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Performance Analysis of Various Substrates for H-slotted Microstrip Patch Antenna with DGS for Wireless Communications

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Abstract

This research article puts forward a constructive outlook for configuring an extremely compact rectangular patch antenna for wireless applications. As the reachable dielectric constant for the substrate is 2.2≤ εr ≥12, we have chosen nine dielectric substrates in-between this range. The innovation of this work affords multi-effects such as an efficient antenna which adopts the various substrates at 2.4 GHz operating frequency, size reduction, multiband operation, tuned antenna characteristics, and coverage of C-band applications such as satellite communication, WiMAX, WLAN, Wi-Fi. It is realized here by adding an H-shape and a rectangular slot to the patch and a modified Pi-A defected ground structure (Pi-ADGS). The designed antenna is presented and examined using HFSS 13.0 software. The reflection constant, bandwidth, gain, radiation efficiency, radiation pattern. Penda-bands, quad-bands, dual-bands -resonant frequencies are attained for various substrate materials such as Silicon, Sapphire, Taconic TLC, Rogers RT-Duroid 5880, and FR4, respectively. It is found that Taconic TLC (tm) offers dual- band with the highest gain of 4.49 dB. The enhanced bandwidth of 0.99 GHz is achieved by FR4 at a dual-band nature, and the highest efficiency of 99% is provided by RT-Duroid. All the considered substrates provide a good radiation pattern. The specification research reveals that the shape and proportions of the determinate ground plane and slots in the patch are the vital mechanisms and the economic tact in upgrading the transmission capacity, multi-resonant frequencies, and antenna parameters. The novel outcome of this research work is the review of various substrates on the slotted and defected ground structure of the antenna, which offers more benefits for the essential needs of the modern communication field.

Keywords: Antenna miniaturization; H-Slotted, rectangular slot; Pi-ADGS; Microstrip feed line; C-band

1. Introduction

At the moment, the speedy forwarding of contemporary communication systems has a need for assignable equipment for certain noteworthy features that incorporate uncomplicated scheming, weightless, tiny, well suited with microwave, and millimeter-wave integrated circuits, economy, and easy manufacture of microstrip antennas [1]. In recent years, there has been a significant increase in the investigation of antennas. Weighed up against conventional antennas, microstrip patch antennas have further precedence and preferable probability. With the massive data charge, the magnitude of systems becomes tiny gradually and it is more essential to the descendants in the network field. We need a structured and compact antenna to achieve the victory of the progression of two foremost qualities: Wi-Fi (WLAN) and Wi-MAX in wireless applications in everyday life [2]. Several useful communication systems are still required on a small scale in traditional MPAs to meet definite space constraints [3]. Essentially, the MPA has a demand for high gain, small size, wide bandwidth, extensibility, ease of fabrication, etc. [4]. It could be employed by utilizing diverse substrates whose dielectric constants appear to the extent of 2.2–12. Improved efficiency and extensive impedance bandwidth are imparted by the lower dielectric constant of the substrates. Obtaining various patch shapes and inserting patches with various types of slots and notches are effective methods for increasing the MPA's bandwidth [5].The most recent advancements in dielectric substrate technology have also heightened interest in microstrip antennas. There are various types of substrates available, and a specific question now arises regarding the choice of substrate material and thickness for a given antenna implementation and the performance achievable [6]. From fluency in wireless communication and radar systems, conformability to different frameworks is a necessary thing for concealing multi-band implementations [7]. Slotted patch antennas are designed to achieve multi-band characteristics [8]. Currently, defected ground structure (DGS) microstrip fix receiving wires have been hastily established for multi-band and wideband in broad band equivalence schemes [9]. A compact multi-band antenna gave an account for the application of military and satellites at the frequencies of S, C, and X bands. A reduced-size antenna is needed whereas notice is given on behalf of the miniaturized antenna with multi confined slots and slits for multiband implementation in the field of communication systems such as mobiles, laptops, tablets, and diverse tiny compact systems. Loading slots on the patch may be a quiet technique for patterning a multiband MPA [10]. With the fastest development of the mobile Internet and smartphones, data traffic is raising aggressively in modern mobile communication systems [11]. An option of the substrate could be a pivotal pace in order to configure an efficient antenna. The substrate is an essential thing in an antenna to keep up the mechanical reinforcement of the antenna metallization. The substrate demands of the accommodation of a dielectric material, which may influence the electrical execution of the antenna to supply the mechanical reinforcement [12]. The proposed design is analyzed for both multi-band and wideband characteristics by using a partial ground plane. For the actualization of the above deliberation, we put forward a compact H-shape, and rectangular slot-loaded microstrip patch antenna, which go along with the Pi-ADGS, which exposes multiband bearings. It also accomplishes a considerable reduction in size with the multiband operation. The resonance frequency is regulated by using various five dielectric substrates. The antenna characteristics of return loss, VSWR, gain, directivity, radiation efficiency, radiation pattern, and bandwidth are examined and compared. Thus the research article bestows a survey of MPA and its outcome with various dielectric substrates. The configured antenna is analysed for diverse substrate materials, and the consequences are compared and conceded in this research article. Finally, it provides a concise overview of recent advancements in the MPA configuring slots and DGS method through their implementations in the real world. Thus, the research article winds up with the comparison of diverse substrates and their advancements along with the defected ground structure at a particular working frequency of 2.4 GHz, which leads to the C-band applications.

