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GPS ANTENNA WITH METALLIC CONICAL STRUCTURE FOR ANTI-JAMMING APPLICATIONS

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Abstract—This paper presents a cost effective and simple anti-jamming method for global positioning system (GPS) antennas in the GPS L1 (1.563–1.587 GHz) band. The proposed structure is composed of a metallic conical structure with a microstrip patch antenna, which is selected as the basic element. To overcome intentional jamming signals coming from low elevation angles, the structure is applied around the low profile patch antenna. It is found that the maximum anti-jamming performance is achieved when the lower diameter (l), height (h), and upper diameter (d) of the structure are 90, 190, and 380 mm, respectively. The experimental results show that the peak gain in the horizontal plane for the jamming signal decreases by about 6.2 dB from -6.16 to -12.36 dBic, while the peak gain in the vertical plane for the GPS signal increases by about 5.58 dB from 1.32 to 6.9 dBic. Moreover, it is shown that an improvement in the circular polarization (CP) characteristics is also obtained with the proposed structure. The measured fractional bandwidth is about 3.7% (1.561–1.62 GHz).

1. INTRODUCTION

The global positioning system (GPS) signals transmitted from GPS satellites are in a relatively low signal level state, and as a result the signal is very susceptible to accidental or intentional interferences, such as unwanted in-band interference or jamming signals [1]. In particular, in many GPS timing based systems, the intentional jamming signal renders the GPS receiver inaccurate and ineffective. In most cases, these interference signals come from low elevation angles when the receiver is mounted in the horizontal plane, because the jammer

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is usually located near the horizontal plane [2]. Thus, to keep the GPS signal level above the noise floor, minimizing susceptibility and maximizing tolerance of the jamming signals are the important requirements for the GPS receiver. For this reason, it is necessary to provide anti-jamming techniques to enhance GPS signal reception probability in noisy environments.

Many studies have searched for ways to implement robust GPS receivers: isolation of the jamming signal using a temporal filter [3], space-time adaptive processing (STAP) [4], space-frequency adaptive processing (SFAP) [5], modified GPS arrays [6], and non-planar type spherical cap adaptive antennas [7]. However, these anti-jamming methodologies require systematic approaches, including additional hardware and/or software implementations, even though they provide considerable enhancement against jamming signals.

This paper presents and analyzes a low cost and simple anti-jamming GPS antenna that operates in the GPS L1 (1.563–1.587 GHz) band. The proposed anti-jamming structure consists of a microstrip patch antenna and metallic conical structure. By applying the structure, anti-jamming performance can be enhanced for the jamming signal incident to the GPS antenna. In addition, with optimization of the proposed anti-jamming structure, the signal strength of the jamming signal is minimized, while the peak gain for the GPS signal is maximized, so that maximum anti-jamming performance is achieved.

2. DESIGN CHALLENGES AND SPECIFICATIONS

In general, because most GPS antennas are required to receive signals from all the GPS satellites for good positioning performance, the radiation pattern needs to be nearly hemispherical. However, to suppress the interference signals mainly coming from the low elevation angles, a very sharp slope of the radiation pattern is desirable near the horizon. For this reason, a high-precision GPS antenna should have a very broad and uniform radiation pattern from zenith down to the low elevation angle which is moving higher toward zenith due to increasingly higher interference noises near horizon. Moreover, it should suppress the interference signal below the low elevation angle for any azimuth angle [8]. It is very difficult to obtain these two requirements concurrently.

In this paper, by applying the metallic conical structure in jamming environments, the proposed GPS antenna has more directional radiation pattern in elevation angle compared to without the structure. Therefore, it is possible to limit the detection of the signal from GPS satellites. To clarify this problem, the design

Table 1. Design specifications of the proposed anti-jamming GPS antenna.

