Design of 2-element Conformal GPS Antenna with Wide Beamwidth for a Cylindrical projectile

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Abstract

This paper presents a 2-element conformal microstrip patch antenna design for GPS L1 Band (1.575GHz) mounted on a cylindrical projectile body. Two microstrip patches with coaxial feeding structure make up this GPS antenna. The 2-elements are placed 180° apart, on two conformal substrates as opposed to one substrate over the whole perimeter providing more flexibility in the design. The substrate chosen has a low flexural strength, the property that allows bending the substrate for a smaller radius. This design provides a large beamwidth of 154.3° and an omnidirectional radiation pattern. Both the elements are covered with radome material (PTFE) with thickness 2mm. The results achieved using this method of design are like, S_{11} and S_{22} parameters below -21 dB, bandwidth of 14 MHz and a gain of 1.42 dB over the beamwidth.

Keywords: *2-Element, conformal, GPS antenna, linear polarization, flexural strength.*

1. Introduction

It is now recognized that by utilizing satellite positioning techniques such as Global Navigation Satellite Systems (GNSS) the accuracy of conventional artillery projectiles such as mortar shells, artillery shells of different caliber can be improved significantly [1]. The ammunition within the shell is desired to explode within a narrow limit of error probability. This technology of Precision Guidance Kit (PGK) for artillery shells require highly miniaturized antenna, generally placed around the projectile fuze, where the space constraints severely limit the design choices for the antenna [2]. For GPS applications, conformal microstrip patch antennas must be small in size having low-profile in order to be easily integrated into portable equipment, cars, and other systems with space constraint. The antenna's space coverage must be omnidirectional [3]. The distribution of electric and magnetic Fields differs significantly when the conformal antenna substrate adapts to the surface, changing the performance of the antenna parameters [4]. There are different design techniques of feeding, such as array of conformal microstrip patch antennas with a series feed network for missile telemetry [5] have been proposed. A cavity-backed arrangement and a proximity-coupling feeding mechanism is proposed in [6].

In this paper, a 2-element conformal linearly polarized microstrip patch antennas (LP-MPA) for GPS application using probe feeding technique is presented. Instead of using a single substrate that may not bend over the whole perimeter, we propose two substrates separated over 180° from one another as shown in Fig 1.

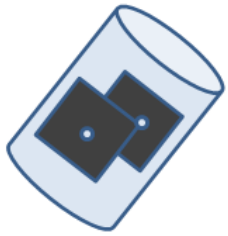


Figure 1. 2-element conformal GPS antennas on a cylindrical projectile.

In the next subsection the criteria for selection of the dielectric material in the design of conformal antenna is described. The method followed in the design of the 2-elements and their physical arrangement is discussed in Section 3. The simulation results of the conformal antenna properties are reported in Section 4. The paper is concluded in Section 5.

2. Selection of Dielectric Material

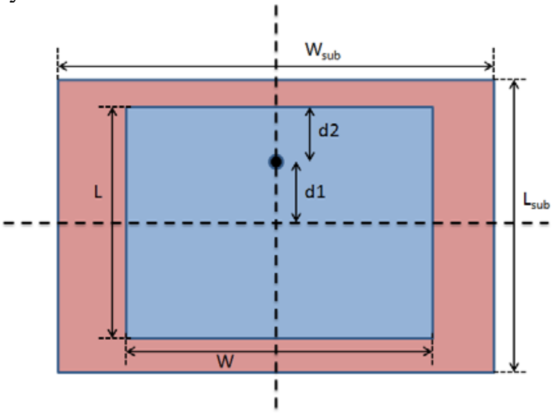
The conformal property of the design is heavily influenced by the properties of the dielectric substrate material, such as its thickness, rigidity, temperature coefficient, and flexural strength. The physical dimensions of the rectangular MPA are calculated by mathematical formula given in [7]. Bandwidth and radiation efficiency of the MPA depend on the thickness and the value of ε_r of the substrate material. The relationship between radiation efficiency and percentage bandwidth with respect to substrate height for dielectric constant 2.2 and 10.2 are given in [7]. The lower the flexural strength the better the material will bend for lower value of radius. Therefore, a lower value of flexural strength with a higher value of ε_r is considered for the design. Different dielectric materials are compared and shown in Table 1.

