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Research Article

Design of microstrip antenna using high frequency structure simulator for 5G applications at 29 GHz resonant frequency

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Abstract
Microstrip antennas are good candidate for wireless communication due to its low profile, light weight and ease of creation. Microstrip antenna is broadly used based on its application. This paper pronounces the design of microstrip antenna for 5G applications at a resonant frequency of 29 GHz with Rogers RT/Duroid 5880, Taconic thin layer chromatography (TLC) and flame retardant 4 (FR4) as substrate materials. The Microstrip line feeding mechanism is used for feeding the patch. The proposed antenna design and simulation output was attained by high frequency structure simulator (HFSS) software. In suggested design, Rogers RT/Duroid 5880 provides a high radiation efficiency of 97.4% when compared with others Taconic TLC (95.2%) and FR4 (78.6%). And also, Rogers RT/Duroid 5880 provides return loss of -36 dB, bandwidth of 1.8 GHz, gain of 5.9 dB and voltage standing wave ratio (VSWR) as 1. FR4 material provides high bandwidth of 2 GHz when compared with others.

Keywords
HFSS, Microstrip/patch antenna, Resonant frequency, Rogers RT/Duroid 5880, Taconic TLC and FR4 epoxy material.

1.Introduction
In modern years foremost happenings around human beings are based on wireless communications. The antenna shows an energetic character in wireless communication. Specifically, in the past few years, countless research works are going in 5G applications [1]. The antenna is used to renovate electrical current into radio waves with a radio transmitter and translate radio waves into electrical signal with the help of radio receiver. Owing to technological advance like mobile phones, the need for antenna raises widely in the forms of global positioning system (GPS), wireless fidelity (WIFI), near-field communication (NFC), etc. Different types of antenna are presented in literature. Among different types, microstrip antenna is used for most of the applications because of its slight size, light weight, low cost, good efficiency, wide range of frequency band, high gain and can directly be printed on circuit board.

Microstrip antennas have wide range of applications like mobile communication, satellite communication, radar applications, radio-frequency identification (RFID), etc. [2]. The development in mobile communication attracts many researchers towards its evolution. This motivates the authors to contribute their works in antenna design for 5G application. The reduction of the size of the mobile phone has need to the evolution of small size antenna structures [3, 4]. The conventional antennas are replaced by different antenna structures used in mobile communication. The microstrip patch antenna shows multi-band characteristics and has a compact structure and hence has emerged as a suitable one for mobile phones [5].

Microstrip antenna has three sections, namely ground, substrate and patch. The patch is a transmitting component and plays a vital role. Numerous works on the design of microstrip antenna based on different parameters are presented in the

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literature [6−9]. This article details the different substrate materials used for designing microstrip antenna analyses the antenna parameters and summarizes some conclusions about the effects of substrate materials on the performance of the antenna like gain, bandwidth, efficiency, etc. A microstrip patch antenna with millimetre wave for 5G applications is proposed with four different resonant frequencies mobile communication [10]. The objective of this research work is to design a microstrip patch antenna for 5G applications with three different substrate materials and analysis their parameters like return loss, bandwidth, gain and voltage standing wave ratio (VSWR) using high frequency structure simulator (HFSS) software.

2.Literature review

Colaco and Lohani [11] have designed a microstrip patch receiving wire at a resounding recurrence of 26 GHz with dielectric constant of 2.2. The FEKO programming is utilized for plan and recreation. The planned receiving wire has a transmission capacity of 3.56 GHz, return misfortune (S11)-33.4 dB, VSWR<2, acquire 10 dB and radio wire radiation effectiveness 99.5%. Elsayed et al. [12] have fostered a rectangular patch receiving wire at double full frequencies of 33 GHz and 46 GHz. The substrate having dielectric material of Rogers RT 5880. The computer simulation technology (CST) programming is utilized for plan and re-enactment. The planned receiving wire has a transmission capacity of 1 GHz, return misfortune (S11) of beneath - 10 dB and a gain of over 10 dB.

Liu et al. [13] have designed a low radar cross section microstrip antenna with the help of frequency selective surface with microstrip resonator with 3-10 GHz frequency range. Palaniappan and Dhamodaran [14] have proposed a pentagonal split bow-tie patch antenna for defence applications with 3.2 mm thickness flame retardant 4 (FR4) material substrate with 4.3 as a dielectric constant. Proposed systems attained a resonant frequency of 6.523 GHz, return loss of -22.5 dB, 5.84 dB as maximum gain and a good VSWR value as 1.16. Pathak et al. [15] have proposed a duel feed multiband microstrip antenna for 5G cellular communications using circularly polarized wave and simulated the proposed antenna with HFSS at resonant frequencies of 3.48 GHz, 6.24 GHz and 7.5 GHz and attained gain values of 9.8 dB, 5.06 dB and 7.58 dB for corresponding resonant frequencies.

Anguera et al. [16] have fabricated a microstrip antenna for high directivity based on TModd-0 modes. This antenna didn't require the feeding network and it achieved the directivity of 14.6 dB. Farooqui and Kishk [17] have presented a tunable microstrip antenna with 27.2% frequency tuning range. Kumar and Kumar [18] have suggested a circular patch antenna at 28 GHz. The substrate has dielectric material as RT/Duroid 5880. The coaxial feeding and microstrip line feeding are used for feeding the patch. In coaxial feeding, the proposed design has a bandwidth of 0.792 GHz and a gain of 7.69 dB. In microstrip line feeding, this design has a bandwidth of 0.66 GHz and a gain of 7.75 dB. The CST software is used for design and simulation.

Dash et al. [19] have developed a microstrip antenna with equally spaced U shaped slots loaded on the patch and defected ground structure. The dielectric material used in the substrate is FR4 Epoxy layer which has a dielectric constant of 4.4. The designed antenna has a reflection coefficient less than -10 dB, maximum bandwidth of 910 MHz and maximum gain of 6.61 dB. Liu et al. [20] have proposed a differentially fed microstrip antenna. The proposed antenna has a broader impedance bandwidth of 55% (1.62-2.85 GHz) and achieved a profile property height of 0.06 free space wavelengths. Soliman et al. [21] have modelled a microstrip antenna at resonant frequencies of 28 GHz and 38 GHz with different dielectric materials, substrate heights and feeding mechanisms and compared the results.

