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High Gain Miniaturized Multi-band Microstrip Patch Antenna Using Slot-Cutting Techniques for C, and X Band Applications

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P Arockia Michael Mercy* and KS Joseph Wilson

PG & Research Department of Physics, Arul Anandar College, Madurai Kamaraj University, Madurai - 625514, Tamilnadu, India

***Corresponding Author:** P Arockia Michael Mercy, PG & Research Department of Physics, Arul Anandar College, Madurai Kamaraj University, Madurai - 625514, Tamilnadu, India.

Abstract

This research paper bestows a rectangular slot-loaded microstrip antenna in possession of DGS, which may give multi-band and the highest gain for C-band, X-band, and Ku-band applications. The distinct antenna structure is simulated through HFSS 13.0 simulation software for the illustrative investigation of enhanced gain. The newborn evolution of the advancement of wireless internet means of approach is concerned with the insistence on multi-band antennas. The investigation of nine-band frequency antennas is an achiever of 6.0350 GHz (Global Navigation Satellite System (GNSS), 6.7950 GHz (Satellite TV), 7.46 GHz (Long-distance Communication), 8.5050 GHz (Terrestrial Broadcast Radar), 11.45 GHz (Space Communication), 13.35 GHz (detector), 15.06 GHz (Military), 17.24 GHz (Aerospace), and 19.05 GHz (Astronomical observation). The multi- band aspect is accomplished by novel U-slot cuttings and rectangular slots in the antenna. It resonates at quad- band without any patch or ground modification; when a U- slot cutting is made at the left and top of a patch, it resonates at six bands; and when rectangular slot cuttings are united at the ground plane, it resonates at nine bands. The slot length, width, and position are optimized to attain the highest gain. The achieved gains of the proposed antenna are 1.5865 dB, 1.1344 dB, 1.0416 dB, 0.92179 dB, 3.7586 dB, 6.2776 dB, 5.1998 dB, 14.679 dB, 5.4279 dB, 6.0350 GHz, 6.7950 GHz, 7.4600 GHz, 8.5050 GHz, 11.45 GHz, 13.3500 GHz, 15.0600 GHz, 17.2450 GHz, and 19.0500 GHz. In wireless communication, a successful multi-band antenna is advantageous.

Keywords: Multiband Microstrip antenna; Slot cuttings techniques; DGS; C; X and Ku band

Introduction

The world's need for antennas and their advancement make them indispensable for wireless communication and information passing, making use of mobile devices [1]. The microstrip patch antenna (MPA) is easily more apt in all communication devices because of its small size and lightweight composition [2]. The configuration of MPA having more than one band (dual-band, multi-band, or even ultra-wideband) effectiveness goes well with an empirical request in the recent wireless communication. Subsequently, this antenna plays a crucial role in reducing the device's size and increasing its portability by merging several communication qualities into a unique, concise setup [3]. A multi-band antenna could accomplish several wireless implementations, while it may be in charge of multi-frequency bands. It competes for a pivotal role in wireless communication systems for different wireless applications like GSM (Global System for Mobile Communication), WLAN (Wireless Local Area Network), Wi-MAX (Worldwide Interoperability for Microwave Access), and Wi-Fi (Wireless Fidelity) [4]. Broad bandwidth, slitter conductor loss, preferable insulation in the middle of the radiating element, and a feed network are exceptional benefits of a slot antenna. Additionally, it yields the advantages of low posture, economical, compact, quiet integration with additional circuits, and contentment to a formed external [5].

When the ground plane is modified or etched to alter its conformity, this is normally known as a "defect" [6]. The DGS structure is configured by etching the shape of a regular or irregular design into a microstrip line, a coplanar waveguide, and another microwave transmission line. It holds a forbidden band with similar photonic bandgap features (PBG); even so, there is no need to be periodically etched as with PBGs [7]. A triple-band antenna with a size of 60 x 25 is presented in [8] and consists of a parasitic upside-down-L wire for portable systems, but a triple-band operation is only fulfilled by this design. In [9], a concise monopole-printed triple-band antenna having the measurements 26 x 20 is designed for WLAN/WiMAX applications, but this antenna covers short-range applications only. Mobile wireless applications are achieved by a triple-band MIMO antenna with a dimension of 100 x 65, which is presented in [10]. However, this antenna is quite large. The gain effect of a multi- band antenna having a proportion of 60 x 30 is investigated in [11] based on composite rectangular SRRs, yet it has a limitation in its triple-band operation. A triple-band ground radiation antenna is analyzed in [12], along with a size of 120 x 60 for GPS and WiFi applications, but this design, which is large in size, also resonates at three bands only. The concise triple-band slotted antenna is presented in [13], together with a size of 35 x 30 for WLAN/WiMAX applications, even though it doesn't have the advantage of broadband. In [14], a multi-band compact antenna with the size of 28 x30 possessing $\lambda/4$ rectangular stub filled and with metamaterial is presented for IEEE 802.11N and IEEE 802.16E. In any case, it only gets four bands. A multi-band slot antenna is designed in [15] 48 x 18 for GPS/WiMAX/WLAN systems, despite the fact that it has the demerits of short-range implementation.

