# Design of Slotted Microstrip patch Antenna with Resistance, Capacitance and Inductance for 5G Application

**Dr. Ila Kumari**
*Faculty Physics, Dept. Of Science, Mewar Institute of Management, Vasundhara, Ghaziabad, India*

**Abstract -** As we move towards the fifth generation (5G) of the communication system the demand for compact, high speed and large bandwidth systems. These types of communication systems require new and highly efficient antenna designs. This paper consists of the antenna design for the 5G application which will use microstrip patch antenna with slots loaded on radiating patch to improve the performance of the antenna in terms of gain, radiation pattern and bandwidth at 5-6 GHz spectrum. Microstrip antennas have several advantages like low profile, low cost and ease of fabrication. However, the major disadvantage of the microstrip patch antenna is its inherently narrow impedance bandwidth. By loading some specific slots in the radiating patch of a microstrip antenna we can achieve in obtaining a compact or reduced size of microstrip antennas. In this paper RT Duroid material is used for the 1.6 mm thick substrate.

**Key Words**: antenna; microstrip antenna; antenna 5G; 5G wireless system; broad-band antenna

## 1 Introduction

The world is progressing at a faster pace and so is the need of fast data transfer. The existing 4G, with the increasing demand of fast network speed and increase in the number of people having access to Internet of Things (IoT) and mobile devices, is unable to deliver the expected speed and data transfer. This limitation of 4G paved the way for the fifth generation technology standard for broadband cellular networks popularly known as 5G. Like its predecessors, 5G networks are cellular networks, in which the service area is divided into small geographical areas called *cells*. The higher the frequency, the greater the ability to support high data-transfer speeds. This increased speed is achieved partly by using additional higher-frequency radio waves in addition to the low and medium band frequencies used in previous cellular networks. However, higher-frequency radio waves have a shorter useful physical range, requiring smaller geographic cells. For wide service, 5G networks operate on up to three frequency bands – low, medium, and high. A 5G network will be composed of networks consisting of up to three different types of cells, each requiring specific antenna designs as well as providing a different trade-off of download speed to distance and service area.

The wide-scale deployment of a 5G network requires preparation of antenna infrastructure and implementation of new technological solutions. A significant number of antennas (apart from antennas used for mobile devices) will be to be installed inside buildings, especially public utility buildings, including stadiums, railway stations, and shopping centers. It should be noted, at this point, that antennas installed in locations close to crowds would be smaller than those used in current macro cell transmitters. This is a fundamental difference and a common misunderstanding in public discussion. In a traditional antenna system, the power is radiated according to the established spatial characteristics. Therefore, the area in which users can be located, is predefined. In contrast, the power in a 5G antenna is radiated directionally, and focused on individual users or groups of users. Antenna radiation directions can change almost automatically, to focus on mobile users .

5G Technology means 5th Generation Mobile Technology. 5G technology will use cell phones within very high bandwidth. 5G is a packet switched wireless system with wide area coverage and high throughput. 5G technology uses millimeter wireless which has data rate greater than 100Mbps at full mobility and higher than 1 Gbps at low mobility. The 5G technology will include all types of advanced features which make 5G technology most powerful and in huge demand in the near future. Such a huge collection of technology being integrated into a small device. The 5G technology provides the mobile phone users more features and efficiency.

Microstrip antenna consist of patch which is very thin metallic strip or sheet placed above ground plane separated by a substrate of dielectric material. The performance of the microstrip antennas depends on the height of the substrate and dielectric constant of the substrate. The performance of microstrip antennas are good for thick substrate with lower dielectric constant of substrate material. The major limitation of Microstrip antenna is impedance bandwidth is lower for thin substrate. But, for handheld devices and wireless communication, the antenna size should be small and for that the height of substrate should be as small as possible.

This paper mainly contains the sections in which design equations of conventional rectangular radiating patch, technique to improve performance of antenna with loading slot on radiating patch, theoretical calculation of Return loss and VSWR and proposed antenna for 5G application are described.

