Design of Single Band 60GHz Millimeter Wave Patch Antenna

Sridhara K, Pankaj Mahoorkar, Asst., Professors, Dept., of E& CE, PDACE, Kalaburagi

***Abstract*— In the recent years, it happens to be significant changes from first generation analog mobile to the third generation including rapidly growing 4G/LTE. The current mobile technology not only experience improved voice communication but also provide users access to a new global communication reality. The attempt is to make communication at all times and from all places. Spectrum scarcity as well as the need for high data rate and mobility has necessitated intense research on 5G systems recently. Planar, E-H slotted and array antennas are designed for the millimeter wave frequency. The single band antenna with H slot and E slot is designed with 50 ohms microstrip line feeding. The antenna is simulated on a Rogers RT5880 dielectric substrate having relative permittivity 2.2, and height 0.127mm. The simulated results of planar patch, E-H slotted and antenna array on VSWR, realized gain radiation pattern and return loss is presented.**

***Keywords*— Microstrip, Patch antenna, Millimeter wave, Planar patch antenna, E-H Slotted antenna, Array patch antenna**

I. INTRODUCTION

Microstrip antennas which are simple, low weight and tiny size are well suited for mobile, radar and aerospace applications. These antennas have a patch of metal placed on a ground substrate and operate at low power which make attractive for low-power transmits and receive applications. The rapid increase in the use of smart phones increases the mobile data and creates a problem for the wireless service providers to accommodate additional bandwidth requirement. As the year progresses beyond 2020 wireless network will faces new challenges and to implement new technology to serve the demands of the customers. As one step to cater this situation the millimeter wave mobile communication is introduced. The millimeter wave mobile communication offers larger bandwidth allocations and helps to increase the data transfer rate. It also fulfills the needs of the service providers to increase the channel bandwidths beyond 20 MHz channel. Due to smaller wavelength of millimeter wave technology the base station to device and device to base station links can handle higher capacity than 3G and 4G networks. 5G technology offers low latency, real-time response, and reliable communication and also more adaptive to users need and demand. This paper presents the design of single band 60GHz millimeter wave patch antenna for 5G mobile communication.

From the allocated unlicensed band from 59-64 by Federal Communications Commission a millimeter wave at 60GHz frequency of higher bandwidth being is being selected. The 60 GHz band covers the Wi-Fi and Wi-Gig standard IEEE 802.11ad service. The data transfer rate more than 7Gbps with minimum interference at different levels of bandwidth is achievable using this spectrum. The Wi-Gig standard provides multi gigabit rate wire communication.

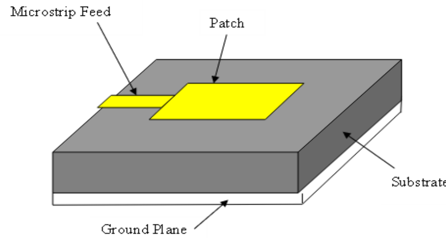

Figure 1. Microstrip patch antenna structure

Different forms of microstrip patch antennas are available; however each form has a single patch of conductor that is placed on the upper surface of a grounded dielectric substrate. When the characteristic dimension of patch is near to the one half of the wavelength the patch antenna radiates with resonant frequency.

The side view of microstrip patch antenna shown in Figure 1 consists of three layers namely substrate, patch layer and ground layer. A patch act as main radiating element in this antenna and is terminated by the 50 ohm microstrip line. The simulation of antenna is done using CST microwave studio, EM simulation software with Rogers RT5880 dielectric substrate having relative permittivity 2.2, loss tangent 0.0009, and height 0.127 mm.

II. OVERVIEW OF MICROSTRIP PATCH ANTENNA

The transduction principle of an antenna is used to transmit or receive electromagnetic waves. Compare to conventional microwave antenna microstrip antennas are simple in structure and therefore are widely used in many practical applications. Simple configuration of microstrip antenna is shown in Figure 2. It consists of a radiating patch on one side and ground plane on other side.

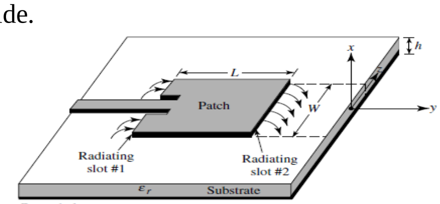

Figure 2. Microstrip Patch Antenna

The feed lines and radiating elements on the patch is photo etched on the dielectric substrate. The radiating element may be of any shape such as thin strip, circular, elliptical, triangular square, and rectangular.

