

Design and Kinematics of Deployable Mesh Reflector Antenna for Space Applications

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ABSTRACT: There is a high demand for the design and fabrication of communication satellites in the recent past. The strength of the system needs to be such that, it is capable of operating in extreme conditions supporting its proposed functionalities. Deployable mesh reflector antennas are required to be designed such that they do not compensate on the high gain used for communications and observations, to support such missions. CubeSats that carry the antenna are being designed that consumes less power and are light weighted than the present airborne satellites. The design and analysis become more crucial as such CubeSat allow the high gain antennas, fit in a highly constrained volume which is about $\frac{1}{5}$ th the size of the deployed state. The Computer-aided designing has been carried out on DS SolidWorks and the Kinematics of the Deployment mechanism of the Antenna is done using Unigraphics NX for superior understanding of the animation. The Constant Force (CF) spring has been analysed and incorporated to facilitate the deployment process situated at the hinges. The simulations and analysis mentioned were carried out accordingly, which were proven safe for the operating conditions, before moving on to the detailed design procedures.

KEYWORDS: Mesh Reflector Antenna, CubeSat, Kinematics, Deployment, Constant Force Spring.

I. INTRODUCTION

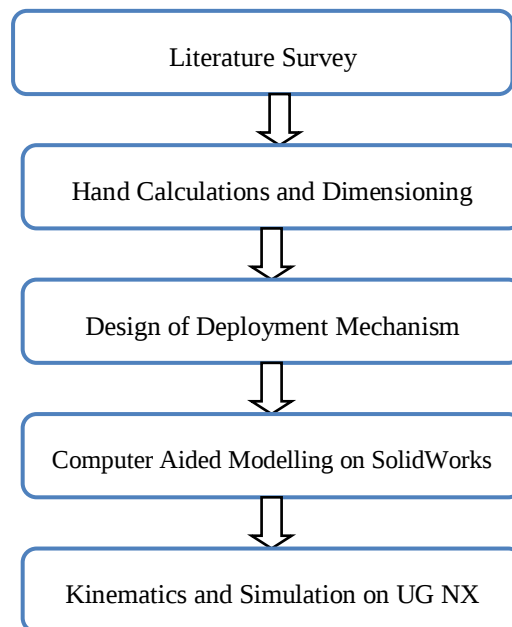
Over the past few decades, satellites have been developing at an alarming rate. With the developments of the satellites, requirements have also advanced in various domains. There are various components involved in a satellite, the most important components are antenna and transponders which receive and transmit signals. The propulsion system of its own other than the rocket as the position of the satellite changes one or two degrees per year because of the gravitational force of the Moon and the Earth. Higher frequency bands give access to wider bandwidths, these bandwidths are degraded by the atmospheric air, rain, snow and other conditions. Thus there is a need for larger aperture reflectors which provide high data services with higher gain. This creates a challenge in supporting the reflectors in terms of mechanical supports in a cost-effective manner. Stowing such huge bodies in a constrained volume of launch vehicles creates a problem. To solve these problems, designs like inflatable antennas, piezo-electric antenna systems, phased array have come up. A deployable antenna made of wire mesh and cable net structures and molybdenum sheet between the ribs have high packaging efficiency, less mass and effective signal transmission, as weight and power consumption are important factors in satellites. So there is always a requirement of state of the art technologies, high specific stiffness and strength with low thermal expansion materials for the spacecraft. In this regard, CubeSats which are expressed in standard size as "1U" or "One Unit" which is 10x10x10 cm were made. The mass of a standard CubeSat is less than 1.33kg. CubeSats are not very heavy, the rocket does not need a lot of fuel for the liftoff and since these are very small, they can be sent into space in a rocket which also carries another big satellite which is very economic. Such CubeSats are developed and deployment of the Antenna occurs more effectively.

II. RELATED WORK

There has been a lot of research carried out in the field of Mesh Reflector Antenna and the development of the structure over the past decades. The report by Yahya Rahmat-Samii and Randy L. Haupt [9] introduces to the various types and structures of Antenna with the development in the domain. In the report by Li Pei [4], the author discusses a type of mesh reflector, AstroMesh which has been analysed through Form-Finding and Modal Analysis method by using Force Density Method (FDM) and Minimum Norm Method (MNM). The influence of mesh tension force usually Molybdenum is analysed herewith. Further, Eva Peral [6] discusses the Ka-Band Mesh Reflector and the critical components involved in the CubeSat missions.