Banuprakash et al. [22] has developed a patch antenna with frequencies of 10.5 GHz and 26.9 GHz with reflection coefficients (S11) of -25.98 dB and -26.07 dB respectively. The rectangular shaped slot is introduced on the ground of the antenna. The dielectric material used is FR4 Epoxy. The proposed design yields VSWR of 1.1057 at 10.5 GHz and 1.1046 at 26.9 GHz and a gain of 5.45 dB at 10.5 GHz and 9.0 dB at 26.9 GHz. Punith et al. [23] have implemented multiband microstrip antenna operating in the frequencies of 23.9 GHz, 35.5 GHz and 70.9 GHz with justified return loss and a good gain with positive VSWR value. Sahoo et al. [24] has established a circular patch antenna using the HFSS software at a resonant frequency of 3.5 GHz. The proximity coupled fed feeding method is used. The following results are obtained: Reflection coefficient (S11) of -40.2827, gain is 5.8263 dB, VSWR is 1.02, bandwidth 200 MHz and efficiency is 88.40%.

Mohammed et al. [25] have derived a mathematical model for microstrip antenna with a centre frequency of 28 GHz using air substrate with 5.43 × 4.54 × 0.5 mm^3 volume for different 5G applications. Developed antenna provides 9.47 dBi gain, 1.72 GHz impedance bandwidth and 90.1% performance efficiency. Santhya et al. [26] have applied rectangular microstrip antenna (RMPA) substrate material with 33.5 mm × 33.5 mm size and bandwidth of 12.49% and 4.49%. Proposed antenna met the necessary conditions for applications with 5G technology. Singh et al. [27] have proposed a simple microstrip antenna for Ka-band applications (26.5-40 GHZ) using Rogers RT/Duroid 5880 (tm) substrate, 0.0009 dielectric loss, 2.2 relative permittivity and 0.79 mm height. Proposed antenna is simulated with HFSS and the performance parameters of the antenna like gain, VSWR, radiation efficiency, S11, surface current distributions and radiation patterns are calculated.

Nowadays, the greatest constraint for antenna design is to develop an antenna with small size, wide bandwidth and high gain for wireless applications like 5G. In this article, a small size microstrip antenna with 29 GHz resonant frequency has been designed using three different substrate materials with HFSS software for 5G applications and the antenna parameters are compared for three substrate materials. *Table 1* summarizes the different types of antennas with examples and applications.

Table 1 Different types of antennas with examples and applications

S. No.	Antenna type	Examples	Applications	Reference
1	Wire Antennas	Monopole antenna, Dipole antenna, Loop antenna and Helix antenna	Personal, automobiles, space crafts, buildings, textile and ships.	[28, 29]
2	Aperture Antennas	Waveguide antenna and Horn antenna	Flush-mounted, air-craft and space craft.	[30,31,32]
3	Reflector Antennas	Corner reflectors antenna and Parabolic reflectors antenna	Radio astronomy, Microwave, satellite communication	[33, 34]
4	Lens Antennas	Convex-plane antenna, Concave-plane antenna, Convex-convex antenna and Concave-concave lenses antenna	Applications in high frequency range	[35−37]
5	Micro strip Antennas	Rectangular-shaped antenna Circular-shaped antenna and metallic patch above the ground plane	Mobile phones, missiles, cars, etc.	[38, 39]
6	Array Antennas	Micro strip patch array, Aperture array, Slotted waveguide array, Yagi-Uda antenna	Applications with high gain and where it needs to control the radiation pattern	[40, 41]

In this article the design of the proposed microstrip antenna, simulation results from HFSS software for three substrate materials, discussion on obtained results and conclusion with future scope on this research area are discussed in section 3, 4, 5 and 6 respectively.

3.Methods

Design of antenna

Due to rapid development in wireless communication, especially mobile communication, researchers are forced to design an antenna with smaller size, larger bandwidth and gain. For these requirements microstrip antennas are the best choice and plentiful research works are in progress. Microstrip antenna consists of radiating metallic patch [copper] on one side of the dielectric substrate which has a ground plane on the other side. Lots of work has been carried out on antenna design with different types of substrate materials. Among different substrate materials FR-4 offers good results like efficiency of 99.60 % at 5.8 GHz resonant frequency with -14.73 as return losses and 9.8 dB as gain [42]. In the proposed antenna design, three different types of substrate materials are used as dielectric material.

The microstrip line feeding mechanism is used to feed the patch. The design of antenna and simulation results is acquired using HFSS software. *Figure 1* depicts the design of proposed microstrip antenna. *Figure 2* shows the design of proposed antenna with defected ground structure is implemented in the above diagram. Here the ground structure is defected by cutting some portion of the ground plane with the length of 0.4mm and width is 0.4mm.

