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Frustum Shaped Conformal Antenna for Spinning Aerial Platform

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ABSTRACT

A novel approach to design and develop frustum shaped conformal antenna for transmission of telemetry data from a missile like spinning aerial platform is described. The requirement necessitates for an omni directional radiation pattern in the roll plane. However, the criteria is not feasible to achieve by using a monopole or a dipole as the omni coverage due to these antennas are restricted only in yaw or azimuth plane of the aerial platform. A conformal antenna appropriately wrapped on to the surface provides potential solution and accordingly has been configured for meeting the requirements of a practical application. The antenna artwork has been designed to conform to the exterior geometry of the intended portion of conical surface and printed on a microwave substrate which is essentially thin and flexible. A corporate feed distribution scheme has been designed and tailored to match with the impedance of the microstrip radiator at multiple locations and also printed along with it making the frustum antenna very compact and of aerodynamic supportive form. The antenna produces required omni coverage in the plane normal to the roll axis. A step-wise method for the design and development of the frustum conformal antenna through simulation and experiment approach has been discussed.

Keywords: Frustum antenna; Conformal antenna; Roll plane omni pattern

1. INTRODUCTION

The requirement of radiation coverage or patterns of on-board antenna for an aerial platform is system specific and is primarily decided by the expected operational manoeuvres of the airborne system. The antenna patterns as installed on the aircraft play an important role to configure it for a particular application. However, additional features such as compactness and low profile structure are also considered while selecting the type of antenna which is most suitable for the specific airborne use. Conventional omni antennas such as monopoles and dipoles are generally used for most of the airborne platforms which cruise mainly in the yaw plane. However, these antennas fail to provide unbroken radio link for data communication while the manoeuvring of the airborne system is permitted to spin in the roll axis. This is due to the presence of significant nulls in the roll plane (elevation cut or E-Plane) of the omni antenna. Combination of dual or quad monopoles or slotted blade transmission line antennas placed orthogonally partially improves the nulls in the patterns. However, the external projections of multiple antennas on the surface contribute adversely to the flightworthiness of the spinning aerial platform.

The stringent antenna requirement for the critical application has motivated to design a surface flushed radiator that can prominently be used, fulfilling the inherent aerodynamic feature without compromising the functional requirements. A conformal wrap around antenna for cylindrical surface may be designed with relative ease as the shape of the antenna is rectangular and the artwork is symmetrically distributed. However, a frustum shape due to its longitudinal asymmetry in structure adds complexity to the design and construction. This asymmetry leads to gradual change in the dimensions of feed-line and the radiating part as well.

In the present work, a frustum shaped wrap around antenna has been designed for airborne separation inertial system to investigate weapon trajectory characteristics during and post-release from an inflight combat aircraft such as Tejas. The inertial sensors are mounted onto the weapon test store with a transmitting antenna to telemeter in *L* band and log the data at ground station in real-time. Uninterrupted radio communication link with the ground telemetry station must be ensured to get the data during cruise. The dynamic and random spinning nature of the trajectory of the weapon system demands for a specific radiation-coverage of the antenna which can be met by conformal configuration and the structural geometry of the test store confirms a frustum antenna shall meet the requirement.

2. FRUSTUM ANTENNA CONFIGURATION

The necessity has emerged from the limitation that the only space available for antenna installation on the envisioned spinning airborne platform, is of frustum shape. A comprehensive approach of understanding the geometry along with the configuration of antenna to conform to the geometry has been adopted.

