Printed Cross-Slot Wideband Conformal Antenna for GPS Application

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Abstract **─** A novel cross-slot printed wideband conformal antenna is proposed for GPS application. Initially a planar antenna with cross-slot is designed at a slightly higher frequency and then the planar antenna is transformed to the corresponding cylindrical conformal antenna with the desired radius of curvature. The combination of partial ground plane and cross-slot on patch are used for bandwidth enhancement. The proposed conformal antenna exhibits a fractional bandwidth (for the definition of -10dB) of 79.28% operating from 1091 to 2524 MHz, which is suitable for all GPS bands, GLONASS and GALILEO applications. The radiation pattern exhibits an omnidirectional pattern and gain of proposed conformal antenna is 2.37 to 5.33dBi within operating frequency range.

Index Terms **─** Conformal antenna, GPS application, printed antenna, wideband antenna.

I. INTRODUCTION

Global Positioning System (GPS) requires wideband antenna for receivers installed on moving vehicles, missiles and hand held devices. These antennas play a vital role in the GPS receiver as they have to receive weak signals from satellites and as well work in remote areas. GPS antennas are to be placed on convenient location on the platform where omnidirectional coverage is assured without any obstruction of the signal transmitted from satellites. The platform for mounting the antenna is not always flat. Some cases, it is recommended to make the antenna conformal to the device to reduce aerodynamic drag, less visible to human eye and omnidirectional coverage for example on missile or aircraft [1-4]. So, there is a requirement to develop conformal antennas with omnidirectional coverage for GPS receivers.

For bandwidth improvement of patch antenna, a few methodologies have been proposed [5-14]. A three-dimensional microstrip feed line is reported in which an additional plastic supporting post is required in between ground plane and radiating patch to obtain a bandwidth of 31% in [5]. Combined utilization of both L-probe feeding and patch loaded with U-slot are used, where an extra foam substrate is required between ground and patch for the bandwidth of 42.7% in [6]. A similar foam layer is used in L-probe feed antenna designed by Guo, et al. in [7]. A capacitively probe-fed structure has been implemented in the microstrip antenna design to enhance the bandwidth up to 35% by using hard foam material which can be considered as a shortcoming [8].

A microstrip antenna loaded with chip resistor is proposed in [9]. These antennas are designed using lossy material which is a drawback and bandwidth obtained is only 9.8%. A patch antenna is designed with U-shaped slot for reactive loading and the presence of air or foam medium in between ground plane and patch is difficult to implement in [10]. The bandwidth obtained in this design is 12.4%.

An antenna with two gap coupled parasitic patches and a directly coupled patch is proposed to obtain broadband characteristics with 12.7% of bandwidth in [11]. But in the design, stacking of four patches are used. Various resonators and thick substrates with low dielectric constant have been utilized to design the patch antenna on a planar surface for obtaining bandwidth up to 20 to 32.3% [12-13]. Pues et al. have designed an impedance matching system to enhance bandwidth up to 12% [14].

Applications are developed for Global Positioning System in L_1 (1.57 GHz), L_2 (1.22 GHz), L_3 (1.38 GHz), L_4 (1.37 GHz) and L_5 (1.17 GHz) bands. The L_1 band is required for C/A procurement, and the L_2 is necessary for military and P(Y) codes. The L_5 band is used for safety life of civilian and the L_3 band is used for atomic explosion identification. The L_4 band is under development for climatic analysis. Along these lines, it can be viewed that use of GPS bands reach out from L_5 to L_1 bands.

Few circularly polarized antenna designs have been reported [15-17] for GPS application on planar surfaces. But according to [18], in the multi path environment, the linearly polarized signal is less vulnerable to distortions compared to circularly polarized signal. So, the omnidirectional linearly polarized antenna can also be applied for receiving purpose. A few literatures are published on GPS antenna on planar surfaces and working at the single band with narrow operating bandwidth. A cylindrical conformal antenna array for GPS in L_1 band

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with 20 MHz bandwidth and a gain of 1.65 dBi is proposed in [19].