Operating frequency	1.575 GHz
Bandwidth	1.563–1.587 GHz
Polarization	RHCP
Axial ratio	3 dB
Minimum gain within coverage	−6 dBic in RHCP
Minimum beamwidth within coverage	84 degree

specifications for this anti-jamming GPS application are listed in Table 1. It is assumed that the minimum gain within coverage for the GPS signal is about −6 dBic in RHCP (right-handed circular polarization) [9]. And also, the minimum beamwidth within coverage is 84 degree since a minimum of four GPS satellites is needed to compute the information among the satellites. The degree of 84 is calculated assuming that the number of GPS satellites is 32 and all satellites are uniformly distributed [8]. These specifications ensure operation of the GPS receiver sufficiently, which do not provide a high-precision GPS performance, though.

3. PROPOSED GPS ANTENNA CONFIGURATIONS AND ANTI-JAMMING CHARACTERISTICS

3.1. Design of the GPS Antenna and the Concept of the Metallic Conical Structure

Figure 1(a) shows the configuration of a microstrip patch antenna that is selected as a GPS receiver operating at the center frequency of L1 (1.575 GHz) band [10]. The size of the antenna is $60 \times 60\,\mathrm{mm}^2$. A corner-truncated radiating element, having a length of 45.6 mm, is printed on an FR-4 substrate with a relative permittivity (ε_r) and loss tangent ($\tan\delta_d$) of 4.2 and 0.02, respectively. The length of the truncated corner for implementing RHCP characteristics is 7.5 mm. The ground of the antenna is located in the horizontal plane (X-Y plane), and a coaxial probe, having a distance of 15.7 mm along $+x$-direction between the feed point and the center of the radiating element, is used to excite the antenna.

The proposed GPS anti-jamming structure is presented as shown in Figure 1(b). To suppress the jamming signal impinging from the low elevation angle and enhance the GPS signal from the higher angle, the metallic conical structure is proposed. The length of the lower diameter

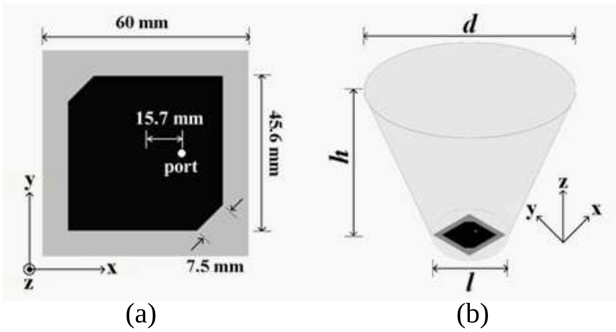


Figure 1. Proposed anti-jamming GPS structure. (a) Microstrip patch antenna for the GPS receiver. (b) Metallic conical structure.

(l) of the structure is chosen to be 90 mm to allow the patch antenna to be enclosed by the lower circle of the structure. In addition, the height (h) is fixed at 190 mm, which is about one wavelength at 1.575 GHz, considering the fact that the characteristics of the proposed structure are similar with that of a conical horn antenna [11]. It is found that the impedance matching characteristics becomes worse if the length of the upper diameter (d) is similar than one wavelength and the resonant frequency variation is very sensitive.

3.2. Jamming Susceptibility of the GPS Antenna

Figure 2 shows the simulated reflection coefficient of the patch antenna without and with the metallic conical structure as a function of the upper diameter. As can be seen, good impedance matching in the L1 band is achieved for the patch antenna, referred to the -10 dB bandwidth. Because the GPS signal received by the antenna is very weak, most GPS antennas need good impedance matching characteristics [12]. Moreover, the metallic conical structure does not significantly affect the impedance matching and resonant frequency of the GPS antenna as long as the upper diameter (d) is greater than $1\lambda_0$. Therefore, the structure can be used with the planar GPS antenna to enhance anti-jamming performance.