2.1 Frustum Geometry

The goal of many crucial designs is achieved with the

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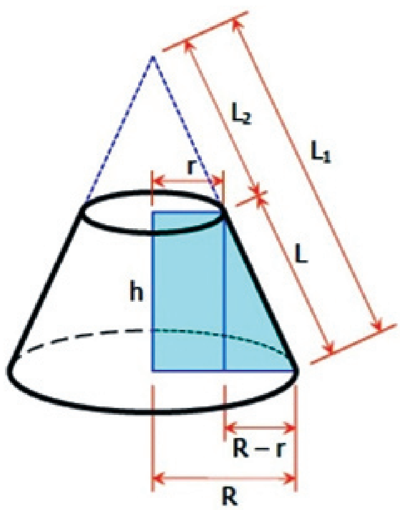
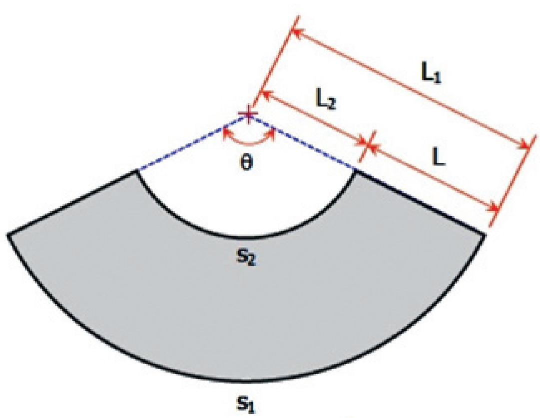
creation of flattened geometry from the three-dimensional counterpart. To configure and design a conformal antenna, it is mandatory to understand the exterior surface of the structure on which the antenna is intended to be formed. Geometrical details of curved surface provide essential technical inputs for the design of a complex surface-mountable antenna. In general, the geometry of a conical frustum is produced by slicing a right circular cone at the top with a cut which is parallel to the base. This leads to the formation of a structure with lower and upper circular bases which are parallel to each other and of different radii R and r respectively. A typical three-dimensional frustum structure indicating its curved surface is as shown in Fig. 1(a). The frustum geometry when unfurled in to its planar form, takes the shape of the angular section of an annular ring in strip as shown in Fig. 1(b). The angle of cone, α determines the angle of the unfurled frustum, θ which in turn decides the shape and size of the intended geometry. The dimensional details of the planar frustum are obtained from the geometrical ratio and proportion of the actual three dimensional shape as given in the following.

$$L_1 = L\frac{R}{R-r}\ ;\ L_2 = L\frac{r}{R-r}\ ;\ \theta = \frac{S_1}{L_1} = 2\pi\frac{R}{L_1} = 2\pi\sin\frac{\alpha}{2}$$



(a)



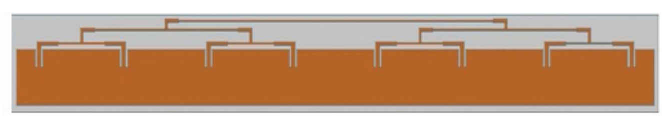
(b)

Figure 1. Frustum surface geometry: (a) Intact form and (b) Unfurled form.

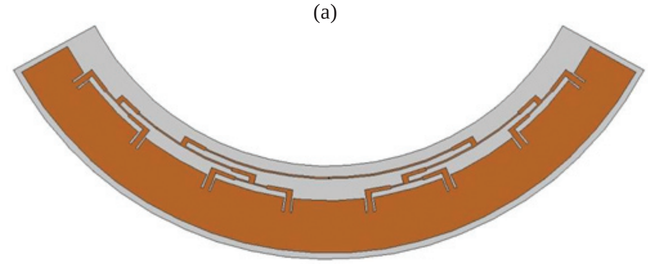
2.2 Frustum Conformal Antenna

A well-known concept of wrap around antenna for cylindrical surfaces, as shown in Fig. 2(a), is the basis for the design and configuration of a frustum shaped conformal antenna. Geometrically being simpler, the wrap around antenna is designed with a long rectangular shaped microstrip radiator. Inset type microstrip feed at multiple locations and equally distributed feed network are designed and configured to excite the flexible antenna. Primarily, the design and artwork of antenna and feed network are printed on the unfurled geometry through photo etching of copper cladded microwave substrate and subsequently wrapped firmly on the intended cylindrical platform for use[1]. Efforts have been made to utilise this antenna for a conical surface also where the diameter of circular curvature changes gradually. This has resulted into a complex installation scheme of 'geodesic curve' on the surface, however with limited scope of utility. The configuration is difficult to install and it occupies more surface area and also results in the degradation of radiation pattern and polarisation properties[2].

The limitation of the scheme led to the evolution of a frustum antenna development. Though frustum antenna is of complex planar shape as indicated in Fig. 2(b), it simplifies the installation on conical surface with minimum space. In addition, desired omni pattern and polarisation symmetry can be maintained only through use of a frustum shaped antenna. However, to design a printed curved microstrip radiator and to match its impedance to the feed network in the form of gradually varying dimensions, offers significant challenge for realisation.



(a)



(b)

Figure 2. Unfurled Conformal antennas with feed network: (a) Wrap around antenna for cylindrical surface and (b) Frustum antenna.

