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DESIGN AND SIMULATION OF A MICROSTRIP RECTANGULAR PATCH ANTENNA SUITABLE FOR APPLICATION IN THE MILLIMETER WAVE BAND

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Abstract

This paper examined the design of a simple rectangular microstrip patch antenna suitable for application in the millimeter wave band. The proposed antenna was design to resonate at 39GHz with the corresponding return loss of -21.6dB, covering about 3.05GHz bandwidth which makes it more efficient for the fifth generation (5G) wireless communication devices. The comprehensive profile of the designed structure is 5.34 × 4.59 × 0.50 mm^3 other parameters such as VSWR, gain, and radiation pattern are also examined. The modeling and simulation of the microstrip patch antenna was performed using High Frequency Simulation Software (HFSS). The result obtained shows that 90% of the power is intercepted by the antenna which is a well establish standard for mobile communication. Similarly, a gain of 5.7dB was achieved which satisfy the minimum requirement that 5G devices and the VSWR value achieved at resonant frequency of 40.4000 GHz is 1.1813.

Key Words: Band Width, Fifth Generation (5G), Patch Antenna, Microstrip Feed, Millimeter Wave, MPA, Wideband

Introduction

Today there are 7 billion internet-connected devices worldwide, by 2025 there will be an estimated 21 billion of such connected devices using 13 times more data than we are using today. Many of these new devices will be things that power and monitor our homes, city infrastructure, transport and more; this network is what is commonly known as Internet of Things (IoT) as pointed out by (Lee, 2010).

(Guangyi & Dajie, 2000) Presented a global outlook as regard projected trend in mobile communication towards 2020 and beyond concerning data usage, device connection and emerging new devices as follows:

i. ***Explosive Growth of Data Traffic.*** There will be explosive growth in traffic; the global data traffic will increase by more than 200 times from 2010 to 2020 and about 20000 times from 2010 to 2030.
ii. ***Great Increase of Devices in Connection.*** While smart phones are expected to remain as the main personal devices, the number of other kinds of devices, including wearable devices and MTC devices, will continuously increase.
iii. ***Continuous Emergence of New Services***. Different kinds of services, for example, services from enterprises, from vertical industries, and from Internet companies, will be exploited.

In the light of the above, only 5G networks can shoulder such huge responsibility in meeting up the expected expansion in mobile communication.

Below are the uses of 5G network that makes it a suitable solution to the ever expanding demand for mobile communication, the advantages of the use of 5G network according to (Gallagher and DeVine 2019) are, it offers increased bandwidth, constant connectivity, and low latency services which can enhance and expand the use of mobile technologies for consumers and business and also 5G networks are expected to support interconnected devices (e.g., smart homes, medical devices), and advanced IoT systems, such as autonomous vehicles, precision agriculture systems, industrial machinery, and advanced robotics. IoT technologies are expected to be integrated into systems to automate processes and to optimize operational efficiencies. 5G Antennas are generally required to be light weight, having low profile (compact size), with effective low manufacturing cost, having features for easy installation, conformable to planar surface and also compatible with microwave integrated circuit. Microstrip antennas meet all the above requirement despite its narrow bandwidth, Small power capacity and low radiation efficiency reported by (Gayatri & Usha, 2021).

Methodology

I. Materials used for the Antenna design

Table 1. Dimension of the proposed Antenna

S/n	Antenna Component	Symbols	Dimensions (mm)
1.	Ground Plane Length	Lg	4.5920
2.	Ground Plane Width	Wg	5.3407
3.	Patch Length	Lp	1.5808
4.	Patch Width	Wp	2.3400
5	Height of Substrate	H	0.5000
6.	Width of Feedline	W_f	0.2581
7.	Feedline insertion point	F_i	0.4900
8	Insertion Feed gap	F_{gab}	0.2027
9	Permittivity	ε_r	4.4000