In addition to the impedance matching characteristics, it is important that the overall structure has a high gain for the GPS signal, while it renders a minimum gain for the jamming signal. Figure 3 shows the simulated radiation patterns of the patch antenna without the structure at 1.575 GHz. For the patch antenna without the conical structure, the horizontal plane (X-Y plane) has an almost constant gain of -7.1 dBic, and in the vertical plane (X-Z plane) it

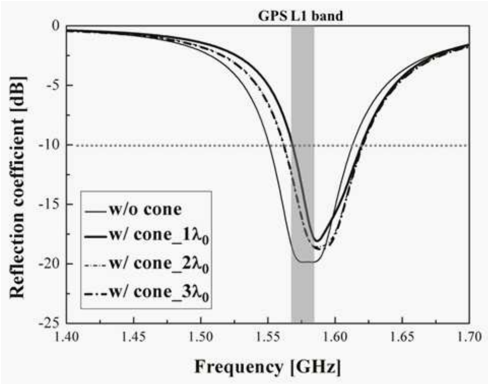


Figure 2. Simulated reflection coefficient of the patch antenna without and with the metallic conical structure as the variation of the upper diameter from 1 to $3\lambda_0$.

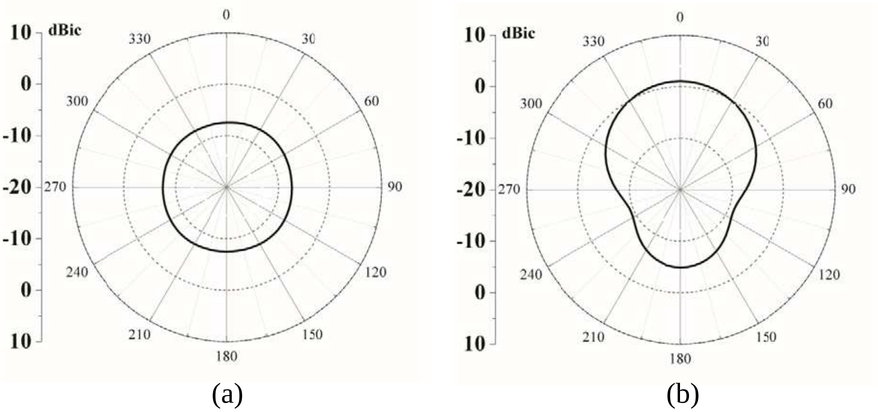


Figure 3. Simulated radiation patterns of the patch antenna without the metallic conical structure at 1.575 GHz. (a) X-Y plane (horizontal). (b) X-Z plane (vertical).

has 1.05 dBic. Therefore, the received GPS signal is susceptible to the jamming signal incident from the horizontal direction having more than 8 dB power.

Therefore, in this work the metallic conical structure is optimized to obtain the maximum anti-jamming performance for a given patch antenna.

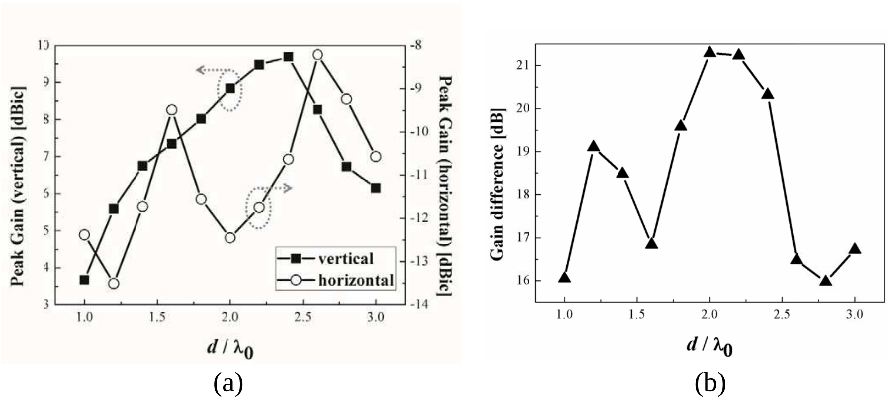


Figure 4. Simulated peak gains of the proposed GPS antenna as the variation of the upper diameter. (a) Peak gain in the vertical and horizontal planes. (b) Gain difference between two planes.