III. PROPOSED METHODOLOGY AND DESIGN

Initially, as stated above, understanding of the various types of Reflector Antenna was done with the further implementation of bands for the range of functionality. Since stowing a 0.5m diameter High Gain Antenna in a 1.5 U CubeSat is quite a challenge, to overcome this, the preliminary design was based on hand calculations, further review and verification of each component was carried out. Further, Deployment mechanism with the use of springs and its functionalities for the effectiveness of Deployment was carried out with the detailed design and Assembly of each component was executed, which undergone on DS SolidWorks. Further, Animation and Simulation of the entire system of Deployment from the stowed stage to the Deployed state were done on Unigraphics NX. In Section IV, a detailed discussion of the Kinematics of the Deployment of the Mesh Reflector Antenna is shown. The below chart shows the organization undergone during the process of the coursework.



The dimension and specification and based on calculation and alteration with verification upon design and simulation along with the help from Cube-Sat Deployment for Ka-Band Antenna^[2]. The Horn, Hub, Hinge, Root Rib, Tip Rib, Sub Reflector, Struts, and Cylinder form the individual parts for the Assembly. Section 3.1 to 3.4 give a brief description of the design and specifications of respective individual components with the Assembly carried out on SolidWorks which is further incorporated for the simulation.

3.1 HORN

This subsystem forms the crucial element for designing where the below Table 3.1 shows the specification of the design procedure and the adjacent Fig 3.1 shows the view of the Horn.

DIMENSIONS (mm)	
Inner Diameter	7.55
Outer Diameter	36.6
Length	123.59

Table 3.1

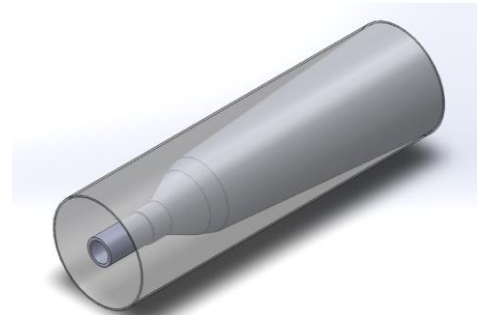


Fig 3.1

3.2 RIB

The design consists of 16 ribs, interconnected with molybdenum web, across the bottom of the horn. For the focal length assumed to be 250mm, rib dimensions' calculation was carried out and the length of the rib was 258.32mm with the radius of curvature to be 500mm based on the calculation. Below Table 3.2 and Fig 3.2 give us the description of the ribs.

DIMENSIONS	
Length	258.32 mm
Count	16

Table 3.2

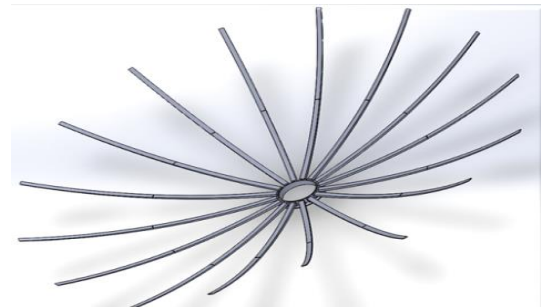


Fig 3.2

3.3 STRUT AND SUB REFLECTOR

The dimensions of strut and subreflector have been noted in the below Tables 3.3(a) and 3.3(b) with the isometric view of the combination in the Fig. 3.3.

Table 3.3 (a)

STRUT	
Length above Horn	109.87 mm
Thickness	1 mm
Count	3

Table 3.3 (b)

SUB REFLECTOR (mm)	
Diameter	59.6
Vertex Diameter	79.6
Foci Diameter	130.2

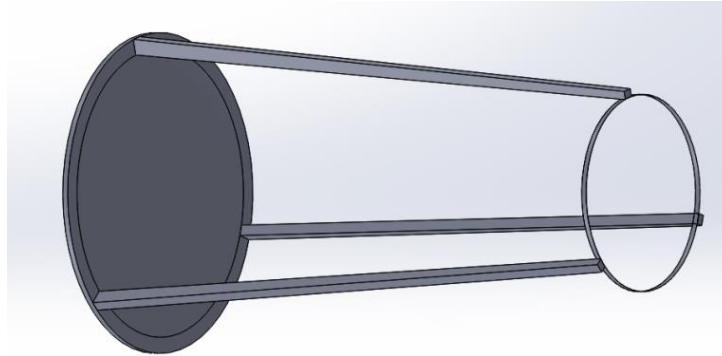


Fig 3.3

3.4 ASSEMBLY

The Fig 3.4, shows the assembly in the deployed state of all the individual components mentioned in this section above, which is carried out on SolidWorks. The gap between the Ribs is occupied by Molybdenum sheet, which helps in the transmission of RF waves.