II. Method adopted for the Antenna design

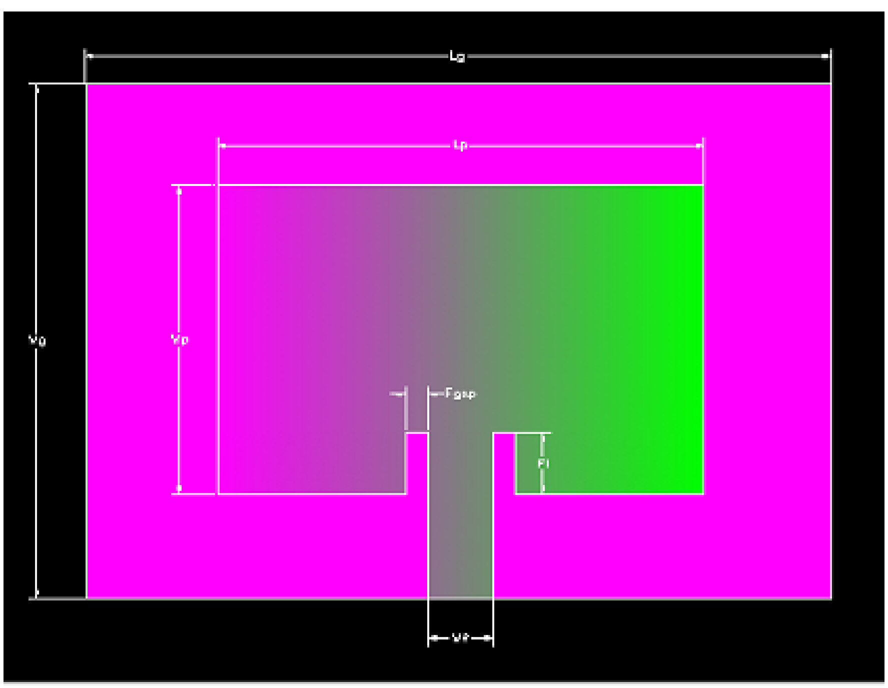

Figure 1: Designed Geometry of Microstrip patch antenna

Figure 1 below shows the geometry of the proposed Microstrip patch antenna. The parameters used in the design includes;

i. Operating Frequency (Fr): The operating frequency often referred to in principle as resonant frequency of the antenna was carefully selected to be 39GHz. This frequency falls within the range of the Millimeter wave spectrum of 30GHz to 300GHz as stipulated by (5G Americas White Paper, 2020)

ii. Dielectric constant of the substrate (ε_r): The dielectric constant of substrate Material used in the design determines the operational capabilities of the patch antenna. A substrate with a high dielectric constant adversely affects the performance of the antenna but reduces its size. In this design my dielectric substrate was chosen to be FR4 material having a dielectric constant of 4.4

iii. Height of dielectric substrate (h): Microstrip Patch antennas are most commonly used in wireless hand-held devices hence; it is expected that such antenna should be less bulky. Hence, for this design we have chosen h to be 0.5 mm.

III. Mathematical Model

After selection of above three parameters, the next step is to calculate the dimensions of radiating element. Equations obtained from the transmission line model analysis of the patch antenna as presented by (Balanis, 2005) were adopted in calculating the radiating element parameters.

i. Patch Width (Wp)

$$Wp = \frac{V_O}{2F_r\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (1)$$

$$= \frac{3 X 10^8}{2 X 39 X 10^9\sqrt{\frac{4.4+1}{2}}} = 0.002340m = 2.34mm$$

ii. Patch Length (Lp)

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

Where

L_{eff} = Effective length

ΔL = change in length

But $L_{eff} = \frac{V_o}{2F_r\sqrt{\varepsilon_{reff}}}$ (3)

Where

ε_{reff} = Effective Dielectric

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} x \left(1 + 12\frac{h}{w}\right)^{-0.5} = \frac{4.4+1}{2} + \frac{4.4-1}{2} X \left(1 + 12\,\frac{0.5}{2.340}\right)^{-0.5} \quad (4)$$

