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ANALYSIS OF 5G COMMUNICATION BASED MONOPOLE ANTENNA ON DIFFERENT TRANSPARENT SUBSTRATE MATERIALS

[1]Jyothi Bandarupalli, [2]Sreevardhan Cheerla, [2]Boddapati T P Madhav, [1]Ghali Srinivasa Rao

[1]Research Scholar, KLEF, ECE Department, Guntur DT. Andhra Pradesh, India.
[2]ALRC-R&D, KLEF, ECE Department, Guntur DT. Andhra Pradesh, India

Mail ids: jyothicnr@gmail.com, sreevardhancheerla@kluniversity.in, btpmadhav@kluniversity.in, srinivas.bharadwaja@gmail.com,

Abstract

In this work, a 5G communication-based monopole antenna has been designed and analyzed for different transparent substrate materials. Various transparent materials like corning glass, Plexi glass, glass, quartz glass, PVC and silicon dioxide as substrate are used in the design of the proposed model. The parametric analysis and performance optimization is done for each substrate material for the optimized dimensional characteristics. The dimensions of the proposed model are 16X16 X1.1 mm^3. This model resonates at different frequencies ranging from 2.5 GHz to 8 GHz and covering the sub-6 band. Also, the proposed model is fabricated on corning glass and the simulated results are compared with the prototyped model measurement for validation.

II. Introduction

Around 60 percent population from across the world lives in urban environment by 2050[1]. As a result, cities are becoming larger, more complex and more important. A smart city seeks to ease several economic, logistic and resource-based challenges within the city through AI, Data analytics and Wireless technology [2]. Also, the challenges of smart city include efficient use of infrastructure which can be done by placing additional access points and signal repeaters into existing infrastructure through insertion of transparent antennas [3]. Due to the flexibility in deployment of transparent antennas, they can be integrated into buildings, windows and other structures without altering their visual appearance. Spectrum in the 1 GHz - 6 GHz range is sub 6 band and it is considered ideal for 5G because it can carry plenty of data while also travelling significant distances [4]. Also, the spectrum from 6 GHz-10 GHz is used for several applications in satellite communications [5]. One of the main considerations in the design of microstrip antenna is proper choice of substrate material. The characteristics of the antenna can be varied by varying the dielectric constant of the substrate. Most of the 5G antennas are designed on opaque dielectrics. The most commonly used substrates are FR4 and RT Duroid. In [6] a modified square spiral antenna is designed with CPW feeding on FR4 substrate with the size of 28X28X1.6mm^2. The two major drawbacks of CPW feeding are, fabrication becomes costlier and relatively thicker substrates are required [7]. Which in turn effects the

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transparency and flexibility of the antenna .In [8] a dual band slot antenna is designed for sub 6 applications on FR4 substrate where the size of the antenna is 31mmX36mmX0.8mm^3.A multi slotted antenna for LTE/5G sub-6 GHz wireless communications applications is proposed in [9] on FR4 substrate with size given by 20X30X1.5 mm^3.In [10],a compact slotted patch hybrid mode antenna for sub 6 GHz communication is proposed which consists of three substrates each made up of FR4 substrate with a maximum size of 100X100X1.6 mm^3 for the bottom substrate. A broadband antenna with integrated CB-CPW for 5G applications is proposed in [11], with CPW feeding and the size of the antenna is 40X40X1mm^3. A slot loaded antenna for microwave and millimetre wave applications is proposed in [12], using RT duroid as substrate with the size of 40X50X1.575mm^3. In [13] aperture coupled stacked layer microstrip antenna for 5G communications is proposed with RT duroid as substrate and of the size 100X100X0.8mm^3. In [14], a semicircular antenna for wireless communications is proposed using RT duroid as substrate, fed with CPW feeding and is of size 24X24X0.127 mm^3. [15] presents two flexible antennas for sub 6 communications using RT duroid as substrate and is of size 32X24X0.064mm^3. Even though all the above-mentioned models are designed for 5G communications, the substrate materials used are opaque and also the size matters. In [16], an optically transparent antenna is designed on glass substrate whose dimensions are given by 50X50X1.1mm^3. In [17], a transparent antenna is designed with a size of 50X50mm^2 using corning glass as substrate. A super wide band transparent antenna on a solar cell substrate is designed in [18] using Plexi glass as substrate and is of size 29X27mm^2. In [19], a transparent monopole antenna is proposed which is designed on PET with the size of 30X30mm^2. Transparent antenna design for WiMax application is proposed in [20] using glass as substrate and its dimensions are 90x50x2mm^3. A transparent wide band dual polarized antenna for sub6 GHz application with poly carbonate as substrate is presented in [21]. It operates in 2.76-4.13GHz band with a size of 55x55x3mm^3. Based on existing researches different transparent substrate materials used are glass, corning glass, Plexi glass, PET etc. In this aspect the current work focuses on analysing a 5G communication-based antenna for different transparent substrate materials namely corning glass, glass, Plexi glass, PVC, quartz glass & silicon dioxide. Reflection coefficient and VSWR are plotted for each substrate material. Later the proposed model is fabricated on corning glass and comparison between simulated and fabricated model exhibited a good similarity.

