Nigerian Journal of Engineering, Vol. 28, No. 2, August 2021, ISSN (print): 0794 – 4756, ISSN(online):2705-3954.

Nigerian Journal of Engineering,
Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria
journal homepage: www.njeabu.com.ng

Design and Analysis of a Rectangular Microstrip Patch Antenna using Different Dielectric Materials for Sub-6GHz 5G Applications

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Research Article

Abstract

Different designers used different substrate materials to design sub-6GHz 5G antennas, therefore, it becomes imperative to carry out different investigations and analysis on the common available substrate materials so as to serve as a research guide for the future antenna designers. In this paper, a comparative study was presented on inset feed rectangular microstrip patch antenna using five different substrate materials, namely; the RT Duroid 5880, FR4 glass epoxy, Taconic TLC-32, Rogers RO4003C and Bakelite at 6GHz operation frequency with a 1.5mm substrate thickness for sub-6GHz 5G applications. All the performance parameters like the VSWR, return loss, bandwidth, directivity, gain and the efficiency were analyzed and investigated using Computer Simulation Technology (CST) studio suit 2016. The RT Duroid antenna present the highest radiation efficiency of 81% with an optimal gain and directivity of 5.934dB and 7.783dBi respectively, while the FR4 antenna gives the highest bandwidth and return loss of 318.5MHz and -31.320dB respectively. The best compact size of 10.90x14.68mm and a perfect match with VSWR of 1.0 was achieved by the Bakelite antenna. The RO4003 and TLC antennas maintained an average performance in between. it can be concluded that, for the designers that want a high gain, high directivity and high efficiency, should go for the RT Duroid substrate material while for those that need high bandwidth and high return loss, should go for the FR4 antenna and for a compact size, the Bakelite antenna should be given preference over the rest.

Keywords
5G; Dielectric Constant; Loss Tangent; MPAs; Sub-6GHz; Substrate Material.

Article History
Received: – Janaury, 2021
Reviewed: – July, 2021
Accepted: – August, 2021
Published: –August, 2021

1. Introduction

The cellular communication trends are in constant revolutions over these few years, starting from first generation (1G) to the fifth generation (5G). These wireless mobile communication standards are the major contributors of the wireless communication evolutions, each of these communication generation trends have its own various wireless technologies, spectrums, speed, modulation techniques, data rates and also some shares some unique features together (Anon., 2019).

The Third-generation Partnership Project (3GPP) describe any system that is using 5G New Radio (5G-NR) systems as 5G network. And also, from the International Mobile Telecommunication (IMT)-2020 release 15 of the International Telecommunication Union, Radiocommunication Sector (ITU-R), the 5G network uses two set of frequency bands described as the frequency range 2 (FR2) otherwise known as the millimeter wave range and the frequency range 1 (FR1) otherwise known as the sub-6GHz (Dilli, 2020). The 5G technology is expected to be efficient with high data rate, good quality of service (QOS) and high traffic intensity (Colaco & Lohani, 2021). The 5G Sub-6GHz attracted so much attention than the millimeter wave due to its compatibility with the existing 3G and 4G backbone networks, it can also cover a very long distance and are not easily hindered by an obstacles even with advancements of beam forming (Olawoye & Kumar, 2020).

A micro strip patch antenna is the perfect candidate for this application due to its several attractive properties such as low profile, ease of fabrication, low cost, light weight, easy to feed, easy to use in an array among others (Sohail, *et al.*, 2019). Some of their applications includes at the aircrafts, satellite communications, missiles, cellphones, telemedicine, radar, GPS, and biomedical systems (Trikolikar, 2008). Micro strip patch antenna is a type of antenna that has a radiating patch on one side of the dielectric substrate with a ground plane on the other side and a substrate material in between which is used to provide mechanical support, and also, it is used to maintain the required precision spacing between the patch element and its ground plane (Rop & Konditi, 2012).

In (Ahamed, *et al.*, 2012), a rectangular microstrip patch antennas (MPA) on different substrate materials for passive wireless communication was designed and analyzed with a resonance frequency of 2GHz and simulated using a MATLAB simulator. The best performance parameters were achieved by using the RT-Duroid substrate material with a dielectric constant of 2.32, that produced a radiation efficiency of 91.99% and a directive gain of 4.98dBi. Analysis on the performance of a rectangular MPA on different dielectric materials was conducted in (Rop & Konditi, 2012). It was observed that, the bandwidth is highly affected by the dielectric substrate material used in its design, which indicates that, a higher bandwidth can be achieved by using a thicker substrate material with a lower dielectric constant value. And also, in (Mumputua, *et al.,* 2019) the effects of dielectric materials on patch antenna were studied at 2.4GHz resonance frequency for Wi-Fi and Bluetooth applications using Rogers RT5870 (tm), FR4 proxy, Duroid (tm), Polyester and Foam with a High Frequency Structural Simulator Ansoft (HFSS) and all the performance parameters of the antennas were studied and investigated using the performance indicators. And finally, (Alkhafaji, et al., 2020) being the most latest work, studied the effect of substrate material and its thickness on the performance of filtering antenna using RT/Duroid 5880, RO3003, and FR-4 with a CST software at 2.412GHz operation frequency. An analytical comparison of the performance parameters of the filtering antenna were studied and investigated for wireless local area network (WLAN) applications.

