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Effects of Superstrate layer on the Performance of 5G Microstrip Antenna Operating at 43.5GHz

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Abstract— **The fifth generation (5G) technology working at mm-wave bands is introduced to achieve high data and large capacity, but mm-waves suffer from space attenuation. 5G systems requires antennas with simple configuration, light weight, and high gain to overcome free space attenuations.**

This paper aims to design 5G microstrip antenna operating at of 43.5 GHz within the frequency band of 42-45 GHz. The proposed antenna is designed on FR4 substrate with dielectric constant of 4.4 and thickness of 0.76mm, and simulated using High Frequency Structure Simulator (HFSS) software. To evaluate the performance of this antenna, the characteristics such as radiation pattern and gain are studied. Moreover, the influence of superstrate on the antenna performance is investigated based on changing dialectic constant and thickness of superstrate.

Index Terms: **5G, 43.5 GHz, Superstrate layer, microstrip antenna.**

I. INTRODUCTION

Nowadays, 5G technology is presented to realize many requirements are need to achieve a proficient communication system. These requirements include, larger capacity, high data rate, less latency, anti-interference, high energy efficiency, and better security [1,2].

5G technology will contribute to improve daily life, such as education, employment, economic, and industry. 5G technology offers high resolution and bidirectional large bandwidths in Giga-bits to make the advance billing interface more attractive and effective with the special provision of multiple paths for data transfer [3]. The 5G wireless technology is a multipurpose wireless network for mobile, fixed and enterprise wireless applications. It incorporates all types of advanced features that make it powerful and in huge demand in near future [4].

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Spectrum allocation of 5G communications is a millimeter wave band that covers the frequency band of 20 GHz to 60 GHz. The expected bands for 5G mobile communications are: 27.5–29.5 GHz, 33.4–36 GHz, 37–40.5GHz,42–45 GHz, 47–50.2GHz, 50.4–52.6 GHz and 59.3–71 GHz [3, 5].

In modern wireless communication systems, the miniature antennas are needed to fit small-scale mobile devices without affecting the function [6]. Microstrip antenna is acceptable antenna for this purpose, because it has many features over other types of antennas, such as low profile planar structure, low cost [7, 8, 9]. Microstrip antennas also have few disadvantages like low gain, narrow bandwidth and low efficiency. There are various methods to overcome the disadvantages; few of them are arrayed configuration, multilayered structure, change in shape of patch and adding different shaped slots in patch in proper position. Also, using low dielectric constant of substrate or increasing the thickness of substrate, proper feeding, using superstrate structure, using different structure like photonic band gap (PBG), substrate integrated waveguide (SIW), and defective ground structure (DGS) are used to enhance the parameters of conventional microstrip antenna [2, 4].

In this paper, a microstrip patch antenna is proposed for 5G wireless communication systems operating at 43.5 GHz. The performance of the antenna is evaluated, also, the effect of superstrate layer on the antenna performance is studied based on the variation of dielectric constant and thickness of the substrate layer. The simulation of antenna is carried out by a HFSS software.

II. DESIGN PROCEDURE

The procedure of antenna design includes design of the radiator patch, the feed line, and the matching element. Refer to ref [3] the specific parameters that needed to design a microstrip antenna are the dielectric constant of the substrate (ε_r), the height of the substrate (h), and the resonant frequency (f_r).

A. *Radiator patch*

The radiator patch design that means determine the width (w), and the length (L) of the patch. These parameters can be determine as following:-

1. For an efficient radiator, a practical width that leads to good radiation efficiencies is as the equation below:-

$$W = \frac{\upsilon_0}{2\, f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

where υ_0 is the free-space velocity of light.