III. Antenna Configuration

The proposed model of dimensions 16X16 X1.1 mm^3 is depicted in figure 1. The antenna is designed using High Frequency Structure Simulator software. Microstrip patch antenna mainly consists of 3 parts namely ground, substrate and patch. The present model is simulated on various substrate materials like Corning glass, Glass, Plexi Glass, PVC, Quartz Glass and Silicon Dioxide.

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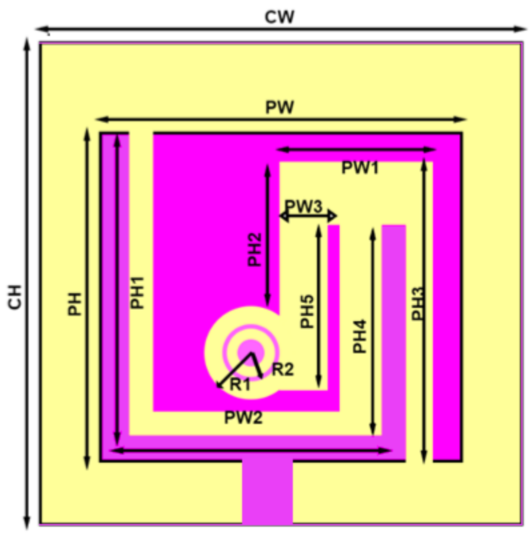


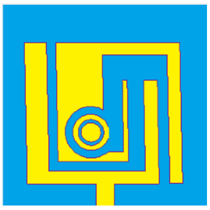
Figure 1. Layout of the Proposed model

The antenna dimensions are depicted in table1.The patch is of dimensions 12 X11 mm^2 and it has slots cut on it. The slots are mostly rectangular shaped. Parametric optimization is carried out for the appropriate reflection coefficient.

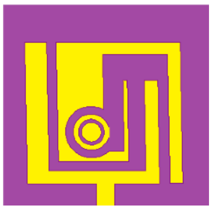
PARAMETER	VALUE (mm)	PARAMETER	VALUE (mm)
CH(c)	16	CW(d)	16
PH(b)	11	PW(a)	12
PH1	9.3	PW1	5
PH2	4	PW2	7
PH3	10	PW3	1.5
PH4	7	R1	2
PH5	5.5	R2	1.4

Table1: Geometric dimensions of the proposed model

Figure 2 depicts the proposed model for all the substrate materials. Figure 2(a)shows the antenna designed on corning glass. Figure 2(b) shows the antenna designed on glass. Figure 2(c)shows the antenna designed on Plexi glass. Figures 2(d-f) shows the antennas designed on PVC, Quartz glass and silicon dioxide respectively. The dielectric constant and loss tangents of all the mentioned substrate materials are given in table 2.