In wireless communication today, most of its applications requires a compact microstrip antenna designs with a high-performance parameter. In antenna designs, the antenna substrate materials are one of the best options to reduce the antenna size and to increase its performance. But to overcome this, there is an urgent need to study and investigate all the available substrate materials and also to test and use all the newly developed ones in order to achieve an optimal antenna designs since the substrate materials are not found naturally but rather developed in laboratories with a negative refractive index. There are large numbers of newly developed substrate but not all are being used in antenna designing today. In this work, five different conventional microstrip patch antennas using five different dielectric materials were designed, simulated and investigated with CST studio suit 2016 at 6GHz operating frequency with 1.5mm substrate thickness for all the five antennas designed for Sub-6GHz applications.

1.1 Properties of the Dielectric Materials

The five antennas are designed using the most common commercially available substrate materials, which are; the FR4 glass epoxy, RT-Duroid 5880, Bakelite, Taconic TLC-32 and Rogers RO4003C respectively (Rop & Konditi, 2012).

1.1.1 FR-4 Gloss Epoxy

The FR-4 glass epoxy is a common substrate material that has a high-pressure thermo set plastic laminate grade with excellent strength to weight ratios. The FR-4 has dielectric constant of 4.3 and a loss tangent (tanδ) of 0.025 as loaded from the CST software (Islam, *et al*., 2016).

1.1.2 Bakelite

The Bakelite is an electrical insulator which is one of the common available substrate materials which is an early plastic, otherwise known as polyoxybenzylmethylenglycolanhydride. It has a dielectric constant of 4.8 and a loss tangent of 0.03045 as loaded from the CST software (Islam, et al., 2016).

1.1.3 RT-Duroid 5880

The RT-Duroid is one of the most widely used substrate material among the five substrate materials due to it is excellent chemical resistance, ease of fabrication and environment friendly. It has a dielectric constant of 2.2 and a loss tangent of 0.0004 as loaded from the CST software (Alkhafaji, *et al*., 2020).

1.1.4 Taconic TLC-32C

Among the five substrate materials used, the Taconic TLC is the cheapest substrate material that is specifically design to meet the objectives of the newly emerging commercial Radio Frequency (RF) and microwave applications. It has a dielectric constant of 3.2 and a loss tangent of 0.003 as loaded from the CST software (Alkhafaji, et al., 2020).

1.1.5 ROGERS RO4003C

The RO4003 is described as the RO4003 Series High Frequency Circuit Materials which are glass reinforced hydrocarbon or ceramic laminates that are designed to have high sensitivity and high volume for commercial applications. It has a dielectric constant of 3.38 and a loss tangent of 0.0027 as loaded from the CST software (Islam, *et al., 2016)*.

For each of the five antennas designed, the antenna model parameters vary due to the use of different dielectric constants. A summary of the different properties of the dielectric substrates are summarized and presented in Table 1 below (Khan & Nema, 2012).

Table.1 Properties of the Different Substrate Materials

Parameters	**Bakelite**	**FR4 Glass Epoxy**	**RO4003C**	**Taconic TLC**	**RT Duroid 5880**
Dielectric constant	4.8	4.3	3.38	3.2	2.2
Loss tangent	0.03045	0.025	0.0027	0.003	0.0004
Water absorption	0.5 - 1.3%	< 0.25%	0.06%	< 0.02%	0.02%
Tensile strength	60 MPa	310MPa	141 MPa	-	450 MPa
Breakdown voltage	20-28 kV	55 kV	<50kv	50kv	> 60 kV
Peel strength	8N/mm	9 N/mm	1.05 N/mm	12 N/mm	5.5 N/mm
Density	1810 kg/ m ^{3}	1850 kg/m^3	1790 kg/m^3	1820kg/m	2200 kg/m^3
Thermal conductivity	0.2 w/m-k	0.29 w/m-k	0.95 w/m-k	0.24 w/m-k	w/m-k

2. Antennas Design

The legitimate choice of a dielectric material is exceptionally subject to its relative dielectric constant or permittivity, height of the substrate material and the loss Tangent (Ramli, Khan Noor, Khalifa, & Abd Rahman, 2020). The micro strip antennas can be designed using different shapes but the most widely used among them are the rectangular and square micro strip patch antennas, in this paper, a rectangular microstrip patch antenna with an inset feed microstrip feed line was used as presented in figure 1 below

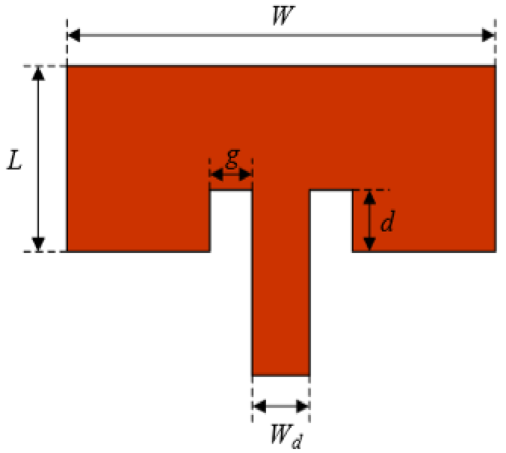


Figure1. Inset feed micro strip patch (HİÇDURMAZ & GÜMÜŞ , 2019).

Where

g= notch width / inset width/gap width.
d= inset depth.
Wd= Width of the feedline.
Wp= width of the patch.
Lp= Length of the patch.

