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Improved Multiband Rectangular Microstrip Patch Antenna for 5G Application

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Abstract

In this work, a multiband microstrip patch antenna for 5G mobile applications was designed and simulation was conducted using HFSS (High Frequency Simulation structure) software. The frequency range of 3.5 GHz through 11.65 GHz was considered and the antenna dimensions were obtained from a well-established design equations. During simulation, the designed antenna was considered for an antenna without an inset feed and an inset fed antenna using layers of RT/Duroid 5880 substrate with a patch size of 33 mm × 28.8 mm and height of 1 mm. The antenna performance was analyzed in terms of S11 parameters, return loss, Voltage standing wave ratio (VSWR), reflected power, and forwarding power. The result showed that the antenna radiates at a frequency of 3.5 GHz, 5.93 GHz, 7.49 GHz, 10.07 GHz and 11.65 GHz with an S11 value of -19.33, -17.40, -25.84, -32.94, -26.25 dB and VSWR of 1.88, 2.35, 1.68, 1.78 and 1.03. The designed antenna can be used for 5G applications that require the frequencies obtained in this research work.

I. INTRODUCTION

A. Background of the Study

In wireless communication technology, the radio frequency spectrum becomes increasingly congested and there is also an increase in interference as the number of users continues to increase. The need to effectively manage the congestion, interference and latency drives modern telecommunications innovation. The fifth generation (5G) communication has been widely discussed to provide high data-rate communications in the future. The design and testing of the 5G communication system hinge on the understanding of the propagation channels, and therefore a large body of channel measurements are required. Currently, 5G mobile systems are broadening their spectrum to support a high data rate. In the World Radio Communication Conference (WRC) in 2015, the 5G candidate frequency bands below 6 GHz have been widely discussed, and the following frequency ranges have been suggested: 470–694, 1427–1518, 3300–3800, and 4500–4990 MHz. Among them, 3.5 GHz has been widely considered, as it can be accepted for most of countries [1].

In November 2019, the Nigerian Communications Commission (NCC) embarked on a Proof of Concept (trial) of the 5G network for a period of three (3) months to access the performance of the technology in comparison with existing technologies, evaluate compliance to health and safety guidelines and use the lessons learnt to guide Policy towards commercial deployment. The trial conducted on the 3.5 GHz and 26 GHz were successful with performance showing 5G improvement over previous technologies with the radiation levels far below the specified human safety guidelines which confirm report of the International Telecommunications Union (ITU) and World Health Organization (WHO) that pronounced it safe to human health [2]. In September 2021, the Federal Government of Nigeria approved 5G network [3] and in December 2021, two slots of the 3.5 GHz spectrum were auctioned for the deployment of Fifth Generation (5G) technology to support the delivery of ubiquitous broadband services in Nigeria. The European Commission adopted a 5G action plan for Europe in 2016 to ensure the early deployment of 5G infrastructure across Europe. The objective of the action plan was to start launching 5G services in all EU Member States by the end of 2020 at the latest. Following this, it suggests a rapid build-up to ensure uninterrupted 5G coverage in urban areas and along main transport paths by 2025 [4].

From the initial 3G network launch in Japan to the first commercial 5G networks in South Korea, countries in the Asia Pacific area have been at the forefront of several mobile technologies. The 5G era is now in its early phases in the mobile sector. 5G had been launched in roughly 70 markets by the end of 2021. Operators in 5G pioneer areas like China, South Korea, Finland, Germany, and the United States have witnessed rapid adoption following their debuts. While 5G is not yet accessible in all markets, it is becoming a more important aspect of operators' network plans, with 5 billion mobile 5G connections predicted by 2030, accounting for more than half of all connections [27].

5G networks can connect many devices, people, applications, and process high volumes of data with minimal delay. Antennas are an integral part of wireless communication applications therefore for 5G applications to work efficiently they require suitable antennas that can operate at the required frequencies. This paper is focused on the design of a rectangular microstrip patch antenna resonating at between

3.5 GHz and 12 GHz. There are many benefits of micro strip patch antennas such as small size, light weight, and ease of integration into portable mobile devices make them suitable for 5G applications

B. Statement of the Problem

Electronic devices and smart phones operate in certain frequencies such as 3 KHz, 6 GHz, and even up to 60 GHz. As more devices come online, there is congestion and interference giving rise to high latency. As the number of users continues to increase, so does the high demand for bandwidth for faster downloads, new applications, services, and functionalities such as smart homes and buildings, 3D video, use of cloud for work and play, remote medical services, massive machine-to-machine communications for industry automation and Internet of Things (IoT). Therefore, there is a need to design an antenna with multiband functionality to cater for the various frequency demands of these smart devices. The aim of this study is to design a multiband rectangular microstrip patch antenna that will operate in 3.5 GHz especially for 5G application. The antenna must be small enough to fit inside small communication devices.