(a)


(b)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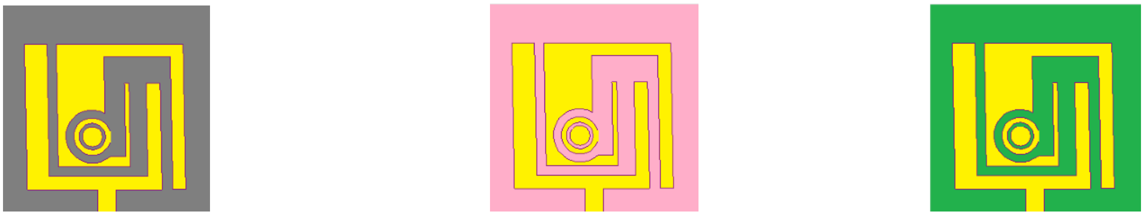

(d) (e) (f)

Figure 2. Proposed model for different substrates:(a) Corning glass. (b)Glass. (c) Plexi Glass (d) PVC (e) Quartz Glass (f) Silicon Dioxide.

SUBSTRATE	DIELECTRIC CONSTANT	LOSS TANGENT
Corning glass	5.75	0
Glass	5.5	0
Plexi Glass	3.4	0.001
PVC	2.7	0.007
Quartz Glass	3.78	0
Silicon Dioxide	4	0

Table 2: Dielectric constants and Loss tangents of substrate materials

V. Results and Discussion

The simulation process for the proposed model is performed using HFSS. Table 3 gives the various bands resonated by the proposed model by all the substrate materials.

Results Comparison a=12, b=11, b=16 &d=16				
Substrate	No. of Bands (1-	Bands (GHz)	Return Loss	VSWR
Corning glass	2	6.22 7.41	-22.83 -22.25	1.15 1.16
Glass	2	6.42 7.70	-10.44 -13.94	1.85 1.50
Plexi Glass	2	2.75 7.34	-15.55 -10.42	1.40 1.86
PVC	3	2.95 5.36 7.90	-17.99 -17.09 -13.75	1.28 1.32 1.51
Quartz Glass	2	2.64 7.63	-13.08 -17.81	1.56 1.29
Silicon Dioxide	2	2.62 7.52	-10.47 -24.41	1.85 1.12

Table 3: Return loss and VSWR of the proposed model

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Figure 3 & Figure 4 depicts the return loss of the proposed models. It can be seen that for Corning glass, glass, Plexi glass, quartz glass and silicon dioxide the proposed model resonated at 2 bands, for PVC it resonated at 3 bands but the third band return loss value is just -13.7560db.