The effective dielectric constant (ϵ_{reff}) is introduced to account for the fringing and the wave propagation in the line. It can also be defined as the dielectric constant of the uniform dielectric material with a value range of 1≤ ϵ_{reff}≤ϵ_r (Balanis, 2005).

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}]\right]^{-\frac{1}{2}} \qquad (1)$$

Where ϵ_{reff} is the effective dielectric constant due to the fringing filed at the edge of the antenna (HİÇDURMAZ & GÜMÜŞ , 2019).

ϵ_r is the dielectric constant

h is the height (thickness) of the substrate material and it was taken to be 1.5mm.

W is the width of patch.

The length extension is calculated as follows (Balanis, 2005).

$$\Delta L = 0.412h\frac{(\epsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \qquad (2)$$

Where ΔL is the length extension due to the fringing field (HİÇDURMAZ & GÜMÜŞ , 2019). Due to the above length extension, the effective length is calculated as follows (Balanis, 2005).

$$L_{eff} = L + 2\Delta L \qquad (3)$$

Where L is the actual length of the patch, while L_{eff} is the effective length, This implies that,

$$L_{eff} = \frac{c}{f_o\sqrt{\epsilon_{eff}}} \qquad (4)$$

Therefore, the actual length of the patch can be calculated using the equation below.

$$L = \frac{c}{f_o\sqrt{\epsilon_{eff}}} - 2\Delta L \qquad (5)$$

The patch width is giving as follows (Gurpreet Kaur, 2016).

$$W = \frac{C}{2f_o\sqrt{\frac{(\epsilon_r + 1)}{2}}} \qquad (6)$$

Where c is the velocity of light, a constant whose value which is $3X10^8 m/s$.

$f_o = 6GHz$ *which* is the frequency of operation.

The dimensions of the ground plane are calculated as follows. (Jin, Deng, Xu, Yang, & Liao, 2020)

$$L_g = 6h + L \qquad (7)$$

$$W_g = 6h + W \qquad (8)$$

Where L_g is the length of the ground plane, while W_g is the width of the ground plane.

Finally, the feedline length (L_f) is giving as; (Jin, Deng, Xu, Yang, & Liao, 2020)

$$L_f = \frac{\lambda_o}{4\sqrt{\epsilon_r}} \qquad (9)$$

Where λ_o is the wavelength of a free space, and is calculated as, $\lambda_o = \frac{c}{f_o}$

Based on the above mathematical model equations (eqaution (1) to (9)), the antennas design parameters were calculated and presented in Table 2 to 6 respectively.

Using the mathematical model eqautions developed above from equation (1) to (9), the dimensions of the design parameters of FR-4 antenna was calculated and tabulated in Table 2 below.

Table 2; Design Parameters of FR-4 Glass Epoxy Antenna

Design Parameters	Corresponding Values (mm)
Width (W)	16
Length (L)	11.50
Feed line Length (Lf)	6.44
Feed line Width (Wf)	4
Inset Depth/Gap depth (d/Fi)	4.2
Feed line Gap (Gpf)	0.3
Copper thickness (Mt)	0.035
Ground Width(wg)	24
Ground Length (lg)	20

Using the mathematical model equations developed above from equation (1) to (9), the dimensions of the design parameters of Bakelite antenna was calculated and tabulated in Table 3 below.

Table 3; Design Parameters of Bakelite Antenna

Design Parameters	Corresponding Values (mm)
Width (W)	14.68
Length (L)	10.90
Feed line Length (Lf)	6.12
Feed line Width (Wf)	3.64
Inset Depth/Gap depth (d/Fi)	4.14
Feed line Gap (Gpf)	0.3
Copper thickness (Mt)	0.035
Ground Width(wg)	22.96
Ground Length (lg)	20.18

Using the mathematical model equations developed above from equation (1) to (9), the dimensions of the design parameters of RT-Duroid antenna was calculated and tabulated in Table 4 below.

Table 4; Design Parameters of RT Duroid 5880 Antenna

Design Parameters	Corresponding Values (mm)
Width (W)	20
Length (L)	16
Feed line Length (Lf)	8.7
Feed line Width (Wf)	2.91
Inset Depth/Gap depth (d/Fi)	6.12
Feed line Gap (Gpf)	0.22
Copper thickness (Mt)	0.035
Ground Width(wg)	27.53
Ground Length (lg)	32

Using the mathematical model equations developed above from equation (1) to (9), the dimensions of the design parameters of Rogers R04003C antenna was calculated and tabulated in Table 5 below.

Table 5; Design Parameters of Rogers RO4003c Antenna

Design Parameters	corresponding values (mm)
Width (W)	16.80
Length (L)	12.97
Feed line Lengt h (Lf)	7.18
Feed line Width (Wf)	4.45
Inset Depth/Gap depth (d/Fi)	4.95
Feed line Gap (Gpf)	0.3
Copper thickness (Mt)	0.035
Ground Width(wg)	26.79
Ground Length (lg)	22.87

Using the mathematical model equations developed above from equation (1) to (9), the dimensions of the design parameters of Taconic TLC antenna was calculated and tabulated in Table 6 below.

Table 6: Design Parameters of Taconic TLC-32 Antenna

Design Parameters	Corresponding Values (mm)
Width (W)	17.04
Length (L)	13.32
Feed line Length (Lf)	7.38
Feed line Width (Wf)	4.65
Inset Depth/Gap depth (d/Fi)	5.07
Feed line Gap (Gpf)	0.3
Copper thickness (Mt)	0.035
Ground Width(wg)	27.39
Ground Length (lg)	23.46

The CST studio suite 2016 was used to design and simulate all the five microstrip patch antennas at 6GHz resonant frequency with a substrate height of 1.5mm for all the five antennas designed as shown in Figure 2 below.