"A miniaturized multi-band slotted MPA with the size of 25 x 25 is analyzed for wireless applications," according to [16], despite the fact that it characterized four bands. A compact UWB-printed slot antenna is configured in [17] with a size of 25 x 28 mm for the implementation of extra Bluetooth, GSM, and GPS bands. The size-reduced, multi-band, evolvable, haphazardly slotted MPA is presented in [18] with a size of 25 x 28 for WiMAX/GPS/ Bluetooth /GNSS/ X-band applications. A miniaturized slotted multi-band antenna is described in [19] alongside a 24 x 16mm substrate for wireless applications. [20] Depicts a multi-band MPA sketch with dimensions of 30 x 30 mm for C and X-band. Although the above MPAs could provide sufficient gain, they are limited by their operating frequency range, which means that they couldn't operate over large ranges for applications requiring higher gain. In comparison to the above-said antennas, the considered antenna offers advantages in terms of compact size, more frequency bands in a wide range, the highest gain, enhanced efficiency, and a better radiation pattern that covers the short-range applications of C-band, UWB of X-band, and a broad band range of K and Ku-band. This research paper introduces U-slot cuttings in the patch and rectangular-shaped slot cuttings on the ground plane (DGS) to cover a broad range of applications in the same antenna. These features of our analysis make the antenna work over a wide range of nine-band frequencies. The mechanism behind our work is the optimized proportions of an antenna and its slots. It has the potential to be used in immobilized devices, handheld devices, communications relay satellites, and radar applications.

The configuration of the suggested antenna

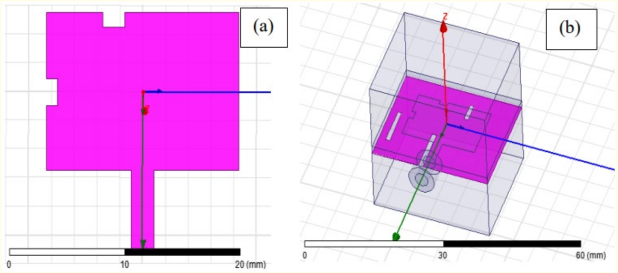


Figure 1: Antenna Configuration (a) Top View (b) Perspective View.

A viewpoint of the suggested antenna configuration has been manifested in Figures 1 (a) and (b), respectively. A prime focus of our current work is the size reduction of the antenna and multi-band for multi-implementation, which is realized by finding a use for dielectric substrate (FR4material) material having a dielectric constant of 4.4, which is very cheap, and the multiple resonance frequencies for multi-operation, which are carried out by the introduction of the slot cuttings in the patch and the ground. The final dimensions of the substrate are 22 mm (L) x 27 mm (W) x 1.6 mm (H). Creatively, double U-slot cuttings and the triple rectangular slots are assembled at the corners of a patch and at the center, left, and right of the ground to coordinate the antenna on target frequency bands. The transmission feed line dimensions are 5.5 mm (L) and 2 mm (W), which are utilized as a source of strength for the antenna. The tuning frequency of our designed antenna is 2.4 GHz. The antenna comes with a pre-owned ground measuring 22 mm by 27 mm. It is simulated using a defined component technique built into the HFSS (High-Frequency Structure Simulator) software. The upgraded proportions of a MPA are displayed on a table. 1.

Antenna parameters	***Measurements (mm)***
Substrate length	22
Substrate width	27
Height	1.6
Patch Length	11
Patch Width	16.9
Feedline length	5.5
Feedline width	2
Ground Length	22
Ground Width	27

Table 1

Evolution stages of the proposed antenna

The different forms and sizes of slots integrated into the patch account for a slotted MPA setup. The electric field in the constructed antenna is interrupted by the technique of cutting slots in the patch, which causes the enlargement of the effective length [21]. The several kinds of slots pre-owned on the radiating layer influence the different distinct features of gain, radiation pattern, radiation efficiency, directivity, and return losses. Two U- slots have been cut at the left side and top of the patch in order to result in miniaturization and additional frequencies for multi-purposes with the best gain. The inset feed goes with the impedance as shown in Fig. 1.