2. Determine the effective dielectric constant of the microstrip antenna using

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\frac{1}{\sqrt{1+12\frac{h}{W}}} \tag{2}$$

3. Determine the extension of the length (ΔL) by using the following Equation (3).

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

4. The actual length of the patch can now be determined by

$$L = \frac{\upsilon_0}{2\, f_r\sqrt{\varepsilon_{reff}}} - 2\,\Delta L \tag{4}$$

B. Z_o *Microstrip feed line*

For a given characteristic impedance and dielectric constant, the $\frac{W}{h}$ ratio for microstrip line can be found as

$$\frac{W}{h} = \frac{2}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\varepsilon_r-1}{\varepsilon_r}\left\{\ln(B-1) + 0.39\frac{0.6}{\varepsilon_r}\right\}\right] \quad for\ \frac{W}{h} > 2 \tag{5}$$

$$\frac{W}{h} = \frac{8\, e^{A}}{e^{2A}-2} \qquad for\ \frac{W}{h} > 2 \tag{6}$$

Where:

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\,(0.23 + \frac{0.11}{\varepsilon_r}) \tag{7}$$

$$B = \frac{377\,\pi}{2\, Z_o\sqrt{\varepsilon_r}} \tag{8}$$

C. *Quarter wave transformer*

The quarter wave transformer is a microstrip line used as a suitable matching technique when there is a possible impedance mismatch. Therefore, the quarter wave transformer is used between the microstrip line and centre point along the width of rectangular patch element for matching their impedances. The length of quarter wave transformer is equal to

$$L_T = \frac{\lambda_g}{4} \tag{9}$$

Where $\lambda_g = \frac{\lambda_o}{\sqrt{\varepsilon_r}}$ is the guided wavelength.

The impedance of quarter wave transformer is given by

$$Z_T = \sqrt{Z_o Z_P} \tag{10}$$

Where Z_o is the impedance of feed line that is equal to 50 ohm, and Z_P impedance obtainable by the patch at the center point along the width of patch.

At the resonant, the input impedance at the centre point along the width is [10].

$$Z_P = \frac{1}{2\, G_1} \tag{11}$$

where

$$G_1 = \begin{cases} \frac{1}{90}(\frac{W}{\lambda_0})^2 W \ll \lambda_0 \\ \frac{1}{120}\left(\frac{W}{\lambda_0}\right) W \gg \lambda_0 \end{cases} \tag{12}$$

D. *Ground plane dimensions (Lg and Wg).*

The similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery [11].

$$L_g = 6h + L \tag{13}$$

$$Wg = 6h + W \tag{14}$$

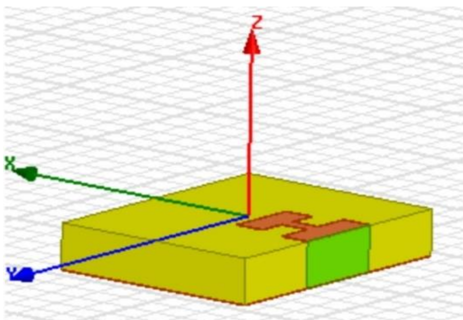
III. DESIGN SPECIFICATION

There are many parameters must be known before designing an antenna in general such as: The frequency range in which the antenna is planned to be propagating (f_r), Dielectric constant of the substrate (Ɛr), Height of dielectric substrate (h) [12].

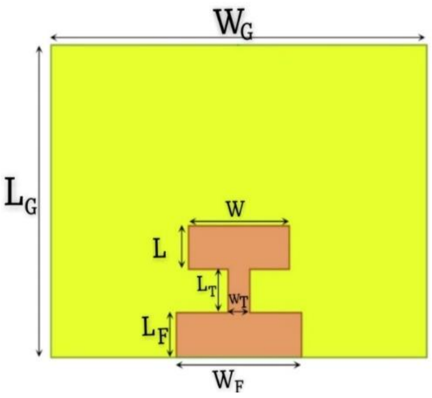
In this work, a single microstrip antenna is designed with the following characteristics:
Resonant frequency: 43.5GHz.
Transmission line impedance: 50 Ω.
The dielectric constant of the substrate: ε_r = 4.4 (FR-4)
Thickness of dielectric substrate (h): 0.76 mm.

IV. CONFIGURATION OF ANTENNA

The microstrip antenna is designed based on the design procedure of microstrip antenna that mentioned in section II. The designed antenna is simulated by using HFSS software. Figure 1 shows the 3D and top view of the designed antenna. Table I shows the dimension of proposed antenna.



(a)



(b)

Figure 1. Suggested antenna, (a) 3D Shape (b) top view.