Although a wideband GPS Antenna has been reported [20], but it is designed on flat surface. In [21], two elements conformal antenna is designed for multi-GNSS reception with narrow bandwidth. A proximity coupled fed circular patch with a cross-slot on the patch has been demonstrated on the flat surface with less bandwidth [22]. So with the rapid development of wireless communication systems and increase in their applications, wideband antenna design has become a challenging topic.

In this paper, a novel high performance cross-slot wideband conformal antenna is proposed. The proposed conformal antenna exhibits wideband bandwidth. The simulation and measurement results showed that the proposed GPS antenna offers overly good performance.

II. DESIGN METHODOLOGY OF ANTENNA AND PARAMETRIC STUDY

A square patch antenna as shown in Fig. 1, fed by a microstrip line feed is considered in the proposed design initially. The width of square patch can be calculated as follows:

$$W = \frac{c}{2 f_r \sqrt{\frac{\varepsilon_r + 1}{2}}}. \quad (1)$$

Where c is the velocity of light, f_r is the resonant frequency of the antenna and $\mathcal{E}_r$ is the relative permittivity of the substrate.

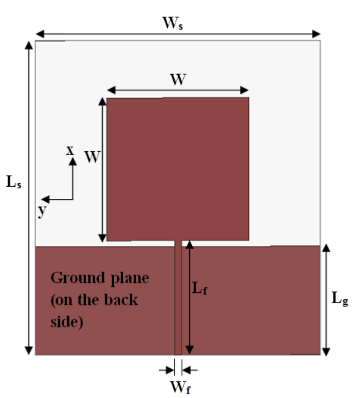


Fig. 1. Geometry of planar antenna: L_s=110 mm, W_s= 100 mm, W=50 mm, L_g=38 mm, L_f=40 mm, W_f=2.4 mm.

For designing this antenna, thermally stable substrate like Rogers RT/duroid 5880 of permittivity ($\mathcal{E}_r$) 2.2 and thickness of 0.787mm with microstrip line feed of 50 Ohm impedance matching is used. The dimension of substrate is 100×110×0.787 mm^3 and dimension of the patch is 50×50 mm^2. In order to achieve wide operating bandwidth and omnidirectional coverage, partial ground concept is selected. The bandwidth is increased because of suppression of surface wave propagation. The geometry of the proposed planar antenna is shown in Fig. 1. The planar antenna in Fig. 1 is transformed to the conformal one on a cylinder of radius 60 mm, which is shown in Fig. 2.

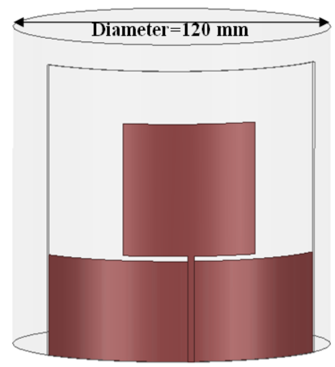


Fig. 2. Configuration of conventional conformal antenna.

The effect of length of the feed-line on the impedance matching is observed. It can be referred that better impedance matching is achieved by increasing the length of feed-line. The optimized value for L_f in the proposed conformal antenna is 40 mm. However, if the length is further increased more than 40 mm value, the variation of bandwidth can be observed in Fig. 3.

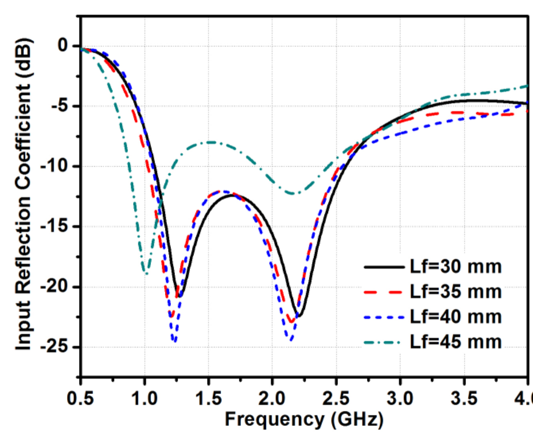


Fig. 3. Input reflection coefficient (dB) of the conformal antenna for different L_f.