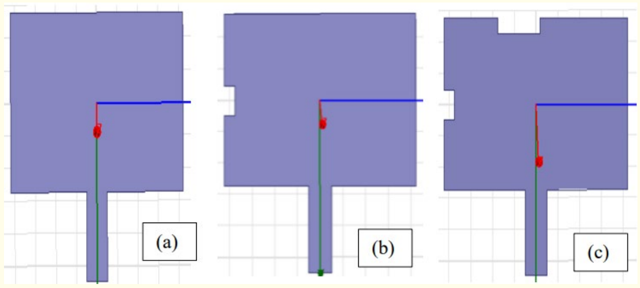


Figure 2: Antenna 1. ***Figure 2:*** Antenna 2. ***Figure 2:*** Antenna 3.
(a). No modification (b). U-Slot on left side (c). U-Slot on top.

No modificationon patch	***Fr(GHz***	***Return Loss(GHz)***	***Gain dB***	***Direc dB***	***Efficiency %***
	5.75	-19.7291	1.6743	3.007	55.679
	9.6450	-16.9511	1.1269	2.0441	55.13
	10.88	-19.9263	4.1342	6.4081	64.516
	13.36	-21.0084	3.1458	5.427	57.966
	15.7250	-24.5597	5.1028	6.0673	84.103

Table 2: Performance comparison of antenna in Figure 2 (a) - No Modification on antenna.

Modification on patch	***Fr(GHz)***	***Return Loss(GHz)***	***Directiv-ity dB***	***Gain***	***Efficiency***
Left side cutting					
	5.94	-20.1689	3.3472	2.0869	62.348
	9.93	-18.7915	2.7609	1.6088	58.272
	11.07	-20.9769	6.2839	3.9758	63.269
	13.8250	-15.7380	6.7223	4.2333	62.974
	16.1050	-17.3566	5.8539	5.151	87.992
Right side cutting					
	6.0350	-30.6668	3.191	1.8733	58.706
	10.2150	-20.8039	2.6337	1.4308	54.326
	11.3550	-25.6312	6.2515	3.9891	63.81
	14.3950	-10.7775	4.682	2.6749	57.132
	15.44	-12.5923	5.5449	4.3657	78.734
	16.2950	-22.9022	7.0829	6.0346	85.199

Table 3: Performance comparison of antenna in Figure 2 (a) (b), (c) after an introduction of slot-cuttings on patch.

Table 4 portrays the simulated profits of different MPA stages for distinct frequency dispositions. This part put forward the effects of the insertion of U-slots on the patch and the variation in the dimension of the rectangular-shaped slots that caused the defects in the ground structure (DGS). Miniaturization, multi-band operations, and the highest gain are accomplished in six steps, as further explained. By tuning the proportions of the cutting slots on the patch and the ground structure, the required frequencies are obtained. Fig 2(a) to 2(c) show the different grades of moderation of the patch as the progression of various antennas, and the corresponding simulated results are shown in tables (2) and (3), which display the correlated simulated details for a suggested compact multi-band slotted MPA in view of multi-band, S11, gain, directivity, and radiation efficiency. Step 1: First of all, a rectangular-shaped "antenna 1" having the dimension of 11 mm × 16.9 mm is configured, as exhibited in Fig. 2. At this point, neither the patch nor the ground have been altered. The attained resonance frequencies of the presented antenna 1 are five, such as 5.75 GHz, 9.6450 GHz, 10.88 GHz, 10.88 GHz, 13.38 GHz, 13.35 GHz, and 15.7250 GHz, and its attained gains are 1.6743 dB, 1.1269 dB, 4.1342 dB, 3.1458 dB, and 5.1028 dB. In the first step, "Antenna 1" got reduced by implementing a conception of slot-cutting techniques as exhibited in Fig. 2(b). On account of this initial replication of U-slot insertion on the patch at the left side with the optimized proportions of 0.95 mm x 1.9 mm, positions (1, -8.5, 0), then in the 2nd step ("Antenna 2") gets miniaturized, simultaneously revealing the multiband fact that this newly introduced slot on the path also brings out five resonant frequencies of 5.94 GHz, 9.93 GHz, 11.07 GHz, 13.8250 GHz, and 16.1050 GHz with the maximized gains of 2.0869 dB, 1.6088 dB, 3.9758 dB, 4.2333 dB, and 5.151 dB. In the 3rd step, additional renewal of U-Slot is employed (Antenna 3) at the top of the patch with the measurements of 1x3.9 mm, with the view to further miniaturize "Antenna 2", and attain better gain. As a result of this replication, the input impedance of the antenna further comes to have improved. This alteration carries out good results also stores six resonance frequencies of 6.0350 GHz, 10.2150 GHz, 11.3550 GHz, 14.3950 GHz, 15.44 GHz, and 16.2950 GHz with the realized gain of 1.8733 dB, 1.4308 dB, 3.9891 dB, 2.6749 dB, 4.3657 dB, 6.0346 dB, respectively. The patch refashioning holds a maximum gain of 6.0346 dB. The detailed results are given in the above table 3.

