A 2 shape slot microstrip patch antenna for global positioning system satellite communication applications

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ABSTRACT

In this paper, a compact two-shape slot microstrip antenna is proposed for global positioning system (GPS) satellite application. The proposed antenna is designed with FR 4 substrate with a height of 1.6 mm, a dielectric constant ε_r of 4.3 within a compact size 56 x 56 mm^2 area. The design parameters are optimized to achieve good performance. At the optimum setting of design parameters, this antenna shows good characteristics to cover L1 band 1,575.42 MHz, ± 12 MHz frequency which is used for GPS satellites. At the 1,572 MHz resonance frequency, this antenna achieves a minimum return loss of -30 dB covering a frequency bandwidth of 50 MHz (1,550 MHz – 1,600 MHz) at -10 dB reference level which ensures 100% bandwidth coverage of the L1 band. Besides, the proposed antenna achieved a maximum gain of 8.3 dBi and a beam width of 1010 at -3 dB point. In terms of other performance, such as voltage standing wave ratio (VSWR), directivity, radiation pattern, the proposed antenna shows good performance for the application of GPS satellites.

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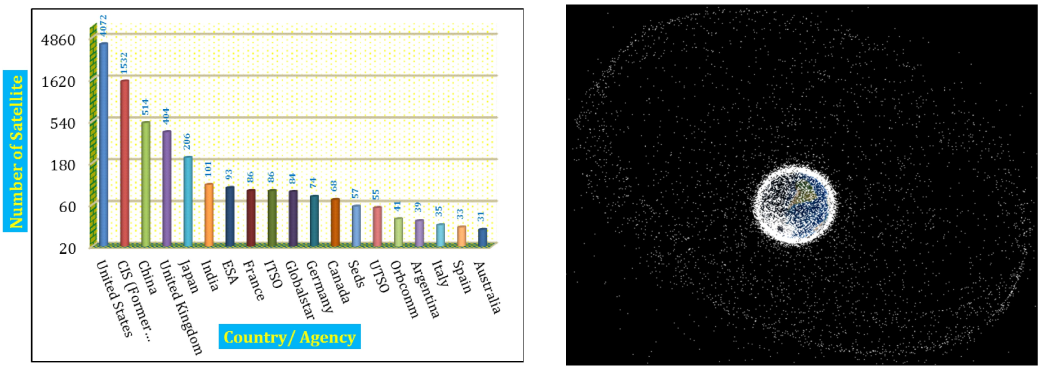
1. INTRODUCTION

Satellite is an inseparable part of the wireless communication system where the number of satellites in earth's orbit is increasing day by day [1], [2]. Right now, more than 25,000 satellites are rounding our earth which has been launched by different country or organization [3], [4]. Global positioning systems (GPS) is one of the important application fields of these satellites [5], [6]. Nowadays, GPS plays an important role in military, civil, and commercial applications in ways that make their work more productive, safer, and easier [6], [7]. The GPS is a radio-navigation system consisting of 24 satellites in six orbits which used for land, sea, and air navigation to provide time and location navigating objects. Figure 1 shows statistics of global satellites, where Figure 1(a) illustrates the number of satellite launched by different country/agency and Figure 1(b) illustrates the satellite orbits around the earth.



(a) (b)

Figure 1. Global satellite statistics: (a) number of satellite launched by different country/agency and (b) satellite orbits around the earth

In this case, GPS antenna is the main element of any GPS system that provides the wireless linkage required for any satellite-based system. The antenna designed for GPS application operates at L1 (1,575 MHz) and L2 (1,227 MHz) bands [8], [9]. The increasing numerous applications of GPS satellite service , has drawn the attention of different research groups to design a miniaturized efficient antenna for GPS systems [9]-[16]. In this regard, microstrip patch antenna could be a good candidate like other various applications [17]-[24].