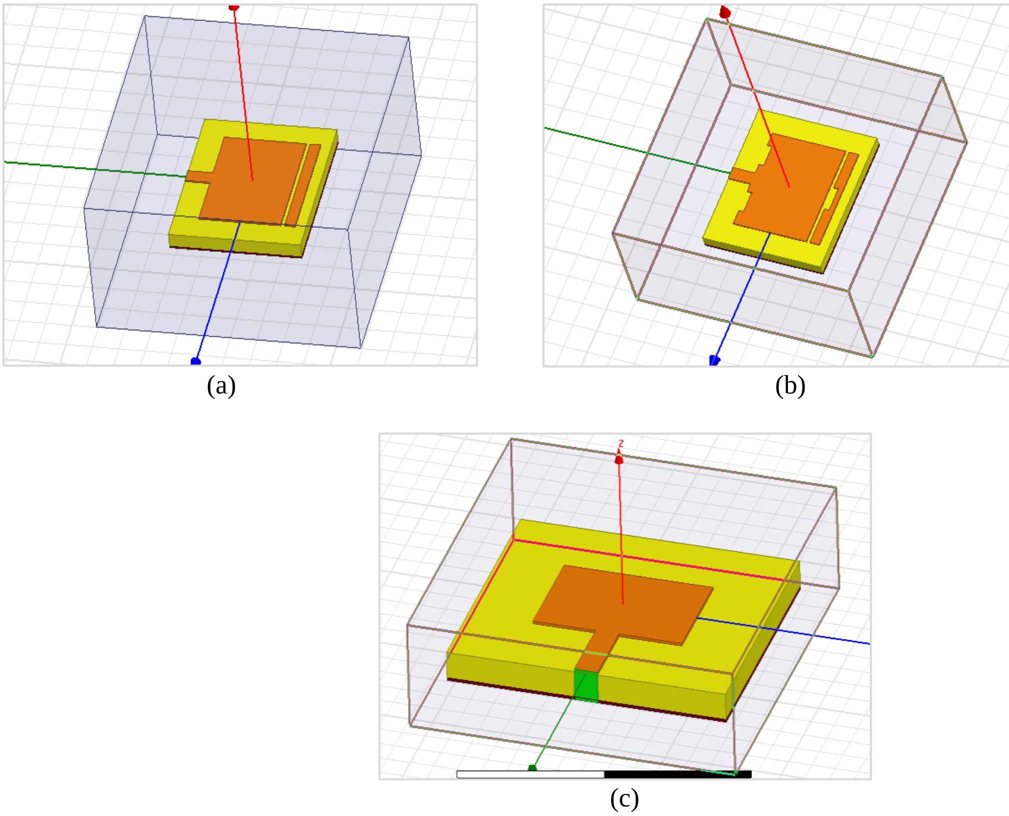


Figure 1 (a) Parasitic patch on substrate (b) Slots on patch and parasitic patch (c) Design of proposed antenna

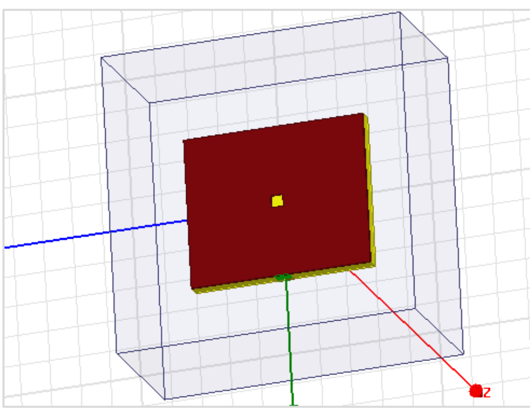


Figure 2 Proposed antenna with DGS

The length (l) and width (w) of the patch are calculated using the given formulae (Equations 1-3).

$$w = \frac{c}{2f_0\sqrt{\frac{\varepsilon_R+1}{2}}} \qquad (1)$$

$$\varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \frac{\varepsilon_R-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{w}\right)}}\right] \qquad (2)$$

$$l = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{\left(\varepsilon_{eff}+0.3\right)\left(\frac{w}{h}+0.264\right)}{\left(\varepsilon_{eff}-0.258\right)\left(\frac{w}{h}+0.8\right)}\right) \qquad (3)$$

Where,
c - Speed of light in free space
ε_R – Relative permittivity
ε_{eff} – Effective permittivity
f_0 – Frequency
h – Height of antenna

Figure 3 shows the flow chart for the proposed antenna design using HFSS. *Figure 4* represents the block diagram of the proposed antenna design.

Table 2 Different dimensions used in proposed microstrip patch antenna. *Table 3* shows the different dimensions of ground, substrate, patch and feed for the proposed microstrip antenna. The proper selection in dimensions of substrate materials plays a major role in the performance of designed antenna. Here, dimensions of substrate material, patch, ground, transmission line, and wave port are selected in order to work the proposed antenna in 29 GHz resonant frequency.