The size reduction, the gain, and the bandwidth enhancement of the antenna could be achieved by manufacturing slots of an apt measurement in a ground structure [22]. The suggested antenna's DGS is manifested in Fig. 2 (d), (e), and (f). It causes the antenna to resonate in a multi-band manner. The performance of the antenna in relation to the size of the slots has been shown in the following table 4.

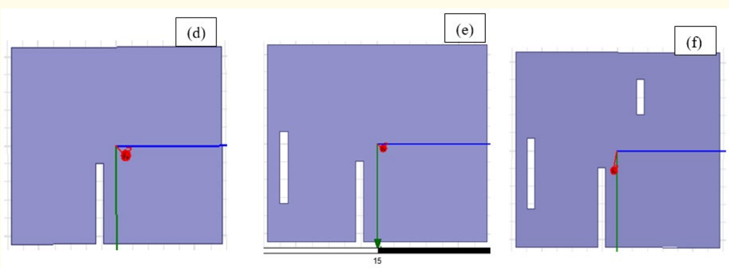


Figure 2: Antenna 4. ***Figure 3:*** Antenna 5. ***Figure 4:*** Antenna 6.
(d). Rectangular slot on center (e). Rectangular slot on left side (f).
Rectangular slot on right side.

Modification on ground	***Fr (GHz)***	***Return Loss(GHz)***	***Directivity (dB)***	***Gain (dB)***	***Efficiency***
Center slot					
	6.0350	-18.1345	3.0097	1.5769	52.393
	6.8900	-20.5216	2.4213	1.0581	43.7
	7.3650	-23.3934	1.8749	0.94544	50.427
	8.5050	-23.8351	1.8562	0.99424	53.563
	11.4500	-15.1246	6.4542	3.9879	61.787
	13.3500	-22.4778	9.4255	6.3117	66.964
	14.9650	-16.8057	6.3386	4.8483	79.328
	17.15	-13.6853	9.7185	9.9733	1.0262
	19.05	-11.4934	7.1373	8.5119	1.1926
Left slot					
	6.1300	-15.7192	3.0731	1.6291	53.01
	6.8900	-20.4786	2.6011	1.1481	44.137
	7.4600	-30.2637	1.9589	0.99901	50.999
	8.5050	-21.6334	1.8165	0.99182	54.6011
	11.5450	-15.0127	5.8552	3.6724	62.72
	13.4450	-20.0903	9.1822	6.4768	70.536
	15.1550	-19.5499	7.1358	5.5047	77.142
	17.3400	-13.0611	7.9201	7.8278	98.836
	19.2400	-13.9272	4.6553	7.5836	1.629
Right slot					
	6.0350	-16.1336	3.0899	1.5865	51.344
	6.7950	-22.9755	2.6466	1.1344	42.863
	7.4600	-46.0990	2.0019	1.0416	52.03
	8.5050	-20.7813	1.7334	0.92179	53.178
	11.45	-14.7621	5.9954	3.7586	62.691
	13.3500	-17.1490	9.3706	6.2776	69.625
	15.0600	-18.4456	6.6017	5.1998	78.765
	17.2450	-13.6466	11.391	14.679	128.86
	19.0500	-14.3246	5.1527	5.4279	105.34

Table 4: Performance comparison of antenna in [Figure 2 (d), (e), (f)] for the introduction of slots on Ground.

The realization of multi-band in the third stage of MPA (“Antenna 3”) is preserved through remodeling the ground, as illustrated in Fig. 2(d). Step 4: For the purpose of a broadband range with magnified gain, “Antenna 3” is miniaturized by the introduction of the rectangular slots with the optimized measurements. A rectangular slot is introduced at the center part of the ground structure with measurements of length (9 mm) x width (1 mm) at the position (2, -2.65, -1.6), which causes the "Antenna 4" to resonate at nine-band frequencies of 6.0350 GHz, 6.8900 GHz, 7.3650 GHz, 8.5050 GHz, 11.4500 GHz, 13.3500 GHz, 14.9650 GHz, 17.15 GHz, and 19.05 GHz. The maximum gain attained by the "Antenna 4" is 9.9733 dB. When a rectangular slot with the dimensions of length (4 mm) x width (1 mm) is added to the circumference of the left side of the ground structure at the position (-8, 2.5, -1.6). It resonates at nine-band frequencies, namely 6.1300 GHz, 6.8900 GHz, 7.4600 GHz, 8.5050 GHz, 11.5450 GHz, 13.4450 GHz, 15.1550 GHz, 17.3400 GHz, and