C. Review of Related Work

In 2019, [6] designed an elliptical Microstrip patch antenna that operates at 3.5 GHz band for 5G applications. Substrate was designed using a box having material FR4 EPOXY with dielectric constant (ε_r.=4.3) The size of the substrate was 25.2 × 48 mm with a height (h) of 1.6mm with respect to the z-axis. The ground plane is made at the bottom of the substrate which results in the coplanar waveguide structure. The outer box was designed using air material and assigned with radiation. CST microwave studio software was used to design and simulate the antenna. Results after simulation obtained resonating frequency of 3.5 GHz and return loss is -30 dB. The antenna had a gain of 5.01 dB and the efficiency of the antenna was -0.1478 dB or 96.67%.

[7] designed a microstrip rectangular patch antenna in ADS and HFSS for a resonant frequency of 4.1 using Glass Epoxy substrate (FR4) with dielectric constant (ϵr = 4.4), loss tangent (tan δ) equal to 0.02. Results obtained from the simulation showed a narrow bandwidth and an S11value of -19.5454 dB @4.4160 GHz. It was further optimized to increase the bandwidth. For optimization a goal function was put from the ADS tools palette into the circuit designed and the bandwidth increased to 2 GHz (from 3 GHz to 5 GHz) at a resonant frequency of 4.3 GHz with a return loss below -10 dB. The design was also simulated in HFSS, and the results obtained are a resonant frequency of 4.3 GHz, S11 of -30 dB and VSWR OF 1.6

[8] designed a Microstrip Patch Antenna for High Gain & Directivity at 3.5 GHz by Simulation studies using ADS for WiMax applications. The antenna was designed using Fr-4 dielectric material which has a dielectric constant of 4.6 and height of substrate taken as 1.6 mm. The results obtained are an S11 value of -19 dB and a bandwidth of about 20 MHz. A Rectangular Microstrip Patch Antenna was designed using stepped cut at four corners for Broadband/ Multiband application by [9]. Four stages were used for the proposed broadband rectangular microstrip patch antenna design. The first stage was a single mode rectangular microstrip patch antenna and by increasing steps at the corner of the patch antenna a dual band, multiband and broadband were obtained. By increasing the number of steps at the corner of the patch, the number of exited resonance frequencies increased. The corners' lengths and widths decreased at every stage as shown in figure 1.

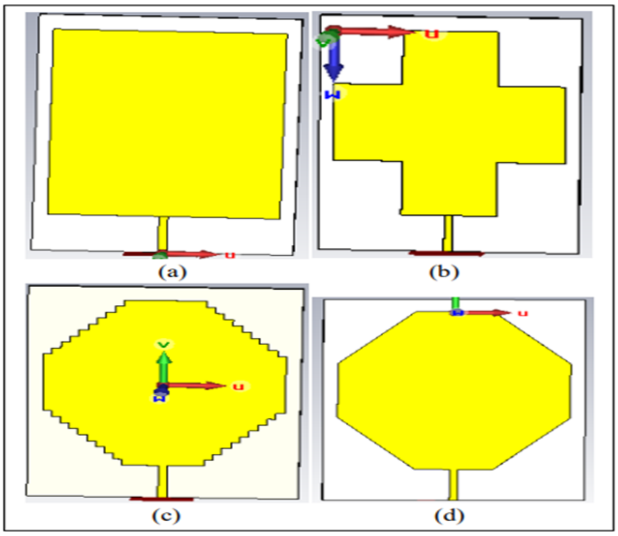


Figure 1. Designed Structure of Different Rectangular Microstrip Patch Antenna (RMPA) [6]

[10] proposed a 60 GHz millimeter wave micro strip patch antenna for high-speed wireless communication systems. The antenna was analyzed in the 50-70 GHz range using HFSS and an epoxy substrate whose dimensions were 8 mm x 8 mm × 0.5 mm and dielectric constant εr = 4.4. An antenna operating at 60 GHz having a bandwidth of 7 GHz (from 57 GHz to 64 GHz) was realized. Using electromagnetic band gap materials for surface wave suppression and in phase reflection the research showed that the electromagnetic band gap material produced a band gap frequency that prohibited the propagation of surface waves thereby enhancing the antenna gain, directivity, and multi-band operation. Results obtained showed a return loss of -33 dB and a bandwidth of 11 GHz.

[11] presented an approach for millimeter wave mobile communication antenna for 5G that works on 28 GHz and 38 GHz. ADS was used for the design and analysis of a 38 GHz micro strip antenna. The antenna consists of two rectangular patch elements using a single layer RT/Duroid substrate of thickness 2.124 mm and all calculations were done based on transmission line model. The S11 parameter in this analysis gave a value of -42.78 dB at a resonant frequency of 38.11 GHz and VSWR of 1.089. The peak gain and Directivity of 9.025 dB and 10.0336 dB respectively were obtained with a bandwidth of 1.27 GHz which is below the maximum of 10 dB. It was observed in this research that efficiency of the 1 × 1 array antenna (88.361%) is higher than that of a single patch antenna (77.63%).