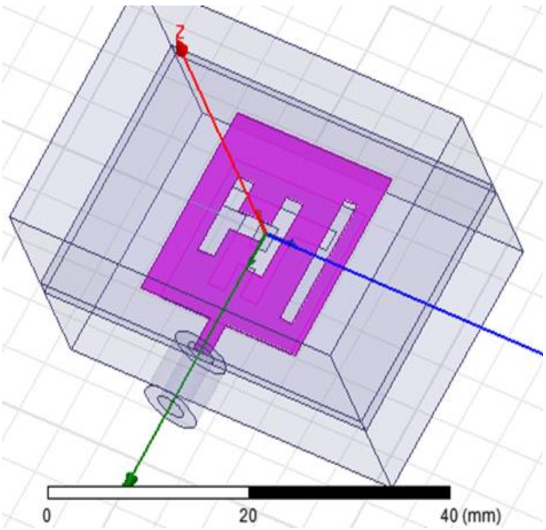


Fig.1 The proposed Microstrip Patch Antenna The optimum configurations specifications of the selected MPA have been conveyed in table 1

Table.1

S.No	Parameters	Measurements
1.	Design frequency **fr**	2.4 GHz
2.	Substrate height **h**	1.43 mm
3.	Substrate width $\mathbf{W_S}$	40 mm
4.	Substrate length $\mathbf{L_S}$	26 mm
5.	Patch width $\mathbf{W_P}$	16.2 mm
6.	Patch length $\mathbf{L_P}$	15.12 mm
7.	Ground plane width $\mathbf{W_G}$	19.3 mm
8.	Ground plane length $\mathbf{L_G}$	19.27 mm
9.	Feed line width $\mathbf{W_F}$	3.3 mm
10.	Feed line length $\mathbf{L_F}$	9 mm

2. Antenna Design Specifications

This research mainly focuses on compact, multi-bands, and enhanced outcomes of antenna characteristics by utilising H and rectangular slots within a radiating patch and also 'Pi-ADGS' upon the ground for various substrates. The primary stage in the provision of the microstrip antenna is to prefer working frequency and suitable substrate resolution. The operating frequency in our plan is taken to be 8.5GHz, which is the S-band region. The successive phase in the antenna shaping is to pick up a suitable substrate. The optimized height and dielectric constant of the substrate are determined by the antenna's electromagnetic properties [13]. As a consequence, for simple investigation, an easy single-coated MPA with direct edge feed is preferred here.

