International Journal of Electrical, Electronics and Data Communication, ISSN(p): 2320-2084, ISSN(e): 2321-2950
Volume-7, Issue-11, Nov.-2019, http://iraj.in

BEAM TILTING ANTENNA USING VARACTOR DIODE

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Abstract - The objective of this paper is to design a patch antenna array system that is able to tilt the major lobe of radiation pattern in different directions. From different tilting methods available, phase shifting method is most appropriate for the designing. The direction of the beam is expected to change in different directions by changing the phase of input signal. The phase variation of input RF signal is obtained by using varactor diode. Simulation and designing of 2 x 2 patch array corporate feed network was performed on ANSYS HFSS at a frequency of 2.4GHz. The implementation of this design will help in picking up the signals from desired direction. In this project the beam tilts approximately 8 to 10 degrees in a particular direction.

Keywords - Corporate Feed Network, ANSYS HFSS, Phase Shifting.

I. INTRODUCTION

An electronic element that radiates signals wirelessly is called as an Antenna. Static antenna structures do not possess the capability to change the radiation pattern thus limiting the antenna use to Beam steering is picking up importance due to its relevance to beam forming requirements in 5G systems. 5G Wireless systems has the capability of large data rates and also pick up intended signals in the presence of interference signals. It is highly essential that the receiver steers/tilts its beam in the intended direction. These steering methods are complicated if done in the RF domain, hence hybrid beamforming techniques are suggested. In this work steering of the beam using varactor diodes is attempted using RF phase shifters, it is possible to steer the beam towards intended directions. This is the reason due to which the term “Beam steering” is introduced [1] Beam steering with relative apertures is performed using electronically rotating reflecting surface. Limited beam steering is achieved by changing the feed location of a reflective surface or by altering its direction of incidence. In this paper, a method of electronic beam steering using a varactor diode is designed and implemented with the help of printed array antennas which can improve the gain and directivity as compared to single patch antenna [2]. The antennas are connected to the input RF signal through a corporate feed network which divides the power equally to all the patches [3]. The phase shifter network is implemented using varactor diodes, it is simple with no moving parts. In antenna arrays the main beam is steered via phase shifters to the direction of interest. This array is called phased arrays or scanning arrays. This general approach of phase shifting has been referred as electronic beam steering and in this process the phase of the current at each antenna element is changed directly [4]. Beam steering is used to improve focusing location of the major lobe. It reduces the power wastage by radiating the power only in the desired direction. Configuration of beam direction becomes easy. Steering the beam can provide stability to the antenna and by implementing this there will be no moving parts in the antenna structure [1]. It can provide smart solution to existing problems faced by GSM antennas.

II. DESIGNING OF ANTENNA

In order to design an array of antennas a single patch was first designed and simulated using ANSYS HFSS. A rectangular patch antenna is selected as shown in the Figure 1 which is designed and optimized to operate at a frequency of 2.4GHz. The dimensions of the patch antenna are calculated, the substrate used is FR4 epoxy copper clad board which was used for fabrication of the antenna. Corporate feed is used as an input feed for the 2x2 patch array antenna. Patch array antenna work on the principle of pattern multiplexing. Array of antenna is used to improve the gain and directivity of the antenna. Since Antenna is designed to give an impedance of 50 ohms to match the input SMA connector impedance which is also of 50 ohms.

Equations used for calculating dimensions [6]

Dimensions of the Patch:

$$\lambda = \frac{c}{f} \tag{1}$$

$$W = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon r+1}} \tag{2}$$

$$\Delta = 0.412h\frac{(\varepsilon reff+0.3)(\frac{W}{h}+0.264)}{(\varepsilon reff-0.258)(\frac{W}{h}+0.8)} \tag{3}$$

$$L = L_{eff} - 2\Delta L \quad (4)$$

where,

w=width of the patch.

c=velocity of light.

f=resonant frequency.

L=length of the patch.