[12] proposed an antenna that operates at dual band of 24.25 GHz and 38 GHz for wireless communication system. A RogersRT5880 type of substrate with thickness of 0.787 mm with relative permittivity Ɛr = 2.2 and tangent loss of 0.0009 was used. The patch of the antenna consists of copper material of dimensions 4.6 mm × 3.6 mm and thickness 0.035mm. The CST Microwave Studio Software was used to design, and result showed an antenna with gain value of 7.23 dBi at 24.25 GHz and 3.69 dBi at 38 GHz and an efficiency of 75%. The S11 values for 24.25 GHz and 38 GHz were -25.204 dB and -13.625 dB respectively.

[13] designed a single band micro strip patch antenna for 5G wireless communication that operates at 60 GHz using CST software. The substrate used was the RT5880 which has a dielectric constant of 2.2, a loss tangent 0.0009, and height 1.6 mm. A copper plate with dimensions of 8mm x 7.5 mm and thickness of 0.003 mm is used as the ground plane. The H and U slot cut on the patch help to enhance the impedance bandwidth, the length and width is 1.5 mm and 1.35 mm. Using an inset feed transmission line with length and width of 0.41mm and 3.25 mm for the design, the outcome of the result showed a return loss of - 41.648731 dB, a very wide bandwidth of 30 GHz, a gain of 8.82dB, VSWR of 1.8.

[14] reviewed various methods used to develop an antenna for mm-wave at 28 GHz, 38 GHz, and 60 GHz such as broadband designs, multiband designs, compact designs, circular polarization, increased directional design, reconfigurable designs, and array designs. The research showed that antennas that require a low profile can be made using a lower dielectric constant. The array designs, which come in the form of linear or planar MPAs, used two or more antennas combined to improve the performance such as increase in overall gain, provision of reception of diversity and determination of the incoming signals. Increased directivity designs use multilayer dielectric covered layer structure and increased patch dimensions to increase directivity. To increase bandwidth and directivity, the use of parasitic patch and air gap between the ground plane and the feed patch is employed. The research showed a gain approximately 56% higher than that of conventional rectangular patch antenna. Circular-Polarization designs radiate circular polarization with the use of single or multiple feeds where the single feeds are relatively easy to implement but have narrow axial bandwidths whereas the multiple feeds have a wider bandwidth but are more complicated to implement. Reconfigurable designs use reconfigurable or adaptive antennas, a method for improving spectrum use, and have capabilities for beam-steering, frequency tuning or polarization agility.

II. MATERIALS AND METHOD

A. Method

1) Microstrip Patch Antenna Design

This design was carried out using the High Frequency Structure Simulator (HFSS) software which is commercial finite element method solver used for electromagnetic structures. It is used for antenna design and the design of complex radio frequency electronic circuit elements such as filters, transmission lines and packaging.

Dimensions of a microstrip patch are calculated using the equations from established antenna theory [8], [15]:

The wavelength, λ is calculated using

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

Where c is the velocity of light (3×10^8m/s), and f_r is the resonant frequency.

The width of the microstrip patch was calculated using equation (2).

$$W_p = \frac{c}{2f_r}\sqrt{\frac{2}{(\varepsilon_r\ +1)}} \tag{2}$$

where W_p is the width of the patch

c is the velocity of light ($3\text{x}10^8$m/s)

$f_r$is the resonant frequency

$\varepsilon_r$is Relative permittivity of the substrate

The length of the microstrip patch $L_p$is calculated using equation (3).

$$L_p = L_{eff} - 2\Delta L \tag{3}$$

WhereL_{eff} is the Effective length of the antenna and is given as [15]:

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \tag{4}$$

Where ε_{reff} is Effective dielectric constant, given as [14], [16]:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+\frac{12h}{W}\right]^{-\frac{1}{2}} \tag{5}$$

Due to fringing effect, the normalized extension in length,ΔL , which is given by change in dimension of length is given as [19]-[22]:

$$\Delta L = 0.412\text{h}\,\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \tag{6}$$

Where W is the width of the patch and h is the height of the substrate.

The length and width of the substrate were determined using equations (7) and (8) [14]:

$$L_g = \text{L}+6h \tag{7}$$

$$W_g = \text{W}+6h \tag{8}$$

Where L_g and W_g are length and width of substrate and h is determined using equation (9).

$$h_i = \frac{0.0606\lambda}{\sqrt{\varepsilon_r}} \tag{9}$$

A microstrip feed line was used to feed the patch which is the radiating element. The input impedance of the microstrip patch, Zp was calculated as [22]:

$$Z_p = \frac{90\times(\varepsilon_r)}{\varepsilon_r-1}\times\left(\frac{L_p}{W_p}\right)^2 \tag{10}$$

Where L_p is the length of the microstrip patch and W_p is the width of the microstrip patch.