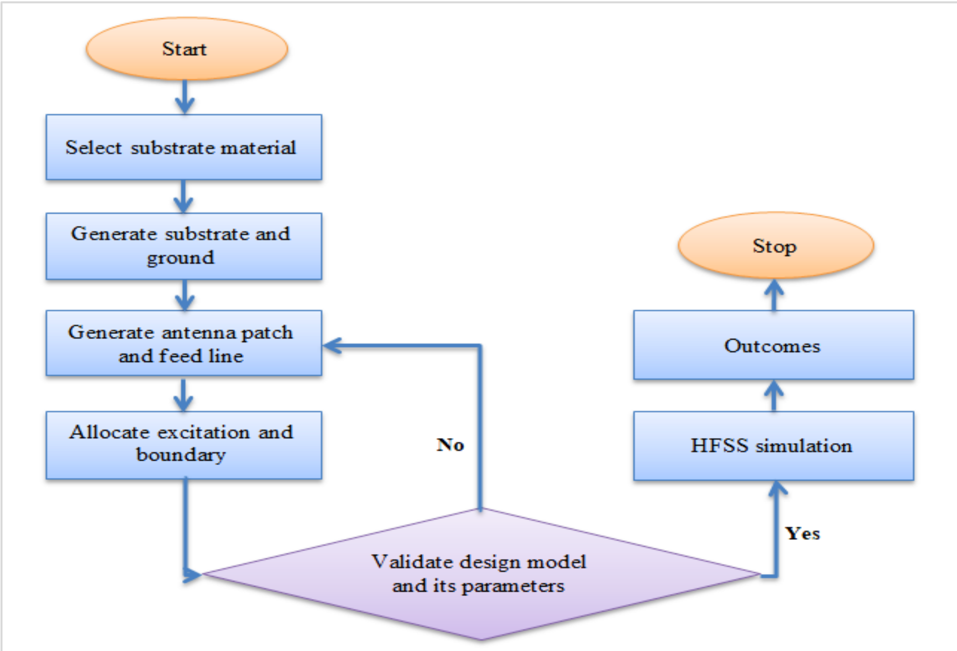


Figure 3 Flow chart for the proposed antenna design using HFSS

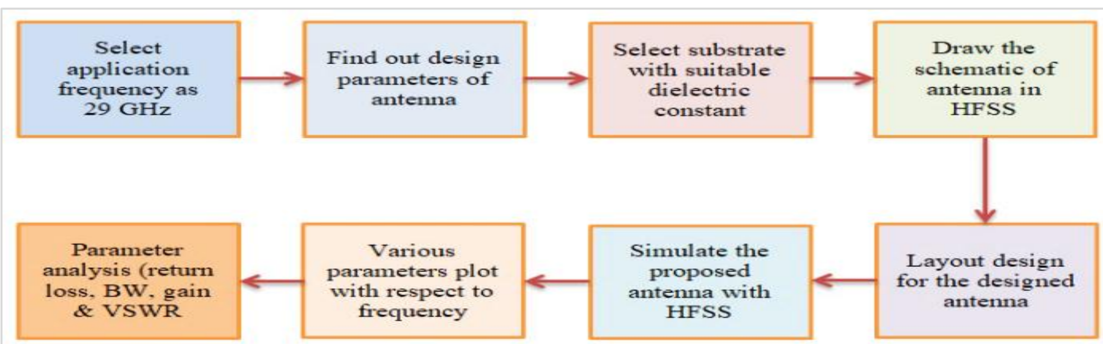


Figure 4 Block diagram of proposed microstrip patch antenna

Table 2 Different dimensions used in proposed microstrip patch antenna

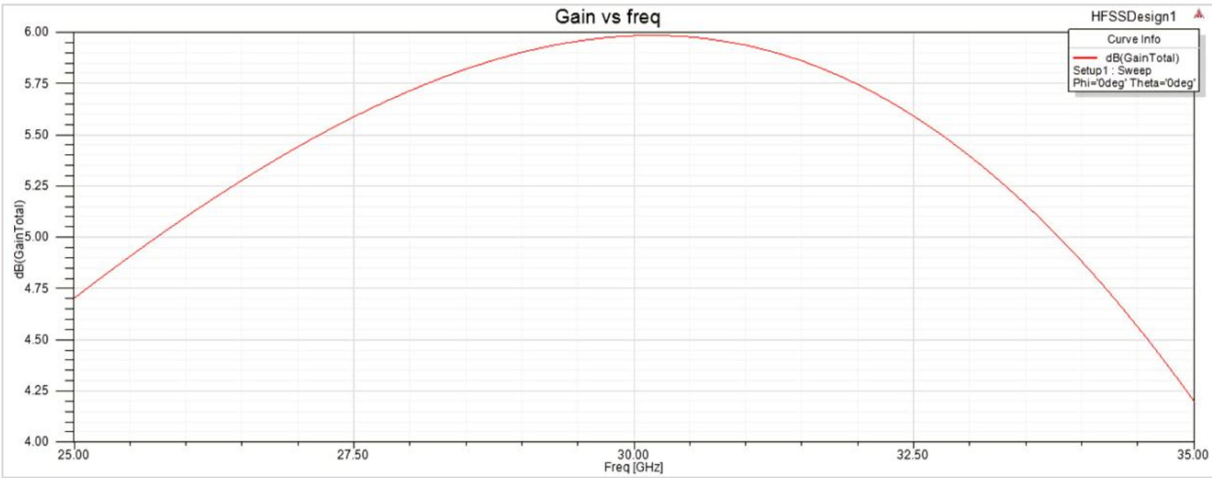
	Coordinate	Position (MM)	X – Size (MM)	Y – Size (MM)	Z – Size (MM)
Substrate dimension	Global	-2.5, -3, -0.5	5	6	0.5
Patch dimension	Global	-1.55, -2.1, 0	3.1	4.2	0.05
Ground dimension	Global	-2.5, -3, -0.55	5	6	0.05
Transmission line dimension	Global	1.2, -.025, 0	1.3	0.5	0.05
Wave port dimension	Global	2.5, -0.25, -0.55	0.3	0.5	0.6

Table 3 Different dimensions of substrate materials

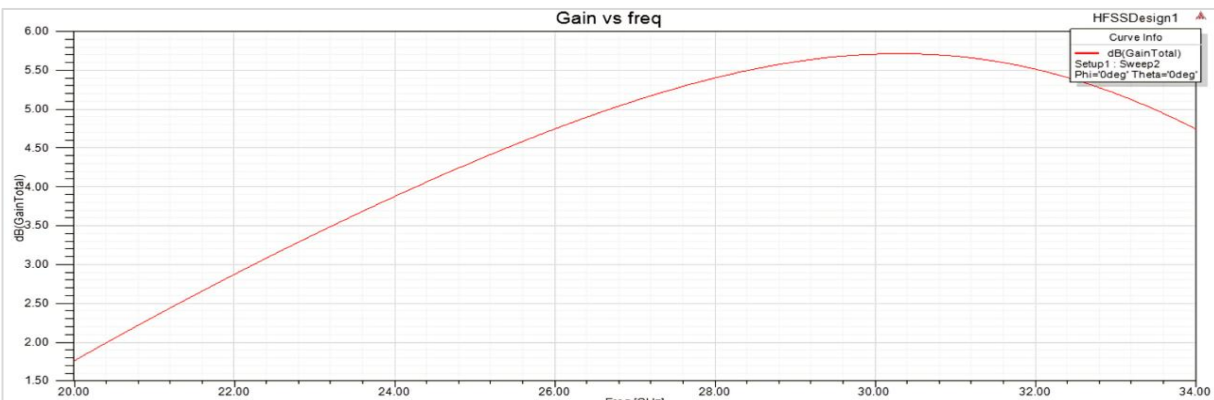
Substrate material	Length (MM)	Width (MM)
Rogers RT/Duroid 5880	3.1	4.2
Taconic Thin layer chromatography (TLC)	2.5	3.6
FR4	2.1	3.2

4.Results

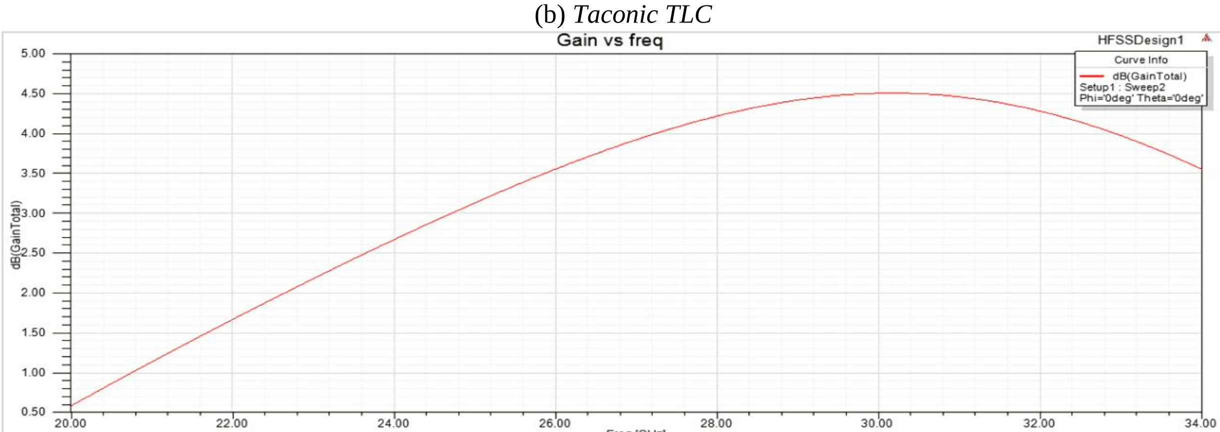
In this chapter 4, the simulated results of each substrate materials are discussed. Simulation was done by using HFSS software at constant resonant frequency value of 29 GHz. *Figure 5* depicts the gain plots of Rogers RT/Duroid 5880, Taconic TLC and FR4 substrate materials respectively. From these plots it is clear that Rogers RT/Duroid 5880 substrate material provides a good value when compared with others as 5.9 dB at the specified resonant frequency.



