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Performance Analysis of Different Shapes of Microstrip Patch Antenna Having Partial Ground for X and Ku Band Applications

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Abstract: The shape of the radiating patch exerts a great influence on the performance of the microstrip patch. The vital target of this research article is to constitute the microstrip antennas of rectangular, elliptical, triangular and square patches on FR4 substrate employing partial ground that notably lower the shape complexity and hence the antenna size reduction with profitable results on the basis of the center frequency of 8.5 GHz. The execution specification, such as S-parameter, gain, VSWR, and the directivity of the antenna, is investigated using ANSYS HFSS 13.0 software, *w*hich reveals beneficial outcomes of dual-band operation over the entire band frequency range of 5-15 GHz. The antenna gives poor results without any modification to the ground structure. But good bandwidth, dual band nature, better gain directivity, VSWR, and the best efficiency are achieved by the introduction of partial ground in the design of all the shapes. This is applicable for Marine Radar Communication (SART), Effective Satellite Communications, and Wireless Communication applications like weather monitoring, defense, and military purposes.

Keywords: Microstrip Patch Antenna, Rectangular Circular, Elliptical, FR4 Epoxy, Return Loss, Bandwidth, Gain, Directivity, Radiation Pattern and Radiation Efficiency

1. Introduction

The understanding of the content, scope, criteria, and breed of antennas is enclosed by the cosmos of antennas [1]. At present, Microstrip Patch Antennas (MPAs) are one of the most rapidly developing antennas in telecommunications fabrication [2]. The claim for compact, low-profile, and broadband antennas is escalating outstandingly with the broad advanced extension of wireless communication technology a short time ago. To meet the requirements, the micro-strip patch antenna has been configured because of its low profile, lightweight, and low cost [3]. MPAs bring a lot of improvements over quality antennas, such as lighter weight, lower volume, lesser cost, low-profile, trivial dimension, ease of fabrication, and compatibility. They are used in a number of applications such as radars, telemetry, navigation, radio frequency identification (RFID), biomedical systems, mobile and satellite communications, missile systems, and a global positioning system (GPS) for remote sensing on account of their compact size and planar structure [4]. It mainly incorporates three elements, such as a patch, a substrate, and a ground plane. A copper-made part is called a radiating patch that is placed on the upper layer while the ground plane is fixed on the lower layer of a dielectric substrate. MPAs have been one of the optimal aspirants for wireless applications due to their conformity and ability to attain any analytical profile or dimension [5]. The MPA is popular since it can be easily integrated with many other active and passive circuits such as filters, amplifiers, oscillators, and mixers [6]. In general, there are various shapes for MPA that are accessible, such as square, rectangular, dipole, circular, elliptical, triangular, disc sector, circular ring, and ring sector [7]. DGS can be designed by manufacturing a simple slot in the ground plane of the antenna, which results in the diffusion of the current in the ground plane and guides a restrained propagation of Electromagnetic waves (EM) through the dielectric layer. It causes bandwidth improvement, minimization in size (i.e contraction), and contributes to good impedance matching, thus delivering better turnout results. The antenna also covers Wi-MAX frequencies [8]. Ultra-Wideband Wireless Communication has attracted noteworthy attention in the last two decades, particularly–since the Federal Communications Commission promoted the uncredited band for commercial utilization from 3.1 to 10.6 GHz [9]. In this paper, the MPA is proposed and analyzed for shapes like rectangular, elliptical, triangular, and square. The partial ground is brought out to achieve dual-band, assuring their competent activity for potentiating the impedance bandwidth and high radiation efficiency in the antenna design. The X and Ku–band frequency ranges are defined by IEEE for radar applications and include the range from 8 to 12 GHz and, for satellite applications the range from 12-18 GHz. Applications such as military, civil, weather forecasting, monitoring, and police radars for vehicle speed detection are carried out in this frequency range.

