A Novel Approach to Design Conformal Frustum Wrap Around Antenna

Diptiman Biswas, Dr. V Ramachandra

Aeronautical Development Establishment
Defence R & D Organisation, Ministry of Defence
Govt. of India Bengaluru – 560093

diptimanbiswas@yahoo.co.in

Abstract:
The paper describes an innovative approach of designing microstrip based wrap around type conformal antennas for conical surfaces. A symmetrical distribution of feed network with complex and converging geometry has been designed to match appropriately to the impedance of the radiators. Two schemes with discrete multiple radiators and a continuous radiating strip have been designed and developed for being perfectly conformal on frustum geometry and produce omni directional radiation pattern in the plane normal to the axis of it.

Key Words: Conical wrap around antenna, Frustum antenna

I. INTRODUCTION

The commonly used wrap-around antennas are suitable for conformal mounting on cylindrical surface which has uniform radius along its length i.e. in the direction of its axis. However, it is difficult to mount these antennas on the surface of a cone or a frustum as the design is not as simple as in the previous case. The varying radius along the length of a conical surface of frustum seriously affects the performance of the wrap-around antenna due to its mismatch in impedance and degradation in the radiation characteristics influenced by the critical changes in its geometry. A conical frustum antenna in its unwrapped planar form is no longer a symmetrical rectangular shape as in the case of conventional wrap around antenna and it takes the shape of the section of an annular ring with concentric inner and outer arcs.

The scope of the present task is to design a frustum antenna to be symmetrically wrapped on the conical section of an airborne platform. When the antenna is energized with a transmitter and allowed to spin on its axis, the receiving station at a distant location shall receive RF signal with marginal or no variation; in other words it shall have omni directional radiation pattern in the roll plane. The aim is to incorporate required tailoring in the geometry of the conformal radiator and feed network to meet surface mountable and aerodynamic requirements without compromising on the antenna bandwidth and its radiation characteristics.

We have designed frustum wrap around antenna using multilayer proximity coupled feed technique and the conceptual part is realized in two stages. Initially, multiple radiators in the form of concentric array has been designed and developed to produce a frustum shaped antenna. The design concept is further extended by replacing multiple printed radiators with a single and continuous type. The designs have been simulated and optimised using an electromagnetic simulation tool (Feko 6.1).

II. WRAP AROUND ANTENNA & FRUSTUM

The flexible microstrip based wrap around antenna on cylindrical surfaces are essentially used for many airborne applications because of their inherent nature of conformality and specific radiation coverage. Wrap around antenna placed on the cylindrical surface produces radial omni pattern with nulls at the axis.

An effort to put wraparound antenna conformal to a conical or frustum surface results in a unique geodesic geometry which is very close to the "neck collar" configuration. The asymmetric installation of antenna consumes more space and the configuration significantly distorts its omni directional radiation pattern and polarization symmetry. The detailed study of patterns due to geodesic installation of wrap around antenna has been discussed in [1]. To overcome the limitations of non-symmetrical conformal antenna configuration has inspired to design and adopt the technology for frustum shaped conformal antenna.

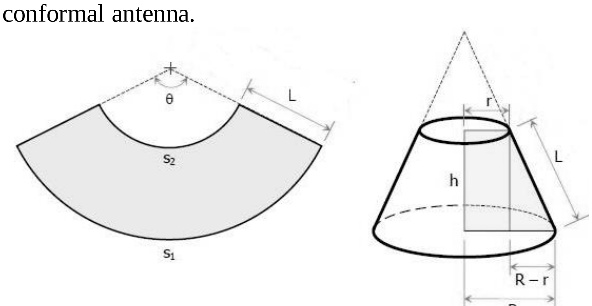

Figure 1. Frustum geometry – (a) planar & (b) 3D form

To design an antenna with frustum geometry in its planar form is little bit complex, though it can be wrapped comfortably on the skin of a conical surface with less space occupied. In addition, a desirable omni pattern and polarization symmetry can be maintained only through use of a frustum shaped antenna. The frustum geometry in its planar and wrapped around forms are shown in Figure.1.

Very few works have been reported till date on conformal antennas for conical surfaces and these are restricted to mainly for single patch or small microstrip arrays being conformal and limited to a small portion of the frustum geometry. However, we have adopted a novel and step wise conceptual design approach for frustum shaped conformal antenna which can be wrapped fully on the frustum curvature and produce omni radiation coverage in its radial direction.