3. DESIGN APPROACH AND SIMULATION

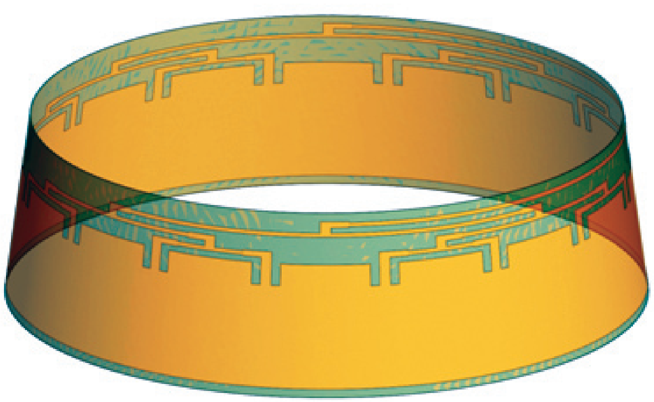
The conceptual design of frustum antenna has been evolved through several phases of design and development. Initially, multiple rectangular patches were configured in a linear array form across circular cross-section on conical surface. A proximity coupled corporate type feed network was printed on a different layer of substrate. Although the scheme met requirements bandwidth, it suffered undulations in the roll plane pattern due to multiple discrete radiators and also it presented difficulty in installation of two layers with precise alignment. The issue of undulation in pattern was resolved by joining multiple radiators to form a single radiating strip with proximity feed at multiple locations[3]. Further optimisation carried out to make the design compact and smart by exciting a continuous radiating element with a monolithic corporate feed network. The antenna gives 99 per cent of omni coverage with a gain greater than -8 dBi[4,5].

The advancement of frustum configuration from ‘multi-layer and multi-radiator’ to the compact ‘single layer and single radiator’ scheme has been achieved and executed through a process of optimisation through design, development, evaluation and continual improvement. The number of feed locations, N_F is decided by the circumference of the frustum antenna. It is essential to be $N_F > N_\lambda$; where N_λ is the number of guided wavelengths across the length of the feeding edge circumference of the frustum. Further, $N_F = 2^n$; where n = 1, 2, 3, …. as decided by the number of level of power division required in the corporate type feed network[6]. The feed network design has been optimised by using Genetic Algorithm. Electromagnetic simulation tool, FEKO has been used to create frustum geometry with calculated dimensions of different configuration to optimise and predict results. The meshing of the optimised design of the antenna and the feed network and the artwork in three-dimensional form is as shown in Fig. 3(a); and the same as printed on thin microwave dielectric substrate, is as shown in Fig. 3(b).

The substrate thickness and its dielectric constant influence the impedance bandwidth of the antenna. However, the bending flexibility requires a thin substrate and 32 mils has been considered for the present application. A precise depth for the feed location of the inset type feed has been calculated and designed for proper impedance matching at that point between the feed and the radiator. This ensures optimum operational bandwidth of the antenna. Further, angle of frustum is a critical parameter for impedance matching. A study has been carried out by varying the frustum angle and monitoring its impact on input impedance of the antenna. It is found that with the increase in the frustum angle, the antenna bandwidth reduces. The simulated VSWR plots to compare the effect due to frustum angle has been indicated in Fig. 4. Simulated radiation patterns of the frustum antenna in the two dimensional planes of roll and azimuth (plane normal to roll) are as shown in Fig. 5.

Even though, the antenna is of frustum shaped and fully conformal on to the intended section, the complete weapon structure in real scenario likely to affect its performance, particularly in the radiation pattern. A structure which is very close to the actual platform of the test store, that can represent it effectively has been created for simulation through FEKO and obtained radiation pattern for comparison.

(a)



(b)

Figure 3. Frustum antenna and feed network for simulation: (a) Meshing of artwork for computation and (b) Artwork on microwave substrate.

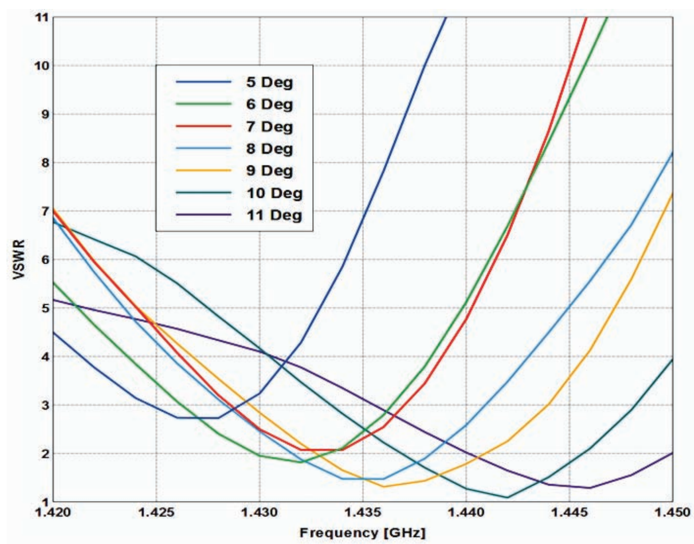


Figure 4. VSWR plots with varying frustum angle.