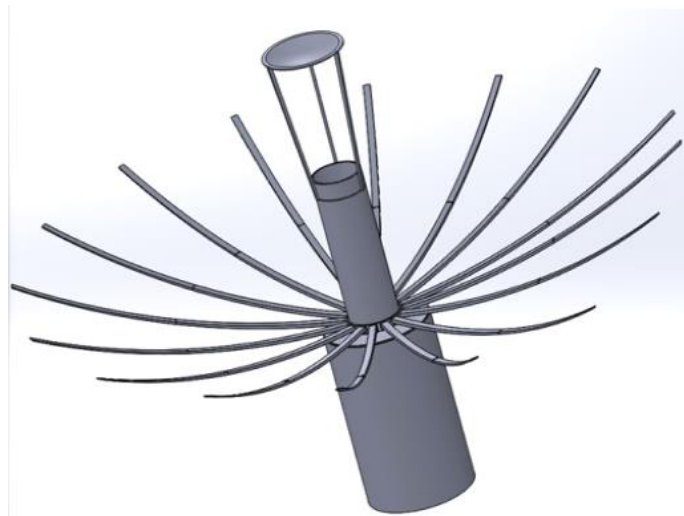


Fig 3.4

IV. SIMULATION ON UNIGRAPHICS NX

In order to get the accurate surface, providing an infinite ribs would create an ideal parabolic shape, but there occurs a limitation in the number of ribs owing to the constrained volume. The challenge here is balancing the Radio frequency (RF) performance, which is dependent on the number of ribs, as the ribs increase the performance also improves with the mechanical simplicity and the practicality. Assuming 16 ribs, there is an increase in the performance while still maintaining the space between each rib so that the antenna doesn't jam on deployment^[2] and also there is no much loss in frequency. The Figures 4.1 to 4.6 give an idea of the stages of Deployment from a constrained undeployed state situated in the CubeSat to a completely deployed state in space. Our approach is to use the strain energy stored in the Constant Force spring to enhance the exploitation of ribs and thereby deploying the antenna

The antenna deployment is the one-time occurring sequence which causes the antenna turn from stowed condition to a deployed state. This process begins with the antenna being held in place by a thermal knife launch lock. The heated source cutting through the polymer wire is used to release the launch lock. Next, the canister is slowly lifts

the base of the antenna up and out of the CubeSat with the help of the gas pumped in. Further, the hub is pushed upwards by the compressed gas pushing on a piston. Fig 4.1 and Fig 4.2 show the process of ejecting the stowed Antenna out of the cylinder until the hub is held in position at the top of the cylinder.



Fig 4.1

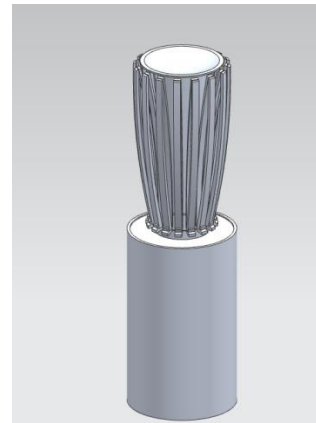


Fig 4.2

In the following phase, as the hub starts to reach the top, the root rib base hinge attaches on a snap ring at the top of the CubeSat canister to restrict its motion further, and the hinge carrying the ribs begin to deploy in a fixed direction until the planes of the hinge and that of the hub match each other. When the body is ejected outside the cylinder, motion of the ribs outwards is caused due to the lesser forces restricting its motion. Fig 4.3 and Fig 4.4 shows the process of Hinge (which gets attached to the Hub) Deployment along with the ribs.

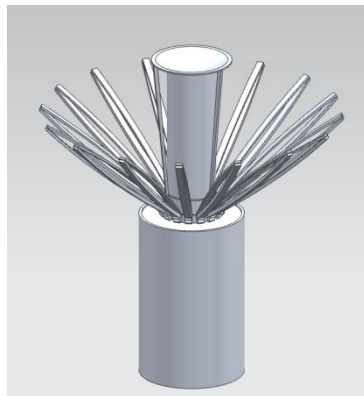


Fig 4.3

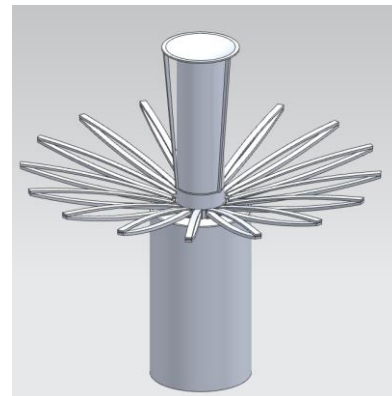


Fig 4.4

Further, the Constant Force (CF) spring located in the middle of the ribs, deploy the tip ribs as the root ribs move outwards. Alongside, the sub-reflector is released by the root rib hinges and the telescopes along the horn pushed upwards and held in the position by a spring. CF spring at the junction of the ribs hold the ribs in position and ensure the ribs are restricted in the opposite direction of its deployment motion. After the model is in fully deployed state, it is then locked and held onto that location by spring-loaded latches which are provided at the top to lock the hub in place to ensure the antenna stays in deployed state, even if the canister depressurizes. This process of locking happens only after the hub reaches the deployed position. Fig 4.5 and Fig 4.6 show the deployment of the ribs along with the subreflector to a deployed stage.