2. Antenna Design Consideration

A microstrip patch antenna can have either shape. The shape variations are helpful for the compactness of the patch antenna in its applications [10]. In this paper, there are five shapes taken for the MPA design, such as the rectangular-shape, the elliptical-shape, the triangular-shape, and the square-shape, which are reviewed beneath. Thick substrates with a low dielectric constant are preferable for good antenna performance as they provide features like better efficiency, loosely bound fields for radiation, and larger bandwidth [11]. The various microstrip patches, implanted over the FR4 substrate have a dielectric constant value of FR4 = 4.4, with a thickness of h = 1.43 mm, and a loss tangent value of 0.02. The incombustible (FR4) is a preferred substrate with a better strength to weight ratio and appreciable mechanical strength with zero water absorption. The presented antenna of size 26 × 40 mm has a compact structure and is endowed with a 50 Ω microstrip feed line of measurements L_f 19.2 mm height and W_f = 3 mm width and L_P 19.3 mm, W_P 19.27 mm. The antenna is now modified with a partial ground of length Lg = 16.2 mm and Wg = 12.12 mm on the backside of the substrate for achieving dual-band characteristics. The location and measurements of the substrate and partial ground plane are conserved constants throughout the analysis. Then the design of the microstrip antennas with rectangular, elliptical, triangular and square patches are carried out with HFSS 13.0 software.

3. Various Shapes of Microstrip Patch Antenna

3.1. Rectangular Microstrip Patch Antenna

The length of a rectangular patch may be normally 0.3333μo < L<0.5μo [12]. The length and width of a rectangular patch are 19.27 mm x 19.3 mm, which is configured on the top side of the dielectric substrate. A rectangular feed line has a length and width of 19.3 mm x 3 mm and is engraved on the same side of the substrate. The overall dimensions of this antenna are 40 mm x 26 mm. The performance of this rectangular-shaped patch could be analyzed by keeping the dimensions of the substrate and the ground constant.

Measurements
Measurements of partial ground
X size: 16.2
Y size: 12.12

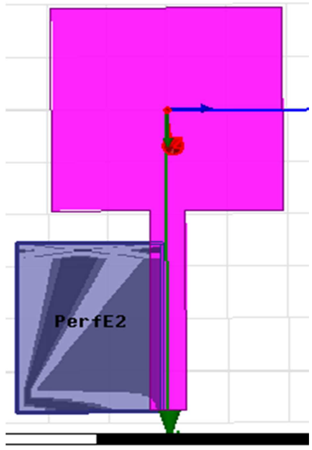


Figure 1. *Shows the geometry of a rectangular patch with partial ground.*

3.2. Elliptical Microstrip Patch Antenna

The elliptical antenna is the less analysed shape because its analysis involves complex functions. [13]. Figure 2: Geometry of the proposed elliptical microstrip patch antenna with partial ground. In addition to dual-frequency, the other advantages of the elliptical shape include flexible design, freedom to change the dimensions like the major and minor axes and eccentricity. Circular polarization (CP) can be achieved with a single feed by locating the particular feed points on the elliptical patch. The analysis of an elliptical patch has a major axis with a radius of 3 mm.