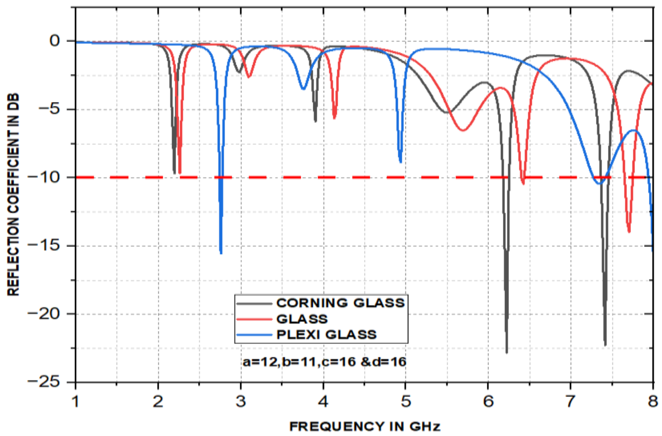

Figure 3: Reflection coefficient of Corning glass, Glass &Plexi glass

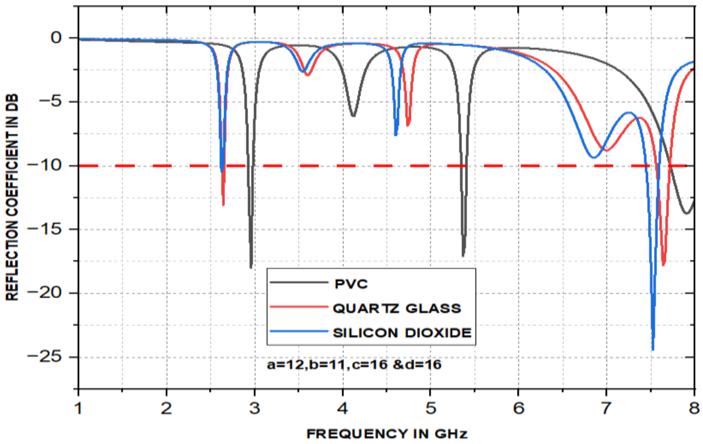

Figure 4: Reflection coefficient of PVC, Quartz glass &Silicon Dioxide

Simulation results showed that only corning glass exhibited good reflection coefficient value. Tables 4-9 depicts the reflection coefficient values after parametric optimization for corning glass, glass, Plexi glass, PVC, quartz glass and silicon dioxide respectively. It can be observed that after parametric optimization the proposed mode with corning glass as substrate resonated at 1 or 2 bands for different values of a, b, c &d. Even though noticeable change is not observed in terms of number of bands, but a new frequency band at around 3.4 GHz is observed as given in figure 5 and table 4.

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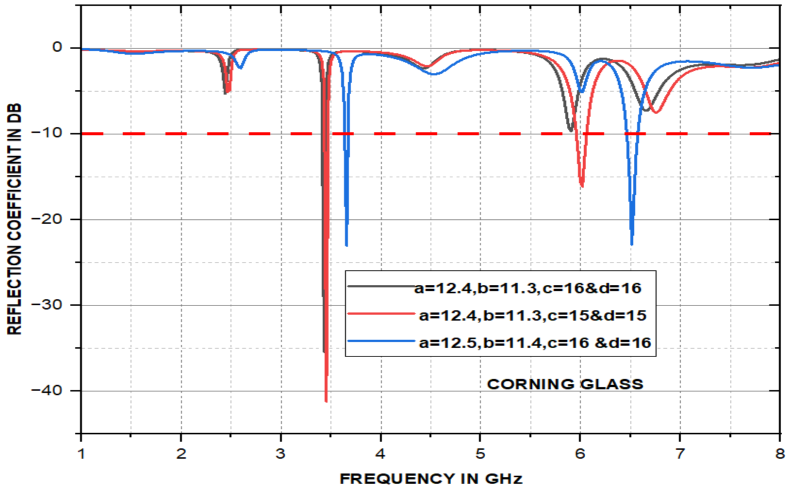

Figure 5:Reflection coefficient of Corning glass after optimization

Parametric Analysis Report: Corning glass				
a, b	**c, d**	**No. of bands**	**Bands (GHz)**	**Return loss**
12.4,11.3	16,16	1	3.43	-35.42
12.4,11.3	15,15	2	3.45 6.01	-41.24 -16.13
12.5,11.4	16,16	2	3.65 6.51	-23.03 -22.92

Table 4:Reflection coefficient of Corning glass after optimization

When glass is used as substrate for the proposed model, parametric optimization resulted in the increase of number of bands but comparatively reflection coefficient value is still poor for most of the resonating bands as observed in table 5 and figure 6.

Parametric Analysis Report: glass				
a, b	**c, d**	**No. of bands**	**Bands (GHz)**	**Return loss**
12.4,11.3	16,16	1	3.49	-21.77
12.5,11.1	16,16	2	3.47 6.17	-19.42 -11.79
12.3,10.7	16,16	3	2.17 6.35 7.50	-12.80 -11.33 -15.95

Table 5: Reflection coefficient of Glass after optimization

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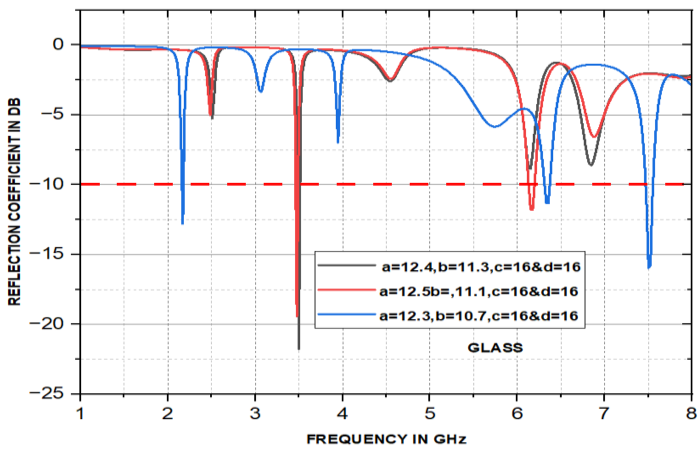