Table 1. The dimension of the antenna

Parameter	(mm)
W_G	6.65
L_G	5.79
W_P	2.09
L_P	1.23
W_T	0.55
L_T	1.4
W_F	1.45
L_F	0.94

A. *Return loss and radiation pattern of proposed antenna*

Figure. 2 shows changing of return loss with frequency of the proposed antenna. From the figure, it can be noted that the value of the return loss at the design frequency (43.5 GHz) is equal to (19.86 dB), and the bandwidth is equal to (9.8 GHz), where it extends from 38.7 GHz to 48.5 GHz, and therefore the impedance bandwidth is 22.53%.

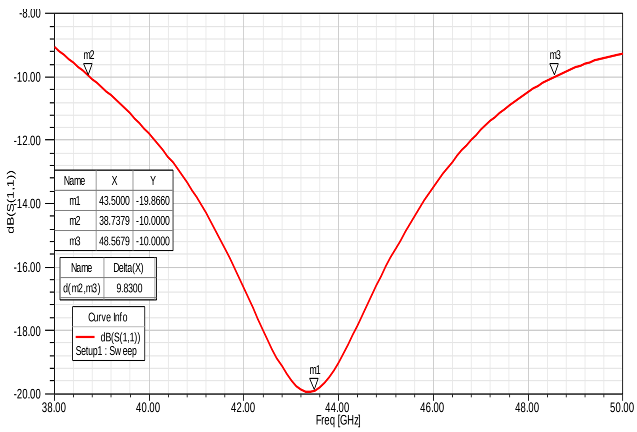


Figure 2. Variation frequency with Return Loss

The 3D radiation pattern of the antenna at 43.5GHz is shown in Figure 3.

From figure 3, it can be noted that the maximum value of the antenna gain is 5.36 dB, and it can be seen that the radiation pattern of the antenna is focused in one direction, and this indicates that the antenna is a directional antenna with some side lobes that can be neglected.

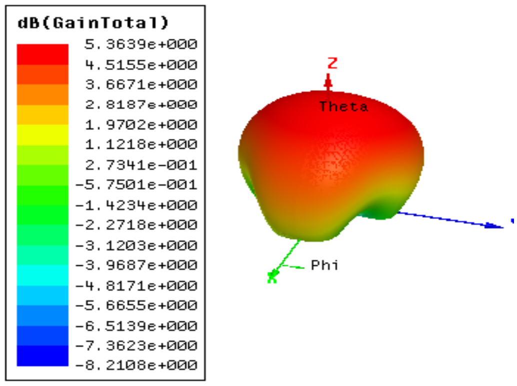


Figure 3. The radiation pattern of the antenna at 43.5GHz

The two-dimensional radiation pattern of the antenna is shown in figure 4 at $Phi = 0$ and $Phi = 90$; From the figure it can be observed that the HPBW is 116.47^o at $\phi = 90^o$ and 104.55^o at $\phi = 0^o$.

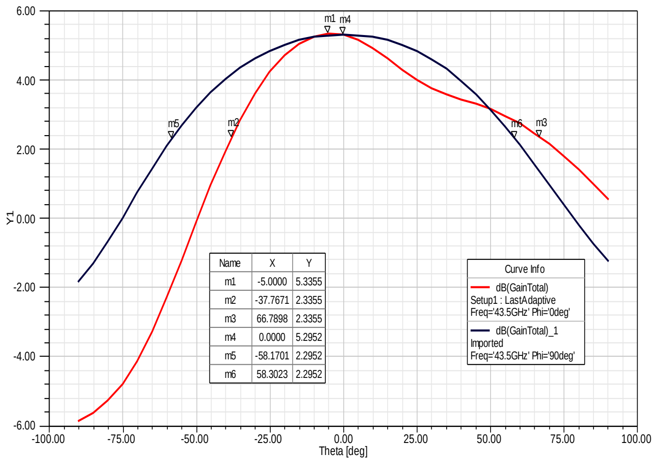


Figure 4. 2D radiation in two dimensions at Phi = 0 and Phi = 90

At 43.5 GHz, the antenna characteristics can be summarized as listed in Table 2.

Table 2. Antenna characteristics at a frequency of (43.5 GHz)

Quantity	value
Radiated power (W)	0. 92
Accepted power (W)	0.98
Incident power (W)	1
Radiation Efficiency (%)	93.2
Peak Gain (dB)	5.3
HPBW	(Phi = 0) 104.5 (Phi = 90) 116.4

B. *The effect of the superstrate on the performance of proposed antenna*

In this part, a superstrate is added to make multi-layer antenna; this antenna is shown in Figure 5.