The antenna geometry is made up of a fully grounded structure beneath the dielectric substrate and a metallic patch, which is on the radiating face and is manifested in Figure 1. The feeding method in use is the microstrip feed line. Diverse dielectric materials are obtainable in merchandise for the production of printed antennas. Each and every dielectric material is the owner of particular effects, and distinct conduction properties that influence the fringing waves in the patch antenna, hence enhancing the overall resources of the antenna. The dielectrics are picked up in conformity with the application and cost. An MPA holds the various shapes of rectangular, circular, slotted, triangular, etc. Rectangular patch antennas are the most frequently used universal MP antennas which we have considered for our analysis [14]. For our analysis, we have considered five dielectric substrates such as silicon, sapphire, FR4epoxy, Tacconic TLC (tm), and RT-Duroid.The proportions of the rectangular antenna are turned down over the introduction of the H-shape and rectangular slot on the patch, as manifested in Fig.2 (a). Its optimized measurements are noted in Fig. 2 (b). In an H-slot, left and right leg vertical length (A), width (B), centre leg horizontal length (D), lastly, the vertical length of a rectangular slot (E) and its width (F) which are tabulated as below

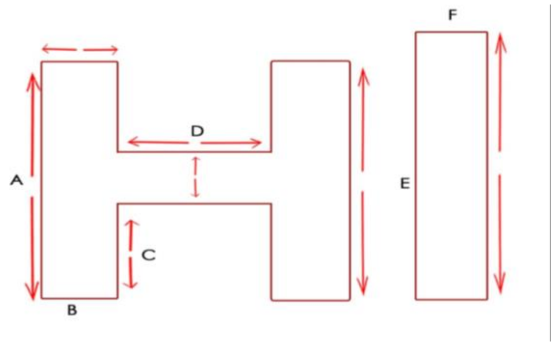


Fig 2(a) The geometry of the slot loaded patch

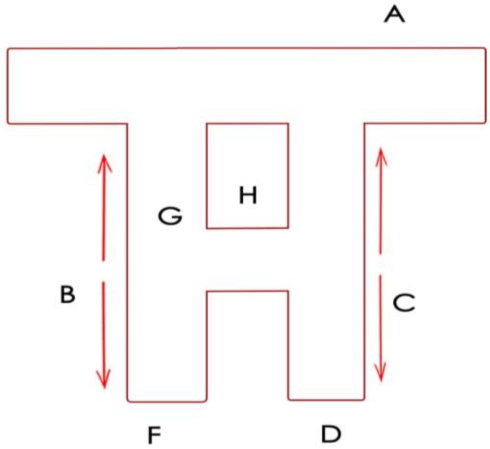


Fig 2(b) The geometry of the Defected Ground

The recommended microstrip ground plane antenna is configured using a length of 15.12 mm and a width of 16.2 mm. The ground structure is defected by the insertion of Pi-A to achieve multi-band resonant frequencies which lead to multipurpose applications in the communications world. The optimized values of Pi-ADGS are tabulated as below

A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)	G (mm)	H (mm)
13	3	7.5	2	3	2	2.5	2

Table.2 (Patch configuration)

A	B	C	D	E	F
8 mm	2mm	3 mm	4mm	13 mm	1.6mm

Table.3 (Ground configuration)

3. Simulation Result and Discussion

The dielectric constant of substrates affects the antenna performance profoundly. In the current work, size reduction, multiband operation, and enhanced radiation efficiency have been achieved by loading H-shape and rectangular slots in the radiating patch and Pi-ADGS in the ground structure. We have analyzed antenna characteristics for five diverse dielectric substrates by keeping the same dimensions of patch, substrate, and ground at the working frequency of 2.4 GHz using HFSS 13.0 software.