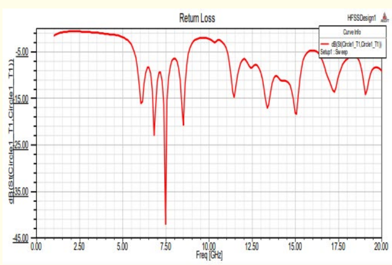
19.2400 GHz, When the rectangular slot is added on the circumference of the right side of the ground with the measurements of length (8 mm) x width (1 mm) at the positions (6.7, -12, 1.6), it produces "Antenna 6" that resonates at nine-band frequencies, namely 6.0350 GHz, 6.7950 GHz, 7.4600 GHz, 8.5050 GHz, 11.45 GHz, 13.3500 GHz, 15.0600 GHz, 17.2450 GHz, and 19.0500 GHz. The highest gain of 14.679 dB is achieved with nine resonance frequencies that cover the C-band, X-band, Ku-band, and K-band applications by the introduction of the rectangular slots on the ground structure. Further, it is evident from the analysis that the slots are again engraved out in the ground plane to extend the lower bands into broadband range with multiple frequencies as correlated to the three stages (“Antenna 1,” “Antenna 2,”, and Antenna 3”). In spite of that, the antenna proposed in this step exhibits the nine resonant frequencies in the frequency range of implementation (6.0354 GHz-19.0554 GHz). The analysis of slot cutting techniques in the microstrip antenna confirms that the insertion of slots with optimized measurements causes multi-resonant resonant frequencies and the best gain achievement in a broadband range. However, the slots in the patch and on the ground play a larger role in reducing the size of an antenna. Further, gain and radiation efficiency are more affected and enhanced by the slots in the patch. The optimized slot length and width achieve the optimum impedance matching of the antenna. The resultant antenna performance could be utilized for satellite communication, terrestrial broadcast radar, and space communications.

Novelty

Normally, several research papers recommend insertion of the U-slots inside the patch only. (i) The originality of the suggested representation is the U-slotted geometry, which is inserted at the sides of the patch.

(ii) The slot-cutting techniques result in miniaturization, and they also provide multi-band in a broadband range with the best gain of 14.09 dB with an enhanced radiation efficiency of 128.86% (iii) The optimized slotted ground plane bestows multi-band, consequently giving elasticity in performance together with concise size, suitable gain, steady current distribution, and a reliable radiation pattern from end to end of the functional.

Simulation and Tuning



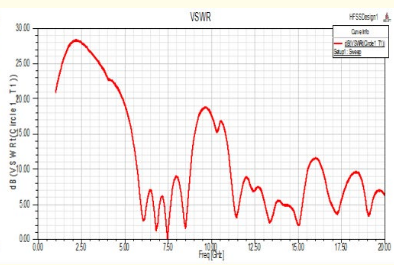


Figure 3: S11 of the suggested antenna***. Figure 4:*** VSWR of the suggested antenna.

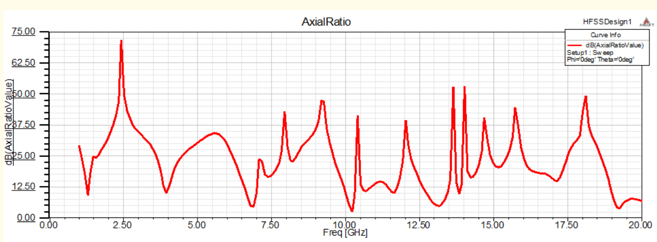


Figure 5: Axial Ratio.

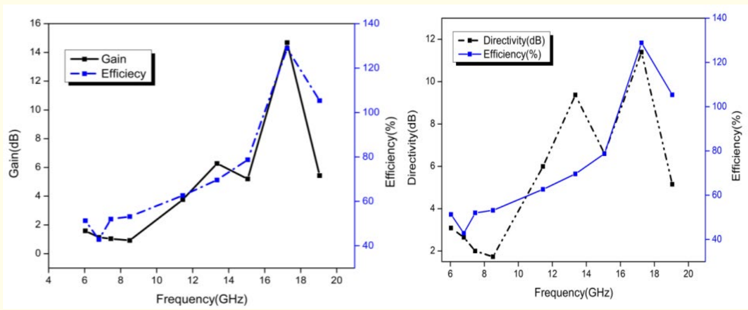


Figure 6: Gain and RE versus frequency. ***Figure 7:*** Directivity and RE versus frequency.