The characteristic impedance of the transmission section is given as [22]:

$$Z_t = \sqrt{(Zo\times Zp)} \tag{11}$$

Given the characteristic impedance of the microstrip line as 50 Ω, the width of the feed line was calculated using equation (13).

$$W_f = \frac{8he^A}{e^{2A}-2}\ \text{For W} \leq 2\text{h} \tag{12}$$

Where $\text{A} = \frac{Zp}{60}\times\surd(\frac{Er+1}{2}) + \frac{Er-1}{Er+1}\,(0.23 + \frac{0.11}{Er}\ )$ and h is the thickness of the substrate.

The length of the 50Ω microstrip feed line L_f was calculated using equation (13).

$$L_f = \frac{\lambda g}{4} \tag{13}$$

Where λg is the guided wavelength and is given by [23]-[30]:

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{reff}}}\frac{Z_0}{Z_t} \tag{14}$$

Since the characteristic impedance of the microstrip patch does not match the 50 Ω characteristic impedance of the microstrip feed line, the inset line feed method was chosen for this design for proper impedance matching and Zt is the impedance for the transmission line.

To use the inset line feed method, the recessed distance (that is the length cutting into the patch), was calculated using equation (15) [31]-[37]:

$$Z_O\ (\text{y} = Y_O) = Z_t\ (\text{y}=0)\ cos^2\left(\frac{\pi}{L}\times Y_O\right) \tag{15}$$

$$\text{Where } Y_O = \frac{L}{\pi}cos^{-1}\left(\surd\left(\frac{Z_0}{Z_t}\right)\right) \tag{16}$$

The geometry of the patch antenna designed is as shown in figure 2.

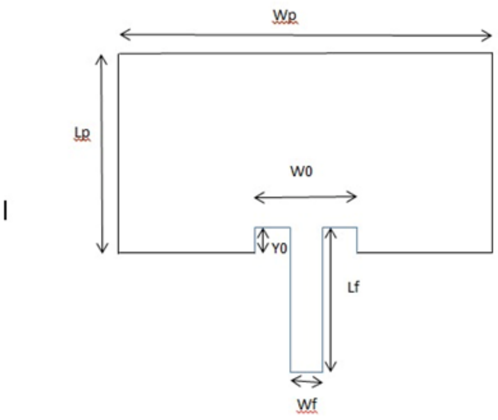


Figure 2. Geometry of the Designed Microstrip Patch Antenna

To carry out the simulation with the HFSS simulator using the calculated values, the ground plane was created using the rectangle tool. The patch was also created on the substrate using the rectangle tool and a feedline was also created using the rectangle tool and then united to the patch. Using a rectangle tool, a rectangle was created on the patch and then it was subtracted from the patch to create the inset and a port was created at the end of the feed line in the zy direction.

The Rogers RT/Duroid 5880 with dielectric permittivity of 2.2 material was assigned to the substrate and a radiation box was created and a frequency sweep set up was added under solution set up and a far field setup was also added under radiation and the Phi and Theta angles added too.

The validation function was used to validate the design, a command was issued for the simulation to start, and results were then obtained. At the edge of the microstrip patch, the impedance Zp is 255.2253 and the characteristic impedance of the microstrip line is 50 Ω. Without an inset, the microstrip line would meet the patch at a point where both impedances do not match. At the center of the patch, the impedance decreases.

The simulation was done in two different ways as described below:

1. The microstrip patch was simulated without an inset as shown in figure 3.

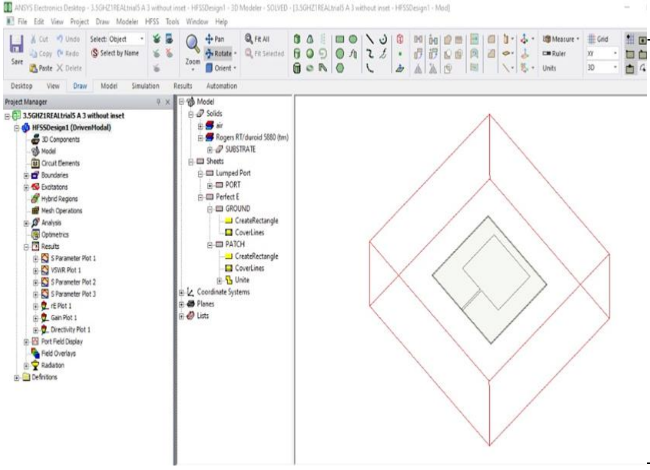


Figure 3. Isometric View of Microstrip Patch Antenna without Inset

2. The microstrip patch antenna was simulated with an inset as shown in figure 4.

To match the impedance of the feedline to the patch without the need for any additional matching element an inset was introduced in the design.