III A NTENNA PARAMETERS

A. Radiation pattern

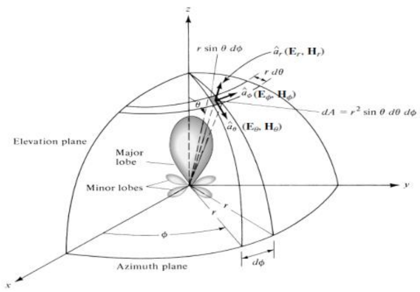

Figure 3a. Radiation Pattern

An antenna radiation pattern refers to the directional radiation properties of the antenna as a function of space coordinates.

A major lobe refers to the lobe of maximum radiation. A side lobe is a minor lobe whose radiation occurs in any other direction than the main lobe. Usually a side lobe is adjacent to the major lobe. A back lobe is a minor lobe which makes an angle 180 degrees with respect to the direction of main beam.

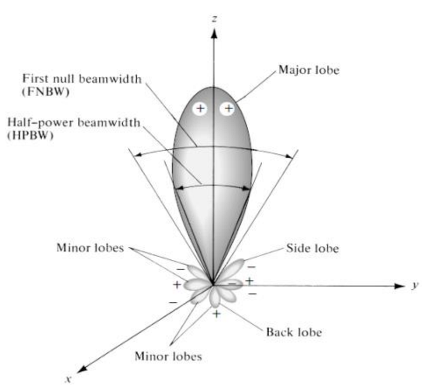

Figure 3b. Radiation lobes and beamwidths of an antenna

B. Field regions

Reactive Near-Field Region: The region that surrounds the portion of an antenna where the reactive field (non radiating) exists is called near-field region.

Far-Field (Fraunhofer) region: The region of the antenna in which the angular field distribution is independent of the distance from the antenna is far field region.

C. Beamwidth

The beamwidth of an antenna is the angular displacement between two identical points on opposite side of the maximum pattern.

In an antenna pattern there are two kinds of beamwidths HPBW and FNBW. HPBW (Half Power Beam Width) in an antenna pattern is a plane of maximum radiation.

First-Null Beamwidth (FNBW) is the angular separation between the first nulls of the pattern.

The beamwidth of an antenna describe the resolution capabilities to differentiate two adjacent radiating sources

D. Directivity and Gain

The ratio of the radiation intensity in the direction to the averaged radiation intensity in all directions

The gain of an antenna is the ratio of intensity in a given direction to the radiation intensity an isotropic antenna

E. Reflection Coefficient

The input reflection coefficient Γin can be calculated using the equation given below

$$\Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$$

Where

Z_{in} = input impedance of the antenna

Z_0 = characteristic impedance

From the calculated value of the input reflection coefficient the resonant location in the spectrum band can be identified

F. Voltage Standing Wave Ratio (VSWR) and Return Loss

The return loss refers to the loss caused due to the load mismatch in the transmission line because of this full power will not been delivered to the load. The return loss is given by

$$\text{Return Loss (RL)} = -20 \log |\Gamma| \text{ dB}$$

For the matched load the reflection coefficient Γ=0 and retun loss is ∞dB. On the other hand when reflection coefficient Γ=1, the return loss is 0dB. The transmission line with improper termination presents the reflected wave converts into standing wave which is oscillating in nature. Increase in the value of reflection coefficient increase the ratio of the minimum and maximum voltages values (Vmax and Vmin). Hence Voltage Standing Wave Ratio (VSWR) along the transmission line is defined as

$$\text{VSWR} = \frac{V_{min}}{V_{min}} = \frac{1+|\Gamma|}{1-|\Gamma|} = \frac{1+S_{11}}{1-S_{11}}$$

For the satisfactory function of an antenna, SVR should be less than or equal to 1.5.

IV ANTENNA FEEDING TECHNIQUES

There exist different techniques to feed mictrosrip patch antenna. These techniques are classified as contacting type and non-contacting type. In contact type RF power is fed directly to the radiating patch and in non-contacting type power is transferred through electromagnetic coupling between radiating patch and microstrip line. Among various feeding techniques microstrip line, coaxial probe, aperture coupling and proximity coupling are popular.