The simulated outcomes reveal the execution of the suggested MPA. Fig. 3 depicts S_{11} of the suggested MPA. The profits of S_{11} are attained at nine resonant frequencies: 6.0350 GHz, 6.7950 GHz, 7.4600 GHz, 8.5050 GHz, 11.45 GHz, 13.3500 GHz, 15.0600 GHz, 17.2450 GHz, and 19.0500 GHz, respectively.

The VSWR (Voltage Standing Wave Ratio) variable is used to control and harmonize the transmitting antennas. The VSWR execution of the suggested MPA is depicted in Fig. 4, which portrays 1.2354 at 6.7950 GHz, 0.1364 at 7.46 GHz, and 1.5922 at 8.5050 GHz. It can be seen from the above figures, a very low return loss of -46.0990 dB and a VSWR of 0.1364 are obtained at the resonant peak of 7.46 GHz among nine resonant frequencies. These simulated results assure the fine fulfilment of the suggested design. As a consequence, the design is sufficiently executed.

The axial ratio of the suggested MPA is represented in Fig. 5. Polarization is considered linear if the level at which it can be discerned is greater than 5 dB. Our design employs linear polarization.

The suggested antenna offers peak gain, directivity, and radiation efficiency, which are depicted in Figures 6 and 7 against frequency. From Fig. 6, it is notable that as the frequency increases, gain and efficiency also increase, and at the same time they attain the magnified gain of 14.679 dB and the increased efficiency of 128% at a particular resonant frequency of 17.2450 GHz in a broadband range. After reaching this peak gain, it started to decrease as the frequency increased. The peak directivity, radiation efficiency versus frequency plot are depicted in Fig. 7. From the Fig. 7 it is obvious that as the frequency increases, directivity and efficiency also increase at the same time, attaining the magnified directivity of 11.391 dB and the enhanced efficiency of 128.86% at a particular resonant frequency in a broadband range as the above analysis shows.

Surface Current Distribution of suggested antenna

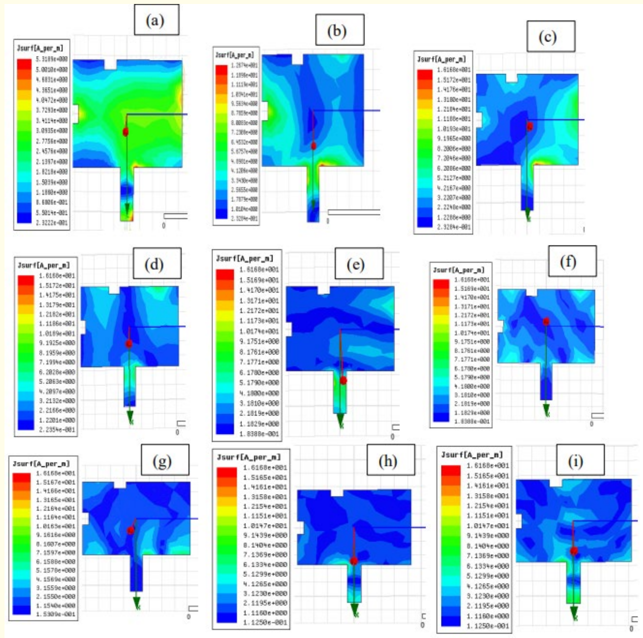


Figure 8: Surface Current Distribution at Proposed frequency Bands (a) 6.0350 GHz, (b) 6.7950 GHz, (c) 7.46 GHz, (d) 8.5050 GHz, (e) 11.45 GHz, (f) 13.35 GHz, (g) 15.06 GHz, (h) 17.245 and (i) 19.05 GHz.

Fig. 8 exhibits the surface current distribution of the microstrip patch antenna at various resonance frequencies of (a) 6.0350 GHz, (b) 6.7950 GHz, (c) 7.46 GHz, (d) 8.5050 GHz, (e) 11.45 GHz, (f) 13.35 GHz, (g) 15.06 GHz, (h) 17.245 GHz, and (i) 19.05 GHz. It circulates the whole patch at the resonant frequencies of 6.0350 GHz to 19.05 GHz. The figure can easily convey to the viewer that the current distribution becomes much stronger by adding the slots on the patch and the ground.