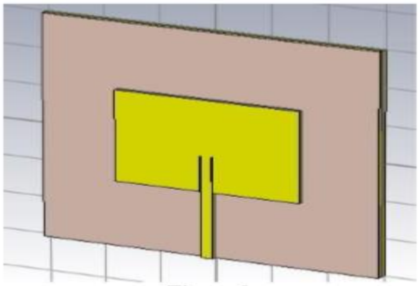


Figure 2. designed rectangular microstrip patch antenna at 6GHz.

3. Results and Analysis

The results of the antenna performances were expressed using the antenna performance indicators which includes the return loss, radiation efficiency, VSWR, gain and the bandwidth for all the five antennas designed at 6GHz. The return loss graphs obtained for these designs are shown in Figures 4a, 4b, 4c, 4d and 4e respectively.

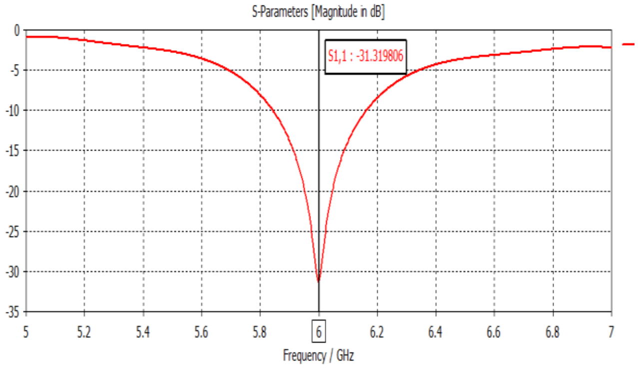


Figure 4a: The return loss graph for FR4 Antenna.

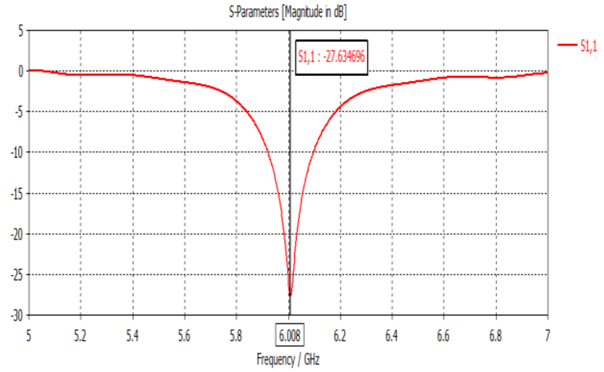


Figure 4b: The return loss graph for Bakrlite Antenna

Figure 4a and Figure 4b shows the simulated results of FR4 and Bakelite antenna with the return loss values of -31.3200dB and -27.634696dB respectively, at 6GHz resonant frequency.

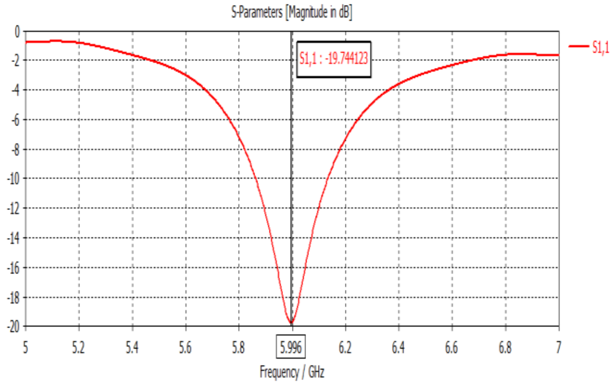


Figure 4c: The return loss graph for TLC Antenna.

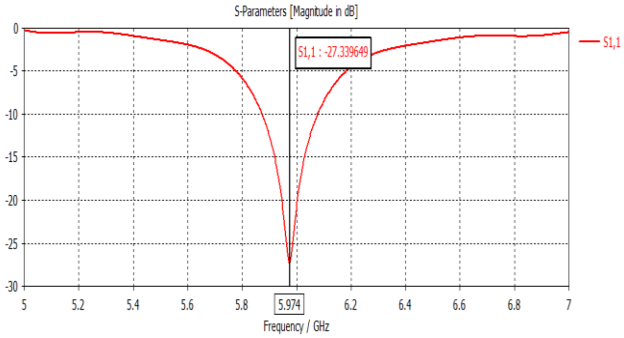


Figure 4d: The return loss graph for RT Duroid Antenna.

Figure 4c and Figure 4d shows the simulated results of Taconic TLC and RT duroid antenna with the return loss values of -19.7442dB and -27.339dB respectively, at 6GHz resonant frequency.

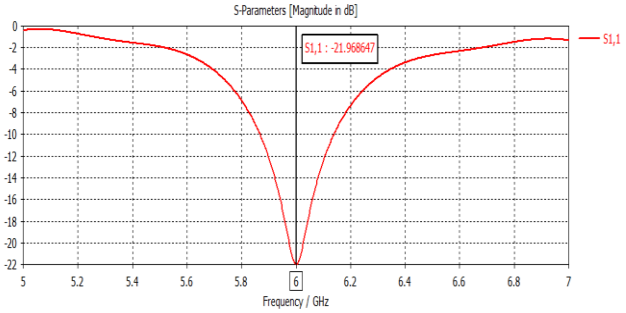


Figure 4e: The return loss graph for Rogers RO4003 Antenna.