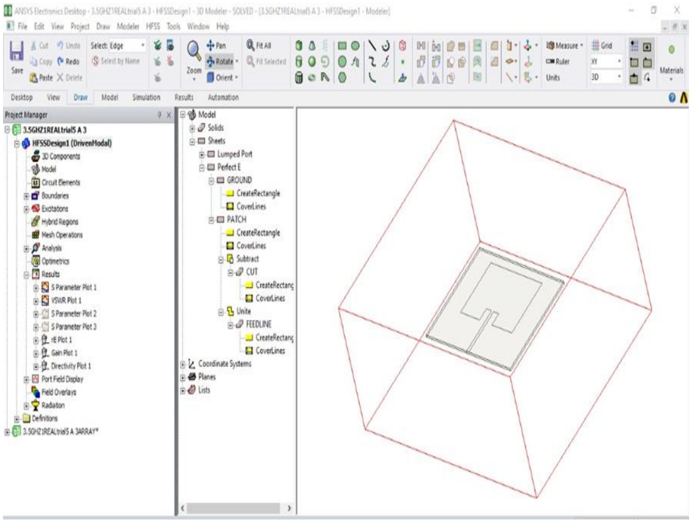


Figure 4. Isometric View of Microstrip Patch Antenna with an Inset

2) *Optimization Process for Design with Inset*

When the simulation was carried out with the calculated values, resonating frequencies of 3.42 GHz, 5.83 GHz, 9.12 GHz and 12.11 GHz were obtained. The optimization process was carried out to obtain the desired resonating frequencies and improve the impedance match of the microstrip patch antenna. Different parameters as input were changed at different times and analyzed. It was carried out in several steps to arrive at the desired output by adjusting the length and width of the mircostrip patch, the inset, and the feedline. The use of an inset feed method is a way of locating the recessed distance. This is the point at which the microstrip strip line impedance matches the microstrip patch impedance which give an improved S11 parameters and VSWR values as compared to [26], [27], and [28]. Table 1 shows the parameters used for the antenna design.

Table 1
Parameters Used for the Design

Description	**Calculated Values (mm)**	**Design without Inset(mm)**	**Design with Inset (mm)**	**Values After Optimization**
W_g	54.8935	54.895	54.895	54.8935
L_g	49.4220	49.420	49.420	49.4220
W_s	54.8935	54.895	54.895	54.8935
L_s	49.4220	49.420	49.420	49.4220
h	1	1	1	1
W_p	33.8815	33.88	33.88	33.5
L_p	24.4100	24.410	24.410	28.2
W_f	0.0332	0.0332	0.0332	1.14
L_f	14.7325	20.44	20.435	23.05
Y_o	10.0586	-	10.056	8
W_o	6.7764	-	6.7764	6.4
ε_r	2.2	2.2	2.2	2.2
Z_0	50	50	50	50
Z_p	255.223	255.23	255.23	255.2253

W_g is the width of the ground plane, L_g is the length of the ground plane, W_s is the width of the substrate, L_s is the length of the substrate, h is the height of the substrate, W_p is the width of patch, L_p is the length of patch, W_f is the width of the feedline, L_f is the length of the feedline, Y_o is the inset length, W_o is the inset width, ε_r is the dielectric permittivity, Z_0 and Z_p are the characteristics impedance of the microstrip line and the patch respectively.

III. RESULTS AND DISCUSSION

A. Microstrip Patch Antenna Design without an Inset Feed

Using the calculated values, the Microstrip Patch antenna was designed and simulated on a structure without an inset fed and the results of S11 parameter and VSWR values obtained are shown in figures 5 and 6 respectively while the resonating frequencies are shown in table 2.

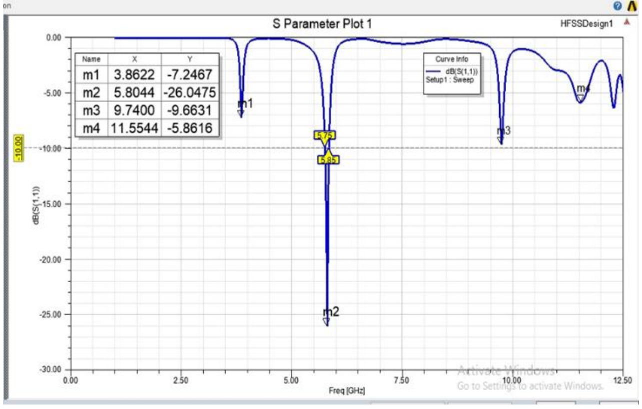


Figure 5. S11 Values for Design without an Inset

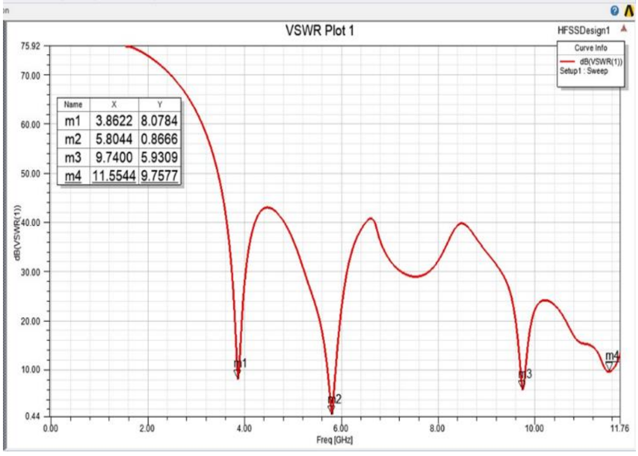


Figure 6. VSWR Values for Design without an Inset

Table 2.
Resonating Frequencies for Design without an Inset

Frequencies (GHz)	S11(dB)	VSWR
3.86	-7.26	8.0784
5.80	-26.0475	0.8666
9.74	-9.6631	5.9309
11.5544	-5.8616	9.7577

Table 2 shows that the desired resonating frequency of 3.5 has not been achieved and the values of S11 and VSWR shows that the reflection is very high which means that the antenna will not radiate properly.