Figure 6: Reflection coefficient of Glass after optimization

Table 6 shows an increase of number of bands, after parametric optimization when Plexi glass is used as substrate for the proposed model, but it can be observed that the reflection coefficient value is not satisfactory except for one band as shown in figure 7.

Parametric Analysis Report: Plexi glass				
a, b	**c, d**	**No. of bands**	**Bands (GHz)**	**Return loss**
12,11	13,15	2	2.75 5.02	-16.54 -12.05
12.3,11	16,16	4	2.68 4.87 7.27 7.93	-27.82 -10.00 -11.77 -11.78
12.4,10.5	16,16	2	2.57 4.91	-30.70 -11.24

Table 6: Reflection coefficient of Plexi Glass after optimization

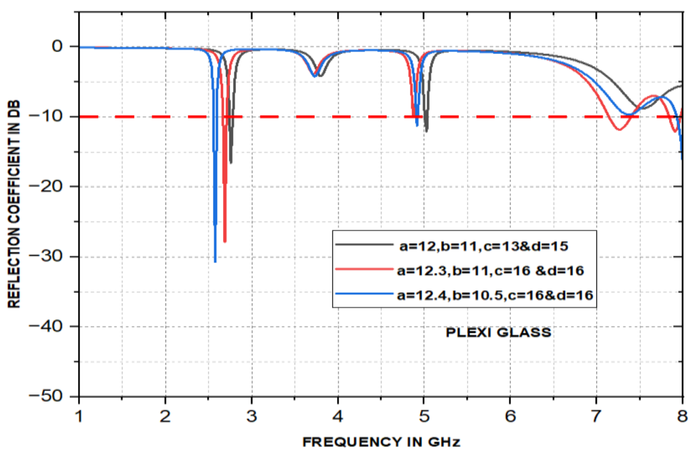

Figure 7: Reflection coefficient of Plexi Glass after optimization

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Even though the maximum number of bands remained same after parametric optimization for the proposed model when PVC is used as substrate, a better reflection coefficient value is observed as given in table 7 and figure 8.

Parametric Analysis Report: PVC				
a, b	**c, d**	**No. of bands**	**Bands (GHz)**	**Return loss**
12.5,10.5	16,16	3	2.77 5.29 7.97	-24.43 -19.00 -16.31
11.6,10.6	14,15	2	3.09 5.50	-16.05 -23.09
11.5,11.2	15,15	1	3.52	-21.42

Table 7: Reflection coefficient of PVC after optimization

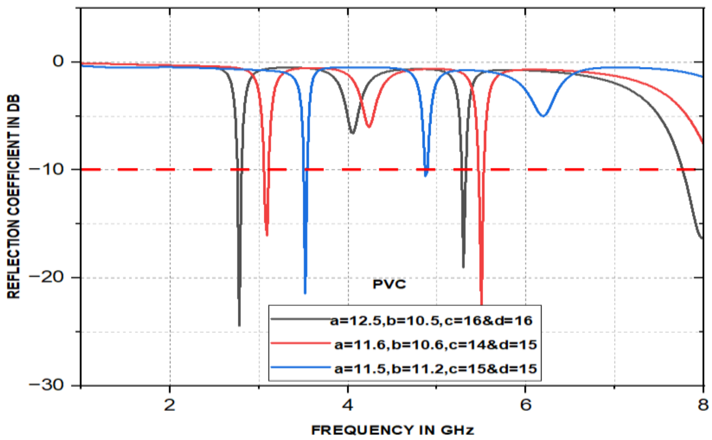

Figure 8: Reflection coefficient of PVC after optimization

After parametric optimization of the proposed model when quartz glass is used as substrate, an improvement in reflection coefficient value is observed for almost all the bands as given in table 8 and figure 9.