3.3. Effect of the Upper Diameter of the Conical Structure

The previous section described a metallic conical structure along with a planar microstrip antenna. To investigate the optimum structural dimensions, the effect of the upper diameter on the gain characteristics was thoroughly studies. Note that only the upper diameter (d) of the structure is varied whereas the height (h) and lower opening (l) remain constant. The peak gain in the vertical and the horizontal plane are analyzed as a function of the upper diameter as shown in Figure 4(a), respectively. As shown in Figure 4(a), the proposed GPS antenna in the vertical plane has a maximum value of 9.69 dBic when the length of the upper diameter of the structure is $2.4\lambda_0$. On the other hand, the gain in the horizontal plane has a minimum value of -13.51 dBic at $1.2\lambda_0$. It is clear that the anti-jamming performance is not only due to maximizing the peak gain in the vertical plane for the GPS signal; minimizing the gain in the horizontal plane also has to be achieved at the same time. Thus, it is reasonable to maximize the difference between them as shown in Figure 4(b). It is clear that the maximum anti-jamming performance is achieved when the length of the upper diameter is $2\lambda_0$, which reveals the maximum gain difference between the vertical and horizontal planes.

4. EXPERIMENTAL RESULTS

For experimental verification, the GPS antenna and the proposed conical structure are fabricated as shown in Figure 5. From the previous section, it is known that the optimal dimensions of the

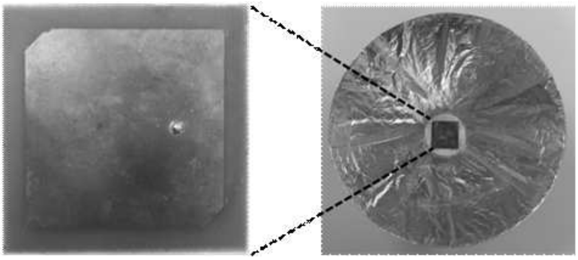


Figure 5. Photographs of the proposed GPS antenna structure.

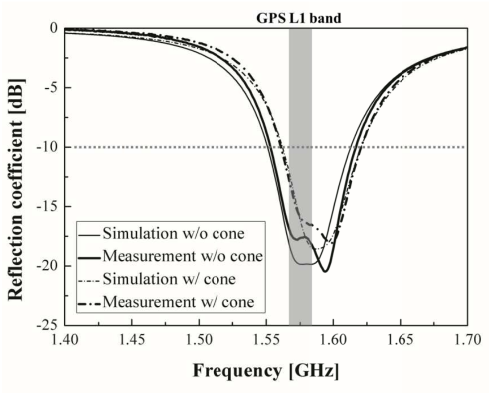
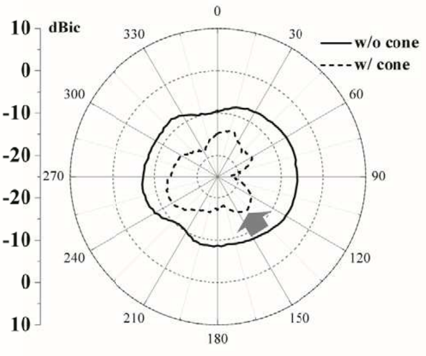


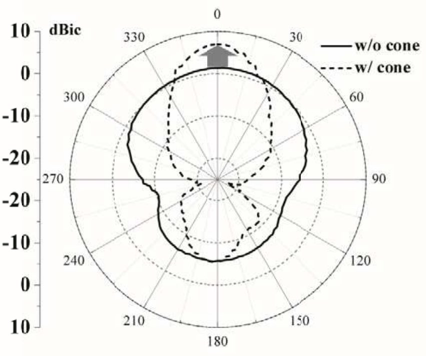
Figure 6. Measured reflection coefficients of the proposed anti-jamming GPS antenna structure.

structure are $d = 380\,\mathrm{mm}$, $h = 190\,\mathrm{mm}$, and $l = 90\,\mathrm{mm}$. Figure 6 depicts the simulated and measured reflection coefficients of the proposed anti-jamming GPS antenna structure based on the optimal configurations. Excellent agreement between simulation and measurement results is obtained. The measured $-10\,\mathrm{dB}$ fractional bandwidth is about 3.7% (1.561–1.62 GHz), which is enough to cover the whole GPS L1 band.