The highest value of S11 parameter otherwise known as the return loss was obtained by the FR4 antenna which was -31.320dB. And also, the lowest value of -19.7442dB was produced by the TLC antenna. It was observed that the better the return loss, the better the antenna performs, that means, the less the value, the better performance. The standard acceptable value of the return is -10dB, which is an equivalent of 11 % reflected power of the antenna.

The effective Gain and Directivities obtained for the respective designs are shown in Figures 5a-9a, respectively.

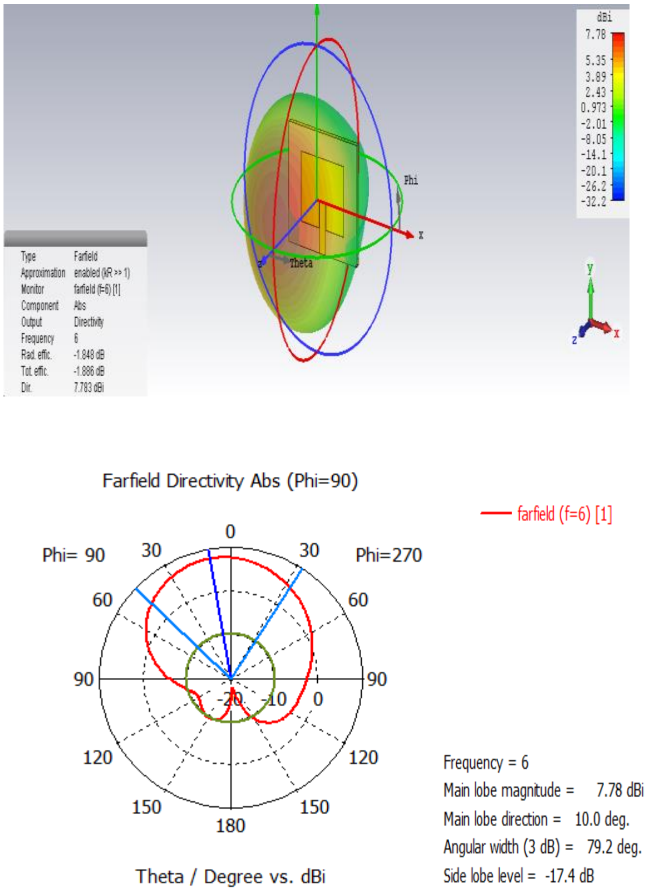
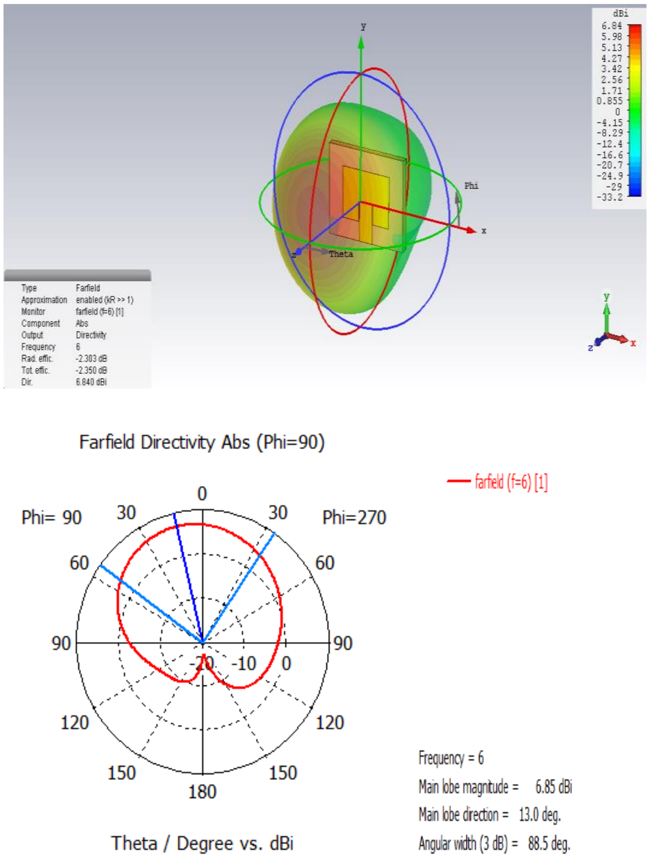


Figure 5(a) Directivity and (b) gain of RT Duroid Antenna.

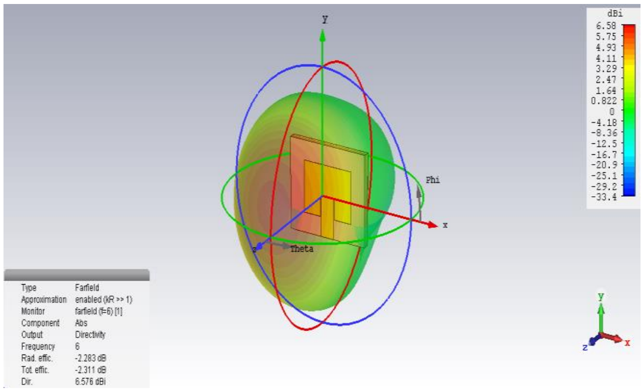


Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=6) [1]
Component	Abs
Output	Directivity
Frequency	6
Rad. effic.	-2.303 dB
Tot. effic.	-2.350 dB
Dir.	6.840 dBi