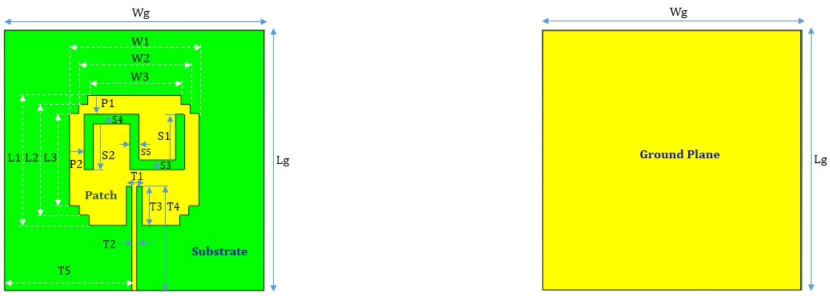
In previous research on GPS antenna, various kinds of microstrip patch antennas with different shapes are presented [7], [8], [16], [18], [25]-[29]. With some applications in the advanced communications [30]-[32]. In order to satisfy the demand for precise and reliable GPS operation, a corner-truncated square shape patch antenna was proposed by Ta and Park [7] on a relatively thick substrate of high dielectric constant. Their proposed antenna achieved maximum bandwidth of 14.42 MHz with a peak return loss -18 dB and gain over the bandwidth 3 dBi which is low. A planar multiarm-curl type antenna was proposed by Bilgic and Yegin [8] that improve the bandwidth and gain up to 7% and 7.3 respectively. However, their antenna dimension was as large as 100 × 100 × 30 mm^3 which was not continent for compact application. Kadiri *et al.* proposed a circularly polarized (CP) planar antenna in [11] L1, L2, and L5 (1,176.45 MHz) bands which significantly improved impedance matching as well as bandwidth whereas the maximum gain was below 6 dBi at L2 brand. A shorting loaded technique was introduced in [12] to design a compact dual-band patch antenna for GPS application which achieved 3 dB gain bandwidth 41 MHz and 57 MHz at the L2 and L1 band, respectively. However, the maximum gain achieved 4.49 dBi in L1 brand. Hence, it is quite clear that, those parameters plays important role in various applications as in wireless, microwave, radio frequency identification (RFID), indoor, cognitive [33]-[39].

Despite of many research, the gain and other performance of antenna are limited for GPS application. However, there is a scope to design the miniaturized microstrip patch antenna which provide 100% coverage of L1 band with higher gain, and efficiency [19], [40]-[44]. Therefore, in this paper, a 2 shape slotted miniaturized microstrip patch antenna design is presented. The design is verified using finite integration technique in computer simulation, where the simulated results indicates good performance of proposed antenna for L1 band which is allocated for GPS application. The major contributions of this work are, i) miniaturized structure of antenna, ii) 100% bandwidth coverage for L1 band, and iii) improved gain and beamwidth. The overall organization of this paper is given as follows. In "antenna design" section, the design methodology of proposed slotted patch antenna with numerical description of antenna dimensions has been presented in details. The archived results, parametric optimization, and discussion have been presented in "result and discussion" section. Finally, concluding remarks are given in conclusion section.

2. METHOD

The configuration of the proposed microstrip patch antenna with 2 shape slot is shown in Figure 2 with top and bottom view in Figures 2(a) and 2(b). The description of design parameters with their dimension is listed in Table 1. The compact size of the proposed radiating patch is 28 x 28 mm^2 with the ground size

56 x 56 mm^2. The radiating patch and ground plane is supported by FR4 lossy substrate with height of 1.6 mm and dielectric constant ε_r of 4.3. The antenna is excited by waveguide port with transmission line feed technique [17], [40].



(a) (b)

Figure 2. Structural geometry and dimension of proposed two shape slot microstrip antenna: (a) top view and (b) bottom view

Table 1. List of parameter and dimension of proposed antenna

Description	Parameter	Dimension (mm)
Dimension of ground plane	Wg = Lg	56.9
Dimension of patch	W1 = L1	28.45
	W2 = L2	24.45
	W3 = L3	20.45
Position and dimension of transmission line	T1	3.5
	T2	1
	T3	8.5
	T4	22.725
	T5	28
Position of slot	P1	4.3
	P2	3.7
Dimension of slot	S1 = S2	12
	S3 = S4 = S5	2

As shown in Figure 2, the proposed antenna has a horizontal “2” shape slot at the upper size of patch. The slot is introduced at the passion P1 = 4.3 mm and P2 = 3.7 mm from top left size of the patch [41], [43]-[46]. The depth of each branch of “2” shape slot is maintained by S5 = 2 mm. The slot has great impact on current distribution in radiating patch as well as resonance frequency.