Radiation Pattern suggested antenna

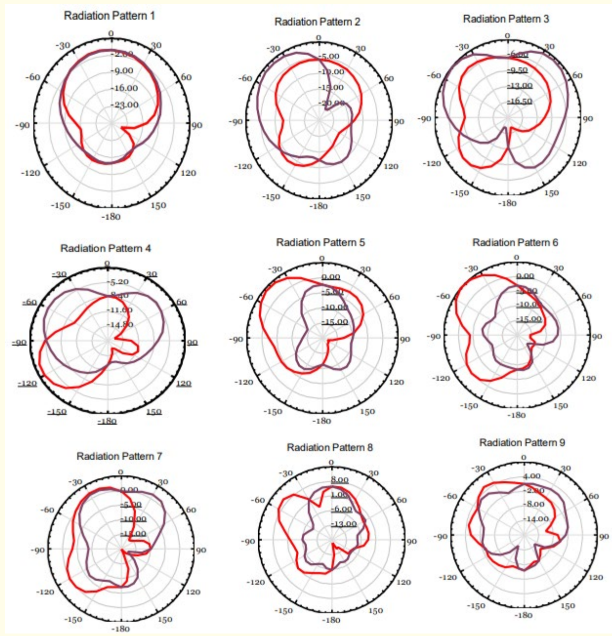


Figure 9: Radiation pattern: (a) 6.0350 GHz, (b) 6.7950 GHz, (c) 7.46 GHz, (d) 8.5050 GHz, (e) 11.45 GHz, (f) 13.35 GHz, (g) 15.06 GHz, (h) 17.245 and (i) 19.05 GHz.

The radiation pattern usually depicts the field strength of the radio waves from the antenna. Fig. 9 exhibits the radiation pattern of the suggested MPA for the obtained resonant frequencies of (a) 6.0350 GHz, (b) 6.7950 GHz, (c) 7.46 GHz, (d) 8.5050 GHz, (e) 11.45 GHz, (f) 13.35 GHz, (g) 15.06 GHz, (h) 17.245 GHz, and (i) 19.05 GHz. The field strength of radio waves that come from the antenna is determined by the radiation pattern. We come to know from the above analysis that it is nearly omnidirectional. Also, it comes to the aid of direction resolution when the antenna emits its supreme potential. It could be perceived that the MPA arrives at an omnidirectional pattern in the H-plane and a bi-directional pattern in the E-plane.

Comparative graphs for with and without slots antenna

The comparative investigation is carried out with the goal of achieving the upgraded proportions of the suggested design, and the finalized dimensions are displayed in the plots below:

i) The execution of the suggested antenna is determined by different structural parameters. Figures 10 (a) and (b) show a comparison of the difference without slots on the patch and ground and with modification. It illustrates a comparison of patches with and without slots. When no modification is made to a patch, it resonates at five bands with a minimum reflection of -24.5597 dB (dashed black line) and an attained gain of 5 dB. In order to achieve the size reduction, multi-band, U-slots are inserted on the left side and top of the patch. It brings off the six resonant frequencies of 6.0350 GHz, 10.2150 GHz, 11.3550 GHz, 14.3950 GHz, 15.44 GHz, and 16.2950 GHz with a better gain of 6 dB (dashed green line). The increase in the number of operating bands in a broadband range is achieved due to the modification of the ground by inserting the rectangular slots at the center, left, and right, parts of the ground structure. As shown in Fig. 11, it resonates at nine resonant frequencies with a minimum reflection coefficient of -46.0990 dB (dashed rose line) and the best gain of 14.679 dB (dashed rose line). The analysis shows how the high performance is achieved by the different stages of modification in the suggested MPA using slot-cutting techniques. Also, it reveals that low peak gain could be attained at lower frequencies as a consequence of the skin depth effect, thus influencing the current distribution and subsequently the gain.

ii) The correlative graphs of MPA's gain, efficiency in comparison to a frequency without and with the slots for our suggested antenna are illustrated in Fig. 11. Figure specifies that the maximum efficiency of the antenna without the slots is 84.103% while the gain is 5 dB at the operating frequency of 15.7250 GHz. Double U-slots in the patch and triple rectangular slots on the ground are made to improve peak gain and radiation efficiency in a broad range while also reducing the size of the MPA. After the modification, the recommended antenna attained the highest gain of 14.679 dB and an enhanced efficiency of 128.86%.

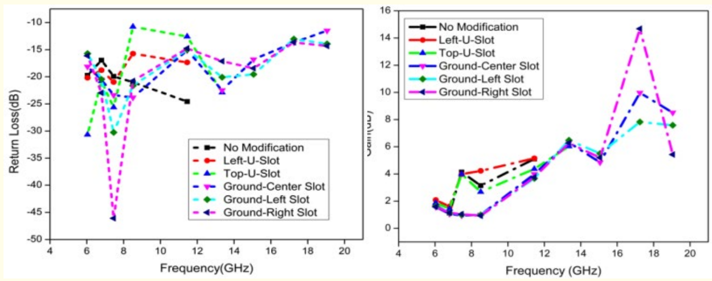


Figure 10: (a) Return loss against frequency, (b) efficiency against frequency.