## 2 Antenna design considerations

Antenna design is very crucial with respect to any communication system and so is for 5G communication system. The antenna design consists of choice of substrate material and thickness of substrate. Following are some of the characteristics to be considered in antenna design for best results:

- Determine operational frequency
- Determine operational bandwidth
- Choose a substrate
- Choose a substrate height
- Determine the dimensions of the patch
- Determine the power supply
- Determine the electrical parameters and characteristics of the antenna
- Optimize the antenna to obtain the best possible parameters in the given frequency range.

## 3 Design Equations of Microstrip Antenna

Microstrip antennas consist of patch which is a sheet or a thin metallic strip placed on a substrate of dielectric material. The shape of the patch may be rectangular, triangular, circular, square or of any type. The dielectric constant of material should be between 2.2 to 12 for antenna designing. The height of the substrate, $h << \lambda_0$ (where $\lambda_0$ = operating wave length). The designing parameters of microstrip patch antennas for rectangular patch are length of patch (L) and width of patch (W). These two parameters depend on the height of the substrate, dielectric constant of the material and the resonant frequency (Resonant frequency should be same as the operating frequency)

In the Microstrip antennas, the patch is main radiating element. For rectangular patch, the width of the patch (W) depends on the resonant frequency ($f_r$) and dielectric constant ($\varepsilon_r$) of the material which is given by:

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

The effective dielectric constant is introduced to account for fringing effect because some of the waves travel in the substrate and some in the air.

For W/h > 1, the effective dielectric constant is:

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

The electrical length of patch is greater than the physical length because of fringing effect. If the extended dimension of the patch length is ΔL, then

$$\frac{\Delta L}{h} = \left(\frac{(\varepsilon\mathrm{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon\mathrm{reff}-0.258)\left(\frac{W}{h}+0.8\right)}\right) \qquad (3)$$

Thus, the actual length of the patch is:

$$L = \frac{1}{2fr\sqrt{\varepsilon\mathrm{reff}}\sqrt{\mu 0\varepsilon 0}} - 2\Delta\mathrm{L} \qquad (4)$$

## 4 Analysis of Slot Loaded patch Antenna

### 4.1 Analytical calculation of Slot

In the conventional Microstrip antenna, the rectangular slot is loaded on the radiating patch as shown in figure1, of length $L_s$ and width a. It is also necessary to load the slot on patch with proper dimensions such that it can improve the performance of the antenna as compared to the performance of conventional antenna. In this section, the slotted Microstrip patch antenna is analyzed. The slot on patch can be analyzed by using duality relationship between the dipole and the slot.

The slot loaded on the patch affects the performance parameter of the antenna. The slot loaded rectangular microstrip patch antenna can be considered as parallel combination of capacitance $C_1$, inductance $L_1$ and resistance $R_1$ and capacitive reactance of the slot.

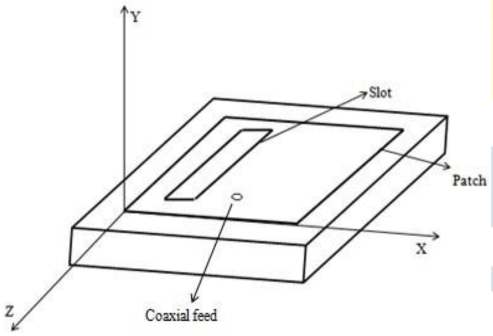


Fig.-1: Slot loaded rectangular microstrp antenna

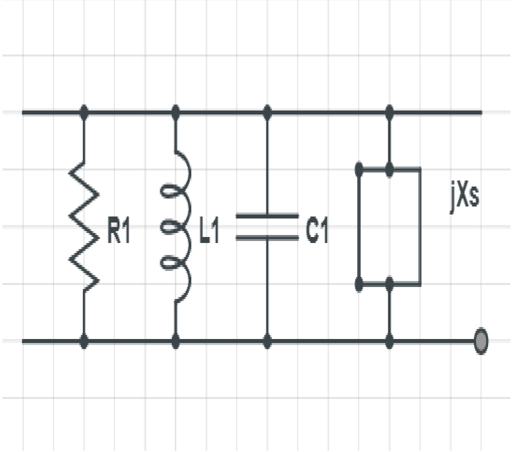


Fig.-2: Equivalent circuit of slot loaded on patch

$$C_1 = \frac{\varepsilon_{eff}\varepsilon_0}{2h} LW cos^{-2}\left(\frac{\pi z_0}{L}\right) \quad (5)$$