A. Microstrip Line Feed

In this method a conducting strip of smaller in width compare to the patch is directly connected to the edge of the microstrip patch. This method of feeding has an additional advantage that the substrate can be etched at the feed line to give a planar structure.

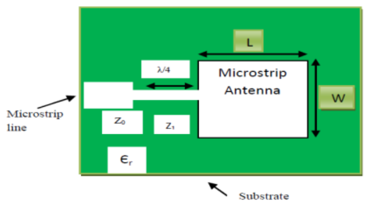

Figure 4a. Microstrip Line Feed

B. Co-axial feed

In this technique the inner coaxial connector is soldered to the radiating patch which has the same dielectric and the outer conductor is coupled to the ground plane. By this method the feed can be placed at any locations inside the patch so as to match with its input impedance

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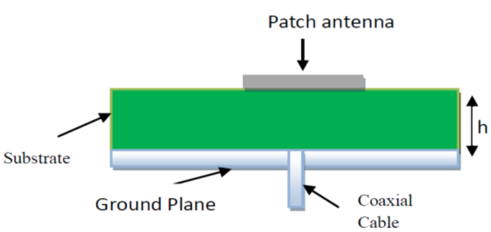

Figure 4b. Coaxial Feed

C. Aperture Coupled Feed

In this method the feed line and radiating patch are separated by ground plane and a slot is created between the patch and the feed line. The created slot is centered in such a way that low cross polarization is attained. Because of the separation between patch and ground plane the unwanted radiation can be minimized. The drawback of this method is that the fabrication of inner layers is difficult and leads to increase in the antenna thickness.

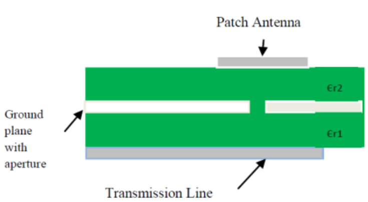

Figure 4c. Aperture Coupled Feed

D. Proximity Coupled Feed

In this method a feed line is inserted between two dielectric substrates. The top of the upper substrate is the radiating patch. This method is also called electromagnetic coupled scheme. By this feeding technique spurious radiation is avoided.

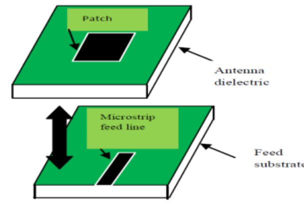

Figure 4d. Proximity Coupled Feed

V DESIGN OF PATCH ANTENNA

The figure 5a, 5b and 5c shows a geometry of single band microstrip (planar, slotted and array) antenna designed at 60GHz millimeter wave. The role of radiating element is realized by patch. The microstrip patch is fed through 50 ohm feed line for proper matching. Dimensions the antenna is 8mm x 8mm. Three models of patch antennas are designed

A. Planar microstrip antenna

The ground plane consists of copper plate with dimensions of 3.592mm x 3.2262mm and thickness of 0.127mm. The length and width of the feed line is 0.339119mm and 3.25mm respectively.

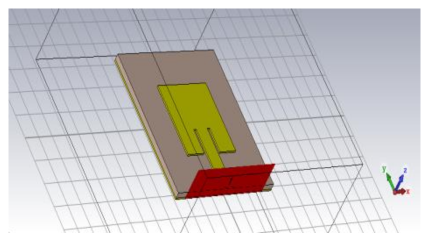

Figure 5a. Planar microstrip patch antenna

B. Slotted microstrip antenna

The slots for E and H are cut on the patch to enhance bandwidth. The feed line width is 0.39119mm. and length and width of the patch is 1.97 mm and 1.613mm.

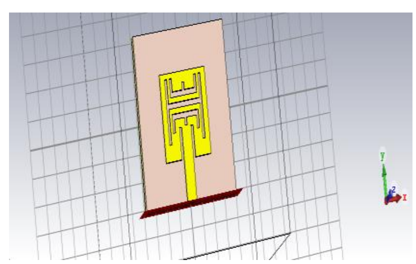

Figure 5b. E and H-slotted antenna

C. Array microstrip antenna

This is a microstrip patch antenna with two antennas are fed with same inset feed line. The design of this antenna is similar to planar microstrip patch antenna. Dimensions of copper plate which is ground plane is 10.77mm x 9.6786mm and thickness is 0.127

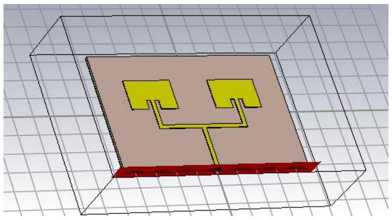

Figure 5c. Microstrip patch antenna array 2X1

VI DESIGN EQUATIONS

Patch antenna width is calculated using

$$W = \frac{c_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$$

Where, w=width of the patch,

c_0=speed of light

ε_r=permittivity of the dielectric substrate

W = 1.976 mm.