Parametric Analysis Report: Quartz Glass				
a, b	c, d	No. of bands	Bands (GHz)	Return loss
11.6,11.3	16,16	1	4.21	-35.75
11.6,11.3	14,16	2	4.30 7.21	-38.32 -10.55
11.6,11.3	13,15	2	3.20 7.36	-14.38 -30.77

Table 8: Reflection coefficient of Quartz glass after optimization

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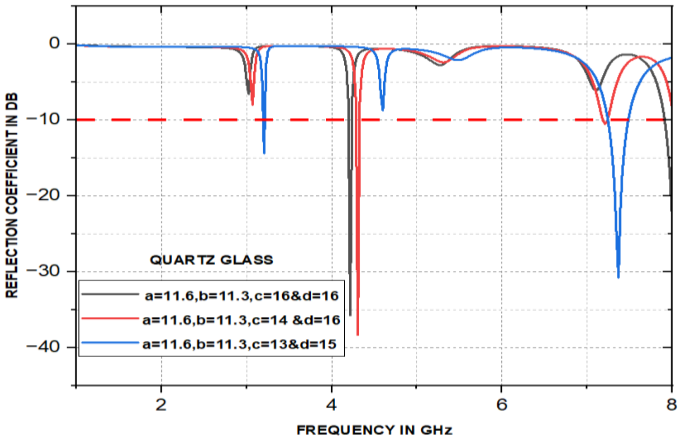

Figure 9: Reflection coefficient of Quartz glass after optimization

It can be observed from table 9 and figure 10 that, the proposed model when silicon dioxide is used as substrate, there is an improvement in reflection coefficient value while the number of bands remained same.

Parametric Analysis Report: Silicon Dioxide				
a, b	c, d	No. of bands	Bands (GHz)	Return loss
11.8,11.3	16,16	2	4.12 7.68	-34.45 -19.36
11.8,112	16,16	2	4.08 7.81	-25.34 -18.52
11.6,10.5	16,16	2	2.57 7.70	-21.26 -21.39

Table 9: Reflection coefficient of Silicon Dioxide after optimization

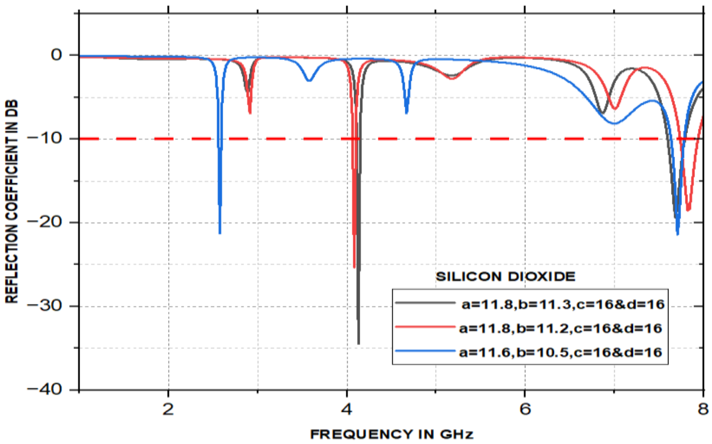

Figure 10: Reflection coefficient of Silicon Dioxide after optimization

Thus, it is observed that for almost all the substrate materials either the number of bands or the reflection coefficient value has to be compromised. But when corning glass is used as substrate

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material for the proposed model, two resonant bands are observed with better reflection coefficient value. Also, a maximum efficiency of 79% is observed as depicted in fig 11. Thus, the proposed model is fabricated on corning glass as shown in figure 12.