$$L_1 = \frac{1}{C_1\omega_r^2} \quad (6)$$

$$R_1 = \frac{Q}{\omega_r C_1} \quad (7)$$

h = Thickness of substrate

$\varepsilon_{eff}$ = Effective dielectric constant

$\varepsilon_0$ = Permittivity of free space

$z_0$ = Feed point location along z-axix

The input impedance ($Z_{in}$) of the above excluding slot can be expressed as:

$$Z_{in} = \frac{1}{\frac{1}{R_1} + j\omega C_1 + \frac{1}{j\omega L_1}} \quad (8)$$

The above equation can be expressed as:

$$Z_{in} = R - jX \quad (9)$$

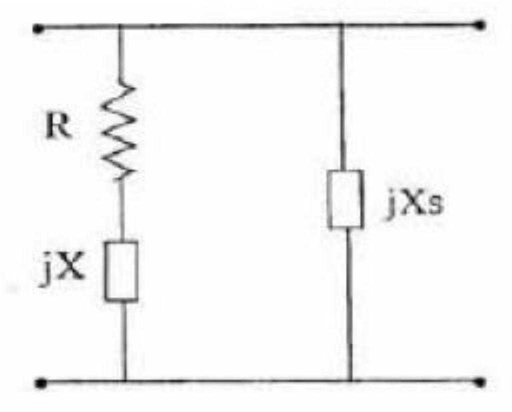


Fig.-3: Modified equivalent circuit of slot loaded on patch.

The input impedence of slot loaded on patch can be calculated using above Figure 4 as:

$$Z_{ins} = \frac{X.X_5 + jR.X_5}{R - j(X - X_5)}$$

$$\text{Reflection coefficient, } \Gamma = \frac{Z_0 - Z_{ins}}{Z_0 + Z_{ins}}$$

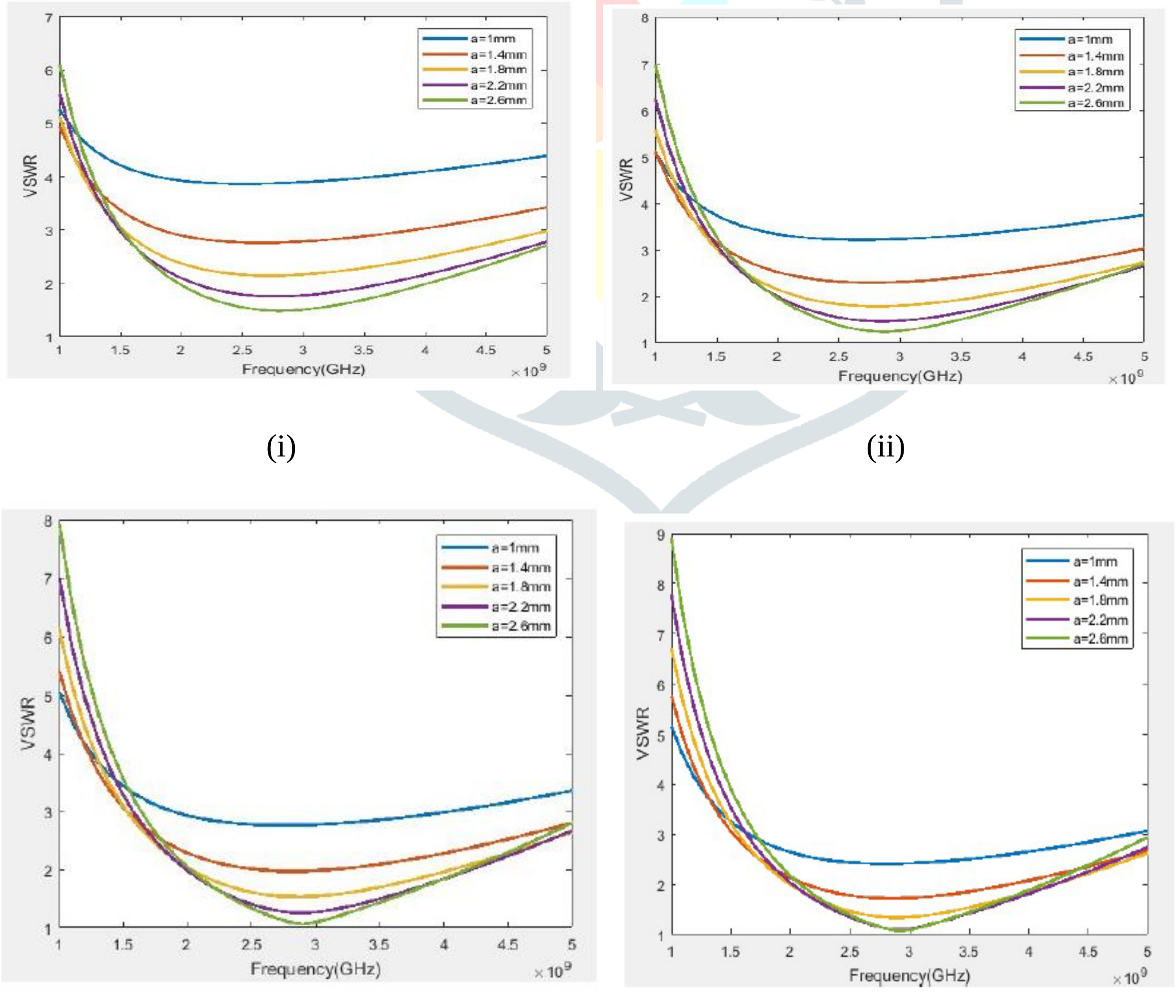
$$\text{Return loss} = 20 \log |\Gamma| \qquad (9)$$