Comparative analysis of Return loss for various substrates

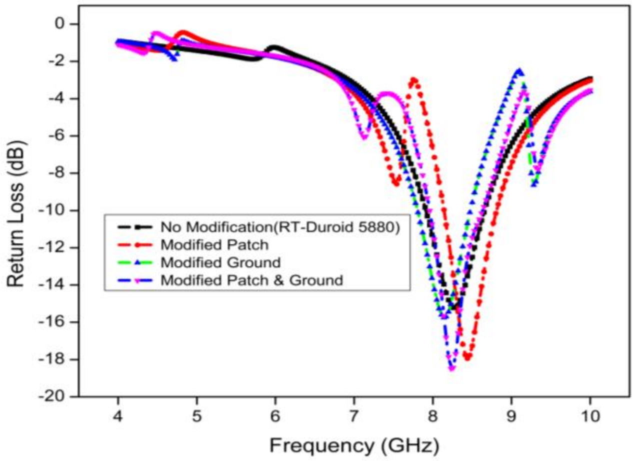


Fig.3 (a) Return loss of RT Duroid 5880

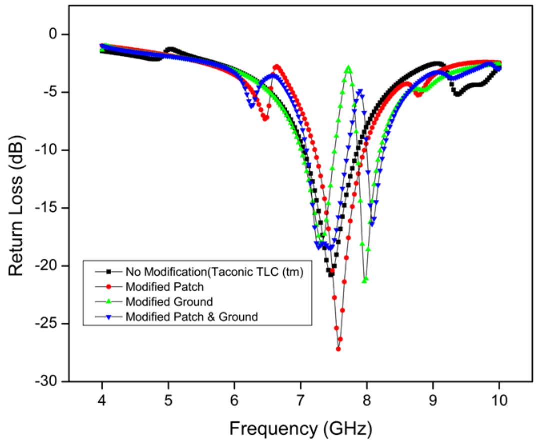


Fig.3 (b) Return loss of Taconic TLC (tm)