B. Microstrip Patch Antenna Design with an Inset Feed

The Microstrip patch antenna was designed using an inset feed method to provide a better antenna impedance match. The introduction of an inset feed showed resonant frequencies and S11 values as shown in as shown in figure 7 below. The results show values of frequencies and S11 obtained which indicate that the desired resonant frequencies and impedance match needs to be improved.

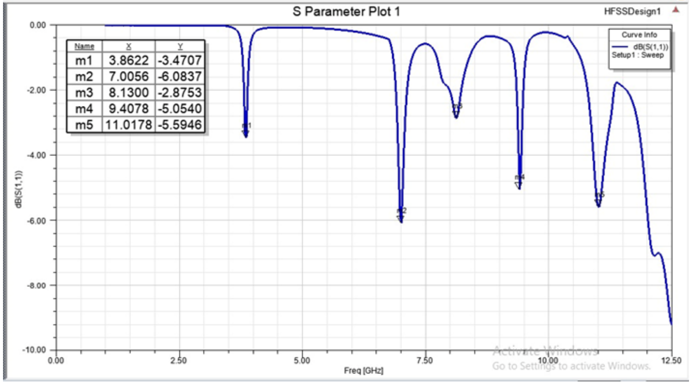


Figure 7. Microstrip Patch Antenna Design with an Inset Feed

C. Optimization Result

The optimization goal was set to achieve the desired frequency and improve the impedance match of the network. Different parameters as input were changed at different times and analyzed which involved several steps to arrive at the desired output. During the optimization process, frequency at 3.86 GHz was reduced to 3.50 GHz by increasing the patch length. By changing the values of the length and width of the cut out (W_o, Y_o) , width of the feedline (W_f), a good mpedance match was achieved as shown on tables 3 through 5.

Table 3
Optimization from step 1 to Step 3

		Step 1		Step 2		Step 3	
		W_p= 33.7		W_p=33.6 and W_f = 0.2		L_p = 26	
Freq	S11	Freq	S11	Freq	S11	Freq	S11
3.86	-3.4	3.86	-7.26	3.88	-2.76	3.76	-5.82
7.00	-6.08	5.80	-26.04	5.90	-8.97	5.90	-9.05
9.40	-5.05	9.74	-9.66	7.13	-11.98	6.95	-5.96
1.01	-5.59	11.55	-5.86	8.05	-6.04	7.87	-8.17
8.13	-2.87			9.68	-6.09	9.68	-2.5
				11.06	-10.25	10.60	-7.15

Table 4.
Optimization from step 4 to Step 6

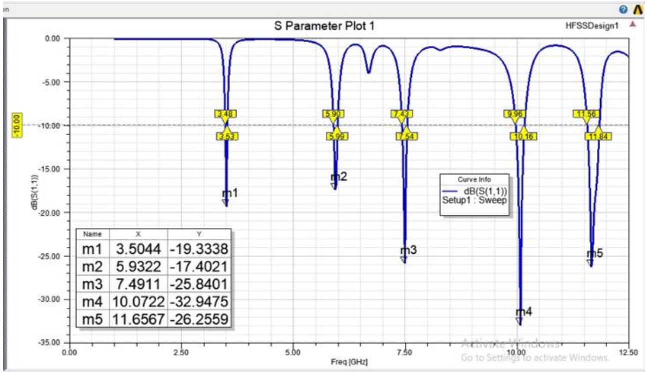
Step 4		**Step 5**		**Step 6**	
L_p = 28.2		W_f = 1		W_f = 1.2	
Freq	S11	Freq	S11	Freq	S11
3.53	-6.24	3.53	-19.10	3.53	-21.39
5.90	-11.42	5.90	-16.54	5.90	-13.43
6.64	-3.10	6.62	-8.50	6.62	-10.23
7.67	-9.22	7.67	-18.15	7.69	-17.61
10.02	-17.45	9.94	-20.47	9.94	-15.78
11.58	-8.85	11.70	-21.88	11.70	-20.86

Table 5.
Optimization from step 4 to Step

Step 7 (final optimization stage)