$$\text{VSWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|} \qquad (10)$$

Thus, return loss and VSWR get affected by the slot on the patch. Bandwidth is dependent on return loss and VSWR plot. So, bandwidth is also affected by the slot on the patch.

### 4.2 Theoretical Calculations of slot

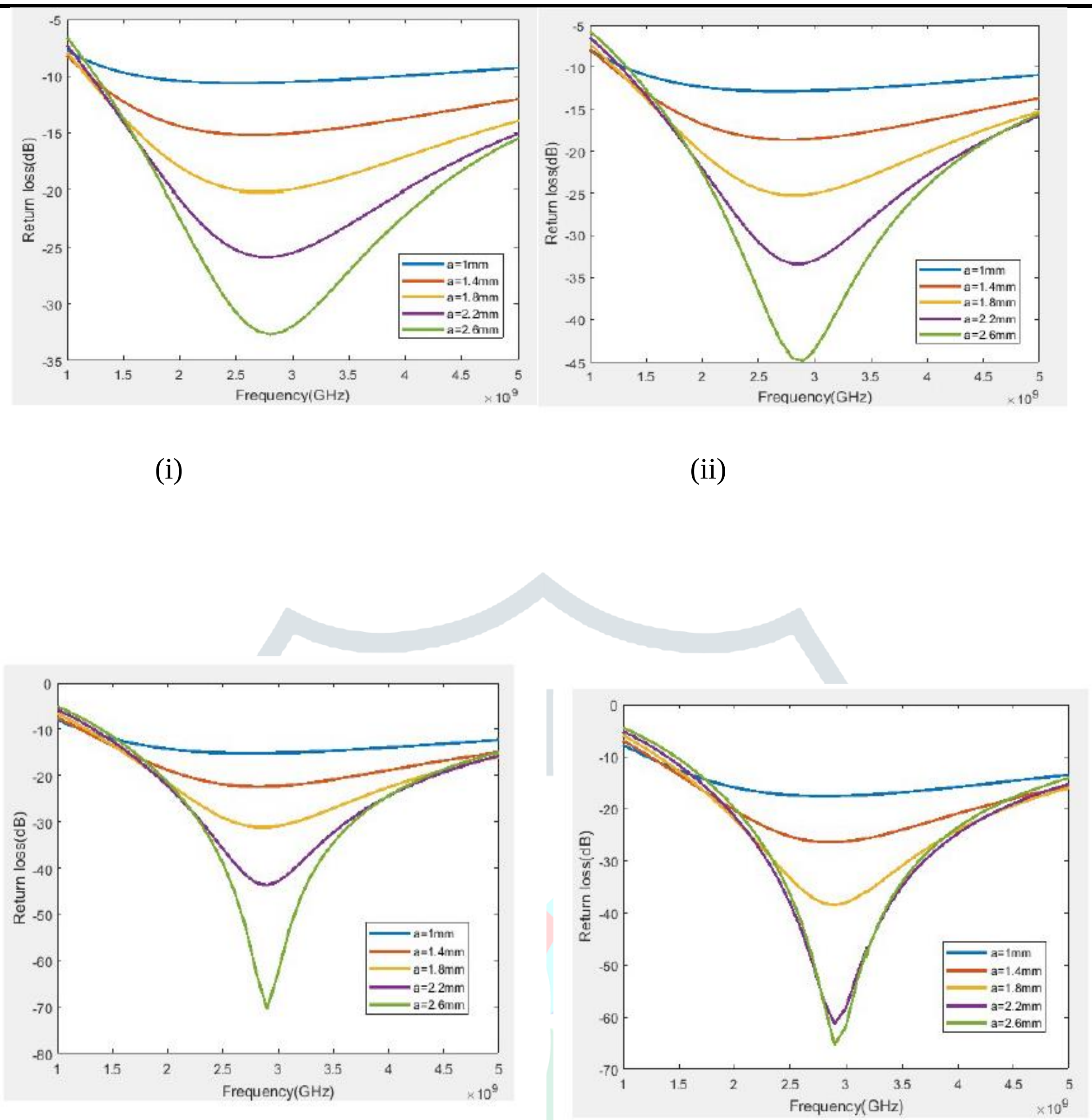
The slotted Microstrip antenna is analyzed in above section and in this section the value of Return loss and VSWR are calculated theoretically using equations described in (III) for different slot width and slot lengths. The patch was designed for frequency 3.0 GHz, dielectric material of substrate RT Duroid ($\varepsilon_r$=2.2) and thickness of substrate is 0.0159λ.