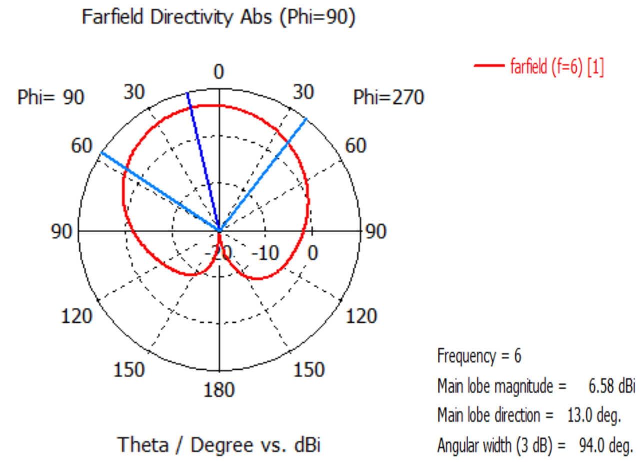
Frequency = 6
Main lobe magnitude = 6.85 dBi
Main lobe direction = 13.0 deg.
Angular width (3 dB) = 88.5 deg.

Figure 6 (a) Directivity and (b) gain of TLC Antenna.

Figure 5 and Figure 6 shows the simulated results of RT-Duroid and TLC antenna with the gain and directivity values of 5.934dB & 7.783dBi and 4.536dB & 6.840dBi respectively, at 6GHz resonant frequency.

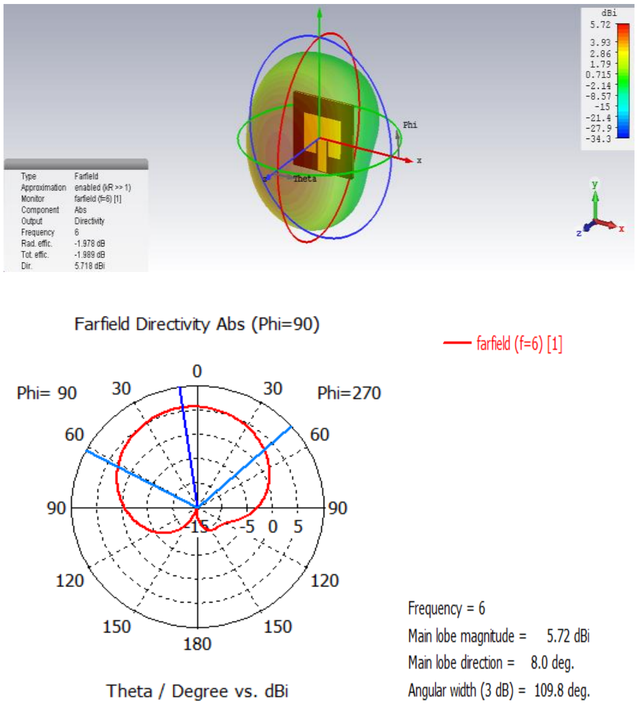


Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=6) [1]
Component	Abs
Output	Directivity
Frequency	6
Rad. effic.	-2.283 dB
Tot. effic.	-2.311 dB
Dir.	6.576 dBi



Frequency = 6
Main lobe magnitude = 6.58 dBi
Main lobe direction = 13.0 deg.
Angular width (3 dB) = 94.0 deg.

Figure 7(a) Directivity and gain of Rogers RO4003 Antenna.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=6) [1]
Component	Abs
Output	Directivity
Frequency	6
Rad. effic.	-1.978 dB
Tot. effic.	-1.989 dB
Dir.	5.718 dBi

Frequency = 6
Main lobe magnitude = 5.72 dBi
Main lobe direction = 8.0 deg.
Angular width (3 dB) = 109.8 deg.

Figure 8(a) Directivity and gain of Bakelite Antenna.

Figure 7 and Figure 8 shows the simulated results of Rogers R04003 and Bakelite antenna with the gain and directivity values of 4.293dB & 6.576dBi and 3.741dB & 5.718dBi respectively, at 6GHz resonant frequency.

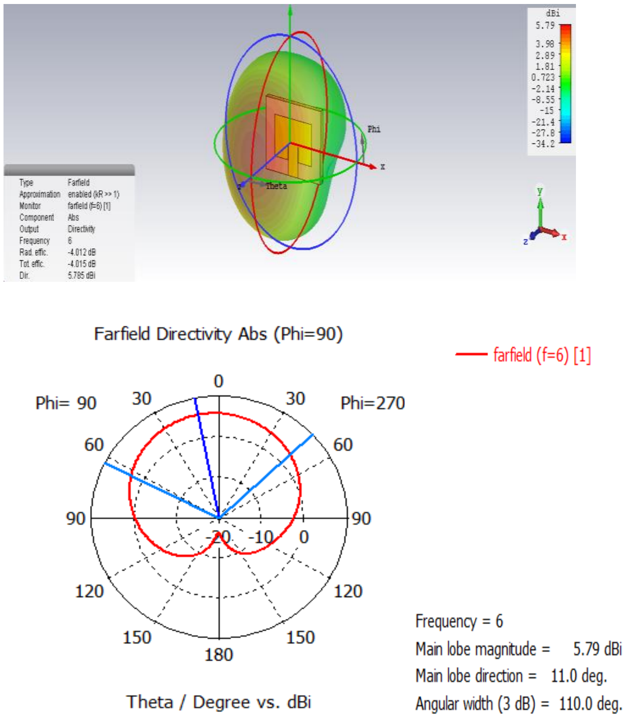


Figure 9(a) Directivity and gain of FR4 Antenna.

