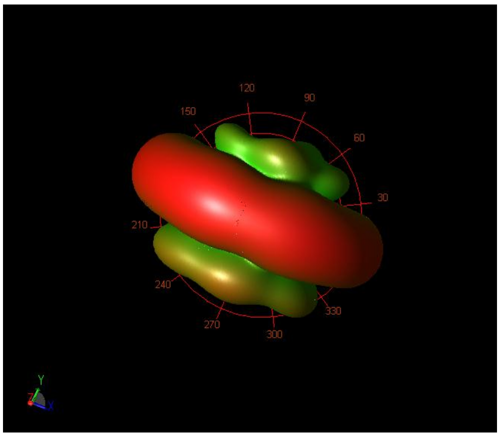

Figure 10. 3D Radiation pattern of 1x4 array antenna

Figure 11 shows the most gain in phase 40 degree as a result of phase shifter blocks added to the final design. It can be seen that the most gain of the antenna belongs to 2.4 frequency.

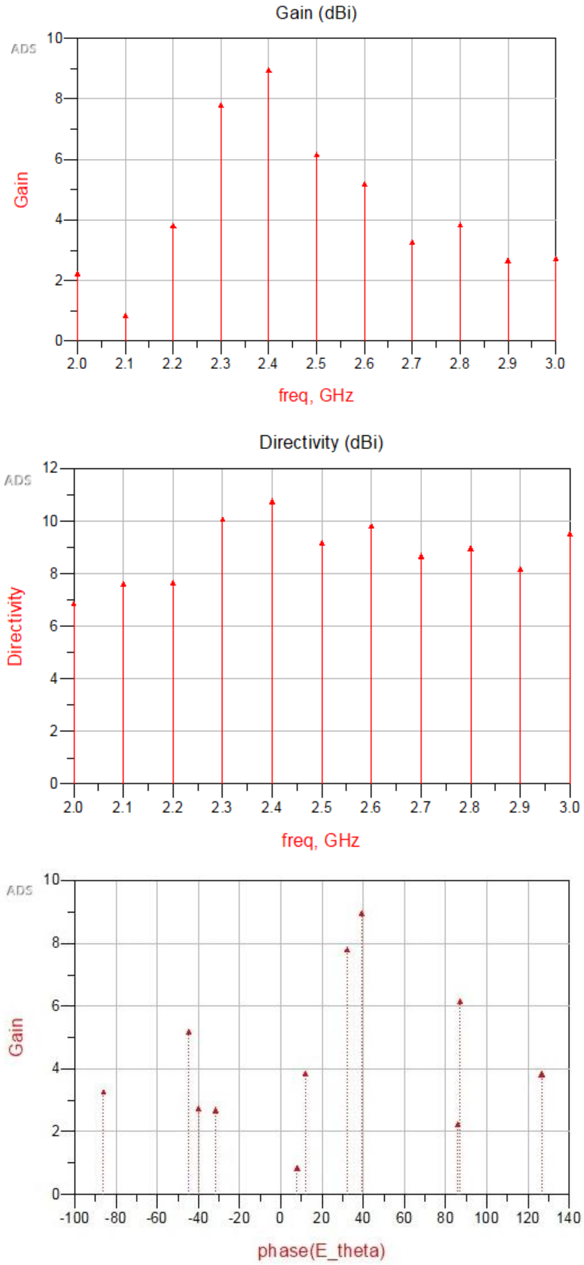

Figure 11. Gain, Directivity and Gain vs Phase (E-Theta)

VI. CONCOLUSIONS

In this paper, an array patch antenna designed for 40° beam steering in 2.4 GHz central frequency. The antenna had four radiating elements fed by microstrip feed lines and parallel feeding network consists of Wilkinson power splitters. As the objective was to steering beam in a specific direction, phase shifters were applied to make proper delay in the line. The return loss at 2.4 GHz was -35 db. The antenna had its highest gain at 40 degree.

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