(i) (ii)

(iii) (iv)

Fig.-4: Variation in VSWR Vs frequency in GHz for different slot width (a) for given slot length ($L_s$) (i) $L_s$ = 10 mm, (ii) $L_s$ = 12 mm, (iii) $L_s$ = 14 mm, (iv) $L_s$ = 16 mm.



(i) (ii)

(iii) (iv)

Fig.-5: Variation in return loss Vs frequency in GHz for different slot width (a) for given slot length ($L_s$) (i) $L_s$ = 10 mm, (ii) $L_s$ = 12 mm, (iii) $L_s$ = 14 mm, (iv) $L_s$ = 16 mm.

From Figure 4 and 5, it can be observed that the resonance frequency decreases with increasing slot width for same slot length. The bandwidth or frequency variation is more for lowest slot length with same slot width. The value of VSWR and return loss also decreases as slot width increases.

## 5 Antenna Design

The antenna design consists of the choice of the substrate material and thickness of the substrate. The RT Duriod material is used with 1.6 mm thickness at 5-6 GHz spectrum of 5G. The conventional patch antenna is shown in Figure 6.

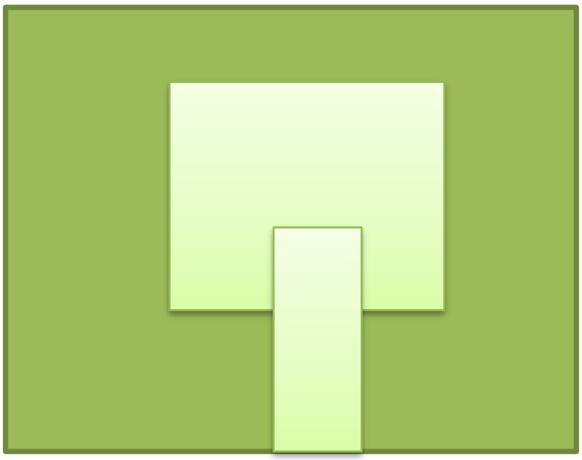


Fig.-6: Conventional Patch Antenna

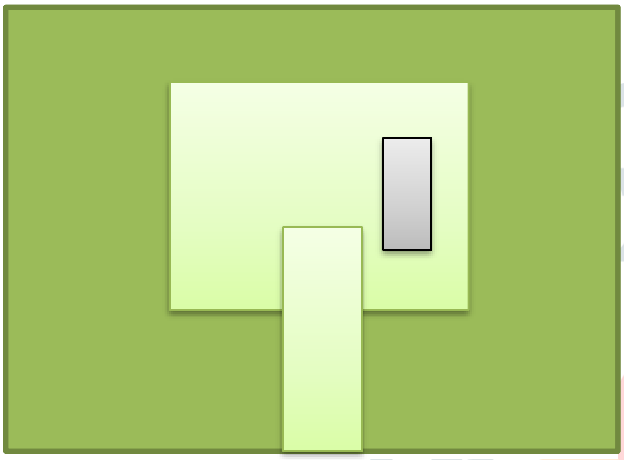


Fig.-7: Slotted Microstrip Patch Antenna

**Table 1: Design Parameters of Patch**

| Length of patch L(mm) | Width of patch W(mm) | Height of substrate h(mm) | Width of feed like(mm) | Length of substrate $L_g$ | Width of substrate $W_g$ |
|---|---|---|---|---|---|
| 12.62 | 16.59 | 1.6 | 2.98 | 6h + L | 6h + W |

The above patch antenna is simulated using HFSS.

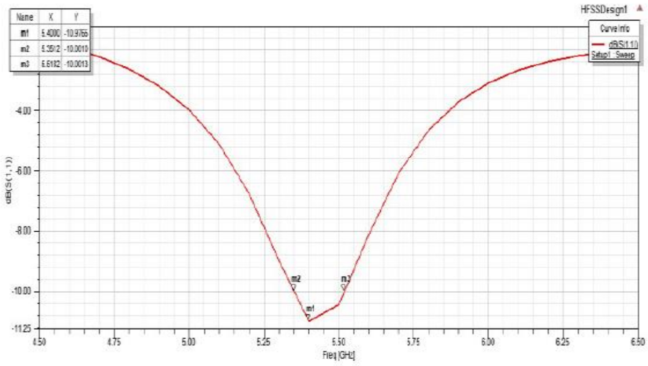
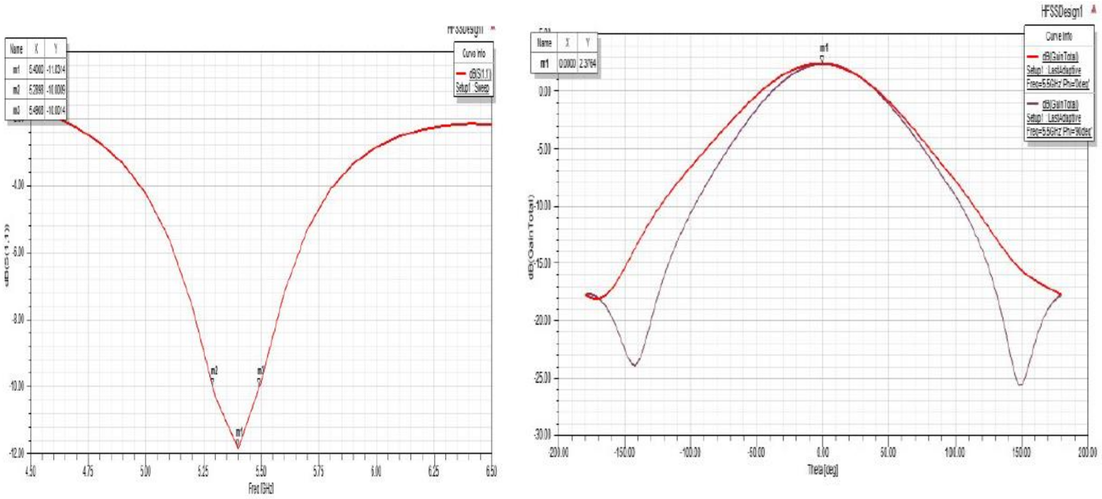


Fig.-8: (i) Return loss (dB) Vs Frequency plot(GHz) (ii) gain(dB) Vs Theta(deg) plot of conventional antenna

From figure 8, it can be seen that the resonant frequency is -10.97 dB, bandwidth is 167MHz and gain is 2.65dB.