Table 1. Comparison of and Flexural Strength for Different Materials

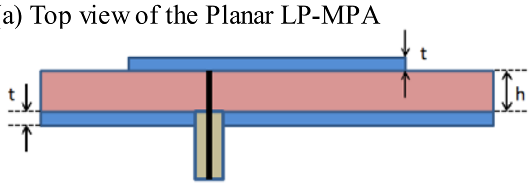
Material Name	Dielectric Constant	Material Name
RO4360G2	6.15 ± 0.15	1468.58 N/mm^2
TMM6	6.00 ± 0.080	103.55 N/mm^2
RF-60TC	**6.15 ± 0.15**	**69 N/mm^2**
RF-60A	6.15	126.2 N/mm^2
RT-DUROID 6006	6.15	2633.7 N/mm^2
RO-3006	6.15 ± 0.15	564.6.7N/mm^2
TMM4	4.70 ± 0.045	109.6N/mm^2
NF-30	3.00 ± 0.04	1010N/mm^2
RO4350B	3.48 ± 0.05	255.1 N/mm^2
RT-DUROID 5870	2.33 ± 0.02	261 N/mm^2
TLY-3FF	2.20	96.91N/mm^2

3. Design and Specifications of the 2-Element Conformal GPS Antenna

The design of the conformal antenna is developed taking the planar LP-MPA as the benchmark. The patch dimensions ($W \times L$) are made distinct from the substrate dimensions ($W_{sub} \times L_{sub}$) in Fig 2(a) along with the location of the feed point from the center of the patch and upper edge of the patch (d_1, d_2). The thickness of the patch (t) and height of the substrate (h) are shown in Fig 2(b). As mentioned in Section 2, the substrate chosen for the GPS antenna is Taconic RF- 60TC with a dielectric constant of 6.15 and a low loss tangent of 0.0020 with a thickness of t= 0.76 mm. The material also has low flexural strength 69 N/mm^2 that allows bending on a cylindrical surface with radius 23.5 mm.



(a) Top view of the Planar LP-MPA



(b) Side view of the Planar LP-MPA

Figure 2. Physical dimensions of the substrate and patch for the planar LP-MPA

The dimensions of each element of the conformal MPA used in the design are given as specification in Table 2. The 3-dimensional view of the cross-sectional arrangement of the 2-element LP-MPA over the hollow Aluminum cylindrical shell surface is shown in Fig 3 where the Radome material is also shown separately. The 2-elements of LP-MPA are placed 180° apart on the circumference for getting maximum spatial coverage of the space. The complete arrangement of the elements on the cylindrical surface is shown in Fig 3. The 2-elements of LP-MPA are simulated along with Radome material. The thickness of the Radome material is 2mm, that minimizes signal loss while maintaining mechanical structural integrity in conformal placement of the radome.

Table 2. Design specifications for the patch and substrate of the conformal LP-MPA

Description	Dimensions
Width of the patch (W)	39.5 mm
Length of the patch (L)	36.7mm
d_1	9mm
d_2	9.35mm
Width of Substrate (W_{sub})	70mm
Length of Substrate (L_{sub})	40mm
h	0.76mm
t	0.035mm
Dielectric constant of Substrate	6.15

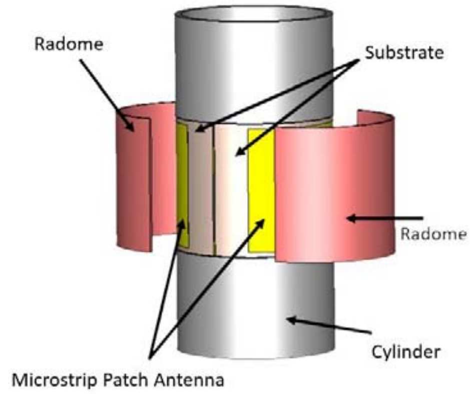


Figure 3. Three-dimensional view of the 2-element conformal antenna with radome material shown separately.

Width of the substrate W_{sub} is 70 mm so the arc angle subtended at the center axis of the cylinder is 152.86°. The arc angle allows us to place the substrates of the 2-elements to be placed 180° apart over the circumference. This way of placement allows some space in between the 2- elements that in turn allows good isolation between the two elements as show in Fig 3. When the two patch elements are positioned near together, the surface waves produced by one element produces mutual coupling in the other requiring physical separation between the elements.

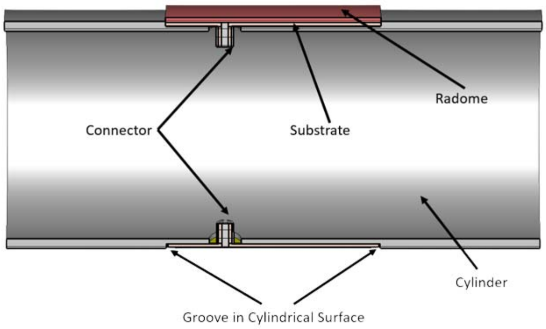


Figure 4. Cross-section of the design of the LP-MPA elements.