εr =Dielectric constant of substrate.

$$\varepsilon_{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}} \quad (5)$$

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon reff}} \quad (6)$$

where,

$\varepsilon reff$ = Effective dielectric constant

L_{eff}=Effective of length

Dimensions of the substrate:

$$W_g = W+6h \quad (7)$$

$$L_g = L+6h \quad (8)$$

where, L_g and W_g are length and width of substrate and h is given by

$$h = \frac{0.0606\lambda}{\sqrt{\varepsilon r}} \quad (9)$$

Feed length calculation:

$$L_f = \frac{\lambda g}{4} \quad (10)$$

$$\lambda g = \frac{\lambda}{\sqrt{\varepsilon reff}} \quad (11)$$

Where,

λ_g = guided wavelength

L_f = feed length

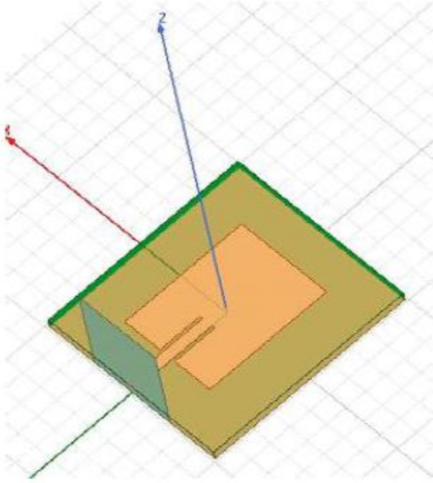

Figure 1: Designing of single patch tuned at 2.4GHz

III. CORPORATE FEED DESIGN

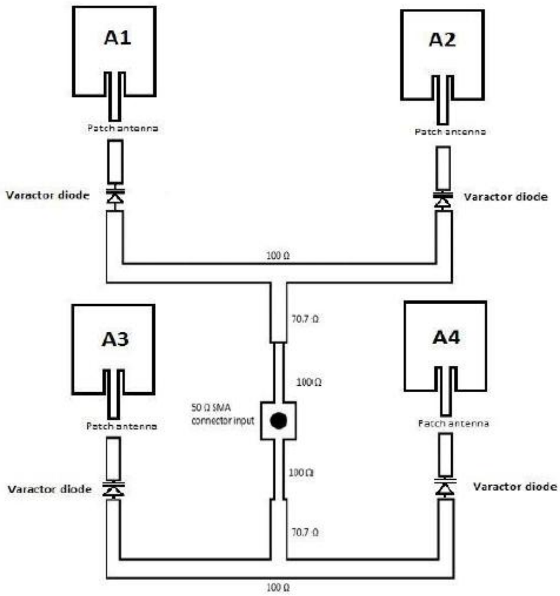

Figure 2: Corporate feed design with phase shifting network

A corporate feed network is calculated and designed to match the impedance of the input SMA and the patches 1:4 element power divider network sends equal amount of power to all the patches from a single input RF signal. The patches are placed at equal lengths from input SMA. The distance between two patches are kept as:

$$D_{\text{(distance between two patches)}} = \frac{\lambda}{2} \quad (12)$$

The impedance of the microstrip line is calculated using Quarter wave equation: [6]

$$Zo = \sqrt{Zin * Zl} \quad (13)$$

where,

Zo = required impedance of microstrip transmission line

Zin = input impedance

Zl = output impedance

To feed the patches in array there are two methods that can be used. 1. Series feed 2. Corporate or parallel feed. In this project we are using Corporate Feed because of the convenience of using a smaller design for the array elements and flexible choice of element spacing. Corporate feed: In corporate feed network, the feed is given as 1: n element using a power divider network which distributes equal amount of power to be fed to each element in the array. The power divider network is placed at an equal path length from each antenna. This feeding technique provides simplicity in design, flexible element spacing, and broad bandwidth and can be easily integrated with other devices.

IV. ARRAY DESIGN

The single patch which was designed to operate at 2.4GHz is used to create a 2x2 array network. To feed the input signal to four patches the designed corporate feed network is connected to the inset fed of the patch. Patch array antenna work on the principle of pattern multiplexing. Individual patterns from all the four patches get multiplexed and forms a single major lobe of pattern with better directivity. Array of antenna is used to improve the gain and directivity of the antenna.