(a) Rogers RT/Duroid 5880



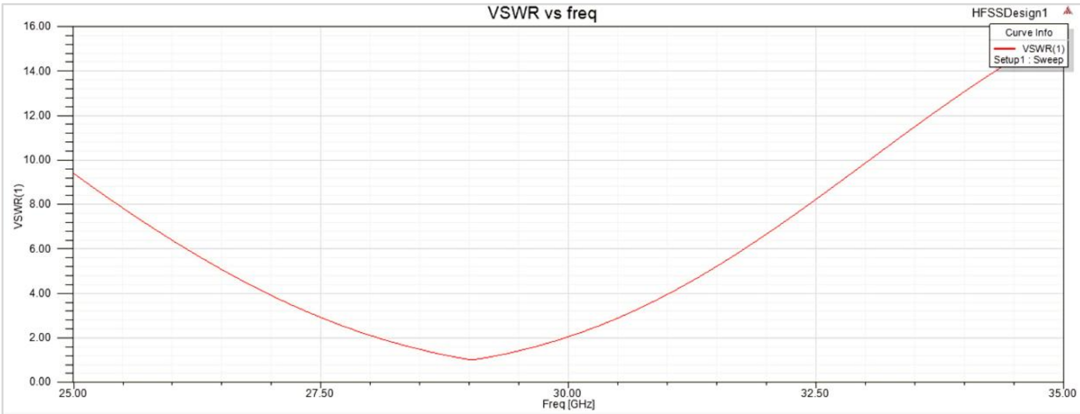
(b) *Taconic TLC*



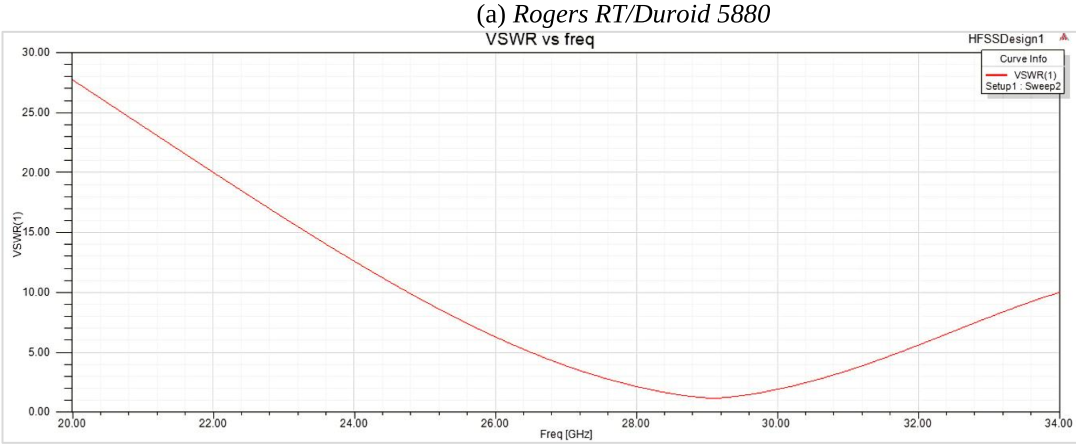
(c) *FR4*

Figure 5 Gain of proposed antennas for different substrate materials

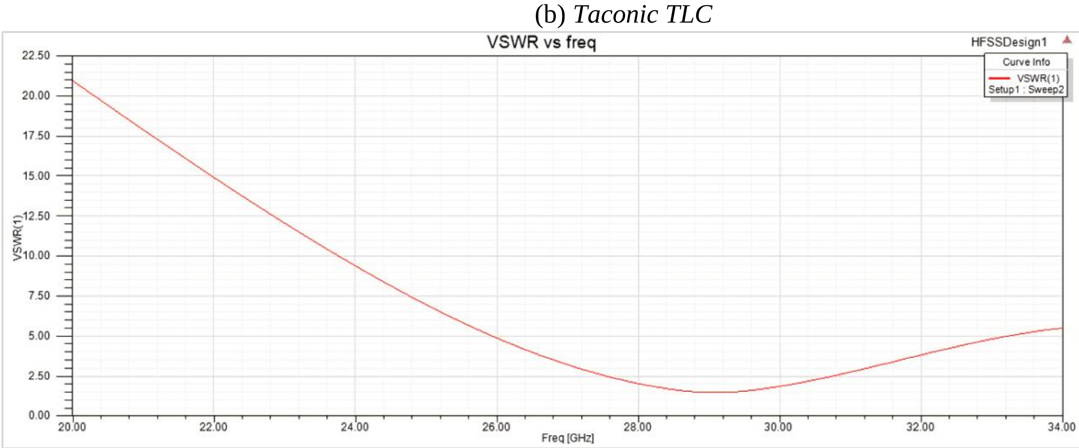
Figure 6 depicts the VSWR plots of Rogers RT/Duroid 5880, Taconic TLC and FR4 substrate materials respectively. From these plots it is clear that FR4 substrate material provides a good value when compared with others as 1.5.