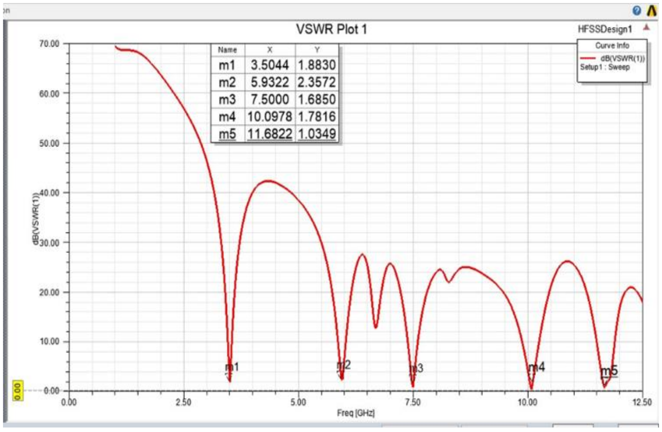
W_o=8, Y_o = 6.4 and W_p= 33.5	
Freq	S11
3.50	-19.33
5.93	-17.40
7.49	-25.84
10.07	-32.94
11.65	-26.25

With the introduction of an inset feed and the application of optimization process, the desired frequencies of 3.5 GHz, 5.9 GHz, 7.49 GHz, 10.07 GHz and 11.65 GHz were obtained. The result of the S11 parameter is shown in figure 8, the VSWR result is shown in figure 9 while the frequencies obtained after optimization are shown in table 6.



Name	X	Y
m1	3.5044	-19.3338
m2	5.9322	-17.4021
m3	7.4911	-25.8401
m4	10.0722	-32.9475
m5	11.6567	-26.2559

Figure 8. S11 Parameters for Design with Inset



Name	X	Y
m1	3.5044	1.8830
m2	5.9322	2.3572
m3	7.5000	1.6850
m4	10.0978	1.7816
m5	11.6822	1.0349

Figure 9. VSWR Values for Design with Inset

Table 6.
Frequencies Obtained After Optimization

Frequencies (GHz)	S11(dB)	VSWR
3.5044	-19.3338	1.8830
5.9322	-17.4021	2.3572
7.4911	-25.8401	1.6850
10.0722	-32.9475	1.7816
11.6567	-26.2559	1.0349

D. Radiation Pattern, Gain and Efficiency

The energy radiated by the antenna is represented by its radiation pattern with a maximum value of 25.5 as shown in figure 10. The intensity of the colour is equal to the energy level.

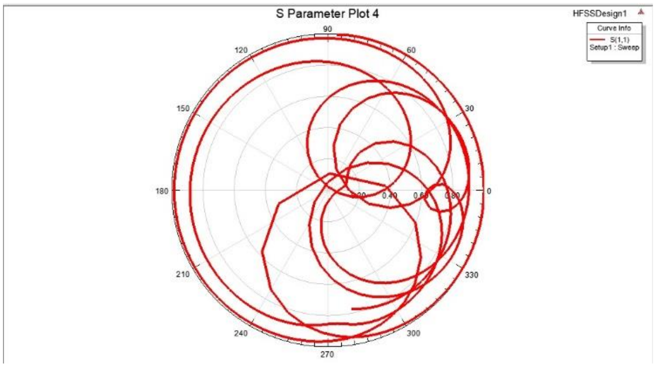


Figure 10. Radiation Pattern for Microstrip Patch Antenna Design

The radiation efficiency of the antenna is recorded as 0.98209. This shows that the designed antenna can radiate 98.209% of power delivered at its input. The antenna peak realized gain is 5.9755 and it describes the strength of the signal that is transmitted in the direction of the peak radiation. In figure 11, the maximum gain is 7.8 dB while the minimum gain is -27.1 dB.