In this work, three types of dielectric materials are selected as a superstrate material which are listed in Table 3

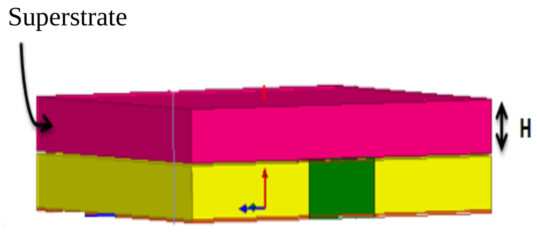


Figure 5. Thickness and position of superstrate

Table 3. Different types of superstrate

Type of material	**Dielectric constant**
FR4-epoxy	4.4
Alumina-96pct	9.4
Teflon (tm)	2.1

The performance of multi-layer antenna is evaluated based on changing of dielectric constant (ε_r) and thickness (h) of superstrate material.

For each superstrate material, the multi-layer antenna parameters are evaluated according to different values of superstrate thickness, which are 0.2 mm, 0.5 mm, 0.76 mm, 1.58 mm, 2 mm.

1. *Effect of FR4-epoxy superstarte material*

Figure.6 shows effect of changing the thickness of the (FR4-epoxy) superstrate on the resonant frequency of the antenna, as well as on the antenna bandwidth; from the figure, it can be noted that the resonance frequency and the return loss value at the resonance frequency are clearly affected by changing the thickness of the superstrate material.

The impact of varying the thickness of FR-4 superstrate material on multi-layer antenna characteristics are tabulated in 4.

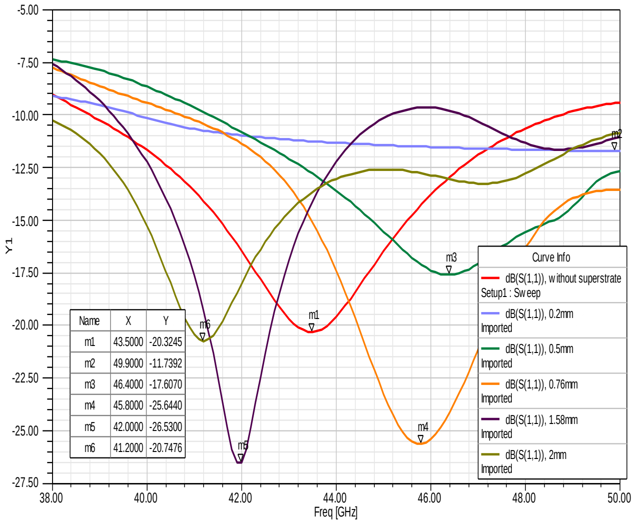


Figure 6. Variation of resonant frequency and Return Loss versus thickness of FR4_epoxy superstrate thickness

Table 4. Effect of FR-4 superstrate thickness on antenna properties

Characteristics		**Thickness of superstrate (mm)**				
		0.2	0.5	0.76	1.58	2
Resonant frequency (GHz)		49.90	46.40	45.80	42.00	41.20
Return loss (dB)		-11.73	-17.60	-25.64	-26.53	-20.74
HPBW	Phi = 0	55.14	44.65	86.19	43.76	41.23
	Phi = 90	107.57	140.76	152.11	76.18	64.67
Gain (dB)		7.13	6.51	6.21	7.66	8.64
Efficiency (%)		92.31	88.98	87.36	81.64	84.00
Incident power (W)		1	1	1	1	1
Radiated power (W)		0. 85	0. 84	0. 85	0. 78	0. 80

From Table 4, it can be noted that the antenna properties are changed significantly due to changing of thickness of superstrate material, where the resonant frequency is decreased with increase the thickness of superstrate, and antenna gain slightly decreases with increasing the thickness of superstrate up to certain value of superstrate thickness, and it starts to increase again. In addition, it can be observed that the changes of half-power bandwidth (HPBW), antenna gain and efficiency values are unstable; these results are produced due to the unpredicted behavior of the material at high frequencies.

2. *Effect Alumina-96pct superstarte*

The effect of changing the thickness of the Alumina_96pct superstrate material on the resonance frequency and the amount of the antenna bandwidth is shown in Figure 7.