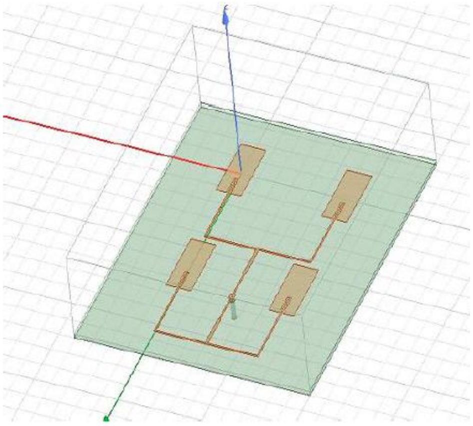

Figure 3: Design of Array antenna on ANSYS HFSS

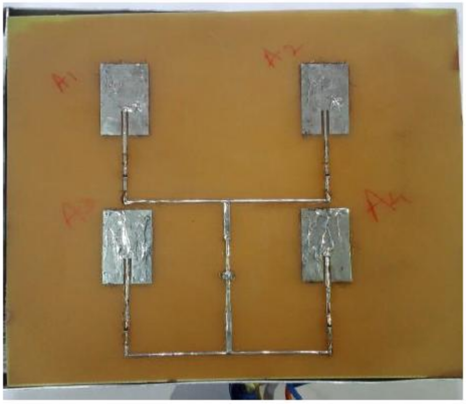

Figure 4: Fabricated beam tilting antenna array

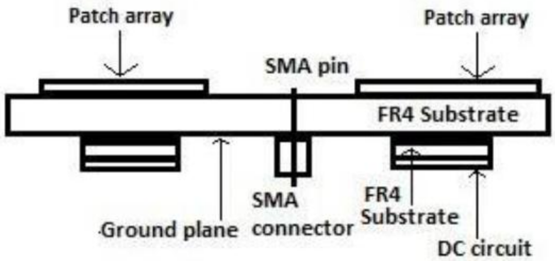

Figure 5: Side view of fabricated beam tilting antenna

V. PHASE SHIFTING BY VARACTOR DIODE

Phase shifters are the key component of systems such as phased arrays. There are many different types of phase shifters such as switched filter and vector modulator, the type we used is varactor diodes. Varactor diode based phased shifters have been used for many decades and have been analysed extensively. They benefit from being very simple circuits that can achieve wide bandwidths.[5]
Varactor Diode used for Phase Shifting: (INFINEON BB545E7904HTSA1). These varactor diodes were incorporated in the feed of the patches, The Infineon 12398 series surface-mount varactor diodes are designed for very low series resistance applications such as RF and microwave VCOs. The varactor was fed with varying reverse bias voltage and the phase difference of the input signal was observed. Varactor diodes when given reverse bias voltage acts as capacitors and these capacitors bring phase shift to the network. It was seen that the variation in the reverse bias voltage caused phase shift in the input signal proportional to the change in the reverse voltage.

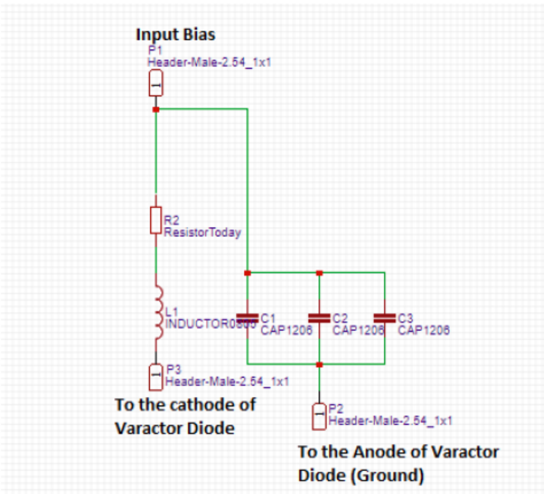

Figure 5: Phase shifting network circuit

VI. SIMULATIONS AND EXPERIMENTAL RESULTS

The designed 2x2 patch array antenna was found operating at 2.38GHz with a good return loss of -26dB, which was evaluated on a spectrum analyser.

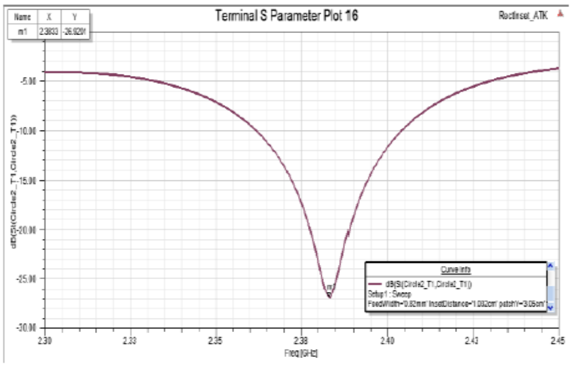

Figure 6: Simulation result of 2X2 Patch array antenna

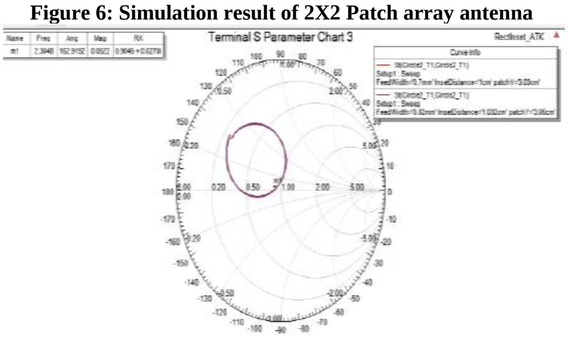

Figure 7: Simulation result (Polar Plot) of 2X2 Patch array antenna

The radiation patterns were taken in E-plane and H-plane. The pattern obtained from the antenna revealed that there was approximately 8-10degree shift in the beam when the reverse bias of varactor from 2V to 10V.