The cross-sectional view of the inner and outer surface of the hollow cylinder for 1-element antenna design is shown in Fig 4. This figure shows the physical nature of the placement of the co-axial feeding line along with the substrate of the conformal patch on the cylindrical surface along with the Radome material for protection. There is a 1 mm groove on the surface of the cylindrical body to fit in the substrates.

4. Simulation Results for the 2-Element LP-MPA

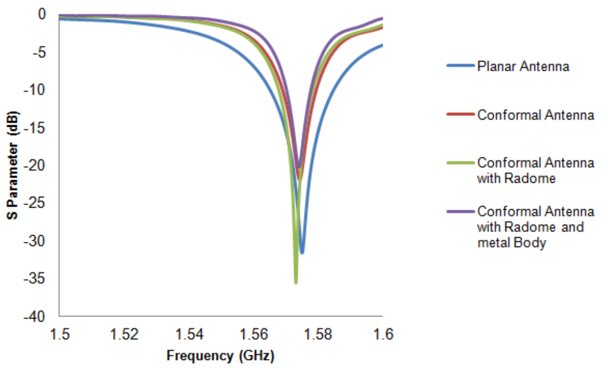


Figure 5. Return loss S_{11} for Conformal antenna with Radome compared with Planar the MPA.

The resonant frequency of an antenna shifts when it gets conformal. When the results of planar and conformal antennas are compared, the properties of the conformal microstrip patch antenna are significantly deteriorated. As shown in the Fig 5, there is a shift in resonant frequency f_r when the MPA is conformed on the metal cylinder. The patch length must be modified in order to optimize f_r, as well as the feed location to improve the Return loss (S_{11}) values and to perfectly match the 50 ohm input impedance with the radiating patch of the conformal MPA. As we shift the SMA connector and patch length, the results of S_{11} parameter are improved. The optimized distance between feed position and center of patch d_1 is 9mm to get the optimum result of S_{11} approximately -22dB and S_{22} of -22 dB at 1.574 GHz are shown in Fig 6 and 7 respectively. After optimizing the length of patch (L) the desired f_r of 1.574GHz is achieved for the conformal LP-MPA. After fitting the two antennas on cylindrical body we are achieving results as shown in Table III. To fit within the available surface area, the components of a conformal antenna are frequently positioned in close proximity to one another. Which may deteriorate isolation. A thoughtful antenna element design and positioning can reduce mutual coupling. Optimized. In order to achieve adequate performance and coverage of the GPS antenna in L1 band, it is generally recommended to strive for a bandwidth of at least 10% to 20% of the centre frequency.

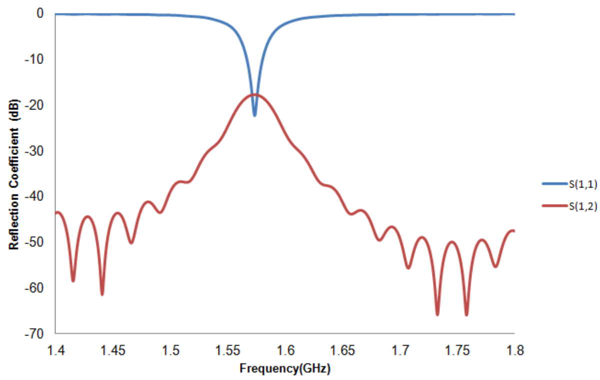


Figure 6. Return loss S_{11} and isolation S_{12} of the first element of LP-MPA.

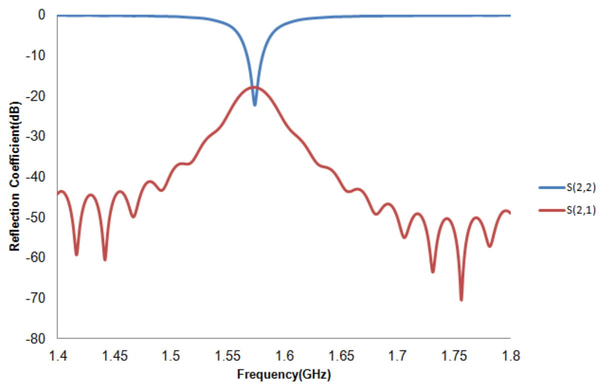


Figure 7. Return loss S_{22} and isolation S_{21} of the second element of LP-MPA.