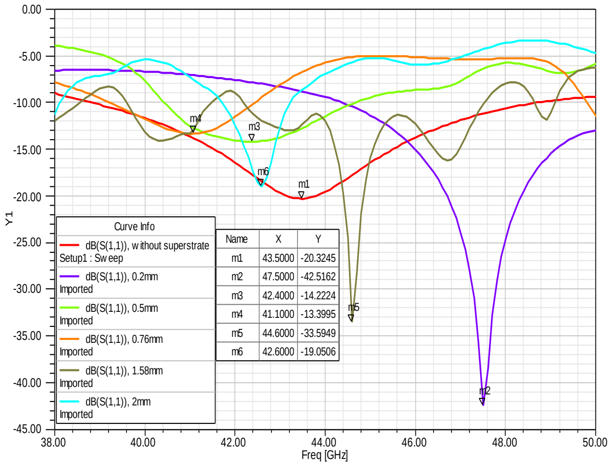


Figure 7. Variation of resonant frequency and Return Loss versus thickness of Alumina_96pct superstrate thickness

Table 5 shows the effect of changing the thickness of Alumina_96pct superstrate material on antenna characteristics. It can be shown that, the radiation efficiency is decreased compare to the antenna without superstrate, and it decrease with increase the superstrate thickness. On other hand, the values of resonant frequency, antenna gain, and radiated power are changed randomly due to unexpected variations in material properties at high frequencies.

Table 5. Effects of Alumina_96pct superstrate thickness

Characteristics		Thickness of superstrate (mm)				
		0.2	0.5	0.76	1.58	2
Resonant frequency (GHz)		47.50	42.40	41.10	44.60	42.60
Return loss (dB)		-42.51	-14.22	-13.39	-33.59	-19.05
HPBW	Phi = 0	42.58	150.65	92.87	105.50	95.86
	Phi = 90	147.98	96.13	108.79	195.06	92.15
Gain (dB)		6.85	5.43	6.15	5.76	6.76
Efficiency (%)		91.52	85.88	78.22	78.09	65.25
Radiated power (W)		0.80	0.81	0.61	0.74	0.56
Incident power (W)		1	1	1	1	1

3. *Effect of Teflon superstarte material*

Teflon is the third material is chosen as superstrate. Figure 8 shows the effect of the Teflon superstrate on the resonance frequency and the antenna bandwidth of proposed antenna.

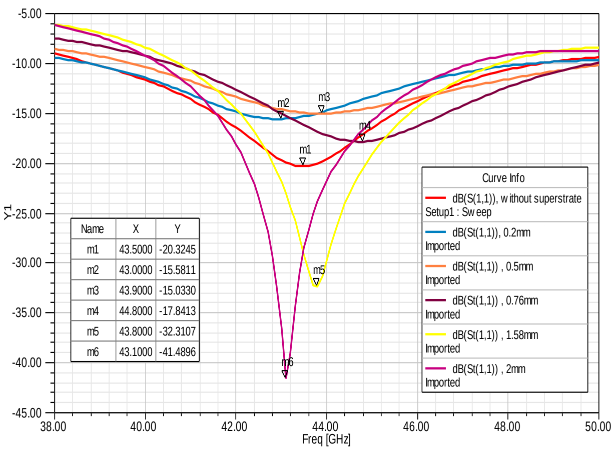


Figure 8. Variation of resonant frequency and Return Loss versus thickness of Teflon superstrate thickness

The variation of antenna parameters values due to add Teflon material as a superstrate is listed in Table 6.

Table 6. Effects of Teflon superstrate thickness on antenna properties

Characteristics		Thickness of superstrate (mm)				
		0.2	0.5	0.76	1.58	2
Resonant frequency (GHz)		43.00	43.90	44.80	43.80	43.10
Return loss (dB)		-15.58	-15.03	-17.84	-32.31	-41.48
HPBW	Phi = 0	77.59	62.74	58.88	53.06	52.25
	Phi = 90	106.96	101.94	102.26	125.72	113.4
Gain (dB)		6.12	6. 75	7.04	6.52	6.96
Efficiency (%)		93.67	93.76	94.57	91.93	91.51
Radiated power (W)		0.90	0.91	0.92	0.92	0.91
Incident power (W)		1	1	1	1	1

From Table 6, it can be noted that the gain of multi-layer antenna is greater than the gain for the antenna without of superstrate material. Additionally, it can be seen that the radiation efficiency increases with increase the thickness of the superstrate from 0.2mm to 0,76 mm, but it decreases at the large values of superstrate thickness.