Different shapes of slots like rectangular, square, circular can be introduced on the radiating patch antenna. These slots introduce capacitance, which counters the feed inductance and additional resonances introduced by slot combines with the patch resonance which produces wideband response. A horizontal dumbbell shaped slot is introduced on the patch initially. The use of circle on the dumbbell shaped slot is the best case among the other geometries. The circle makes the fields on the slots more uniform than the other cases. The cylindrical conformal antenna with horizontal dumbbell shaped slot on 60 mm radius of curvature is shown in Fig. 4.

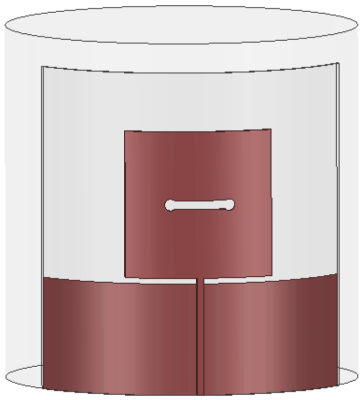


Fig. 4. Configuration of conformal antenna with horizontal dumbbell shaped slot.

The effect of length of horizontal dumbbell shaped slot on the impedance matching is observed in Fig. 5. The optimized dimension of L_h is 20 mm. If the length is increased, there is small change in impedance bandwidth.

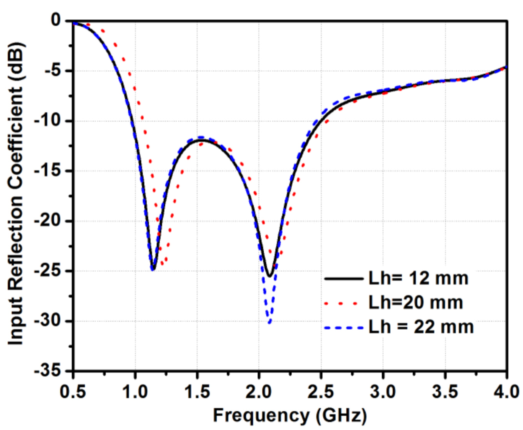


Fig. 5. Input reflection coefficient (dB) of the conformal antenna for different L_h.

A dumbbell shaped cross slot on the patch is shown in Fig. 6. Although there is not much difference in the impedance bandwidths for the designs in Figs. 2, 4 and 6, but better impedance matching for cross slot is obtained when compared with horizontal slot and without slot which is shown in Fig. 7.

The simulated return loss of the planar and proposed cylindrical conformal antennas with a 60mm radius of curvature are compared in Fig. 7. It shows that the return loss of all antennas are obtained below -10dB which indicates a good impedance matching condition. The proposed cylindrical antenna achieves 10dB impedance bandwidth of 1434 MHz, covering the frequency range 1.09-2.524 GHz with 79.28% fractional bandwidth indicating wide bandwidth.

A slight change in resonant frequency can be observed from planar to cylindrical conformal antenna in Fig. 7. This is because of increase in the effective resonant length of conformal antenna due to bending of the planar microstrip antenna structure. The resonant frequency of the cylindrical conformal antenna is shifted towards right. Also there is a change in return loss between conformal antenna without any slot, with only horizontal dumbbell shape slot and cross dumbbell shaped slot. It indicates that the resonant frequency also depends on slot's length. The matching performance of antenna is improved incorporating modification in cross-slot structure.

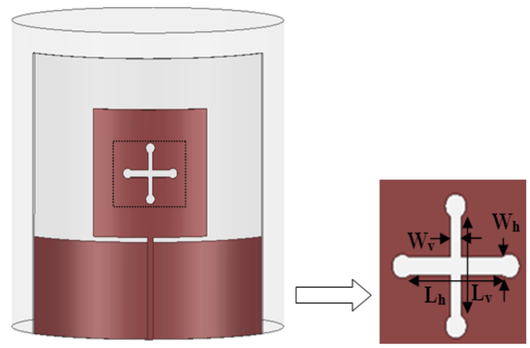


Fig. 6. Top view of conformal antenna with cross-slot: L_h=20 mm, W_h=3 mm, L_v=20 mm, W_v=2 mm; radius of circle=2mm.