(a) *Rogers RT/Duroid 5880*



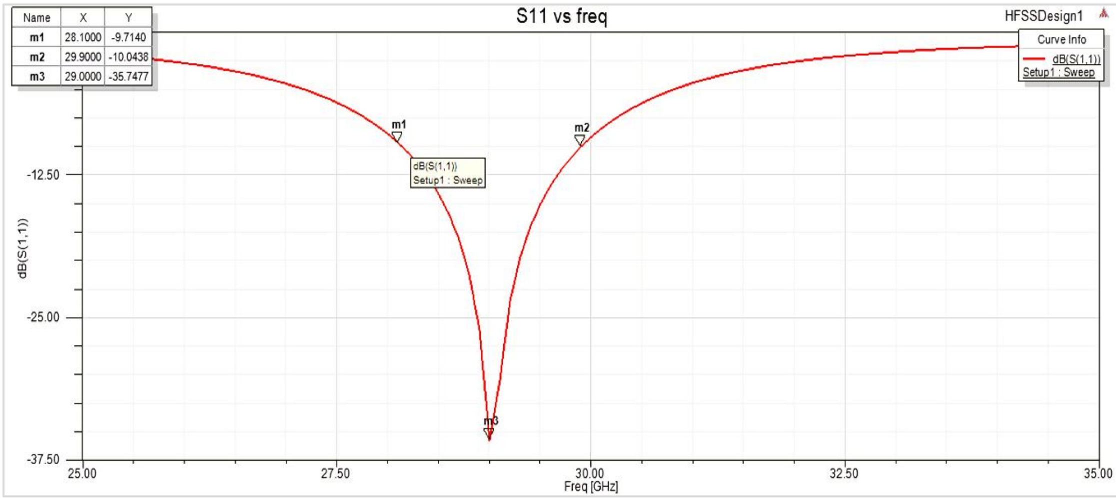
(b) *Taconic TLC*



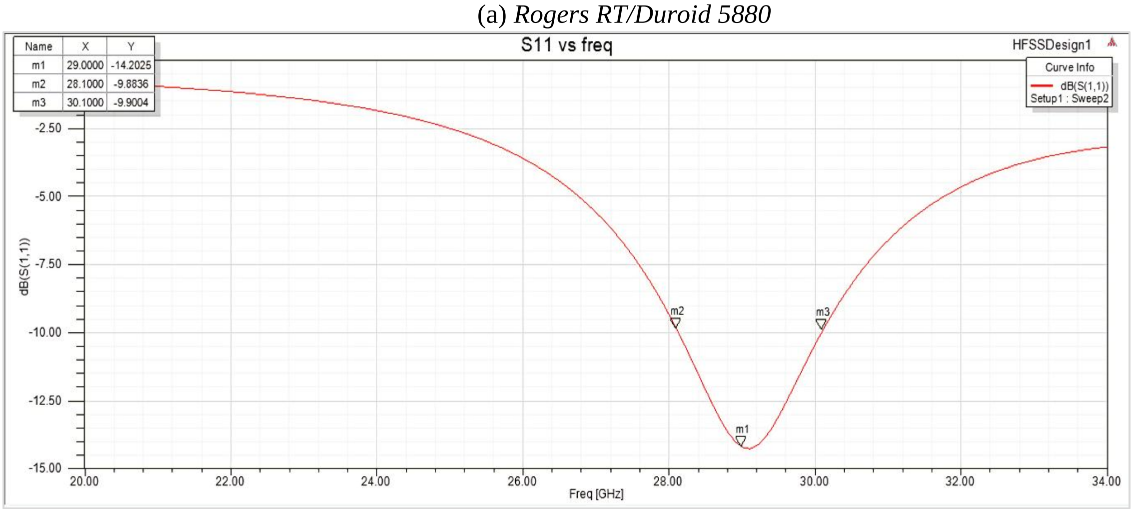
(c) *FR4*

Figure 6 VSWR of proposed antennas for different substrate materials

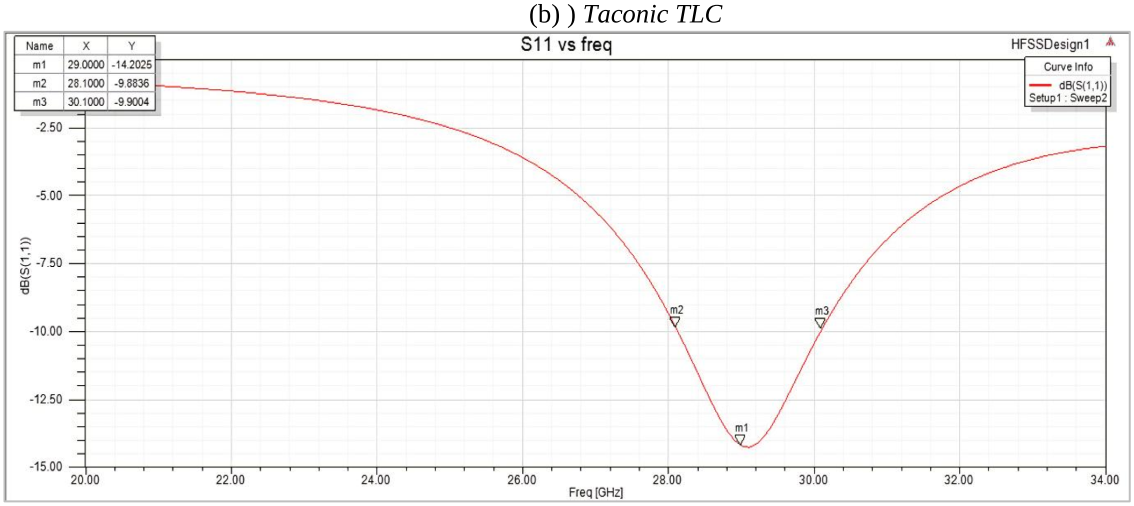
Return loss of the proposed antenna design for three different substrate materials is given in *Figure 7*. From the simulated results, it very clear that, return loss of the substrate materials Rogers RT/Duroid 5880, Taconic TLC and FR4 are -36 dB, -21 dB and -14.2 dB respectively.