3. RESULTS AND DISCUSSION

The performance of proposed antenna has been assessed through analysis of several antenna parameters. The return loss (S-parameter) over frequency of proposed antenna and its variation with a length of “2” shape slot S1 and S2 has been shown in Figure 3. It can be seen from Figure 3 that the resonance frequency of proposed antenna significantly varies with the length of slot. Larger slot length gives lower resonance frequency and lower slot length gives higher resonance frequency with somewhat deterioration of return loss. The best value of return loss, over -35 dB achieved at resonance frequency 1.525 GHz when slot length is 7 mm. The best coverage of L band 1,575.42 MHz, ± 12 MHz is achieved when the slot length is 6 mm. This dimension of slot length gives the bandwidth coverage of 50 MHz from 1.55-1.60 GHz with a peak return loss -30 dB which ensure the coverage of L1 band for GPS satellite application. The variation of voltage standing wave ratio (VSWR) over frequency of proposed antenna has been shown in Figure 4. The curve of VSWR indicates that the proposed antenna has best VSWR at L1 band resonance which is close to the ideal best value 1 and over the bandwidth antenna shows VSWR below of 2. This result of VSWR indicates good impedance matching to ensure maximum power transmission and minimum reflection loss without using any additional matching network.

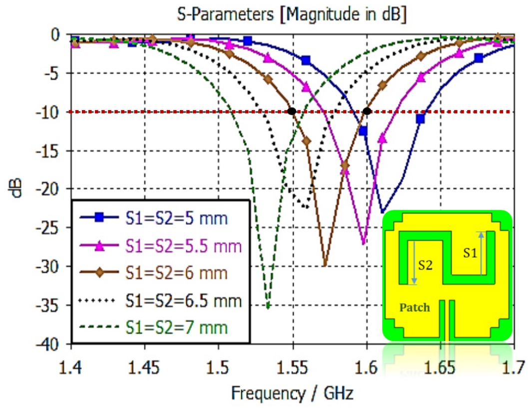


Figure 3. Variation of S-parameter over the frequency for different length of slot (S1 and S2) of proposed antenna

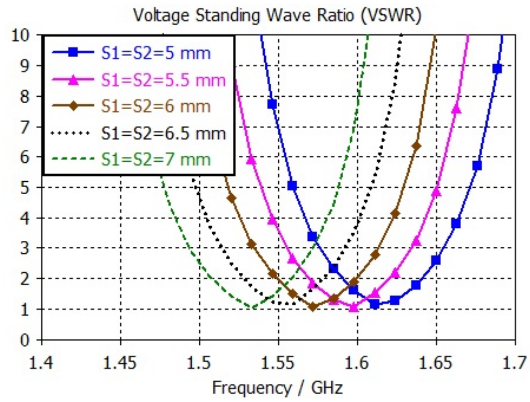


Figure 4. Variation of VSWR over frequency of proposed antenna

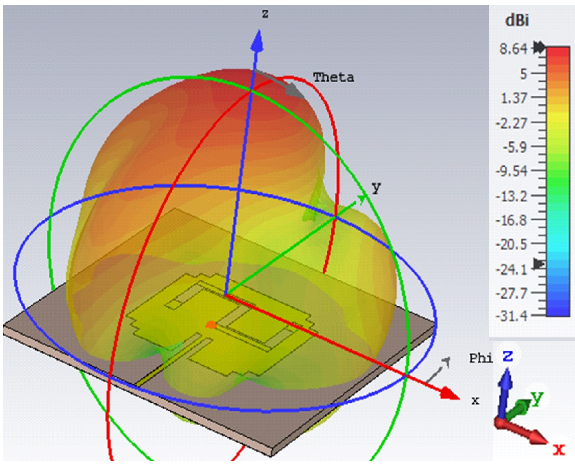
The variation of proposed antenna's resonance frequency, bandwidth and return loss with dimensions of different slots have been further presented in Table 2. It can be seen from the Table 2, I dimension of slots has a significant effect on resonance frequency, bandwidth, and return loss. The dimension of S3 and S4 have a stronger effect on resonance frequency than the dimension of S1 and S2. In order to ensure the full coverage of L1 band, the dimension of all slots required to adjust appropriately.