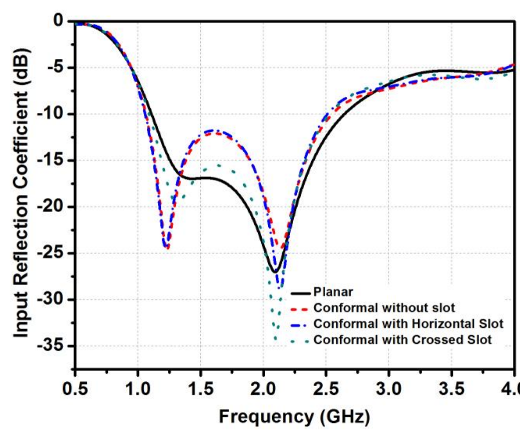
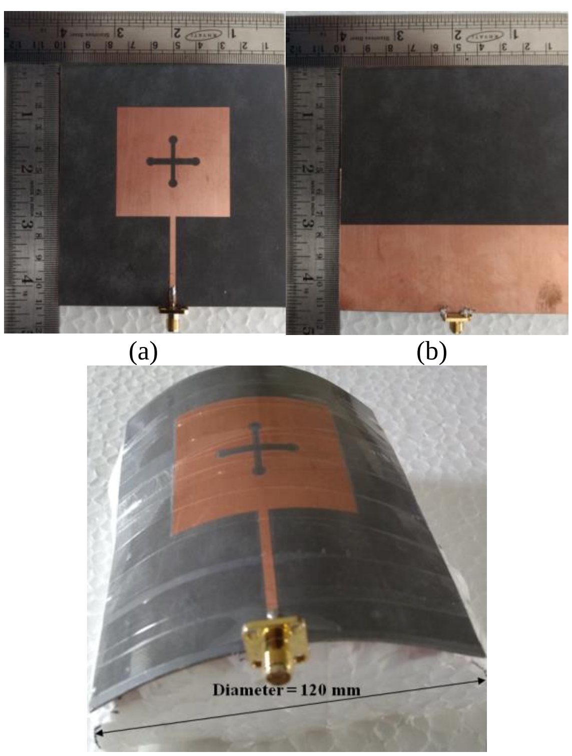


Fig. 7. Input reflection coefficient (dB) of the conformal antenna.

III. RESULTS AND DISCUSSION

The proposed antenna is designed and simulated using CST STUDIO SUITE 2016. A prototype planar antenna is fabricated on RT/duroid 5880 substrate with thickness of 0.787 mm. By using LPKF milling machine S100, the antenna is fabricated on a planar surface as shown in Figs. 8 (a) and 8 (b), and it is rolled up to form a cylindrical shape on foam of radius of 60 mm as shown in Fig. 8 (c). The foam material is used as mechanical support for making 60 mm radius cylinder which has negligible radiation effect on the antenna. Both simulated and experimental input reflection coefficient (S_{11}) in dB of the proposed conformal antenna with 60 mm radius cylinder are demonstrated in Fig. 9. The input reflection coefficient is measured utilizing HP vector network analyzer within the frequency range of 130 MHz to 13 GHz. It is investigated that the designed cylindrical conformal patch antenna has a wide bandwidth of 79.28%, operating from 1.09-2.524 GHz. It can also be investigated that the experimental reflection coefficient (dB) slightly deviates from the impedance bandwidth achieved by using commercially available CST software may be due to tolerances in fabrication and SMA connector.

The radiation patterns at 1.17645, 1.2276 and 1.57542 in both E- and H-planes are illustrated in Fig. 10. The two dimensional patterns of the antenna are obtained in an anechoic chamber. It is investigated that, the two dimensional patterns at various frequencies are similar, which is expected from a wideband antenna. From Fig. 10 it can be referred that, the designed cylindrical conformal patch antenna has symmetrical radiation patterns. A figure of eight pattern and circular pattern are obtained in E-plane and H-plane respectively.