Table 3. Results of the Antenna with ε_r = 6.15

RF Parameters	Antenna 1	Antenna 2
Reflection Coefficient	S_{11} : -22dB	S_{22}: -22dB
	S_{12} : -18dB	S_{21}: -18dB
VSWR	1.17	1.17
Bandwidth	13.6 MHz	13.6 MHz
Impedance	43.15 Ohm	43.15 Ohm
HPBW	Phi= 0°, 154°	Phi= 0°, 154°
	Phi= 90°, 176°	Phi= 90°, 175°
Gain	1.62 dB	1.63 dB
First side lobe level	12.02 dB	12.03 dB
Radiation Efficiency	66 %	66 %
Total Efficiency	64 %	64 %

The conformal MPA's radiation pattern should be optimized to produce broad beam coverage and good directivity in the elevation and azimuthal planes. Fig 8 and 9 depicts the radiation pattern of a conformal LP-MPA with Radome and Aluminum body in the phi= 0° degree and phi= 90° degree planes.

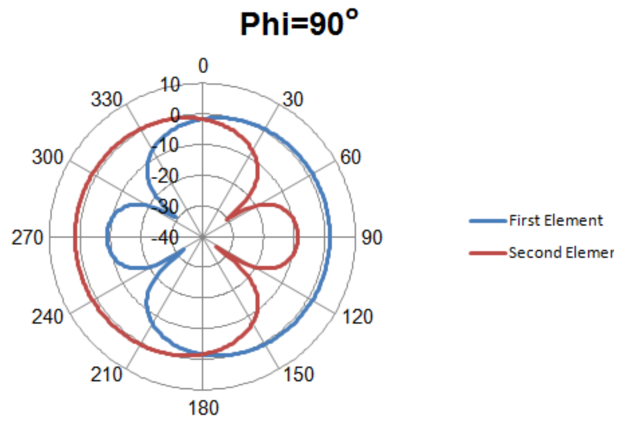


Figure 8. Radiation Pattern of 2-element conformal LP-MPA at Phi = 90°

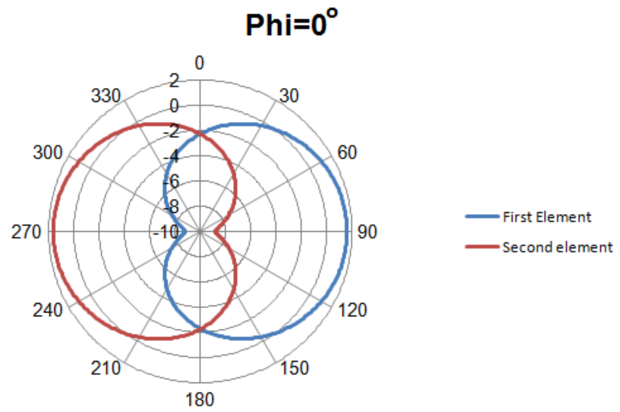


Figure 9. Radiation Pattern of 2-element conformal LP-MPA at Phi = 0°

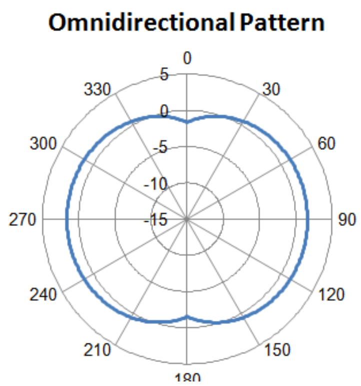


Figure 10. Omnidirectional Pattern of 2-element conformal LP-MPA.

We have achieved the omnidirectional gain of 1.62 dB at 1.574 GHz, for both the elements. The maximum beamwidth is around 154°. The achieved radiation efficiency and total efficiency for both MPA's are 66% and 64%, respectively. The first side lobe level of LP-MPA are 12.02 dB and 12.03 dB respectively. With omnidirectional antennas, coverage frequently comes at the expense of gain. It might be difficult to maintain omnidirectional coverage while achieving high gain. We obtained omnidirectional pattern for GNSS application are shown in Fig 10.

5. Conclusion

The design of a conformal microstrip patch antenna which is mounted on a cylindrical aluminum body operating in the L1 band is presented. Based on the results, the conformal LP-MPA is well suited for GPS applications. The design LP-MPA shows satisfactory radiation properties, including a high gain, minimal return loss, and steady radiation patterns with an acceptable bandwidth over the GPS frequency range. The proposed antenna has advantages of simple structure, flexibility over smaller radius and wide beamwidth. It can have broad application prospect in the field of conformal antennas for various types of projectile bodies.

6. References

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