Major Radius: 3 mm
Ratio: 3

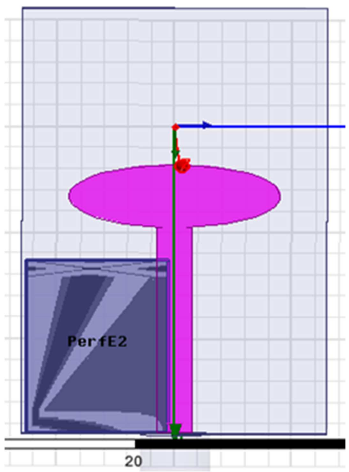


Figure 2. *Shows the geometry of an elliptical patch with partial ground.*

3.3. Triangular Microstrip Patch Antenna

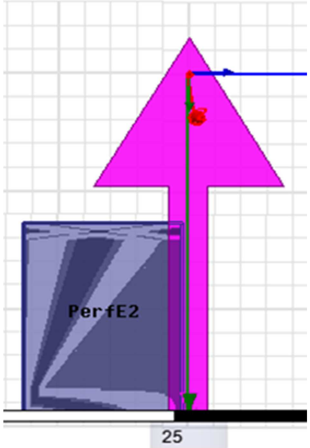


Figure 3. *Shows the geometry of a triangular patch with partial ground.*

The microstrip patch antennas' triangular geometry can be used in both wireless applications and circuit components. Due to its physically smaller size, TPA can be a good substitute for a rectangular patch. In recent years, it has been used as broadband radiators, circularly polarized antennas, designing arrays, and dual-frequency and multiband antennas [14].

In our proposed triangular patch analysis, the substrate and ground plane parameters used for the antenna are the same as those of the above two designs. The configuration of the triangular patch is given as follows:

Start Position: -3, 0, 0

Number of segments: 3

3.4. Square Microstrip Patch Antenna

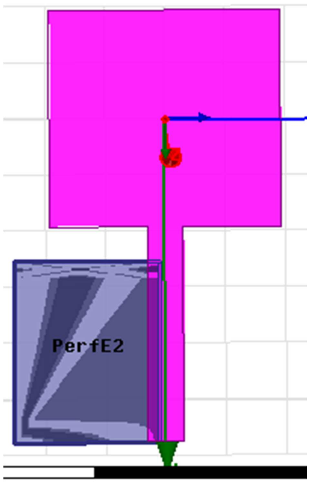


Figure 4. *Shows the geometry of a square patch with partial ground.*

Figure 4 shows the geometry of a square patch antenna. It has the best performance in its results [15]. Our proposed square patch is configured with a length of 16 mm and a width of 16 mm on each side.

The performance of this squared-shape patch could be analyzed by keeping the dimensions of the substrate and the ground constant.

X size: 16, Y size: 16

4. Result and Discussion

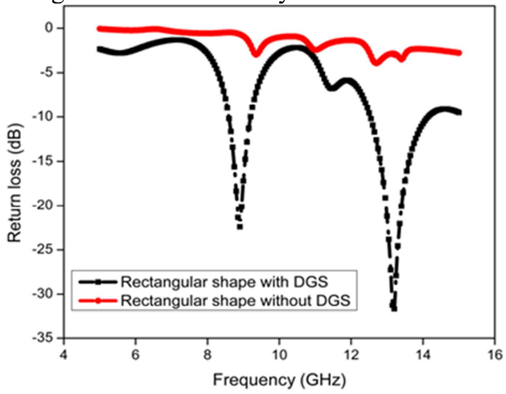
Following the creation of several patches, the simulation is run to determine the performance parameters, including return loss, gain, and bandwidth. These results are then compared with and without the partial ground. The return loss plot of the above-mentioned antenna for various shapes is discussed comparatively in the frequency range of 5-15 GHz. The comparative return loss graph for the rectangular, elliptical, triangular, and square patch antennas with and without partial ground is shown in Figure 5(a) to 5 (d). In Figure 5(a), the return loss is analyzed for the rectangular patch where the return loss is less than -10 dB. The resonance frequencies of the rectangular patch are 8.9 GHz and 13.2GHz, where the achieved return losses are -22.3913 dB, -31.7005 dB, respectively. The elliptical patch resonates at the frequencies of 8.85 GHz, 13.15 GHz where it arrived the return losses are -20.8173 dB, and -40.4281 dB respectively. The investigated return losses of the triangular patch are -21.5377 dB, -37.9475 dB at 9 GHz and 13.25 GHz, respectively. The square patch yields return losses of -20.7558 dB, -41.4431 dB at the resonant frequencies of 8.95 GHz, and 13.2 GHz, respectively.