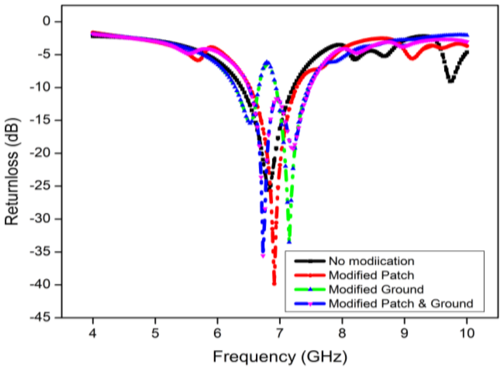


Fig.3 (c) Return loss of FR4

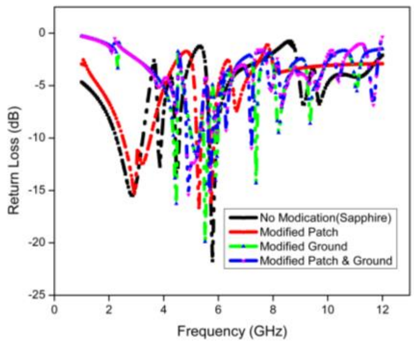


Fig.3 (d)Return loss of Sapphire

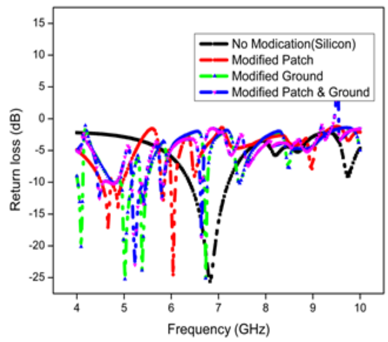


Fig.3 (e) Return Loss of Silicon

The above graph illustrates the comparative analysis of return loss which is carried out on the various substrates having the same dimensions of patch, substrate, and ground. When there is no modification on the patch, the RT Duroid antenna, Taconic TLC (tm) antenna, FR4 antenna, and Silicon antenna obtain a single band only. By adding the slots on the patch, all the selected substrates yield multi-bands with poor directivity and gain. The same thing is happening, when the antenna has DGS only. The antenna with various substrates achieves good bandwidth, enhanced gain, directivity, and efficiency after the modification of the patch as well as the ground structure. The return loss of the RT-Duroid suggested antenna is −18.36 dB at the resonant frequency of 8.26 GHz. The Taconic TLC antenna achieves double-band with return losses of -18.13 dB at 7.38 GHz, and 16.34 dB at 8.09 GHz. The return losses of the suggested antenna of FR4 –epoxy are −35.54 dB, −19.30 dB at the resonant frequencies of 6.72 GHz, and 7.21 GHz, respectively. The recommended Sapphire antenna reaches the return losses of −15.41 dB, -15.07 dB, -10.96 dB at 4.90 GHz, 5.67 GHz, and 7.21 GHz respectively. The recommended silicon antenna achieves return losses of −14.42 dB, -21.96 dB, -12.53 dB, 12.16 dB and -10.44 dB at 4.46 GHz, 5.23 GHz, 5.40 GHz, 5.78 GHz, and 6.66 GHz respectively.

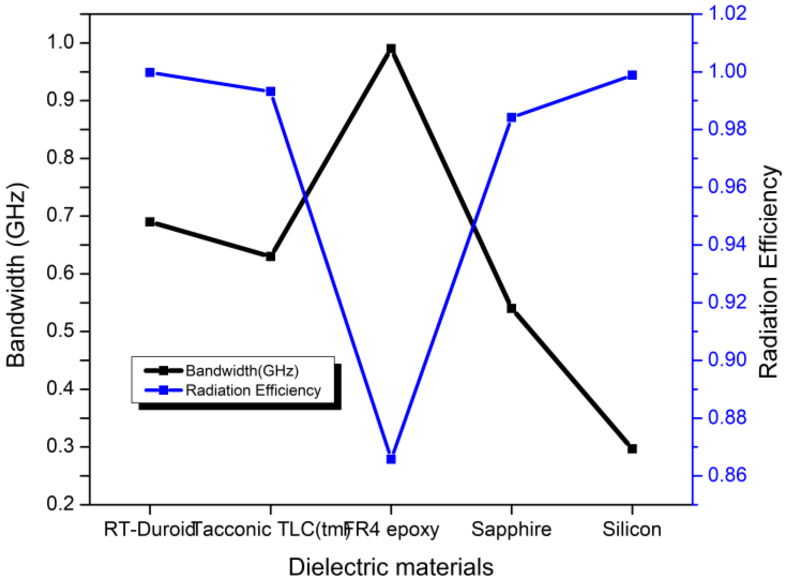
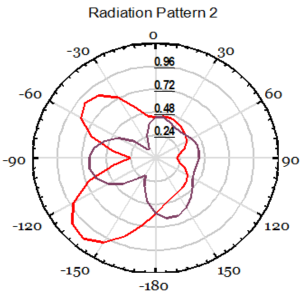


Fig.4. Comparative analysis of Bandwidth and radiation efficiency for five diverse substrate

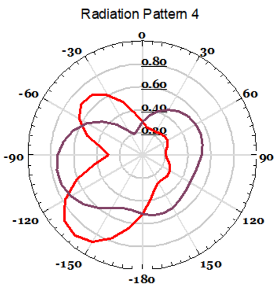
Comparative analysis of Bandwidth and radiation efficiency

Fig.4 shows the comparison between the bandwidth and radiation efficiency for the subsrates of RT Duroid, TLC Taconic, FR4 epoxy, Sapphire, and Silicon. Good bandwidth is achieved by the subsrate of FR4 epoxy, and the maximum efficiency of 99 % is obtained by all the selected subsrates of FR4 epoxy. It covers the frequency range of 4 GHz to 8 GHz, which could be used in C-band applications**.**