(a) (b)

(c)

Fig. 8. Photograph of prototype fabricated antennas: (a) front view of the proposed planar antenna, (b) back view of the proposed planar antenna, and (c) front view of a proposed cylindrical conformal antenna with 60 mm radius of curvature.

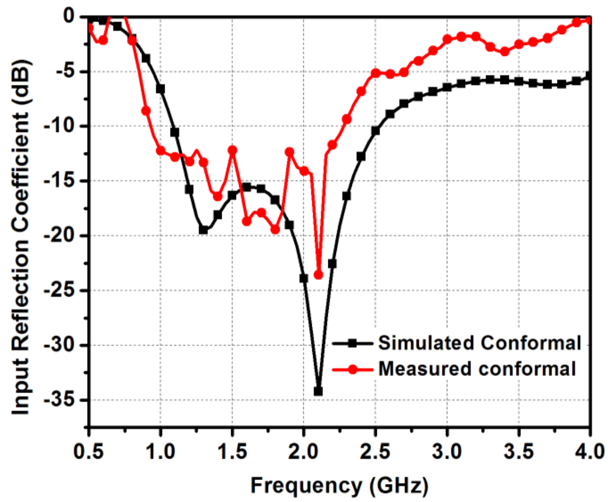


Fig. 9. Input reflection coefficient of the proposed conformal antenna.

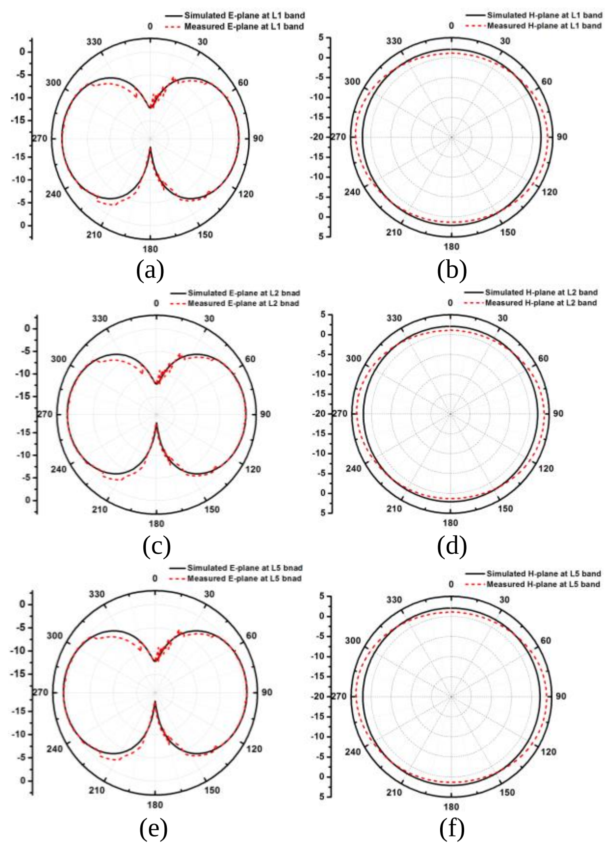


Fig. 10. Radiation pattern of proposed cylindrical conformal antenna at: (a) E-plane at L_1 band (1.57542 GHz), (b) H-plane at L_1 band (1.57542 GHz), (c) E-plane at L_2 band (1.2276 GHz), (d) H-plane at L_2 band (1.2276 GHz), (e) E-plane at L_5 band (1.17645 GHz), and (f) H-plane at L_5 band (1.17645 GHz).

The surface current distribution of the proposed conformal antenna at 1.575 GHz is shown Fig. 11. A strong surface current distribution around the dumbbell shape of the cross slot can be observed.

The gain of the cylindrical conformal antenna and planar antenna are compared in Fig. 12. The antenna gain is varying from 2.37 to 5.33 dBi over the operating frequency band. The gain of conformal antenna is more than the planar antenna. The simulated and measured gain of the proposed cylindrical conformal antenna are compared in Fig. 13.