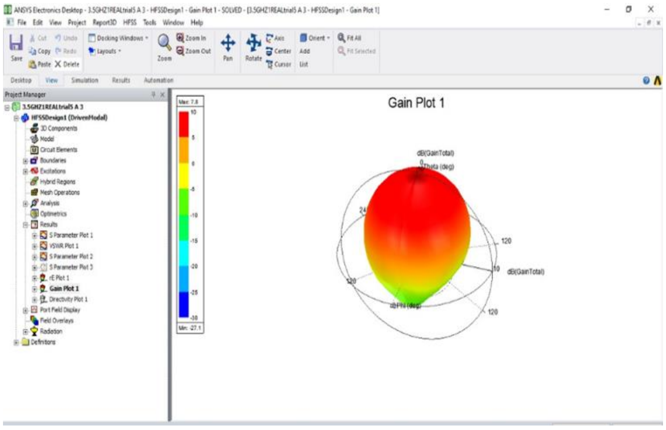


Figure 11. Gain Plot for Microstrip Patch Antenna Design

E. S11 Parameter and VSWR

The results obtained from the simulation showed that without an inset feed the antenna would not be properly matched which will in turn cause the antenna having high reflections thereby producing less radiation. Table 2 showed high values of VSWR indication high antenna impedance mismatch. The feedline connected to the microstrip patch has an impedance of 50 ohm while the microstrip patch has an impedance of 255.2 ohm. For the antenna to have proper impedance match the feedline must be connected to a point on the microstrip patch where the impedance is 50 ohm. The results show that the point is at Yo equal to 6.4 mm. The ideal value of VSWR for an antenna that is properly matched is less than 2. Results of the designed microstrip patch antenna shows that four out of five resonating frequencies have VSWR values that are below 2. Table 7 shows the amount of power that is been reflected from the different antenna designs. The results show the effect of having a good impedance match for the antenna. It can be observed that antenna without an inset has high reflected power because of poor antenna impedance match. Introducing an inset in the antenna design resulted in an antenna with a better performance as seen in the improvement of S11 and VSWR values. Antenna design with an inset has a better impedance match which can be seen from the percentage of power reflected. It recorded a forwarding power up to 99.98%. With very little reflection it can deliver more power to the load. the bandwidths of the designed antenna are 50 MHz, 90 MHz, 110 MHz, 200 MHz, and 280 MHz respectively as shown in table 8. The bandwidths of microstrip patch antennas are known for their small size due to the nature of their resonant nature.

F. Comparative Analysis

Different works on Microstrip patch antennas have been compared with this research work with results ranging from frequency, gain, feed type, S11, VSWR, etc. This proposed antenna design was able to achieve up to five frequencies with good VSWR values of below 2 and forwarding power up to 99.98%. This proposed multiband frequency antenna can easily capture signals with more bands as compared to others in the literature.

The antenna designed in this work is miniaturized which is an advantage for smaller devices and suitable for 5G applications. Table 7 shows the Comparison of S11, VSWR, Return Loss, Reflected Power and Forward Power for design without inset and design with inset.

Table 7. Comparison of S11, VSWR, Return Loss, Reflected Power and Forward Power for design without inset and design with inset.

Frequencies (GHz)	Inset Length	S11 (dB)	VSWR	Return Loss (dB)	Reflected Power (%)	Forward Power (%)	Bandwidth (GHz)	Range
DESIGN WITHOUT INSET	-							
3.86		-7.26	8.07	2.16	60.76	39.24	-	
5.80		-26.04	0.86	-	-	-	0.10	5.75 - 5.85
9.74		-9.66	5.93	2.96	50.61	49.39	-	-
11.55		-5.86	9.7577	1.79	66.25	33.75	-	-
DESIGN WITH INSET								
3.50	6.4	-19.33	1.88	10.30	9.34	90.66	0.05	3.48 - 3.53
5.93		-17.40	2.35	7.89	16.24	83.76	0.09	5.90 - 5.99
7.49		-25.84	1.68	11.91	6.44	93.56	0.11	7.43 - 7.54
10.07		-32.94	1.78	11.04	7.87	92.13	0.2	9.96 - 10.16
11.65		-26.2559	1.03	36.61	0.02	99.98	0.28	11.56 - 11.84

Table 8 Bandwidth

Frequency (GHz)	Gain (dB)	Feed Type	Design Type	S_{11} (dB)	VSWR	Antenna Size(mm)
3.50	5.9755	Inset Feed	Multiple band antenna	-19.33	1.88	33.5 X 28.2
5.93				-17.40	2.35	
7.49				-25.84	1.68	
10.07				-32.94	1.78	
11.65				-26.25	1.03	

IV. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

In this work, a multi band rectangular microstrip patch antenna operating between 3.5 GHz and 12 GHz was designed using Rogers RT/Duroid5880 as substrate and simulated using High Frequency Structure Simulator (HFSS). The dimensions used for the design were calculated using standard equations for microstrip patch antennas. The results were optimized and five resonating frequencies of 3.5 GHz, 5.93 GHz, 7.49 GHz, 10.07GHz and 11.65 GHz and bandwidth of 50 MHz, 90 MHz, 110 MHz, 200 MHz and 280 MHz respectively were obtained.

The multiband antenna was analyzed in HFSS using the S parameter, VSWR, return loss and reflected power as a measure of the performance of the antenna. The VSWR values were below 2 which indicate very reflection and the forwarding power up to 99.98%.

The proposed antenna will be resonating at high frequency in the millimeter wavelength, with a miniaturized size and high gain making it suitable for 5G applications.

B. Contribution to Knowledge

i. In this work, a multi band rectangular Microstrip patch antenna that can easily capture signals up to 5 frequency bands of 3.5 GHz, 5.93 GHz, 7.49 GHz, 10.07 GHz, and 11.65 GHz was designed as shown in table 6 which shows an improved from the existing literature.

ii. Proper impedance matching for the rectangular Microstrip patch antennas which resulted in high forwarding power was also achieved and this has not been reported in the existing literature.

iii. The VSWR values which indicated that impedance was properly matched are 1.88, 2.35, 1.68, 1.78, and 1.03 with forwarding powers of 90.66%, 83.76%, 93.56%, 92.13% and 99.98% respectively.

C. Recommendations

More research work on this antenna design to improve the bandwidth and for future applications.

Having designed an antenna operating at five frequency bands, it is therefore recommended that further research should be carried out to design an antenna that can operate up to 10 frequency bands

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