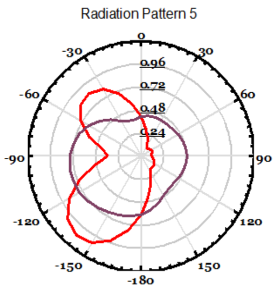
Radiation pattern of various subsrates



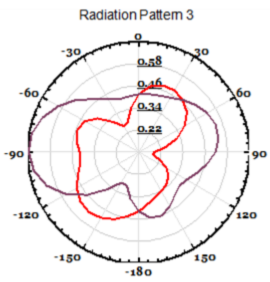
5(a)



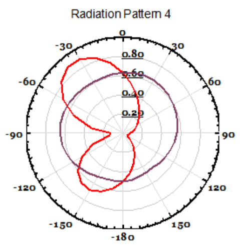
6(a)



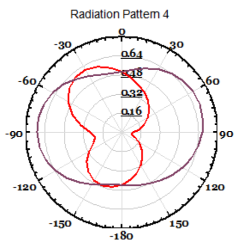
6(b)



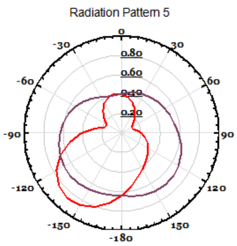
7(a)



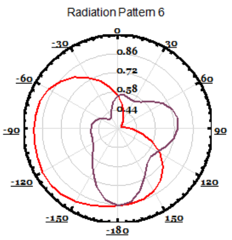
7(b)



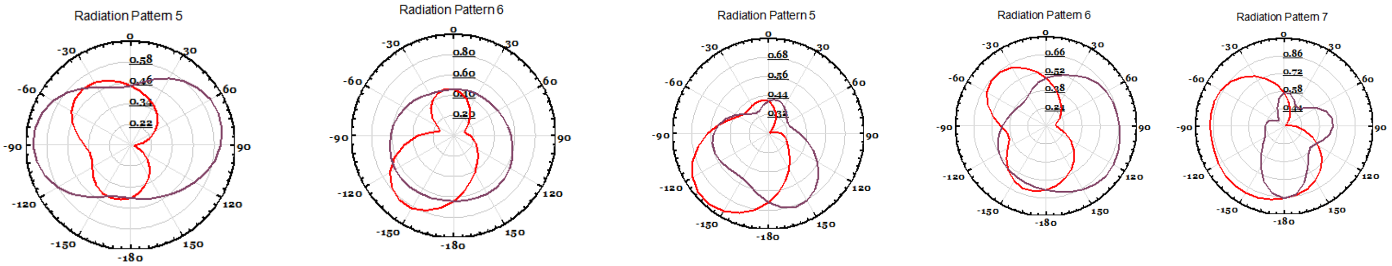
8(a)



8(b)



8(c)



9 (a) 9(b) 9(c) 9 (d) 9 (e)

Fig 5: RT-Turoid Radiation Pattern: (a) at 8.26 GHz

Fig. 6 Taconic TLC (tm) Radiation patterns (a) at 7.27 GHz (b) at 7.43 GHz

Fig.7 FR4 Radiation patterns: (a) at 6.72 GHz; (b) 7.2150 GHz

Fig.8 Sapphire Radiation pattern: (a) at 4.9050 GHz (b) 5.6750 GHz (c)7.2150 GHz

Fig.9 Silicon Radiation pattern: (a) at 4.46 GHz (b) 5.2350 GHz (c) 5.40 GHz (d) 5.78 GHz (e) 6.6650 GHz

Fig.5 to fig.9 display the radiation pattern of the five diverse substrates corresponding to their resonant frequencies. The radiation pattern of the considered substrate reveals the capacity of the antenna where it can be utilized in the modern communication field. The great benefit of this analysis is that all the selected substrates bring out good radiation patterns, which is achieved by the introduction of the slots on the patch as well as on the ground structure.