The optimal gain of 5.934dB at 5.974GHz frequency for RT Duroid antenna was obtained and the lest gain of 3.741dB at 6.008GHz was produced by the Bakelite antenna respectively. The RT Duroid has the lowest value of dielectric constant which technically control the fringing field and causes radiation in the antenna. It's therefore seen that, the lower the εr, the lager the fringes which causes the system to have a higher radiation that increases the performance parameters of the antenna. The RT-Duriod has a very low loss tangent, low water absorption, high tensile strength and high breakdown voltage which greatly helps the antenna to achieve a better radiation. While on the other hand, the Bakelite antenna has a very high dielectric constant of 4.8. The higher the value of the dielectric constant, the slower the signal travels on the antenna wire which lowers the impedance of the given antenna geometry and increase the stray capacitance along a transmission line. The FR4 substrate has also a very low surface resistivity which causes the efficiency to be low with a low gain value. At in between the optimal and the low values of the performance parameters of the two antennas, a reasonable result was also obtained for the Taconic TLC, Rogers RO4003C and FR4 antennas respectively.

The designs were realized for Bakelite, FR4 Glass epoxy, RO4003, Taconic TLC and RT 5880 Duroid substrates respectively. The VSWR graphs obtained for these designs are shown in Figures 10 a-e respectively.

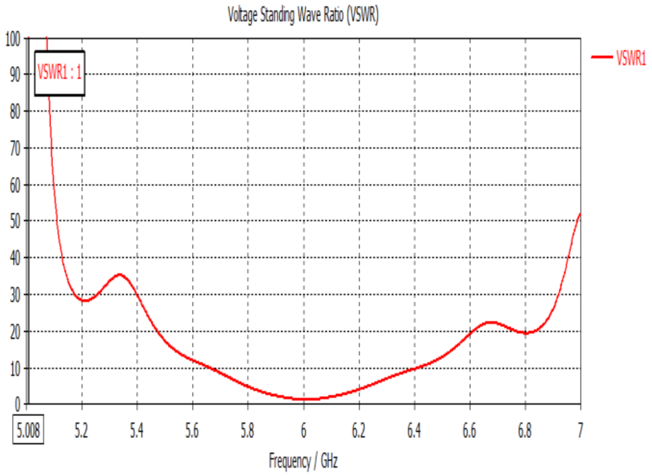


Figure 10(a) The VSWR graph for Bakelite Antenna.

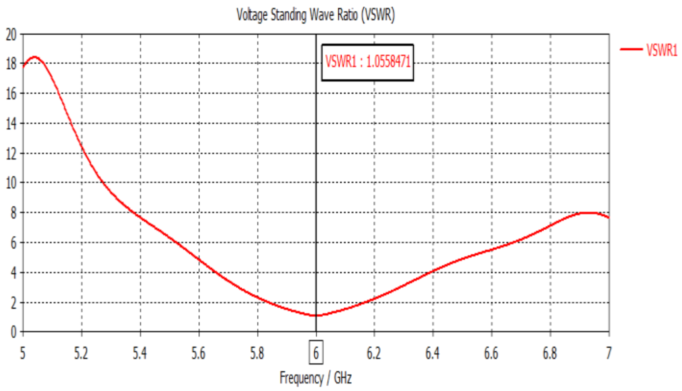


Figure 10(b): The VSWR for RT Duroid Antenna.

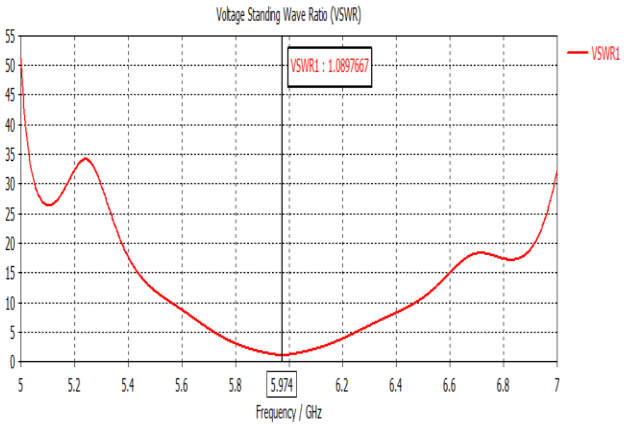
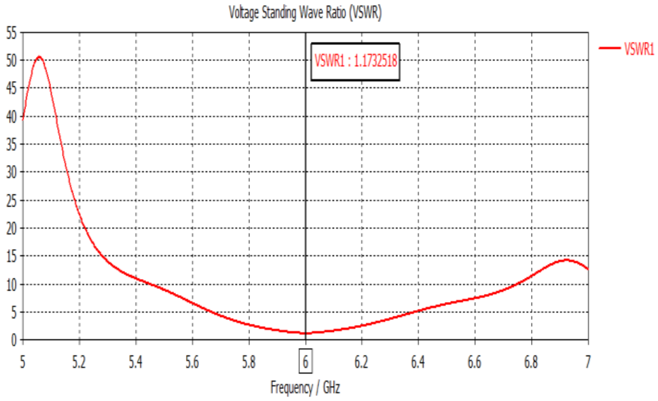


Figure 10(c): The VSWR graph for RO4003C



. Figure 10(d): The VSWR for TLC Antenna.