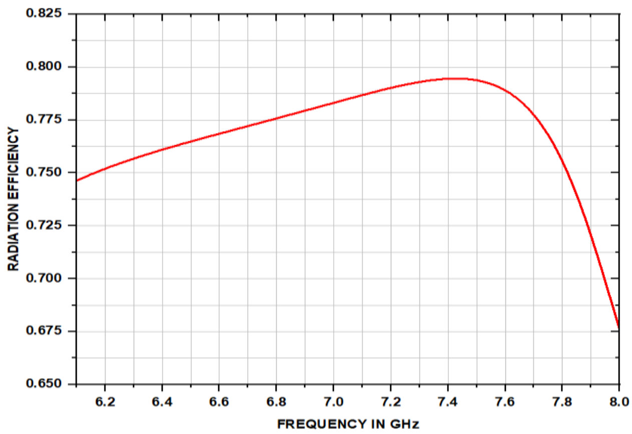

Figure 11: Radiation Efficiency of the proposed model with corning glass as substrate

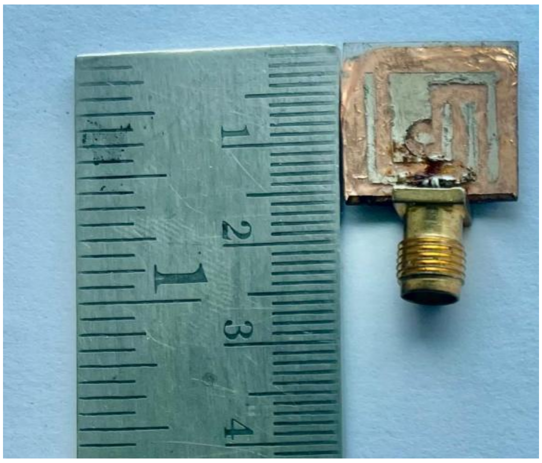

Figure 12: Fabrication of the proposed antenna

The measurement of reflection coefficient using corning glass as substrate is shown in figure13.

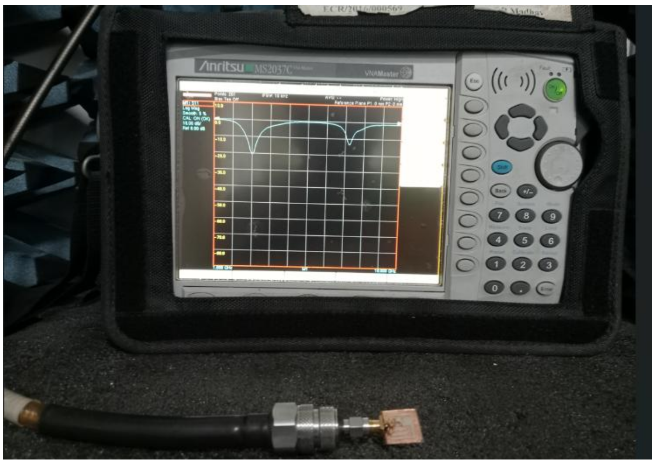

Figure 13: Measurement of Reflection coefficient

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Comparison of simulated and measured values of reflection coefficient and Gain are given in figures 14 and 15 respectively. A good agreement between simulated and measured values is observed.