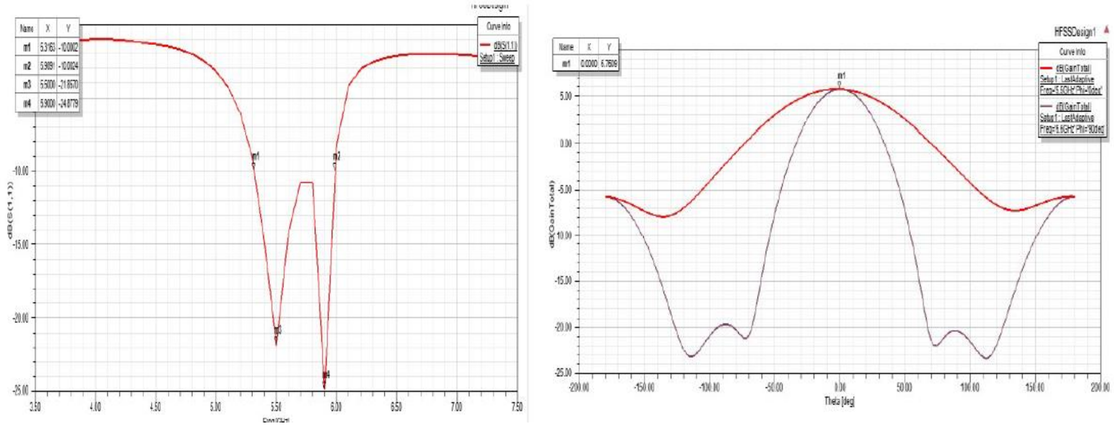
Now, the requirement for the 5G application about gain is that gain should be more than 5dB. The gain can be improved by the array of patches but it does not affect the bandwidth. Thus, to increase the bandwidth, one slot is loaded on the radiating patch as shown in Figure 8.

The length of the slot is 7 mm and width is 2.1 mm. By simulating this slotted antenna resulting in return loss of -11.83dB at resonant frequency of 5.4GHz, the bandwidth is 201MHz and the gain is 2.38dB. Thus, the bandwidth increases by the slot on patch but it does not affect the gain of the patch.



(i) (ii)

Fig.-9: (i) Return loss(dB) Vs Frequency plot(GHz) (ii) gain(dB) Vs Theta(deg) plot of slotted antenna



(i) (ii)

Fig.-10: (i) Return loss(dB) Vs Frequency plot (GHz) (ii) gain(dB) Vs Theta(deg) plot of proposed antenna

Now, for the proposed antenna for 5G application, array of patch is used to increase the gain and slot is used to increase the bandwidth as shown in Figure 10.

The patches are placed on λ/2 distance from each other. From Figure 10, it can be seen that the bandwidth increases and it is 672.8MHz because of slots on the patch. The gain of patch due to array of patches increases to 5.72dB meeting the requirement of gain > 5dB for 5G applications.

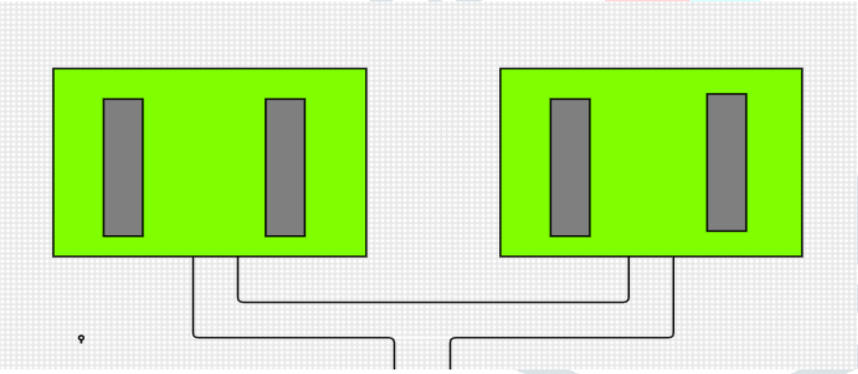


Fig.-11: – Proposed Antenna

## 6 Conclusion

By loading the slot, resonant frequency decreases and bandwidth of antenna increases. Resonant frequency varies slightly for different slot width as compared to patch without slot. The bandwidth also increases with slot width for given slot length. Gain and bandwidth bot can be increased by array of patches with slots on each patch making it useful for 5G communication systems.