III. FRUSTUM ANTENNAE GEOMETRY

1. Multiple Radiator Approach

A linear microstrip array of rectangular elements and proximity coupled feed network in a multilayer scheme has been the basis to this approach. Once the radiator is printed on the surface of a frustum, to be conformal on the geometry, each of the elementary patches take the shape of trapezium in the planar form i.e. the length of the elementθs leading and trailing edges are different. The frustum geometry further drives the linear array into a symmetrical curved one. The feed network also has been tailored accordingly in a converging manner for suitably fitting in the frustum and to energise the discrete radiating elements placed in a curvature and the complete two layer scheme is shown in Figure 2.

2. Single and Continuous Radiator Approach

In second stage of the conceptual design, we planned to configure the frustum antenna replacing multiple radiators by a single radiating strip with concentric edges. The approach is by joining multiple radiating elements together to form a single, symmetric and continuous strip making it a section of an annular ring in the planar form. It becomes frustum shaped when wrapped on the conical structure. In the present case, too, the radiator is energised through proximity coupled and identical feed network as in the previous one. In both the schemes everything else is same except the radiators. The two layer antenna scheme with single radiating strip in the planar form has been shown in Figure 3.

IV. DESIGN & DEVELOPMENT OF FRUSTUM ANTENNA

1. Feed Network

In contrast to the cylindrical wrap around antenna where the feed lines of the feed network are equally spaced, the frustum antenna requires converging feed lines making it critical for impedance matching. The two layer proximity coupled scheme has been considered for obtaining the required operational bandwidth of the antenna. The substrates are stacked and made conformal with the radiator(s) etched on the top substrate and the feed network on a different layer of substrate placed below the radiating element without any gap.

The dimensional change due to radial difference of the substrate layers in the frustum form has been estimated and incorporated for optimising separation between consecutive feeds. The feed network is distributed using a corporate structure in a symmetrical and converging fashion to match a 50Ω co-axial feed at a symmetrically centred and through various level of transformation of impedances. At the final level, the feed terminate open ended at certain specific inset location under the flexible microstrip radiating element(s) where the patch impedance is very close to the feed-line impedance.

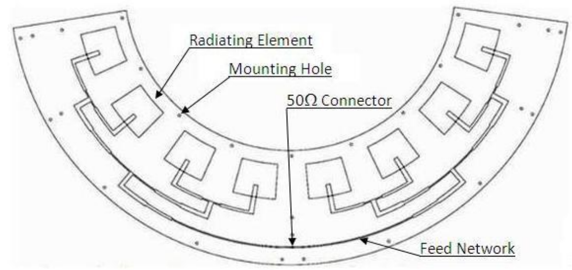

Figure 2. Multiple Element Frustum Antenna & Feed Network in planar form

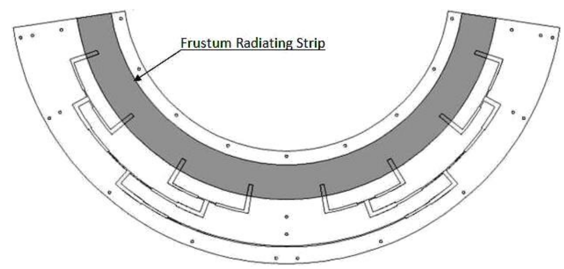

Figure 3. Single Radiating Strip Frustum Antenna & Feed Network in planar form

2. Multiple Discrete Type & Single Continuous Radiators

The two schemes of frustum wrap around antenna have been proposed and their associated geometry in the planar form have been discussed in the previous section. The antennae have been designed for S Band operation.

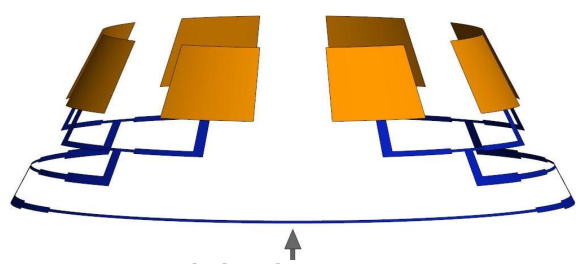

Figure 4. Multiple Radiator Frustum Antenna & Feed Network in wrap around form

The geometrical structure of these antennas in multi layer dasign have been modeled in όCADFEKOô and optimised through a process of rigorous simulation using MoM solver of FEKO 6.1. Fig. 4 and Fig. 5 describe the two layer conformal geometry of radiator(s) and feed network for multiple radiators and single continuous strip frustum antennae respectively. The arrow in these figures indicate the central location of co-axial feed. The presence of substrate in these figures are made transparent to describe the perspective views of antennae and their feed networks distinctly.