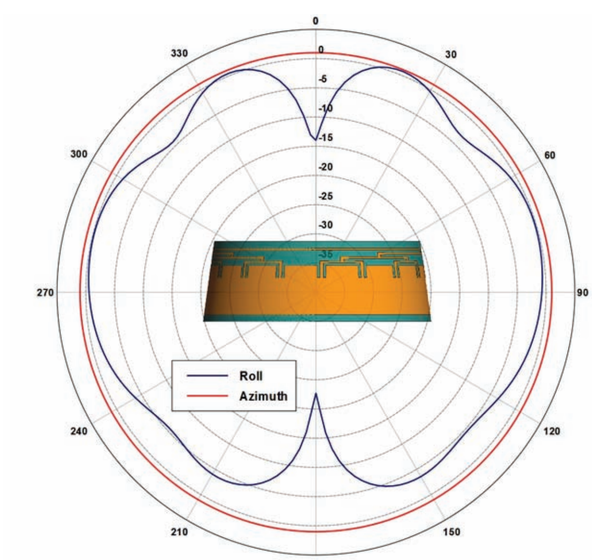
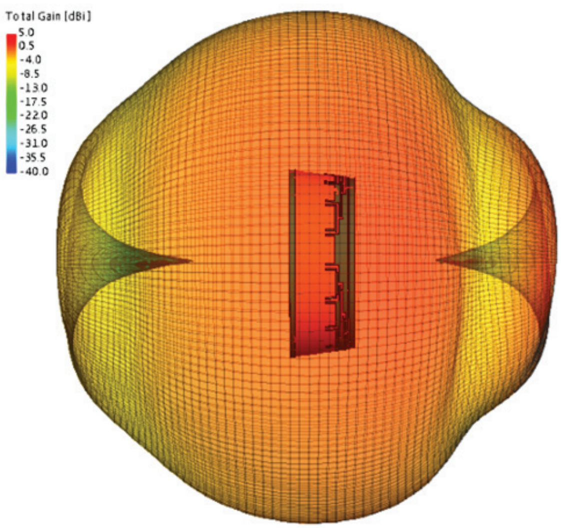
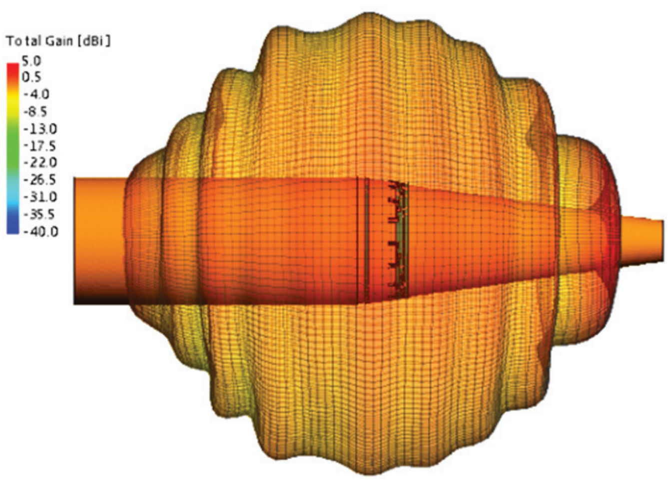


Figure 5. Simulated patterns of roll and azimuth planes.

Three dimensional patterns for both standalone antenna and antenna as installed on the effective simulation structure are as shown Figs. 6(a) and 6(b), respectively. The change in the pattern due to the full structure of the weapon test store is expected and is clearly visible from the patterns in Fig. 6. A comparison of two dimensional patterns in the plane perpendicular to the roll axis is as shown in Fig. 7. Ripple of the order of 2 dB is noticed in the pattern, however is acceptable in meeting the specifications of the present requirement. There is marginal improvement in radiation coverage in this plane with respect to the standalone frustum antenna pattern, which is practically beneficial for the intended application.