ε_{reff} = 3.600058

Recall from equation (3) that $L_{eff} = \frac{V_o}{2F_r\sqrt{\varepsilon_{reff}}}$

$$\mathbf{L_{eff}} = \frac{3 X 10^8}{2 X 39 X10^9\sqrt{3.60058}} = 0.0020269m$$

= 2.0269mm

Change in length = ΔL

$$\Delta L = \frac{0.412 \text{ x h } (\frac{w}{h}+0.264)(\ \varepsilon_{reff}+0.3)}{(\ \varepsilon_{reff}\ -\ 0.258)(\frac{w}{h}+0.813\ )} \quad (5)$$

$$= 0.412 \text{ x } 0.5 \text{ x } \frac{\left(\frac{2.3407}{0.5}+0.264\right)(3.005764+0.3)}{(3.005764-0.258)\ (\frac{2.3407}{0.5}+0.813)}$$

= 0.2230698052mm

$2\Delta L$ = 0.4461396103mm

Recall from equation (2) that L_p = Leff - $2\Delta L$

Lp = 2.0269388103 – 0.4461396103

L_p = 1.5808mm

Calculation of Inset feed Depth (Fi):
For proper impedance matching with a 50Ω connector, a curve fit formula for the inset feed depth is given by (Md, Mohammed and Kartik 2020) as:

$$F_i = 10^{-4}\ (0.0016922\ \varepsilon_r{}^7 + 0.13761\ \varepsilon_r{}^6\ - 6.1783\varepsilon_r{}^5\ + 93.187\varepsilon_r{}^4\ - 682.69\ \varepsilon_r{}^3\ + 2561.9\varepsilon_r{}^2 - 4043\ \varepsilon_r{}^1\ + 6699)\ \frac{L_p}{2} \quad (6)$$

$$F_i = 10^{-4}\ (0.0016922 \text{ x } 4.4^7 + 0.13761 \text{ x } 4.4^6\ - 6.1783 \text{ x } 4.4^5\ + 93.187 \text{ x } 4.4^4\ - 682.69 \text{ x } 4.4^3\ + 2561.9 \text{ x } 4.4^2\ - 4043 \text{ x } 4.4^1\ + 6699) \text{ x } \frac{1.5808}{2}$$

F_i = 0.490mm

Calculation of width of transmission feedline
The transmission feedline width is calculated using equation expressed by (Przesmycki, Bugaj, and Nowosielski, 2021)
2021) as

$$\frac{W_f}{h} = \frac{8e^A}{8e^{2A}-2} \text{ for } \frac{W_f}{h} \le 2 \quad (7)$$

OR

$$\frac{W_f}{h} = \frac{2}{\pi}\,[(B-2) - \text{In}(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}(\text{In}(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}] \text{ for } \frac{W_f}{h} \ge 2 \quad (8)$$

$$\text{Where } A = \frac{Zo}{60}\sqrt{\frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r+1}{\varepsilon_r-1}(0.23 + \frac{0.11}{\varepsilon_r})} \quad (9)$$

Zo = 50Ω is the characteristics impedance of the antenna

$$B = \frac{60\pi^2}{Zo\ \sqrt{\varepsilon_r}} \quad (10)$$

From the geometry of the patch which is the radiating body, the ratio of $\frac{W_f}{h} \le 2$

Hence we apply equations (9) and (7) respectively.

$$A = \frac{50}{60}\sqrt{\frac{4.4+1}{2} + \frac{4.4+1}{4.4-1}(0.23 + \frac{0.11}{4.4})} = 1.468418$$

$$\frac{W_f}{0.5} = \frac{8e^{1.468418}}{8e^{2 \text{ X } 1.468418} - 2} = 0.5161641861$$

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Hence, W_f = 0.2581mm

Ground Plane dimensions were calculated using the formula given below:

$$W_g = 6h + W_p \quad (11)$$

Wg = 2.3407 + 6 x 0.5 = 5.3407mm

$$L_g = 6h + L_p \quad (12)$$

Lg = 1.5920 + 6 x 0.5 = 4.5920mm

Where Wg is the width and Lp is the Length of ground plane respectively.