Figure 10(a) to Figure 10€ shows the simulated results of Bakelite, RT/Duriod 5880, RO4003, TLC and FR4 antennas at 6GHz operating frequency with the values of 1.08, 1.23, 1.17, 1.06 and 1.00 respectively.

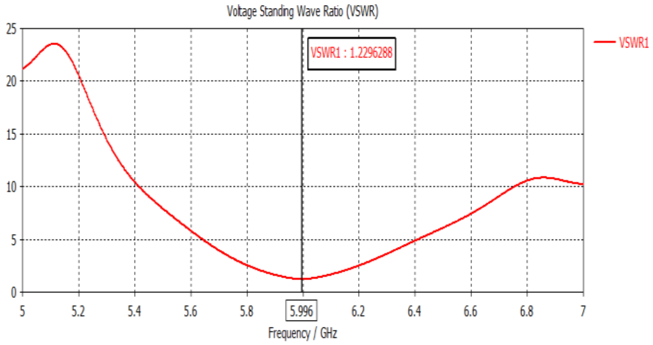


Figure 10(e): VSWR graph for FR4 Antenna.

From the VSWR graphs above it can be observed that a perfect match was only achieved by the Bakelite antenna which gives a VSWR value of 1 due to its very low water absorption. Also, all the other four antennas achieved a very good matching properties with a very good VSWR values. The highest bandwidth value of 318.5MHz was achieved by the FR4 antenna, while the lest value of 184.2MHz was presented by a Bakelite antenna. The dielectric constant also plays a major role in achieving a high bandwidth value.

From the highlighted results in the table 7 below, both the radiation and total efficiencies of all the five designed antennas were presented accordingly. The highest radiation efficiency of 80% was achieved by the RT Duroid antenna. While on the other hand, a low radiation efficiency of 77% was achieved by the TLC and R04003 antenna. The wide differences in the antenna efficiencies is due the differences in the dielectric constants of the substrate materials and the loss tangents (Alkhafaji, et al., 2020). Finally, the Rogers RO4003, Taconic TLC and the FR4 antennas have the efficiencies of 77%, 77% and 79% respectively due to their average dielectric constants, densities and loss tangents. The simulation results for all the five antennas designed have been summarized and tabulated in Table 7 below for all the five models designed based on the performance indicators which include the geometry, gain and directivity, bandwidth, VSWR and return loss.

Table 7; Antennas Simulation Results Comparison of the Different Antenna Performance Parameters at 6GHz

Parameters	**RT Duroid 5880 Antenna**	**Taconic TLC-32 Antenna**	**Rogers RO4003C Antenna**	**FR4 glass epoxy Antenna**	**Bakelite Antenna**
Resonant Frequency (GHz)	5.974	5.996	6	6	6.008
S11 (dB)	-27.339	-19.7442	-21.968647	-31.3200	-27.634696
Bandwidth (MHz)	205.8	270.8	268.7	318.5	182.0
Gain (dB)	5.934	4.536	4.293	3.998	3.741
Directivity (dBi)	7.783	6.840	6.576	5.788	5.718
Radiation Efficiency (%)	81	77	77	79	80
VSWR	1.08	1.23	1.17	1.06	1.00
Total Efficiency (%)	80	76	76	78	79
Elevation Main-lobe Magnitude(dBi)	7.78	6.85	6.58	5.79	5.72
Elevation Main-lobe Direction(deg.)	10.0	13.0	13.0	11.0	8.0
3dB Elevation Angular Width(deg.)	79.2	88.5	94.0	110.0	109.8
Geometry (mm)	15.29x19.76	13.32x17.25	12.97x16.89	11.37x15.35	10.90x14.68

4. Conclusion

In this work, five different substrate materials were used to designed five conventional microstrip 0patch antennas operating at 6GHz in order to study the effects of the substrate materials on the performance of patch antennas for sub-6GHz 5G applications. According to the simulation results, the best performance due to the directivity, gain and efficiency criterion was the RT-Duroid antenna which has the lowest dielectric constant among the five substrates used and the lest performance was obtained with the Bakelite antenna. Furthermore, the best performance due to the return loss and bandwidth criterion was the FR4 antenna which is due to the increase in size of the FR4 antenna geometry as compared to the other antennas. And finally, the best compact size was achieved by the Bakelite antenna while the R04003 and TLC antennas maintained an average performance in between. It can be concluded that, in antenna designs, the major factor to achieving a desired efficiency, high gain, good directivity, high bandwidth and good antenna geometry is the careful selection of the right substrate material. This work is essential in order to predict the effect of the different dielectric materials on patch antennas and to know which substrate should be giving preference over which and why. There are large numbers of newly developed substrate materials but not all are being used in antenna designing today, so there is still an urgent need to study and investigate all the available substrate materials, and also to test and use all the newly developed ones in order to achieve an optimal antenna design. As for the future research area, a careful investigation into designing the microstrip antenna with diffe0rent structures, patch shapes and sizes, effect of the height of the substrate materials and feeding techniques can also be investigated at the millimeter wave range for 5G applications.

Acknowledgment

The author would like to thank the Petroleum Trust Development found (PTDF) scholarship board for sponsoring the research work.

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