Table 2. Variation of resonance frequency, bandwidth and return loss with dimension of different slot

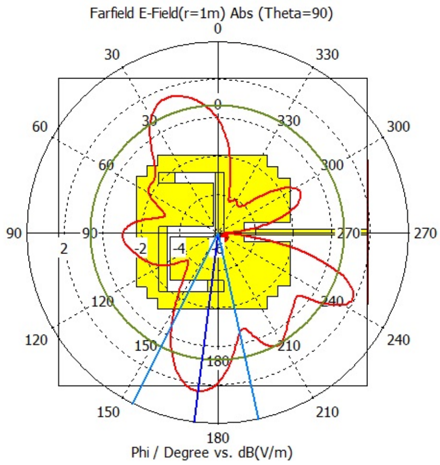
Length of slot S1 & S2 (in mm)	Length of slot S3 & S4 (in mm)	Resonance frequency (f in GHz)	Bandwidth in MHz	Return loss S11 (in dB)
3.0	1.6	1.533	1,509-1,558=49	-37.85
3.5	1.5	1.559	1,528-1,579=51	-22.35
4.5	1.5	1.598	1,569-1,619=50	-27.22
5.0	0.2	1.543	1,529-1,558=29	-21.36
5.0	0.4	1.552	1,537-1,566=29	-21.09
5.0	0.6	1.560	1,545-1,575=30	-21.50
5.0	0.8	1.568	1,554-1,583=29	-21.36
6.25	0.1	1.567	1,553-1,581=28	-31.16
6.25	0.2	1.578	1,564-1,593=29	-30.29
6.25	0.3	1.583	1,568-1,598=30	-30.48
6.50	0.1	1.573	1,558-1,588=30	-35.92
6.50	0.2	1.585	1,570-1,599=29	-34.80
6.50	0.3	1.590	1,575-1,605=30	-34.96

3.1. Antenna radiation pattern

The transparent three- dimensional and two- dimensional radiation pattern of the proposed antenna has been presented in Figure 5. It can be seen from Figure 5 that the proposed antenna has maximum directivity of 8.64 dB. The proposed antenna attained the maximum gain of 8.3 dBi. From the value of directivity and gain the efficiency of the proposed antenna can be computed as 96.5%. From Figure 5(a), it is also clear that the proposed antenna has an almost uniform radiation pattern. The radiation pattern on azimuth (H-plane) and elevation (E-plane) are also shown in Figures 5(b) and 5(c), respectively which indicate good radiation characteristics.



(a)



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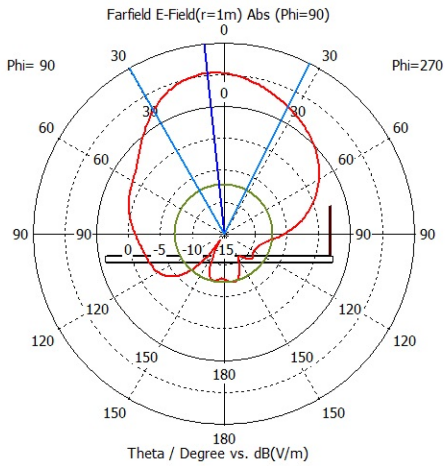

(c)

Figure 5. Simulation of the proposed antenna (a) transparent far field 3D-radiation pattern, (b) H-plane radiation pattern, and (c) E-plane radiation pattern

4. CONCLUSIONS

In this paper, we have presented a “2” shape slotted miscrostrip patch antenna for GPS satellite application covering the L1 band. The performance of the presented antenna has been assessed through important performance indices such as return loss, VSWR, Radiation pattern, directivity and gain. Extensive optimization on performance indices of the proposed antenna has been conducted with various dimensions. The optimum dimension of the proposed design shows good characteristics of antenna performance for GPS satellite application for 1,575.42 MHz brand. At the targeted frequency, the proposed slotted antenna achieves better impedance matching without use of any external impedance matching network, which adds weight and increases design complexity. Finally, we find the optimum design achieved bandwidth of 50 MHz, beam width of 1010 at 3 dB angular point, gain of 8.3 dBi and directivity of 8.64 dBi.

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