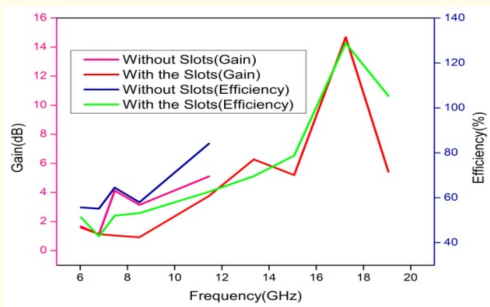


Figure 11: Comparison between with and without the slot antennas.

S. No	***Reference***	***Dimensions (mm)***	***Number of bands***	***Producing frequencies***	***Peak Gain (dB)***
1	[8]	60 x 25	3	2.4 5.2 5.8	2/2.8/2.4
2	[9]	26 × 20	3	2.4/3.5/5.8	2.24/2.8/2.6
3	[10]	100 × 65	3	0.9/1.8/2.6	0.25/0.6/3.28
4	[11]	60 x 30	3	900 MHz	1.3/ 17.5/18.1
5	[12]	120 × 60	3	1.5/2.4/5.8	−0.16/2.62/2.04
6	[13]	35 × 30	3	2.5/3.5/5.5	3.86/3.52/4.32

7	[14]	28 × 30	4	1.6/2.5/5.8/9.5	2.9/2.4/3.1/1.8
8	[15]	48x18	4	1.575/2.45/3.5/5.2	1.355/2.393/3.502 4.486
9	[16]	25x25	4	3.39/4.29/5.46/5.77	-
10	[17]	35x30	4	1.6/2.3/3.4/5.7/10.14	3.9/ 3.7/1.13/ 2.16 /5.36
11	[18]	25 x 28	5	1.5/3/5.5/7.5/9.5/11	-6/-4/2.5/2.5/5/4
12	[19]	24x16	5	3.6/5.8/6.3/8.3/9.5	1.2/1.6/2.1/2.5/2.7
13	[20]	30x30	7	0.77/1.43/2.13/3.48/3.84/5.17/6	1.3/1.5/1.4/1.8/1.9/2.3/2.6
	Proposed	22x27	9	6.03/6.79/7.46/8.5/11.45/13.35/15.06/17.24/19.4	1.5/1.1/1.0/0.9/3.7/6.5/5.1/14.4/5.4

Table 5: Comparative analysis of suggested multi-band antenna with other existing MPA.

Table 5 shows a comparison of the proposed MPA with the MPAs that were investigated. The comparison was conducted with those existing on stage, examined with regards to dimensions, arrived at operating bands, and achieved gain. As shown in Table 5, the comparative literature shows slotted antennas with triple-band in [8-13], quad-band in [13-17], penta-band in [18-19], and hexagon-band in [20]. The suggested antenna possesses the nine operating frequencies from 6 GHz to 19.4 GHz with the highest gain compared to the other antennas. It occupies less area with improved gain and radiation efficiency than the existing antennas.

Frequency (GHz)	***Reflection Coefficient (dB)***	***Gain (dB)***	***Efficiency (%)***
6.0350	-16.1336	1.5865	51.344
6.7950	-22.9755	1.1344	42.863
7.4600	-42.0990	1.0416	52.03
8.5050	-20.7813	0.92179	53.178
11.4500	-14.7621	3.7586	62.691
13.35	-17.1490	6.5243	69.625
15.0600	-18.4456	5.1998	78.765
17.2450	-13.6466	14.679	1.2886
19.0500	-14.3246	5.4279	1.0534

Table 6: The review outcomes of the suggested MP.

Furthermore, Table 6 summarizes the characteristics of the reflection coefficient, VSWR, gain, directivity, and radiation efficiency of the suggested slotted MPA for its nine-peak operation. The achieved minimum reflection coefficient is -42.0990 dB, the VSWR is 0.4, the efficiency obtained is 128.86%, the amplified value of the peak gain is 14.679 dB, and the augmented value of peak directivity is 11.391 dB at a resonant frequency of 17.2450 GHz from simulation studies. According to the results in this table, the presented reconfigurable multi-band slotted defected ground antenna can be an acceptable candidate for various radar and satellite communication applications.

Conclusion

This study examined deep-rooted on-slot introductions to a rectangular patch and ground for broadband operation, which provides nine resonant frequencies with a magnified gain of 14.679 dB and improved radiation efficiency of 128.86%. The design of a reduced nine-band slotted antenna covers the frequency peaks from 6 GHz to 19 GHz. An efficient structure of an antenna achieved a size reduction by introducing double U-slot cuttings in the patch and rectangular-shaped slots above the DGS. The current study concludes that slot-cutting techniques can achieve size reduction, magnified gain, improved radiation efficiency, and wideband range for the desired applications. As a result, this suggested antenna could be more profitable for radar and satellite communication applications.

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