In general, the acceptable value of the Voltage Standing Wave Ratio (VSWR) must lie between 1 and 2. The VSWR plot for the rectangular, elliptical, triangular, and square patches of microstrip antenna is shown in Figure 5(e). From the graph, we come to know that all the shapes we considered yield a better VSWR value of 1.3216 for a rectangular patch, 1.5856 for an elliptical patch, 1.4587 for a triangular patch, and 1.5969 for a square patch. In the bandwidth analysis, a rectangular patch antenna obtained the bandwidth of about 0.6 GHz and 1.75 GHz, the elliptical patch microstrip antenna acquired the bandwidth of about 0.6 GHz and 1.5 GHz, the triangular patch microstrip antenna achieved the bandwidth of about 0.55 GHz and 1.25 GHz, and the square patch antenna attained the bandwidth of about 0.6 GHz and 1.45 GHz for dual bands, respectively.

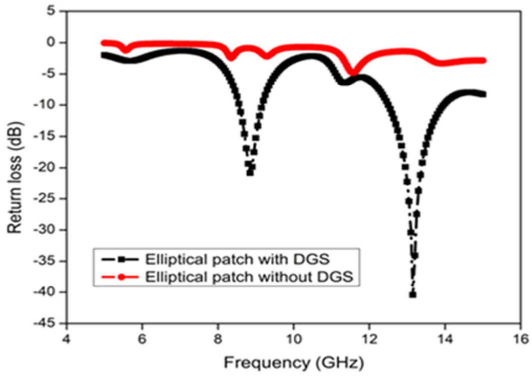
Radiation Pattern

Figures from 6 (a) to 6 (h) show the radiation patterns of the rectangular patch, the elliptical patch, the triangular patch, and the square patch. It offers the best results for C-band and Ku band applications.

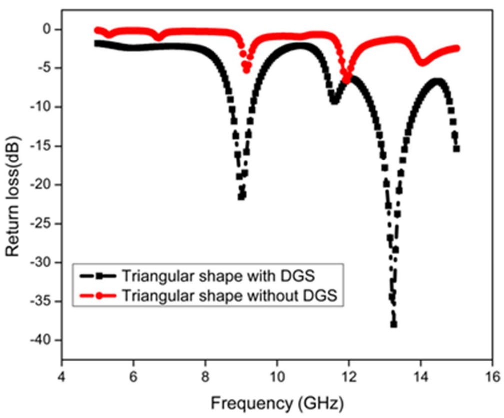
The antenna properties of gain, directivity, bandwidth, and radiation efficiency for rectangular, elliptical, triangular, and square patch antennas are shown in Table 1. Consideration of the gain, directivity, and radiation efficiency of a rectangular patch antenna shows the peak gain for the first band is almost 1.8216 dB, for the second band is 1.9434 dB, and the directivity is about 2.2266 dB and 2.138 dB. Also the antenna yields a high radiation efficiency of around 81% and 90% at 8.9 GHz, 13.15 GHz, respectively. It achieves the highest bandwidth of 1.75 GHz, so the proposed rectangular-shaped antenna is utterly capable of transmitting and receiving with the desired X and Ku band characteristics. For an elliptical patch, the gain for the first band is almost 1.42 dB, for the second band is 2.3709 dB and the directivity is about 1.7267 dB and 2.5514 dB. Also the antenna yields a high radiation efficiency of around 82% and 92% at 8.85 GHz, 13.15 GHz, respectively. It is evident from the above results that the proposed elliptical-shaped antenna is utterly capable of transmitting and receiving in the desired X and Ku band characteristics. Taking the performance of the triangular patch antenna in to consideration the average peak gain for the first band is almost 2.0479 dB, for the second band is 1.8876 dB and the directivity is about 2.4599 dB and 2.1036 dB. The antenna produces high radiation efficiency of around 83% and 89% at 9 GHz and 13.25 GHz respectively. It is clear from the results that the proposed triangular shaped-antenna is utterly capable of transmitting and receiving with the desired X and Ku band characteristics. Taking into account the characteristics of the proposed square patch antenna, the gain for the first band is almost 1.835 dB, the gain for the second band is 1.8176 dB and the directivity is about 2.2508 dB and 1.9891 dB also the antenna yields a high radiation efficiency of around 81% and 91% at 8.95 GHz, 13.2 GHz respectively. The obtained results emphasize that the proposed square-shaped antenna is utterly capable of transmitting and receiving in the desired X and Ku band frequency ranges.