The measured radiation patterns of the antenna with the proposed conical structure at 1.575 GHz is shown in Figure 7 in the horizontal and vertical planes. It is clear that the gain in the horizontal plane decreases several dB with the conical structure, while the gain in the normal direction increases considerably. Specifically, the maximum gain for the jamming signal is suppressed by about 6.2 dB from -6.16 to $-12.36\,\mathrm{dBic}$, while the peak gain for the GPS signal is enhanced by about 5.58 dB from 1.32 to 6.9 dBic. Therefore, the measured gain



(a)



(b)

Figure 7. Measured radiation patterns of the proposed anti-jamming GPS antenna structure at 1.575 GHz. (a) X-Y plane (horizontal). (b) X-Z plane (vertical).

Table 2. Simulated and measured peak gains of the proposed anti-jamming GPS antenna structure.

	Plane	w/o cone (dBic)	$w/$ cone (dBic)	Improvement (dB)
Simulation	X-Y (horizontal)	-7.1	-12.45	5.35
	X-Z (vertical)	1.05	8.84	7.79
Measurement	X-Y (horizontal)	-6.16	-12.36	6.2
	X-Z (vertical)	1.32	6.9	5.58

difference between two orthogonal directions is greater than 19 dB, which is a significant improvement over the normal GPS antenna. The simulated and measured peak gains of the proposed anti-jamming GPS antenna are summarized and compared in Table 2.

Figure 8 shows the measured axial ratio (AR) of the proposed GPS antenna without and with the metallic cone in the normal direction, showing 3.36 dB and 1.97 dB at 1.575 GHz, respectively. In terms of the circular polarization (CP) characteristics, the patch antenna with the anti-jamming structure is better than the original antenna in

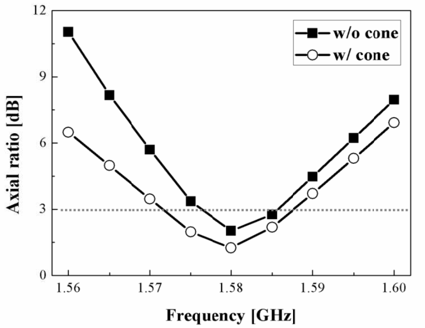


Figure 8. Measured axial ratio of the proposed anti-jamming GPS antenna structure in the normal direction.

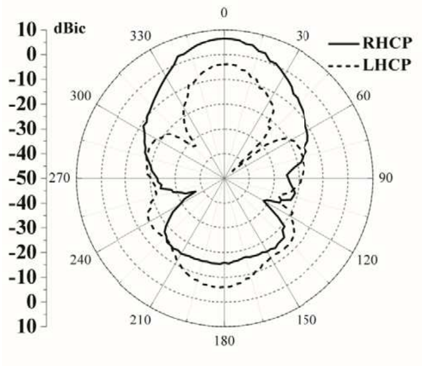


Figure 9. Measured CP radiation pattern of the proposed anti-jamming GPS antenna structure at 1.575 GHz in X-Z plane (vertical).

the measured frequency range. This might due to the fact that the lower and upper circles of the metallic cone have a completely circular geometry. To clarify the radiation pattern for circular polarization, the measured CP radiation pattern of the proposed GPS antenna with cone is presented as shown in Figure 9. It is found that these experimental results meet the above specifications.

5. CONCLUSION

A cost effective and simple anti-jamming technique for GPS receiver antennas is proposed in this paper. The anti-jamming performance of the microstrip patch antenna is enhanced using a metallic conical structure that is located around the antenna. By varying the geometrical parameters of the cone, the peak gain in the vertical and horizontal planes of the patch antenna can be controlled. The optimal dimensions of the structure corresponds to $d = 380\,\text{mm}$, $h = 190\,\text{mm}$, and $l = 90\,\text{mm}$, rendering the maximum gain difference between the horizontal and vertical plane gains. The peak gain in the horizontal plane where the jamming signal impinges is decreased by about 6.2 dB, while the maximum gain in the normal direction is increased by about 5.6 dB. Moreover, the axial ratio is improved. Therefore, it is possible to use the metallic conical structure in GPS antennas in severe jamming environments.

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