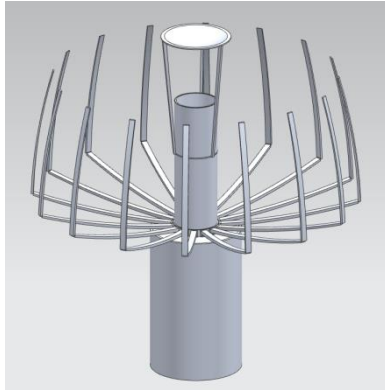


Fig 4.5

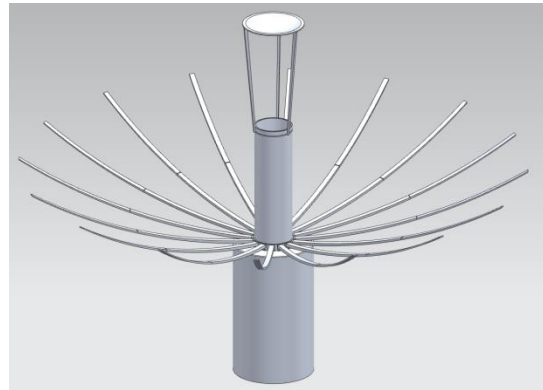


Fig 4.6

V. CONSTANT FORCE SPRING ANALYSIS

A Constant Force (CF) Spring as mentioned earlier is employed at the junction of the Tip and Root ribs which acts as a mediator for the deployment of the ribs to occur as shown in Fig 5.1 with the undeployed to deployed state noted from 1 to 5 respectively. The spring holds the ribs in position and prevents the backward motion. It provides a constant force all the time as in deployment state or stowed state. Also, it does not obey Hooke's Law and the constant force in the spring comes from the preloaded stresses which are induced when it is in the rest position, so the starting or initial force is not zero but a finite value. The CF Spring is also shown in the adjacent figure. The Torsional moment and Wahl correction factor have been calculated for this spring. Assuming Force acting on the spring because of the tip rib while deployment is

$$F = 1.22 * 10^{-6} \text{ N}$$

$$D = 1.2 * 10^{-3} \text{ m}$$

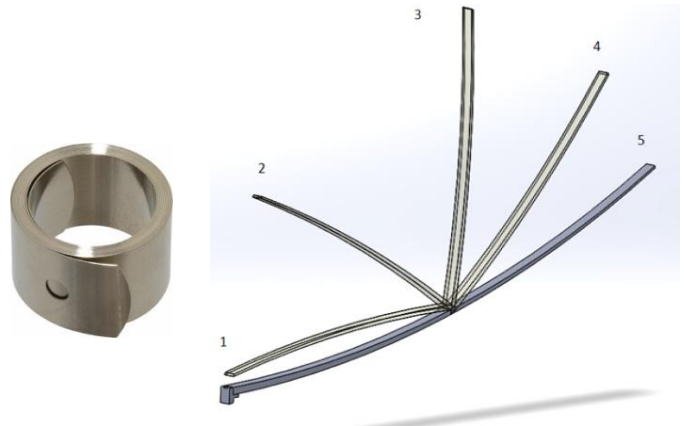


Fig 5.1

Calculation of Torsional Moment

Assumed, $m = 0.124 \text{ kg}$ (material)

$$T = 0.5 * F * D$$

$$= 0.5 * 1.22 * 10^{-6} * 1.2 * 10^{-3}$$

$$= 7.32 * 10^{-9} \text{ N.m}$$

Calculation of Wahl Correction Factor

$$K = \frac{4C - 1}{4C - 4} + \frac{0.615}{C}$$

$$= \frac{23}{20} + \frac{0.615}{24}$$

$$= 1.176$$

VI. CONCLUSION AND RESULTS

The need for a High Gain Antenna for CubeSats is crucial for data transmission between the source and the receiver. This project provides, a detailed description of the CAD Modelling of highly constrained deployable mesh reflector antenna initially undergone on CATIA V5 which was later done on SolidWorks due to its ease of understanding. The Animation of Kinematics of Deployment was further carried out on Unigraphics NX.

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1. Various individual components have been modelled and the Assembly has been designed based on the dimensions and calculation with the respective alterations adhering to CAD Model for the ease of Deployment.
2. The Simulation shows a clear picture of the functionality of the designed prototype and the measurement results show good agreement.
3. The Constant Force Spring attached in the juncture of the ribs, has been analysed and is useful in the Deployment process.

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