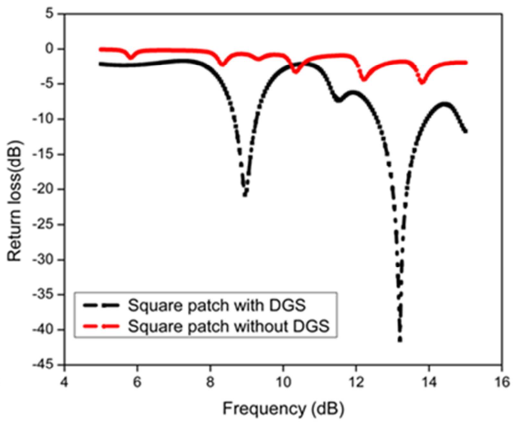
(a)



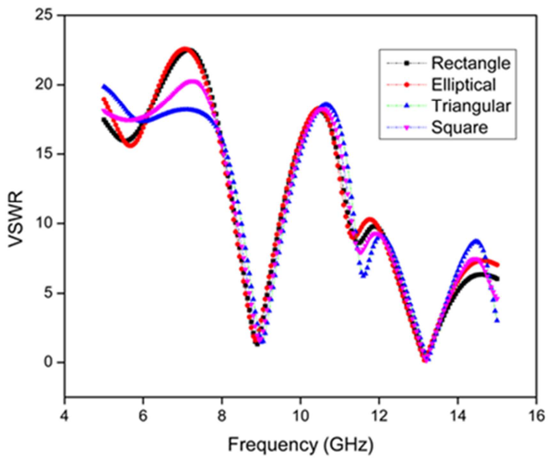
(b)



(c)



(d)



(e)

Figure 5. *(a) & (e) Comparative analysis of Return loss and VSWR for various shapes of antenna.*