The effective dielectric constant is calculated using

$$\varepsilon_{reff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2}, W/h > 1$$

$$\varepsilon_{reff}=\frac{2.2+1}{2}+\frac{2.2-1}{2}\left[1+12\frac{0.127X10^{-3}}{1.976X10^{-3}}\right]^{-1/2} = 2.058$$

Length extension is calculated using

$$\Delta L = 0.412\left[\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)}\right] = 0.0663m$$

The length of the patch is

$$L=\frac{c_0}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L = 1.613mm$$

The length of a ground plane(L_g) and width of a ground plane(W_g) are

L_g= 6h+L = 3.226mm

W_g=6h+W = 3.9528mm

Inset Feed Calculation:

To find the value of inset feedy_0, we use the equation below

$$R_{in}=\frac{1}{2(G_1+G_{12})}cos^2(\frac{\pi}{L}y_0)$$

Where,

$$G_1=\frac{I_1}{120\pi^2} \text{ and } I_1=\int_0^{\pi}\left[\frac{\sin\left(\frac{\beta_0 W}{2}\cos\theta\right)}{\cos\theta}\right]^2 sin^3\theta\, d\theta$$

$$= -2 + \cos(x) + x\sin(x) + \frac{\sin(X)}{X}$$

$$\text{Where } x = \beta_0 W = \frac{2\pi}{\lambda_0}W = \frac{2\pi}{c/f}W = 2.48$$

Then I_1= -2 + cos(x) + xsin(x) +$\frac{\sin(X)}{X}$ = 1.7734

By equation G_1,

$$G_1=\frac{1.7734}{120(3.142)^2}=1.4977x10^{-3}\text{siemen}$$

$$G_{12}=\frac{1}{120}\int_0^x\left[\frac{\sin(\frac{\beta_0}{2}Wcos\theta)}{cos\theta}\right]^2 x\, J_0\beta_0 L\sin\theta sin\theta^3 d\theta =$$

Then $R_{in}=\frac{1}{2(G_1+G_{12})}cos^2\frac{\pi}{L}y_0$

Rearranging the equation

$$cos^2(\frac{\pi}{L}y_0) = R_{in} x\, 2(G_1+G_{12})$$

$$\frac{\pi}{L}y_0=cos^{-1}\sqrt{2R_{in}(G_1+G_{12})}$$

$$y_0 = \frac{L}{\pi}cos^{-1}\sqrt{2R_{in}(G_1+G_{12})} = 0.4374$$

$$f_i=(\frac{L}{2}-y_0)+\frac{\lambda_g}{4}$$

$$\lambda_g=\frac{c}{f\sqrt{\varepsilon_{reff}}}=\frac{3X10^8}{60X10^9\sqrt{2.050}} = 3.492 \text{ x } 10^{-3}$$

Then f_i = 0.571mm

PARAMETER	SYMBOL	DIMENSIONS
Width of ground plane	W_g	3.592
Length of ground plane	L_g	3.2262
Patch width	W	1.9739
Patch length	L	1.613
Width of feed line	W_f	0.39119
Inset feed	f_i	0.571
Gap between patch and feed line	G	0.01148

Table 1: Calculated design parameters

VII RESULT AND ANALYSIS

A. *Planar Microstrip Patch Antenna*

Return loss/Reflection coefficient: Figure 6a shows simulated result of reflection coefficient for planar patch antenna. The centre frequency at 59.701GHz oscillates between 58.895GHz to up to 60.524 GHz with a bandwidth of 1.629GHz.

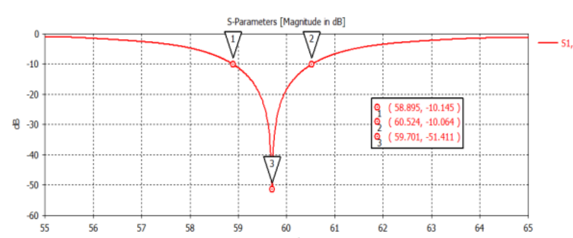

Figure 6a. Reflection coefficient S11versus frequency

VSWR: Figure 6b shows the simulated result of VSWR<2 i.e.is 1.0049 at 59.7 GHz band which shows better impedance matching for planar patch antenna.