(a) *Rogers RT/Duroid 5880*



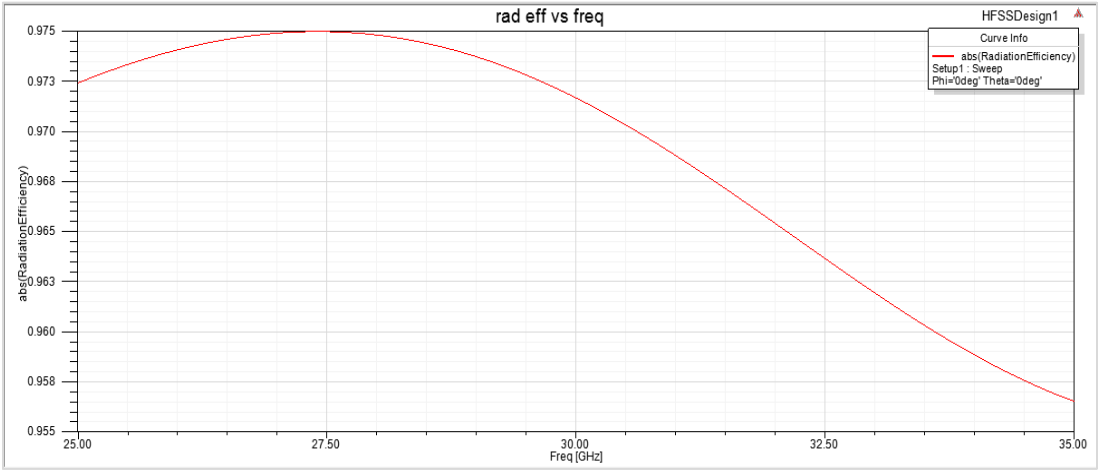
(b)) *Taconic TLC*



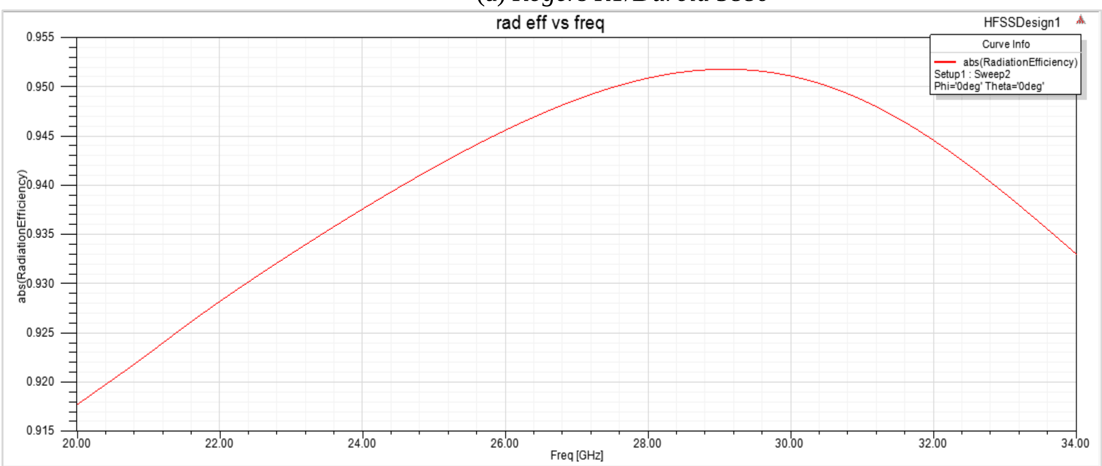
(c) *FR4*

Figure 7 Return losses of proposed antennas for different substrate materials

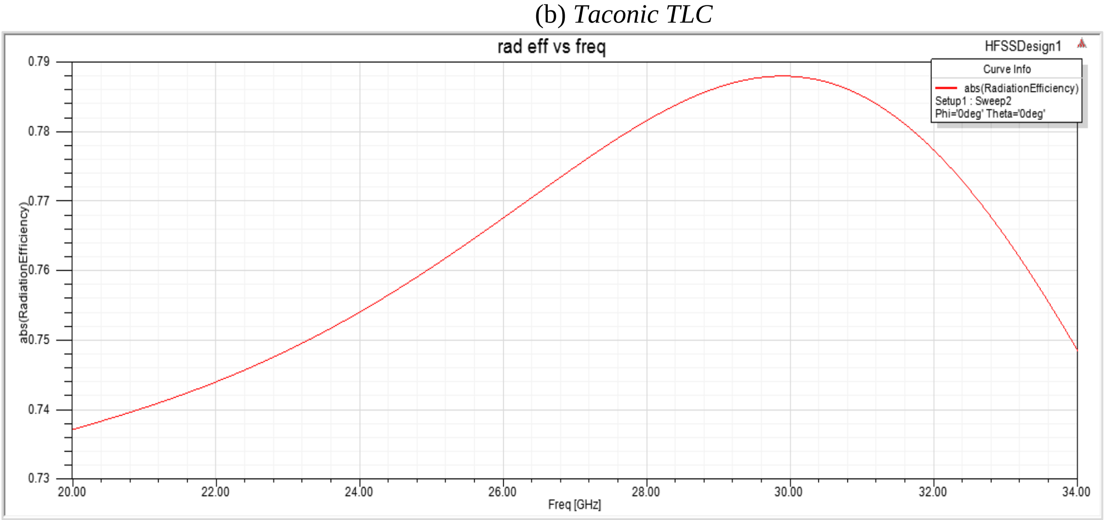
Radiation efficiency of the proposed antenna design for three different substrate materials is given in *Figure 8*. From the simulated results, Rogers RT/Duroid 5880 produces a high radiation efficiency of 97.4% when compared with other two materials as Taconic TLC with 95.2% and FR4 with 78.6%.



(a) *Rogers RT/Duroid 5880*



(b) *Taconic TLC*



(c) *FR4*

Figure 8 Radiation efficiency of proposed antennas for different substrate materials

5.Discussion

The proposed microstrip patch antenna is simulated with the help of HFSS software. The proposed design analysed with different parameters like, return loss, gain, bandwidth and VSWR for three different substrate materials. The comparison of all results obtained for three substrate materials with given specification are given in *Table 4*. From *Table 4*, Rogers RT/Duroid 5880 substrate material provides a good radiation efficiency of 97.4%, while comparing with other two materials at given resonant frequency. But FR4 substrate material exhibits a better bandwidth of 2 GHz. *Table 5* compares bandwidth and gain of different types of steps used in the simulation.