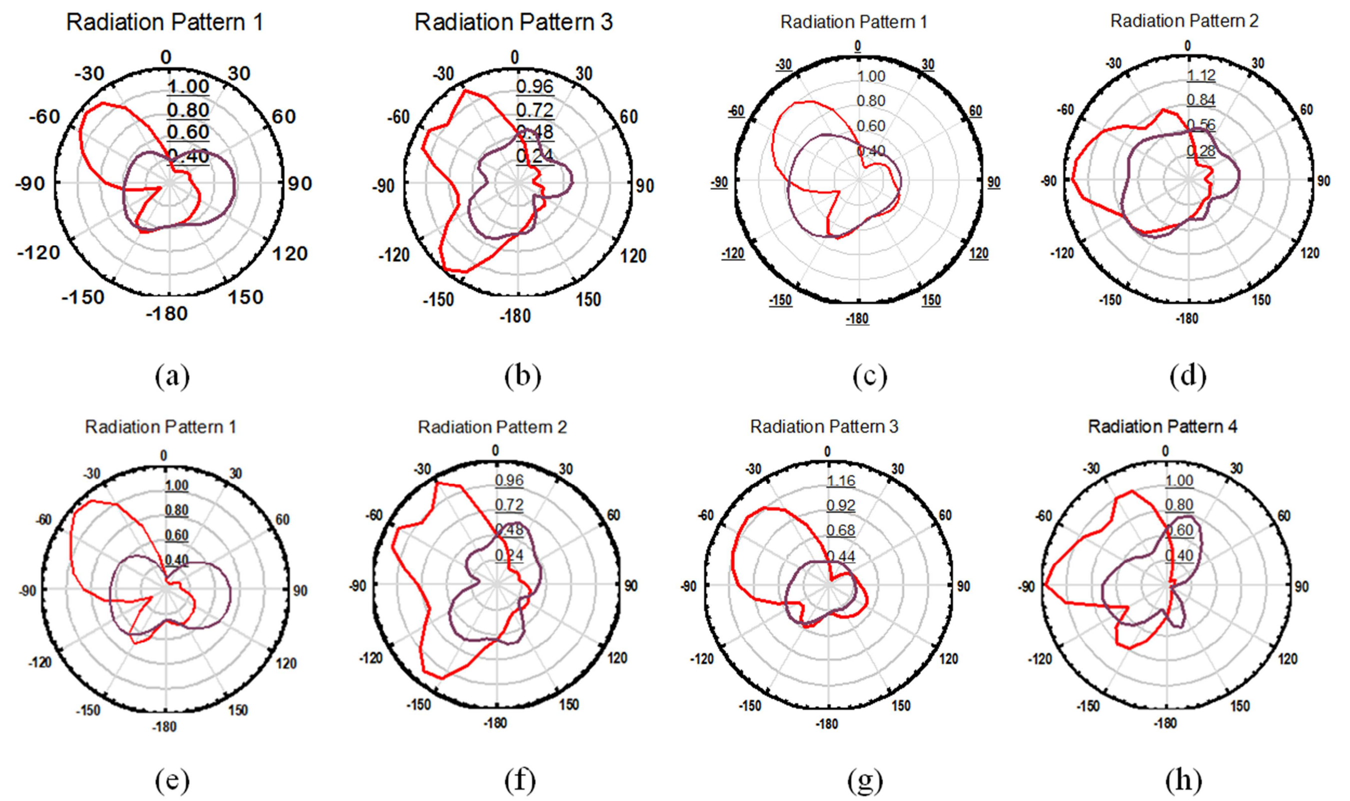


Figure 6. *Show the radiation patterns of rectangular patch, elliptical Patch, triangular patch and square patch. It offers best results for C-band and Ku band applications.*

Radiation patterns:
6 (a) & 6 (b) Rectangular patch at 8.9 GHz; at 13.2 GHz
6 (c) to 6 (d) Elliptical patch at 8.85 GHz; at 13.15 GHz
6 (e) to 6 (f) Triangular at 8.7 GHz; at 13.15 GHz
6 (g) to 6 (h) Square at 8.95 GHz; at 13.2 GHz

Table 1. *Comparison for the various patch shapes.*

Patch shapes	Resonant Frequency (GHz)	Return loss (dB)	VSWR (dB)	Bandwidth (GHz)	Gain (dB)	Directivity dB)	Radiation Efficiency (%)
Rectangular	8.9,	-22.3913,	1.3216	0.6	1.8216	2.2266	81
	13.2	-31.7005		1.75	1.9434	2.138	90
Elliptical	8.85	-20.8173	1.5856	0.6	1.7267	1.4248	82
	13.15	-40.4281		1.5	2.5514	2.3709	92
Triangular	9	-21.5377	1.4587	0.55	2.0479	2.4599	83
	13.25	-37.9475		1.25	1.8876	2.1036	89
Square	8.95	-20.7558	1.5969	0.6	1.835	2.2508	81
	13.2	-41.4431		1.45	1.8176	1.9891	91

5. Conclusion

The proposed microstrip patch antenna was designed for four different patches: rectangular, elliptical, triangular, and square, using the partial ground technique, and the performance parameters such as radiation pattern, radiation efficiency, gain, directivity, bandwidth, VSWR, and return loss were noted simultaneously. The various shapes of patch antennas provide poor results without the introduction of the partial ground, but after the insertion of the partial ground, all the considered microstrip patches of an antenna achieve optimal results in all the antenna parameters. Hence, the analyzed patch antennas are well suited for X-band (Doppler radar) and Ku-band applications having a frequency range from 8 to 15 GHz. The performance analysis gives insights into how the modifications to the ground structure yield multiband nature, broad-band applications, and wider bandwidth. From the above discussion, we can conclude that it is enticing for radar engineering, police radars for measuring the speed of the vehicles, military applications, navigation intentions, finding out the weather forecast, satellite broadcast communication, space-crafts, and wireless computer networks.

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