(a)



(b)

Figure 6. 3D Pattern of frustum antenna: (a) Pattern with standalone antenna and (b) Pattern with effective structure.

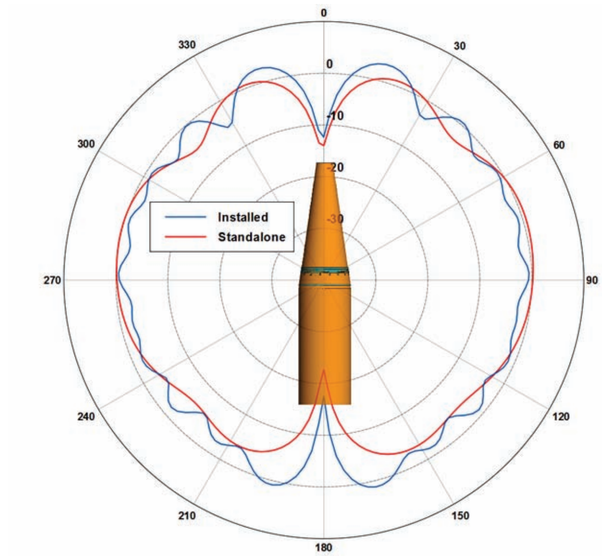
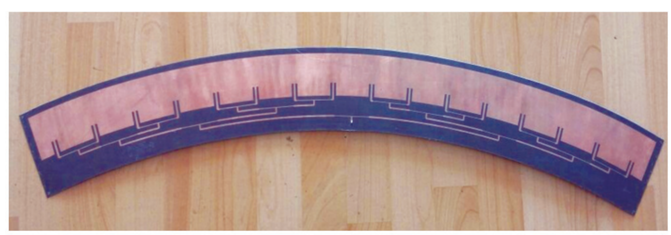


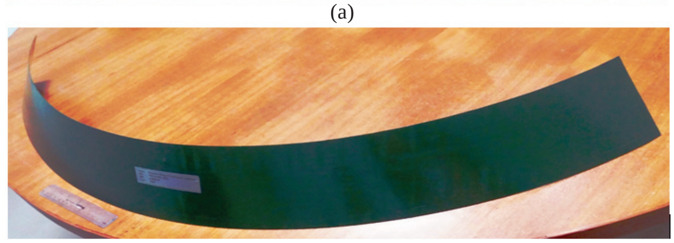
Figure 7. Comparison of patterns of frustum antenna: (i) stand alone and (ii) as mounted on effective structure.

4. HARDWARE REALISATION AND EVALUATION

The frustum antenna has been developed by photo etching of the printed artwork on the thin microwave substrate in the planar form. The substrate is flexible with thickness, t = 32 mils and dielectric constant, ε_r = 2.5. It has been trimmed to the predetermined shape and size as per designed artwork. Aerospace grade non-conductive paint has been applied on the printed pattern for surface finish and colour to match with the weapon. It is ensured that the paint does not have any impact on the antenna functionality and gives required environmental protection. In Fig. 8 (a) and 8(b), the fabricated antennas are as shown without and with paint applied on the exterior surface. The antenna VSWR at resonant frequency is measured and found to be 1.13 with a bandwidth of 3 per cent in applicable L Band for VSWR $\leq$ 2. The VSWR plot of the antenna is as given in Fig. 9.



(a)



(b)

Figure 8. Fabricated frustum conformal antenna: (a) Antenna without paint and (b) Antenna with paint applied on surface.

The radiation pattern measurement set up inside microwave anechoic chamber for the roll plane is as shown in Fig. 10. The measured patterns of roll and azimuth planes are as given in Fig. 11. The experimental outcomes, VSWR and the pattern measurements are in close approximation with the simulated results.

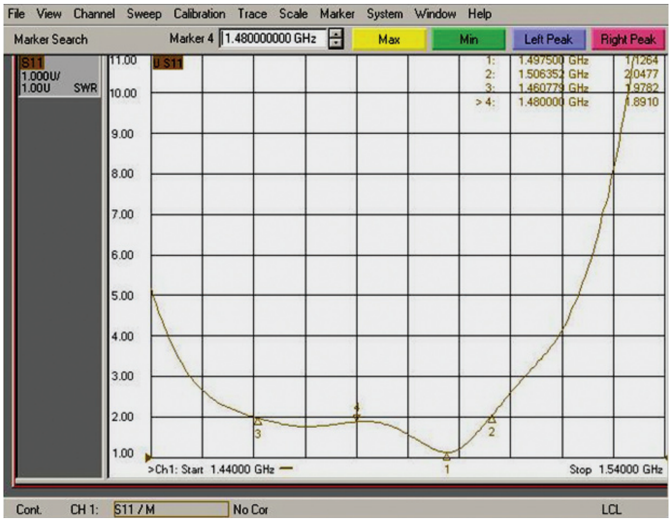


Figure 9. Measured VSWR plot.