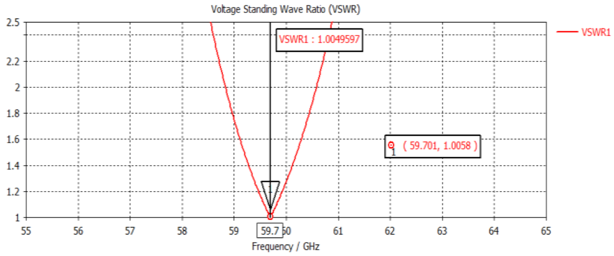

Figure 6b. VSWR curve of patch antenna

Radiation Pattern: The radiation pattern of planar patch antenna has the radiation efficiency of -0.8867dB and Directivity of 8.18 dBi.

Realized Gain: Figure 6c shows the Realized Gain of planar patch antenna and has a gain of 7.29dB.

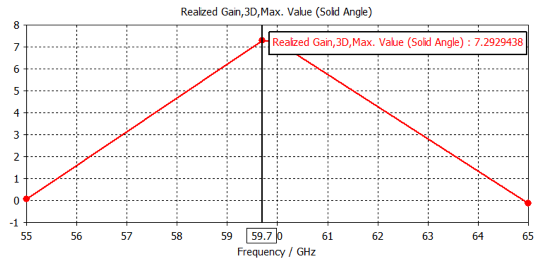

Figure 6c. Realized gain of patch antenna

B. E-H SLOTTED MICROSTRIP PATCH ANTENNA

Return loss/Reflection coefficient: Figure 7a shows the simulated result of reflection coefficient for E-H Slotted patch antenna. The centre frequency at 59.84GHz oscillates between 59.563GHz to up to 60.147 GHz with a bandwidth of 584 MHz.

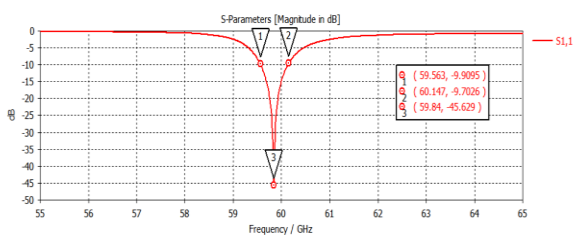

Figure 7a. Reflection coefficient S11versus frequency

VSWR: Figure 7b shows the simulated result of VSWR<2 i.e. is 1.010 at 59.84 GHz band which shows better impedance matching for E-H Slotted patch antenna.

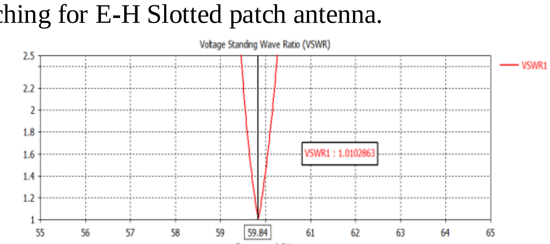

Figure 7b. VSWR curve of E-H slotted patch antenna

Radiation Pattern: The radiation pattern of E-H slotted antenna has the radiation efficiency of -1.698dB and Directivity of 7.68 dBi.

Realized Gain: Figure 7c shows the Realized Gain of E-H Slotted patch antenna and has a gain of 5.79dB

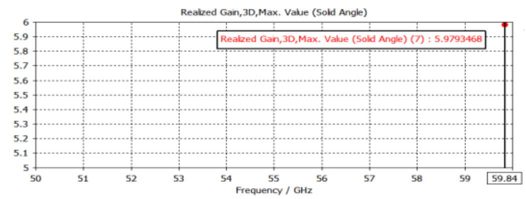

Figure 7c. Realized gain of E-H slotted patch antenna

C. MICROSTRIP PATCH ANTENNA ARRAY 2X1

Return loss/Reflection coefficient: Figure 8a shows the simulated result of reflection coefficient for Antenna Array. The centre frequency at 60.11GHz oscillates between 58.743GHz to up to 61.135 GHz with a bandwidth of 2.392GHz.