Calculation of Inset fed gap F_{gap} using the formula of presented by (Przesmycki, et al, 2021)

$$\mathbf{F_{gap}} = \frac{4.65\ X\ 10^{-18}\ X\ V_o\ X\ F_r}{\sqrt{2\ X\ \varepsilon_{reff}}} \quad (13)$$

$$= \frac{4.65\ X\ 10^{-18}\ X\ 3\ X 10^{8} X\ 39\ X\ 10^{9}}{\sqrt{2\ X\ 3.6005763}} = 0.2027\text{mm}$$

Results Presentation

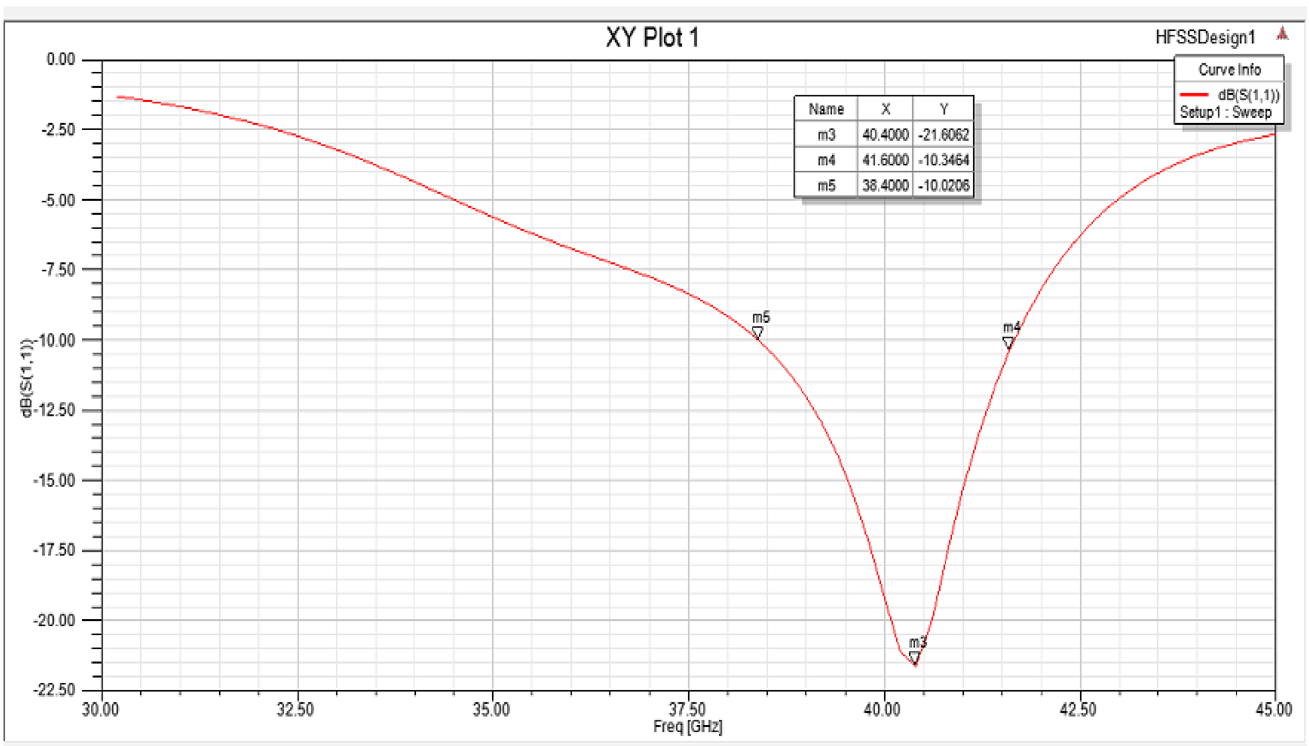

Figure 2: Plot of Reflection Coefficient

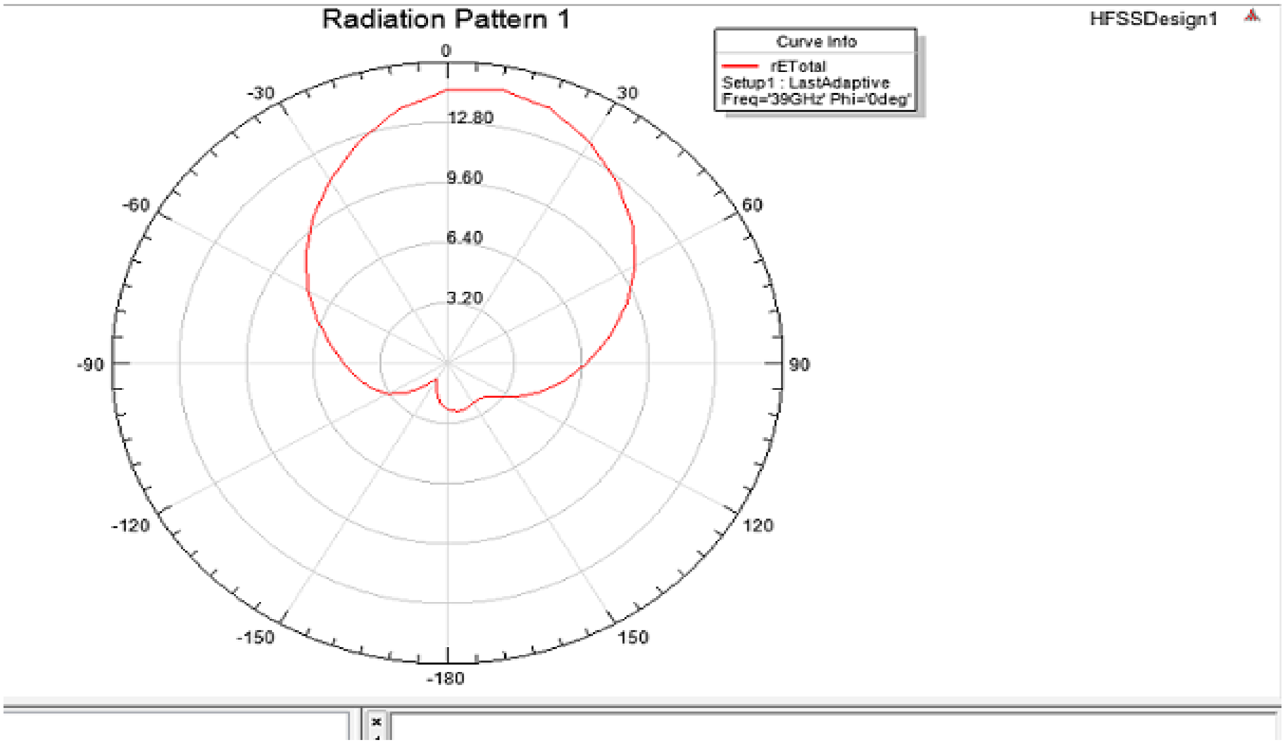

Figure 3: 2-D plot of Radiation Pattern

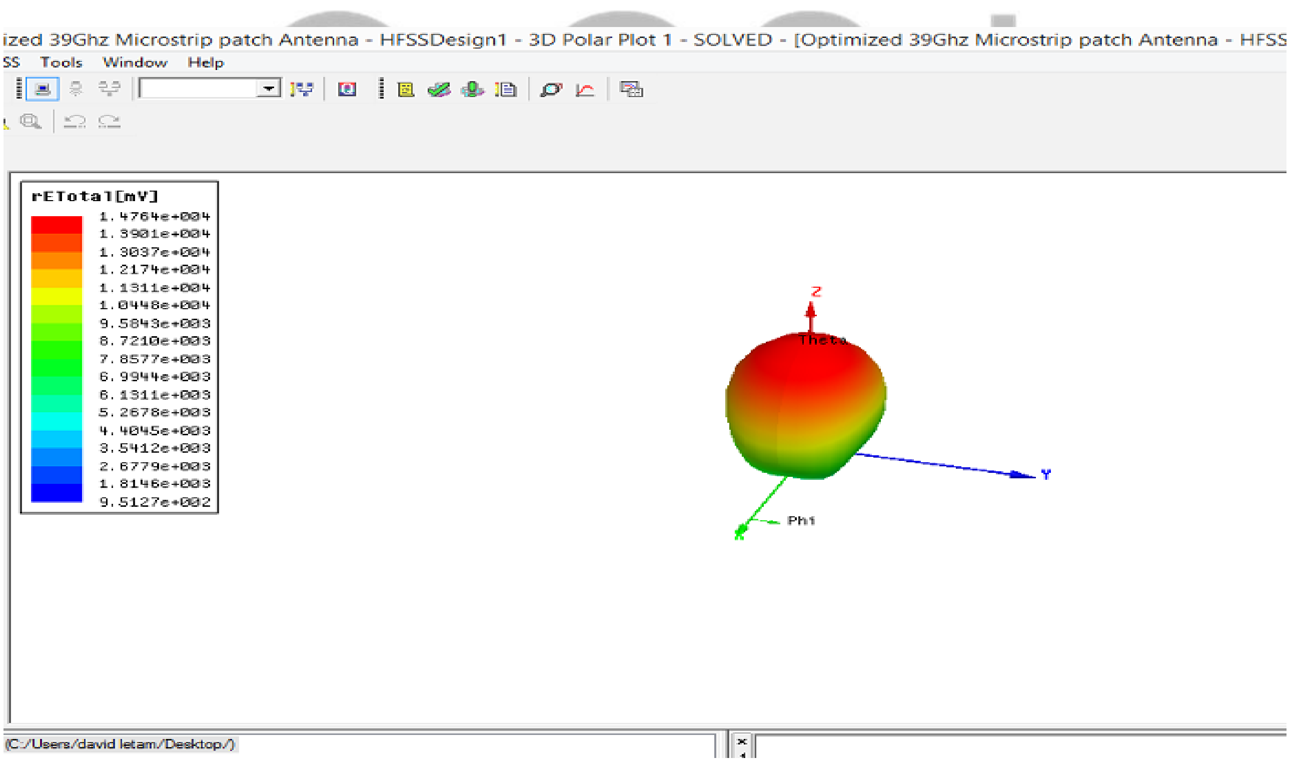

Figure 4: 3-D plot of Radiation Pattern

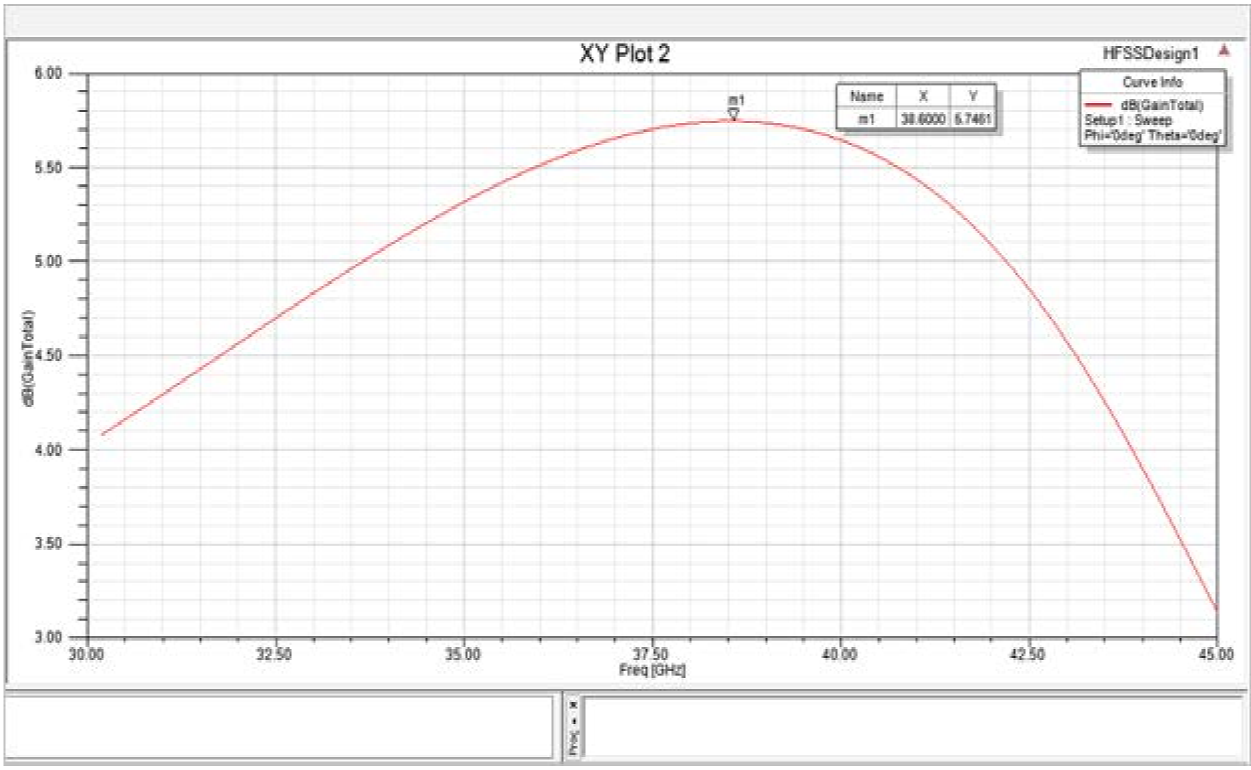

Figure 5: Plot of the Antenna Gain

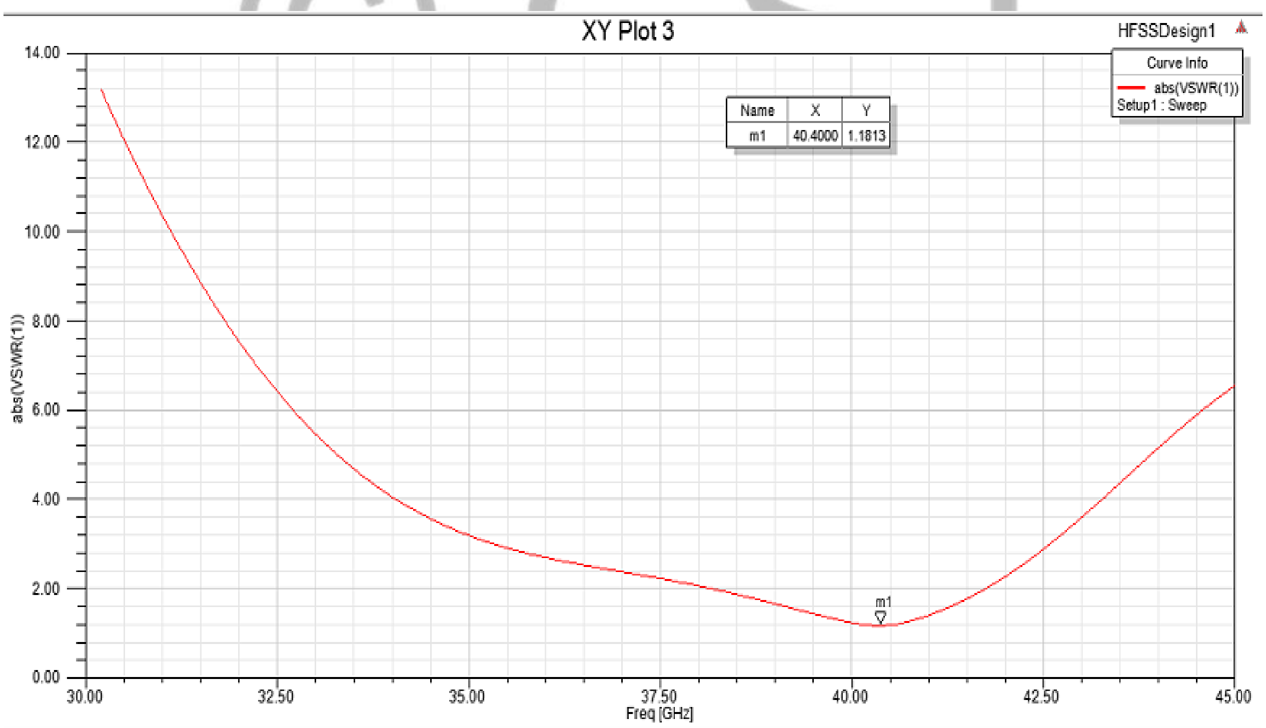