## References

1. Veselago VG. The electrodynamics of substances, with simultaneously negative values of $\varepsilon$ and $\mu$. *Soviet Physics Uspekhi*. 1968;10(4):509–514.
2. Zani MZM, Jusoh MH, Sulaiman AA, et al. Circular Patch Antenna On Metamaterial. *IEEE International Conference on Electronic Devices, Systems and Applications (ICEDSA)*. 2010:313–316.

3. Marta Gil, Jordi Bonache, García–García J, et al. Composite Right/Left–Handed Metamaterial Transmission Lines Based on Complementary Split–Rings Resonators and Their Applications to Very Wideband and Compact Filter Design. *IEEE Transactions on Microwave Theory and Techniques*. 2007;55(6):1296–1304.
4. Pendry JB, Holden AJ, Robbins DJ, et al. Magnetism from Conductors and Enhanced Nonlinear Phenomena. *IEEE Transactions on Microwave Theory and Techniques*. 1999;47(11):2075–2084.
5. Nordin MAW, Mohammad T Islam, Norbahiah Misran. Design of a compact Ultra Wideband metamaterial antenna based on the modified Split ring resonator and Capacitively Loaded Strips unit cell. *PIER*. 2013;136:157–173.
6. Khidre, Kai Fang Lee, Fan Yang, et al. Wideband Circularly Polarized E–Shaped Patch Antenna for Wireless Applications (Wireless Corner). *Antennas and Propagation Magazine IEEE*. 2010;52:219–229.
7. Mahdy MRC, Zuboraj MRA, Al Noman Ovi A, et al. An Idea of Additional Modified Modes in Rectangular Patch Antennas Loaded With Metamaterial. *IEEE Antennas and Wireless Propagation Letters*. 2011;10:869–872.
8. Mookiah P, Dandekar KR. Metamaterial–Substrate Antenna Array for MIMO Communication System. *IEEE Transaction Antennas and Propagation*. 2009;57(10):3283–3292.
9. Jang HA, Kim DO, Kim CO. Size Reduction of Patch Antenna Array Using CSRRs Loaded Ground Plane. Progress In Electromagnetics Research Symposium Proceedings, Malaysia; 2012. p. 27–30.
10. Douglas HW, Haupt Rl, Werner PL. Fractal antenna engineering: The theory and design of fractal antenna arrays. *IEEE Antennas and Propagation Magazine*. 1999;41(5):37–59.
11. Ziolkowski RW. Design fabricating and fabrication and testing of double negative metamaterials. *IEEE Transactions on antennas and Propagation*. 2005;51(7):1516–1529.
12. Kuo YL, Wong KL. Printed double– T monopole antenna for 2.4/5.2 GHz dual–band WLAN operations. *IEEE Trans Antennas Propag*. 2003;51(9):2187–2192.
13. Yizhuo Yang, Christina Lim, Ampalavanapillai N. Investigation on Transport Schemes for Efficient High–Frequency Broadband OFDM Transmission in Fibre–Wireless Links. *IEEE Journal Of Lightwave Technology*. 2014;32(2):267–274.
14. Nikita M. Tarpara, Raju R. Rathwa, Dr. Nirali A Kotak, Design of Slotted Microstrip patch Antenna for 5G Application, *International Research Journal of Engineering and Technology (IRJET)*, 2018.
15. Pradeep AS, Maheshwar M Swamy, Umesh, et al. Design and Performance Analysis of Rectangular Microstrip Patch Antenna using Metamaterial Structure for Improved Radiation. *International Journal of Engineering Research & Technology*. 2015;4(5):1191–1193.
16. Pradeep G, Gunasekaran N. Performance Enhancement of Micro strip Patch Antenna Using Metamaterial. *International Journal of Electrical and Computing Engineering*. 2015:1(4).
17. Ankita Gupta, Garima Tiwari. Metamaterial Loaded Microstrip Patch Antenna for X Band. *International Journal of Engineering Science and Computing*. 2017.