The patches were fed differentially, that is the first 2 patches were given a particular reverse bias voltage, and the next 2 were given a different reverse bias voltage. This showed a shift in the beam. Example the first 2 patches (A1 and A2) were given a reverse bias voltage of 5V and the other 2 patches (A3 and A4) were given a reverse bias voltage of 10V. The experiment suggested beam steering variable direction.

Refer figure 2 for patches A1, A2, A3, A4.

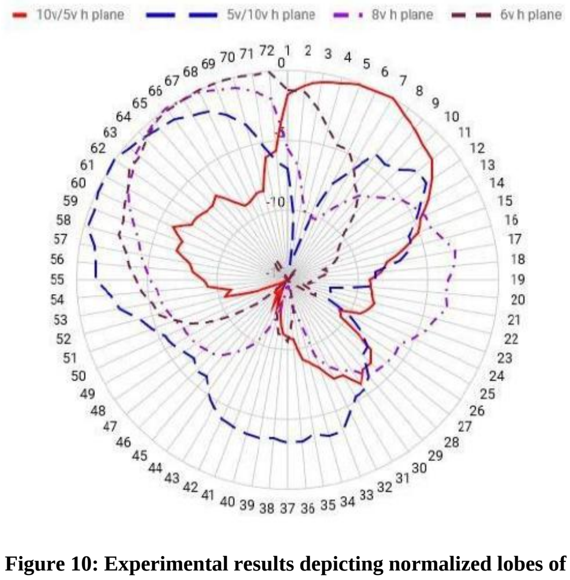

Figure 10: Experimental results depicting normalized lobes of beam for different reverse bias voltages

The above figure is an overlay of the radiation pattern of the various iterations which were done during the analysis of beam shifting. As the image clearly shows a suitable shift in the major lobe of radiation in equal bias and differential bias conditions. The red plots in the image are 10V and 5V to A1 A2 and A3 A4 (refer figure 2) respectively. The blue plots shows the beam at 5V and 10V to A1 A2 and A3 A4 respectively. Both the experiments were done on the H-plane. The above experiment showed a good beam tilt. Similarly in case of equal biasing to A1 A2 A3 and A4 a suitable shift in the beam was observed which is seen in the above diagram. The purple and brown plot is of 8V and 6V equal bias to all the patches in the H plane.

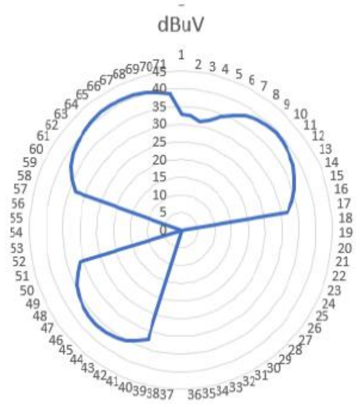

Figure 11: Experimental results depicting major lobe of beam for differential bias (2V to patches A1 and A2, 8V to patches A3 and A4)

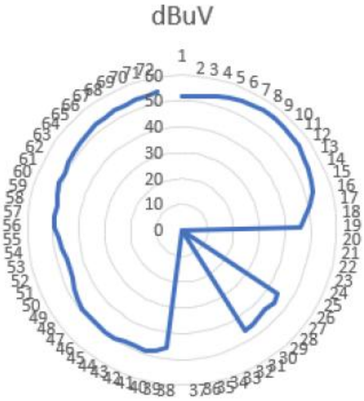

Figure 12: Experimental results depicting major lobe of beam for differential bias (3V to patches A1 and A2, 6V to patches A3 and A4)

VII. CONCLUSION

The simulation of a microstrip patch antenna at 2.4GHz was achieved using ANSYS HFSS. The results showed the performance of the patch antenna at 2.4GHz with an approximate shift of 10 degrees in the angle of beam. This beam shift was achieved using varactor diodes. Beam steering can be obtained in the desired direction by varying the input reverse bias given to each patch of the antenna array.

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