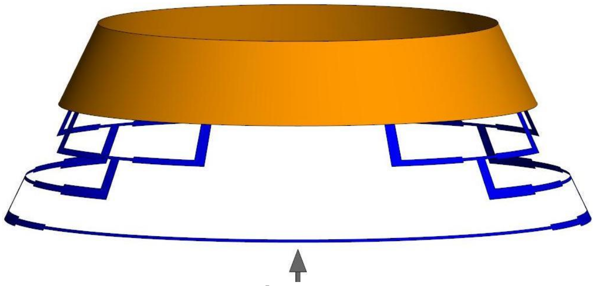

Figure 5. Continuous Radiating Strip Frustum Antenna & Feed Network in wrap around form

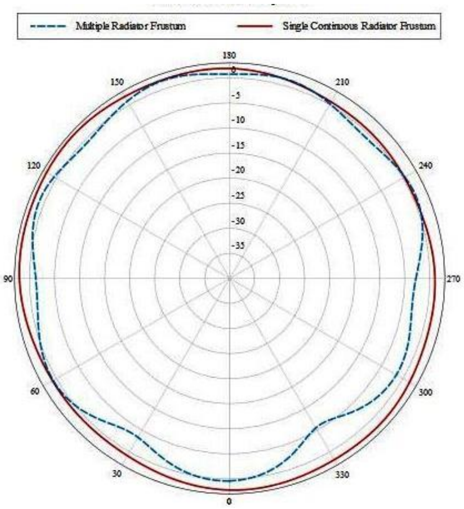

Figure 6. Comparison of Omni Plane Patterns between Multiple Radiators & Single Strip Frustum Antenna

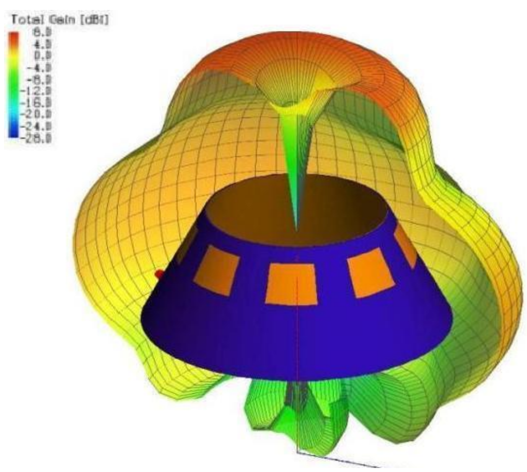

Figure 7. Sectional view of three dimentional pattern along with discrete radiators frustum antenna.

The roll plane omni patterns of these two cases have been compared and shown in Fig. 6. The ripples observed in the omni pattern of the discrete and multiple radiators frustum antenna are minimised as expected in the case of frustum antenna with continuous radiating strip.

The three dimensional sectional patterns of these frustum antenna configurations are given in Fig. 7 & Fig. 8.

The 3D patterns reveal that the distribution of radiation energy in the upward direction of the cone (as indicated in the figure) in the case of frustum antenna with multiple radiators are more when compared with the antenna with continuous radiating strip. However, the continuous frustum radiates relatively more RF energy in the radial direction. Thus the pattern make the continuous frustum antenna more useful for the intended airborne application when compared between the two.

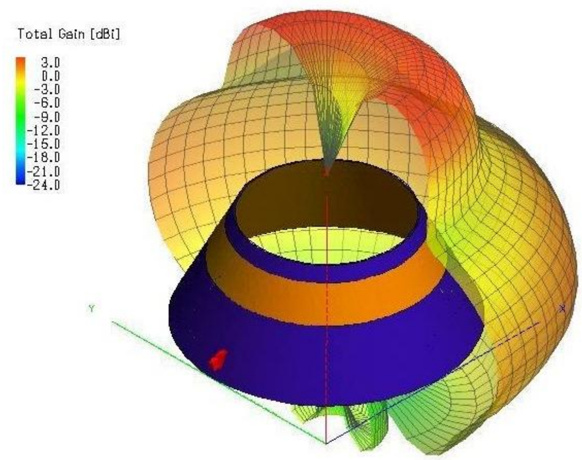

Figure 8. Sectional view of three dimentional pattern along with continuous strip frustum antenna.