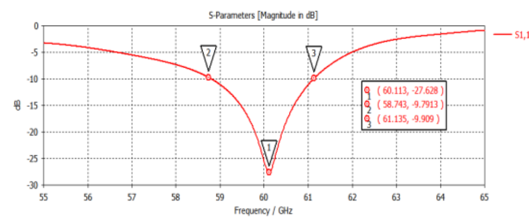

Figure 8a. Reflection coefficient S11versus frequency

VSWR: Figure 8b shows the simulated result of VSWR<2 i.e. is 1.0866 at 60.11 GHz band which shows better impedance matching for Antenna Array.

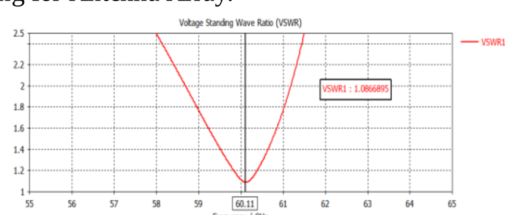

Figure 8b. VSWR curve

Radiation Pattern: The radiation pattern of Antenna array has the radiation efficiency of -0.4468dB and Directivity of 9.49 dBi.

Realized Gain: Figure 8c shows the Realized Gain of Antenna Array and has a gain of 9.04dB.

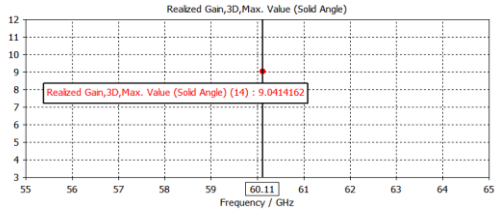

Figure 8c. Realized gain

Antenna	Return loss (dB)	Resonant frequency (GHz)	VSWR	Bandwidth (GHz)	Directivity (dBi)	Gain (dB)
Planar patch Antenna	-51.41	59.7	1.005	1.629	8.18	7.29
E-H Slotted patch Antenna	-45.62	59.84	1.010	0.584	7.68	5.97
Antenna Array	-27.62	60.11	1.086	2.392	9.49	9.04

Table 2: Comparison of Planar, E-H Slotted and Array patch antenna

VII CONCLUSION

In this paper, design of Planar patch antenna, E-H Slotted patch antenna, and Antenna Array are presented which are prominent use in 5G wireless application. Due to slicing of E and H slot, finds more improvement in the bandwidth and impedance. These designed antennas are very simple, cost effective and high efficiency for the applications in GHz frequency ranges. Through intelligence choosing of design parameters one can achieve compactness in the dimension and much better radiation efficiency. By changing the design parameters it is possible to design an antenna operating in any other frequency bands.

References

[1] Jyoti Saini, S. K. Agarwal," Design a Single Band Microstrip Patch Antenna at 60 GHz Millimeter Wave for 5G Application", IEEE Trans. Malaviya National Institute of Technology Jaipur July 01-02, 2017.

[2] G.V.P.Pranathi, Dr.N.Deepika Rani, Dr.M.Satyanarayana, Prof.G.T.Rao, "Patch Antenna Parameters Variation with Ground Plane Dimensions", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 4, Issue 8, August 2015.

[3] B. D. Patel, Tanisha Narang, Shubhangi Jain,"Microstrip Patch Antenna-A Historical Perspective of the Development", Electronics & Telecommunication, College Of Engineering Roorkee, India.

[4] Samir Al- mulla,"Design and Analysis of Microstrip Patch Antenna Arrays", Electrical Engineering Communication and Signal processing, 2011 January.

[5] Sumit Srivastava, Sweta Agarwal, Priya Agarwal, Sweta Srivastava,"Effect of slots on performance of the microstrip patch antenna", IJEEE, Volume 07, Issue 01, Jan- June 2015.

[6] Pramod Dhande, "Antennas and its Applications", DRDO Science Spectrum, March 2009.

[7] A. De, C. K. Chosh and A. K Bhattacherjee,"Design and Performance Analysis of Microstrip Patch Array Antennas with different configurations", International Journal of Future Generation Communication and Networking Vol. 9, No. 3 (2016), pp. 97-110.

[8] Indrasen Singh, Dr. V.S. Tripathi, "Microstrip Patch Antenna and its Applications: a Survey", International Journal of Computer Technology Applications, Vol 2 (5).