Table 4 Comparison of results at resonant frequency = 29 GHz

Dielectric material	Rogers RT/DUROID 5880	Taconic TLC	FR4
Dielectric constant	2.2	3.2	4.4
Return loss (S11)	-36 dB	-21 dB	-14.2 dB
Bandwidth	1.8 GHz	1.8 GHz	2 GHz
VSWR	1	1	1.5
Gain	5.9 dB	5.6 dB	4.4 dB
Radiation efficiency	97.4%	95.2%	78.6%
Length × Width of patch	3.1 mm×4.2 mm	2.5 mm×3.6 mm	2.1 mm×3.2 mm

Table 5 Comparison of steps used in the proposed system

Steps Used	Bandwidth	Gain
General design	1.3 GHz	5.9 dB
With parasitic patch	1.5 GHz	8.08 dB
With two rectangular slots on patch and one rectangular slot on parasitic patch	1.5 GHz	8.06 dB
With DGS	1.6 GHz	8.09 dB

The graphical representations of dielectric constant, bandwidth, VSWR, gain radiation efficiencies are given in *Figure 9* and *Figure 10* respectively. From *Figure 9*, it is clear that FR 4 substrate material provides higher bandwidth and VSWR than the other two materials. *Figure 10*, concludes that Rogers RT/Duroid substrate material provides a high radiation efficiency of 97.4% when compared with other substrate materials Taconic TLC (95.2%) and FR4 (78.6%).

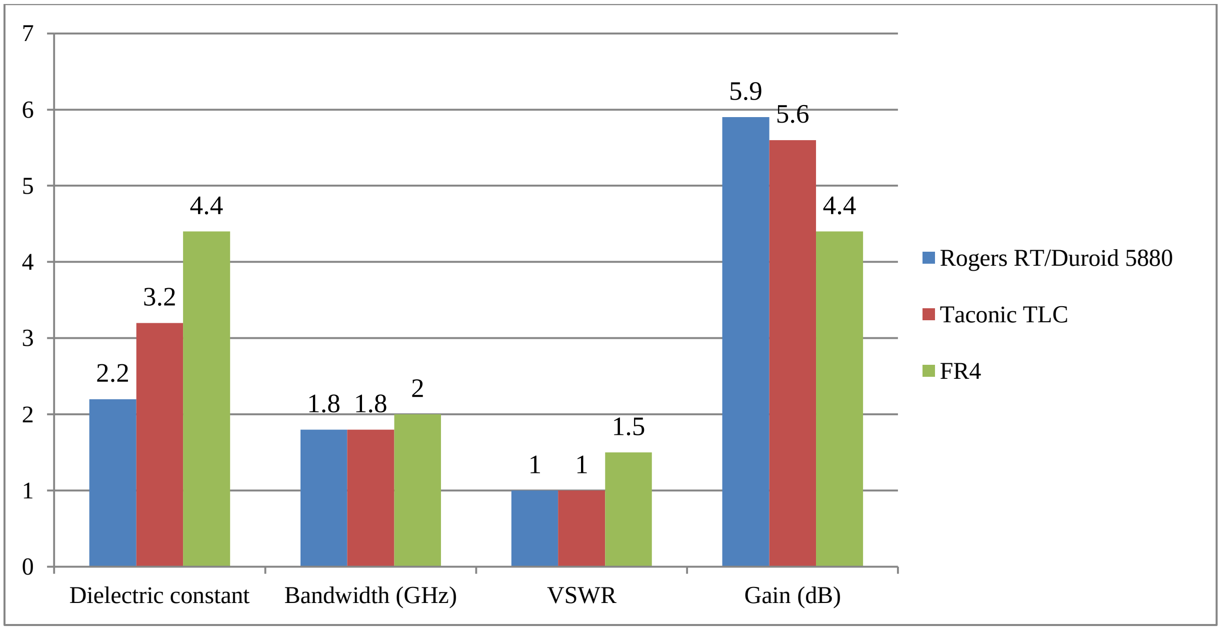


Figure 9 Graphical representation of dielectric constant, bandwidth, VSWR and gain of proposed antenna

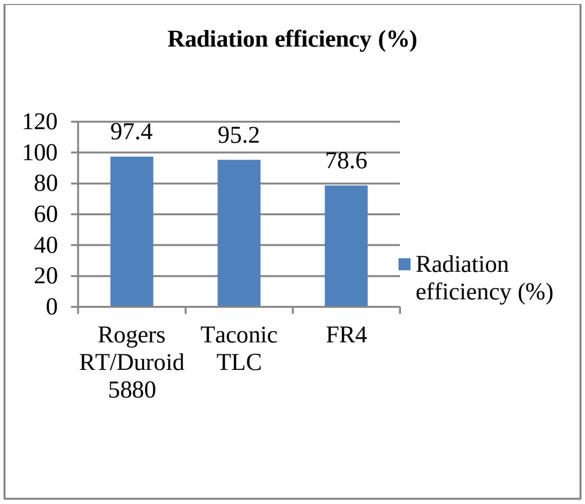


Figure 10 Graphical representation of radiation efficiency of the proposed antenna

5.1Limitations

Due to the limited size, microstrip antennas are not used in applications where the operating frequency is inferior than microwave frequency.

A complete list of abbreviations is shown in *Appendix I.*

6.Conclusion and future work

Microstrip antennas are good candidates for wireless communication due to its low profile, light weight and ease of creation. In this paper three different types of substrate materials were considered for Microstrip antenna design with 29 GHz resonant frequency for 5G applications. The microstrip line feeding mechanism is used for feeding the patch. The proposed antenna design and simulation output was attained by HFSS software. In suggested design, Rogers RT/Duroid 5880 provides high radiation efficiency of 97.4% when compared with others Taconic TLC (95.2%) and FR4 (78.6%). FR4 material provides high bandwidth of 2 GHz when compared with others. In the future, researchers may give more attention on microstrip antenna for textile wearable applications.

Acknowledgment

None.

Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contribution statement

Senthilkumar S, Udhayanila K and Mohan V: Developed the simulation results and drafted the first copy of the article. They also draft the final article and journal formatting. **Senthil Kumar T, Devarajan D and Chitrakala G:** Contributed to develop literature review of this article and contributed to the final article draft.

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Appendix I

S. No.	Abbreviation	Description
1	CST	Computer Simulation Technology
2	FR4	Flame Retardant 4
3	GPS	Global Positioning System
4	HFSS	High Frequency Structure Simulator
5	NFC	Near-Field Communication
6	RFID	Radio-Frequency Identification
7	RMPA	Rectangular microstrip antenna
8	TLC	Thin Layer Chromatography
9	VSWR	Voltage Standing Wave Ratio
10	WIFI	Wireless Fidelity