3. Fabrication

After design optimisation, the art work for radiators and feed network have been printed by photo etching on the thin and flexible substrate and trimmed them to required annular shapes. Antenna with descrete patch radiators are printed such that they will be placed symetrically above each of the feed lines.

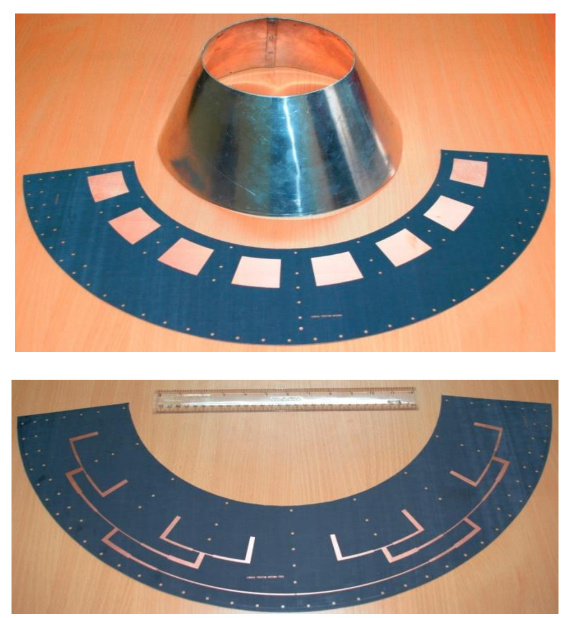

Figure 9. Hardware (a) Multiple Radiator Frustum Antenna along with the metallic frustum (b) Feed Network

Figure 10. Integrated Continuous Frustum Antenna

Figure 11. $|S_{11}|$ Plot of Integrated Continuous Frustum Antenna

Appropriate measure was taken for precise alignment in the stacked and conformal placement of the antenna on metallic frustum base. Further, a continuous frustum strip replaces the multiple radiators making the fabrication simpler as the exact placement of the feed lines are not critical in this case. A 50 Ω coaxial input at symmetrically centred location of the feed network in branches of multiple printed microstrip lines are required and essential for efficient energy transmission to the radiating geometry.

The fabricated hardware with multiple radiators are shown in Fig 9. (a) & (b). Fig 10 shows the complete and integrated frustum wrap around antenna in multi-layer configuration. Its $|S_{11}|$ measurement plot is shown in Fig.11 which indicates the operational bandwidth of the antenna is 40 MHz in S Band.

V. Conclusion

The design and development of Frustum Conformal Antenna was a unique and innovative task. It was a challenging task as even with structural and geometrical change of the antenna, its specific electrical performances are not compromised. This is achieved by above mentioned approaches thereby offering efficient performance by perfectly conforming on the frustum as well as providing desired radiation pattern. The conceptual approach has been supported by required analysis, study, design and simulation. The hardware has been realised through rigours optimization procedure.

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BIODATA OF AUTHORS

Diptiman Biswas: Graduate in Electronics Engg from NIT, Jamshedpur in 1993. M. Tech in Microwave Engg. from IIT, BHU, Varanasi in 1995. Joined ADE as Scientist in the year 1996. At present as Head of Antenna Group, his prime domain of research work include configuration and design of antennas for various indigineous UAV systems. Using innovative & conceptual approach of design, he has produced a number of antennas ranging from conformal, monopulse planar, directional and omni directional types for various operational frequency ranges. He has authored a number of technical papers and presented at various conferences.

Dr.V.Ramachandra: Graduated from Osmania University**.** Post graduated form Kakatiya University, Warangal in 1980 with distinction. Awarded Ph.D. by BHU, Varanasi in 1988. He is presently Scientist óGô and Head of the Technology Division FTTT (Flight Test, Telecommand & Telemetry) at ADE. He has developed a number of Airborne Antennas, Luneberg lenses, Doppler Miss Distance Indicator System. Presently he is working on various technologies related to Communication Systems, Datalink System, Ground Control Station, RF Seekers, Radars, Power Systems, Sensor Instruments etc. He has more than 175 technical publications / reports. He has designed and developed number of import substitutes at ADE. He is a member of IEEE, ATMS, AeSI & SAQR Most of his designs / products have been productionized and the items are being used by Indian Armed Forces.