V. CONCLUSION

In this work, microstrip antennas without and with superstrate material are simulated and evaluated.

Based on the simulated results, it can be concluded that the microstrip antenna without superstrate material operates with good radiation characteristics at 43.5 GHz band, moreover, it has simple configuration and small size which is 6.6 × 5.7 mm^2. In addition, the characteristics of microstrip antenna with superstrate are influenced by changing of superstrate dielectric constant and thickness. Thus, it is possible to improve the antenna gain, and also the resonant frequency of the antenna according to the type and thickness of the superstrate material. Depending on this result, the thickness of the superstrate and its dielectric constant must be taken into account when using the microstrip antenna inside portable or electronic devices to ensure that the antenna works well within the frequency band at which it was designed.

The proposed antenna with and without superstrate material can be used properly for 5G applications at 43.6 GHz frequency band.

REFERENCES

[1] N. Lal, S. Mani Tiwari, D. Khare and M. Saxena, "*Prospects for Handling 5G Network Security: Challenges, Recommendations and Future Directions*", CONSILIO 2020.

[2] A. Ismail, M. Rasid, M. Hamidon, R. Abdullah, N. Shebani, "*Performance Evaluation of Microstrip Antenna Based on Different Shapes of Defected Ground Structure (DGS) at 28 GHz*", International Symposium On Applied Sciences And Engineering (ISASE2021), Erzurum, Turkey, 07-09 April 2021.

[3] A. Kaeib, N. Shebani and A. Zerek, "*Design and Analysis of a Slotted Microstrip Antenna for 5G Communication Networks at 28 GHz*", 2019 19th international conference on Sciences and Techniques of Automatic control & computer engineering (STA), Sousse, Tunisia, March 24-26, 2019.

[4] K. Eze, M. Sadiku, and S. Musa, "*5G Wireless Technology: A Primer*", International Journal of Scientific Engineering and Technology , Volume No. 7, Issue No. 7, PP : 62-64 , 1 July 2018.

[5] M. Khattak, A. Sohail, U. Khan, Z. Ullah, and G. Witjaksono, "*Elliptical Slot Circular Patch Antenna Array with Dual Band Behavior for Future 5G Mobile Communication Networks*", Progress In Electromagnetics Research C, Vol. 89, 133–147, 2019.

[6] A. Kaeib, N. Shebani, A. ALthini and A. Zerek "*Design and Performance Evaluation of Frequency Reconfigurable Antenna for 5G Wireless Communication Applications*", 2021 IEEE 1st International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering MI-STA, May 2021.

[7] N.Priya, G. Sai Sravanthi, K. Narmada, K. Kavya, G. Swamy, and M.Durgarao, "*A Microstrip Patch Antenna Design at 28GHz for 5G Mobile Phone Applications*", International Journal of Electronics, Electrical and Computational System, Volume 7, Issue 3, March 2018.

[8] S. Verma, L. Mahajan, R. Kumar, H.Saini, and N.Kumar, "*A Small Microstrip Patch Antenna for Future 5G Applications, 5th International Conference on Reliability, Infocom Technologies and Optimization (ICRITO)*, Noida, India, 2016.

[9] S. Chandana, P. Deepthi, D. Teja, N. JayaKrishna, and M. Sujatha,"*Design of a Single Band Microstrip Patch Antenna for 5G Applications*", International Journal of Engineering & Technology, pp. 532-535, 2018.

[10] C. Balanis, "*Antenna Theory Analysis and Design*", 3rd edition, John Wiley and Sons, 2005.

[11] L. Alborai, "*Frequency-Reconfigurable Microstrip Patch Antennas for X-Band Applications*", University of Tripoli, Faculty of Engineering; 2017.

[12] A. Barnwal, S. Das, R. Shaw, and J. Bagchi, "*Frequency Reconfigurable Microstrip Patch Antenna*", Bs.Tech. Project, Maulana Abul Kalam Azad University of Technology, West Bengal; 2018.