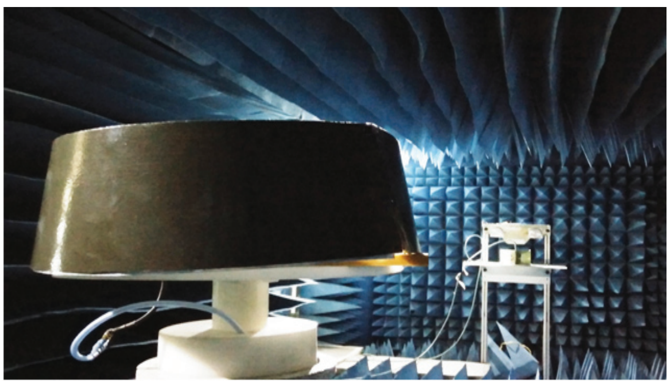


Figure 10. Pattern measurement set up in anechoic chamber.

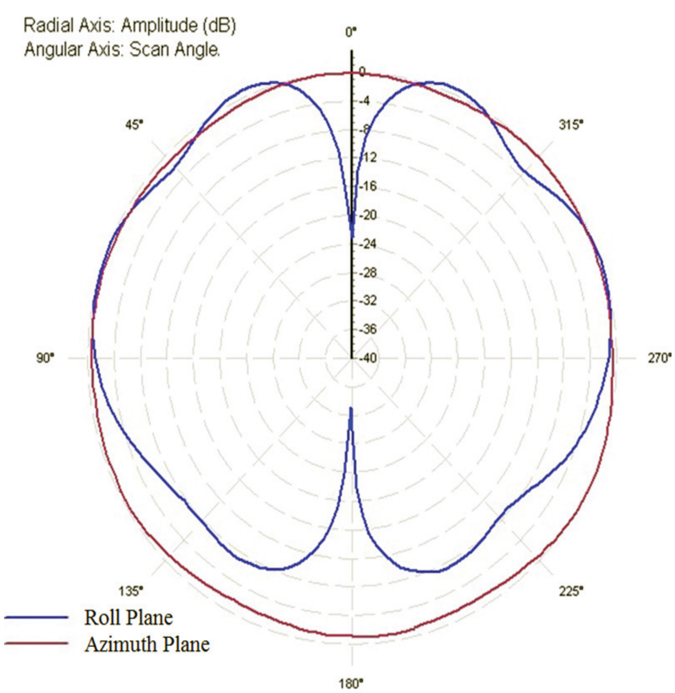


Figure 11. Experimental patterns of roll and azimuth planes.

5. CONCLUSIONS

The frustum conformal antenna for aerial system of weapon test store with spinning manoeuvres has been realised using conceptual and state-of-art design followed by optimising through a series of simulation and experimental evaluation procedure. A multilayer microstrip antenna scheme with proximity coupling has been converted to co-planar conformal configuration. The antenna has been tuned to the desired frequency in *L* band and it produces omni coverage in the roll plane meeting the requirements of a crucial application.

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Mr Diptiman Biswas is BE (Electronics Engineering) from NIT, Jamshedpur & MTech (Microwave Engineering) from IIT, BHU, Varanasi. Presently working as a Scientist at DRDO-Aeronautical Development Establishment, Bengaluru. He is responsible for providing solutions with respect to RF, Antenna and electromagnetic problems for unmanned aerial systems. He received *KU Limaye Award in 2013* and *DRDO National Science Day Award in 2017*.

In the current study, he originated the concept and novelty in design, finalised system specifications and formulated procedure for optimisation of design and realisation of hardware through quality process.

Mr Asif Rizwan received his BE (Electronics and Communication Engineering) from National Institute of Technology, Srinagar in 2010 and presently working as a Scientist at DRDO-Aeronautical Development Establishment, Bengaluru. His area of work includes: Design and development of antennas for airborne platforms, Radome design and EM analysis of onboard systems.

In the current study, he simulated the design using FEKO EM simulation software, optimises design, evaluated hardware performance and compared results.