Figure 6: Plot of Voltage Standing Ratio

Results Discussion

The design, modeling and simulation of this MPA were done using High Frequency Simulation Software (HFSS).

Figure 2 shows the reflection coefficient of the antenna. A quick look at figure 2 shows that the value of -10 dB is taken as the base value of the reflection coefficient which signifies that 10% of incident power is reflected i.e. 90% of the power is intercepted by the antenna which is a well establish standard for mobile communication. The patch antenna resonates at a central frequency of 40.4 GHz with a return loss of -21.6 dB as shown in figure 2 below. The antenna is having a bandwidth of 3.2GHz.

Figure 3 and 4 shows the 2-D and 3-D radiation pattern of the proposed antenna respectively. It shows that the antenna has a directivity of 14.5dBi.

Figure 5 shows a plot of gain in (dB) versus Frequency in (GHz), the MPA designed here has a gain of 5.7dB which satisfy the requirement that 5G devices should have a gain that is more than 5dB as reported by (Tarpara, Rathwa, and Kotak, 2018).

Figure 5 shows the voltage standing wave ratio plotted against frequency. Normally, for a patch antenna, the VSWR should not be higher than 2 and less than 1 along the bandwidth of efficiency. Ideally it should be 1. A cursory look at figure 5, show that for the designed antenna the VSWR value achieved at resonant frequency of 40.4000 GHz is 1.1813.

IV. Conclusion

The simulation was carried out using the Ansoft high frequency structure simulator (HFSS) software which is based on a finite element method, its accuracy and powerful features makes it a good and common tool for antenna designers. The entire designed structure feed by a rectangular feedline was simulated, during which parametric study was carried out for the designed value of patch length (LP) and the width (WP). The structure was simulated and a Return loss (S11) was obtained at < -10dB, implying that 90% of the available power is delivered to the antenna. A gain of over 5.7dB was obtained, the voltage standing wave ratio (VSWR) was gotten to be 1.1813. Also the bandwidth obtained (38.40 – 41.60 GHz) with center frequency of 40.40GHz is more than 500MHz which satisfied the condition for wideband. Theoretically, the antenna was designed to resonate at 39GHz but in actual simulation, it resonated at 40.4GHz this is as a result of proper matching of the feedline. This research leaves a possibility that better resonance frequency can be obtained with better impedance matching section as regard to the feedline. The antenna designed here is suitable for 5G hand held mobile devices because it is within the frequency range of 37–40.5GHz which is one of the viable frequency range proposed by ITU when it released the most recent World Radio Communications Conference paper as reported by (Philip, 2016)

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