Table 4: Proportional outcomes of diverse substrate

S,No	Dielectric materials	Dielec constant	f_r(GHz)	Return Loss(dB)	Gain (dB)	Direct (dB)	Radiation Efficiency	Band width
1	RT-Turoid	2.2	8.26	-18.3637	4.29	4.19	0.9998	715 MHz
2	Tacconic TLC (tm)	3.2	7.38 8.0950	-18.1339 -16.3433	3.62 4.49	3.62 4.54	0.9932 0.9887	628 MHz
3	FR4 epoxy	4.4	6.72 7.2150	-29.2434 -19.5643	2.57 3.02	3.19 3.49	0.80432 0.86581	9900MHz
4	Sapphire	10	4.90 5.67 7.21	-15.41 -15.07 -10.96	1.33 2.10 1.81	1.31 2.09 1.81	1.0082 1.0038 1.0008	4821 MHz
5	Silicon	11.9	4.46 5.23 5.40 5.78 6.66	-14.42 -21.96 -12.53 12.16 10.44	0.93 1.74 1.51 2.29 1.51	0.93 1.73 1.51 2.29 1.50	0.99884 0.9849 0.9995 0.9714 0.9945	3006MHz

Table.4 reveals the performance specifications and the proportional outcomes of the five different substrates. The revelation of the table confirms to us that the selected substrates coordinate well with the dimension of the antenna and also with the working frequency of 2.4 GHz. Each substrate has its own unique properties, achieving better results. It resonates at single, double, triple, and quint bands, which offer C-band applications. All of the substrates chosen for our analysis have higher efficiency, with an efficiency of more than 85%. The Taconic antenna is a low dielectric constant substrate material for our analysis, which resonates at 7.38 GHz, and 8.09 GHz and holds a higher gain of 4.49 dB. The specialty of the silicon antenna produces quint-bands which cover the C-band applications.

The selected substrate materials reveal a bandwidth above 200 MHz, but FR4-epoxy arrives at an enhanced bandwidth of 0.99 GHz among all others.

5.Novelty of this Research Work

Several researchers have attempted to do substrate analysis on antennas. But the substrate analysis with the slotted antenna having DGS is rare. So the novelty of this research work is the execution of slot cuts on the patch as well as on the partial ground, and the outcomes are analyzed carefully for five different substrates. Comparative analysis is done for no modification on the patch and ground, the patch alone is modified by the insertion of H and rectangular slots, modified ground by the introduction of the pi-slots, for the considered antenna The length and width of the slot cuttings and their position play a vital role in the tuning of the characteristics of the antenna. The specification research reveals that the various substrate materials properties can be tuned by using slot cutting techniques for the better performance of Microstrip Patch Antenna. It is the shape and proportions of the determined ground plane, and slots in the patch, that provide the key mechanisms and the economical approach to upgrading the transmission capacity, multiple resonance frequencies, which leads to the enhancement of the antenna parameters..

6. Conclusion

The research article provides a great analysis of slot cutting techniques used on the both patches as well as on ground for various substrates. It yields a highly miniature MPA that covers C-band applications. However, a recommended antenna miniaturization methodology with H-slot and rectangular slot is adapted to configure a portable patch and fractal Pi-ADGS loading scheme on the ground structure, which enables multi-band frequencies for wireless communications. The features of MPA, such as return loss, VSWR, gain, directivity, radiation efficiency, bandwidth, and radiation pattern with different substrate materials are investigated and compared. High and remarkable gain is achieved by the substrate of Taconic TLC (tm), the bandwidth is enhanced in the case of FR4-epoxy, and the best radiation efficiency and good radiation pattern are achieved by all the substrates which we have taken for our analysis. This compact MPA is the most appropriate aspirant for the implementation of C-band applications in wireless communication.

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