The overall performance of the proposed cylindrical conformal antenna is compared with those of previously reported planar antennas at GPS frequency in [13-15] and given in Table 1. In spite of the fact that the proposed cylindrical conformal antenna is more size, yet it gives competitively wide bandwidths. Moreover, the gain is also more than the antennas existing in the literature [3],[5].

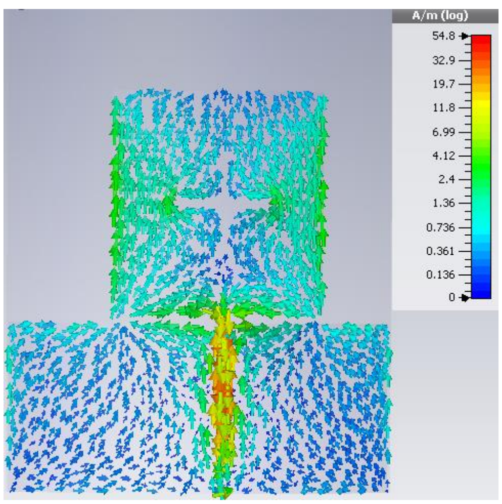


Fig. 11. Surface current distribution of the proposed conformal antenna at 1.575 GHz.

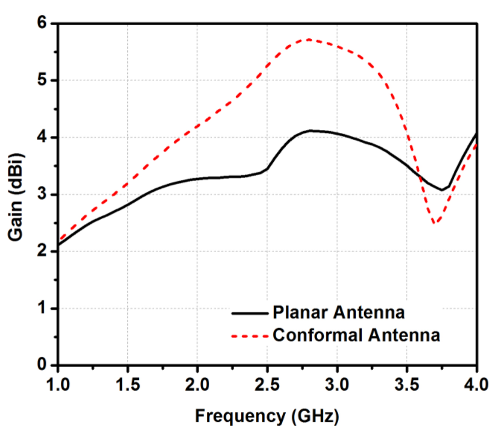


Fig. 12. The simulated gain of the planar and conformal antenna.

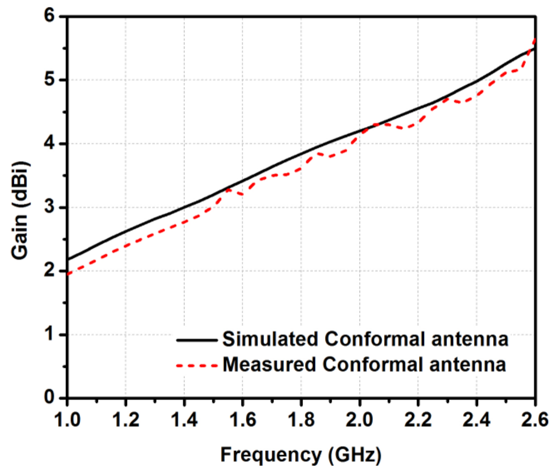


Fig. 13. The gain of conformal antenna.

Table 1: Performance of the proposed conformal antenna compared with planar one existing in the literature

Antenna	Perimeter (mm)	Frequency (GHz)	-10 dB Bandwidth	Gain (dBi)
Proposed work	420	L_1, L_2, L_3, L_4, L_5 BAND	79.28%	5.33
[15]	314.15	L_1	2.1%	-11
[16]	395.84	L_1	20 MHz	6.5
[17]	240	L_1	20 MHz	4

IV. CONCLUSION

This paper presents the design of cross-slot wideband cylindrical conformal antenna with 60 mm radius of curvature. The antenna is designed for planar and curved cylindrical configurations with well maintained radiation characteristics. The designed cylindrical conformal antenna offers a good wideband fractional bandwidth of about 79.28% and covering the bandwidth requirements of the modernized GPS application which can be used to guide the anti-tank guided missile (ATGM). Furthermore, the antenna has an omnidirectional radiation pattern in H-plane with a gain of about 2.37 to 5.33 dBi within the operating frequency range of 1.09 to 2.525 GHz.

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