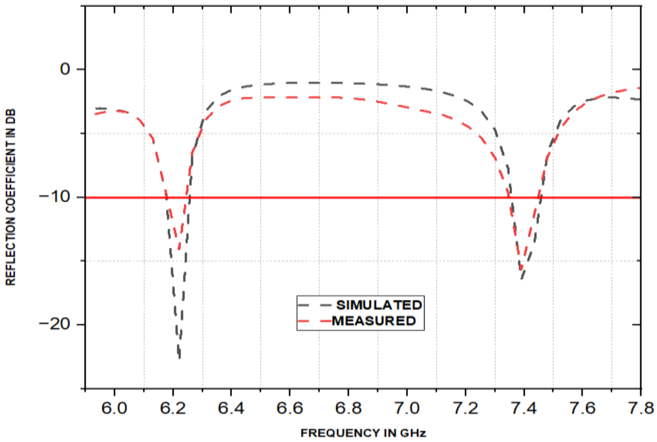

Figure 14: Reflection coefficient of simulated and fabricated antenna

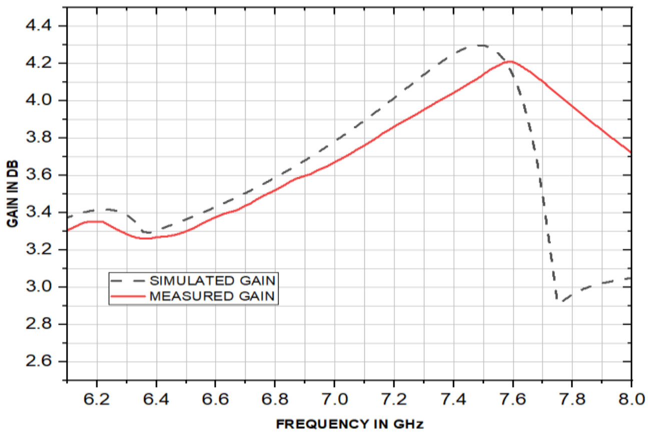

Figure 15: Gain of simulated and fabricated antenna

A comparison between the proposed antenna and other antennas, using both transparent and non-transparent substrate materials operating in and around 1GHz-10GHZ is given in Table 10. As observed from Table 10, it is obvious that the proposed model is more compact than any other models mentioned in the references. The model presented in [6], exhibited high efficiency but has poor gain. Though [8],[10] and [18] presented the designs with better gain and efficiency, but the size of the antennas is too large compared to the proposed model. As the proposed model has planar profile and no vertical space is required it can be easily used in portable communication devices.[9],[14] and [21] proposed designs with lesser gain and efficiency whereas [17] and [20] presented designs with lesser gain and their efficiencies are not mentioned.

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Ref No	Feeding Technique	bands	Dimensions (mm)	Substrate used	Gain (Db)	η(%)	Implementation
6	CPW	915 (MHz) 2.45 (GHz) 3.5 (GHz) 5.8 (GHz)	28X28X1.6	FR4	1.96	83.0	CST FAB
8	LINE	3.2-3.6 (GHz) 4.3-5.2 (GHz)	36X31X0.8		7.17	79.5	CST FAB
9	LINE	3.1-5.5 (GHz)	30X20X1.5		2.35	74.7	CST FAB
10	LINE	3.0-5.0 (GHz)	100X100X1.6		8.0	80	FAB
12	COAXIAL FEED	5.5-9.5 55-95 (GHz)	40X50X1.575	RTDUROID	7	85	CST FAB
13	APERTURE COUPLED	3.4 (GHz)	100X100X0.8		6.4	NM	ANSYSHFSS FAB
14	CPW	2.3 3.7 5.5 8 (GHz)	24X24X0.127		3.8	76	CST FAB
15	CPW	2.45 3.5 4.7 (GHz)	32X24X0.064		3.75	NM	HFSS CST FAB

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16	CPW	3-24 (GHz)	50X50X1.1	GLASS	NM	NM	HFSS
17	COAXIAL	UHF	150X150	CORNING GLASS	0.98	NM	CST FAB
18	LINE	2-32 (GHz)	29X27X3	PLEXI GLASS	8.1	70	CST FAB
19	SMA	1.95 5.58 (GHz)	30X30	PET	NM	NM	HFSS FAB
20	LINE	2.3 (GHz)	90X50X2	GLASS	3.16	NM	CST FAB
21	PROXIMITY COUPLED	2.7-4.1 (GHz)	55X55X3	PC	4.14	73	FAB
This work	LINE	6.22 7.41	16X16X1.1	CG	4.3	85	HFSS FAB

Table10: Comparison Of the Proposed Model with Other Antennas Made of Transparent and Non-Transparent Substrate Materials

V. Conclusion

A 5G communication-based antenna is analyzed with various transparent substrate materials like corning glass, glass, Plexi glass, PVC, quartz glass and silicon dioxide in this work. The analyzed simulated results show that for all the substrate materials, either the number of bands or the reflection coefficient value need to be compromised except for corning glass. The proposed model is designed on corning glass providing dual band at 6.2 GHz and 7.41 GHz respectively with optimized reflection coefficient values. The design exhibiting the maximum gain of 4.3 dB with efficiency more than 85%. The proposed model is providing satisfactory results in real time measurement by comparing with the simulated values.

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