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1. Detail of the project

1.1 The background of the project

CubeSat is a standardized micro nano satellite. Its defination was proposed by Caltech and Stanford University in 1999. Each standard size unit of a CubeSat is called 1U, and its size is 10cm × 10cm × 10 cm, whose weight is less than 1.33 kg. CubeSat can increase in size, based on certain rules, and become a larger CubeSats. Figure 1 shows the standard size of CubeSats and the combination in different ways.

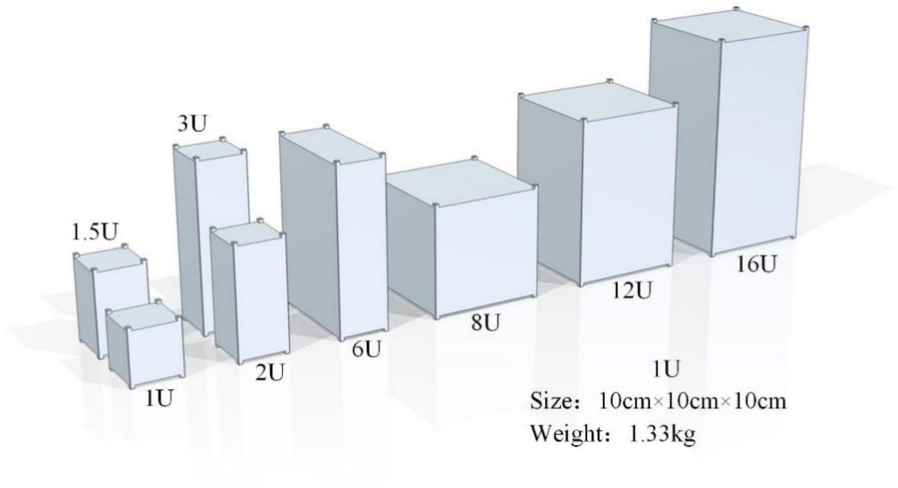
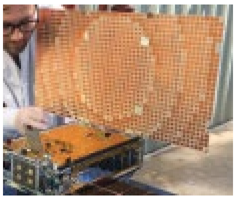
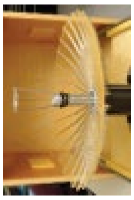
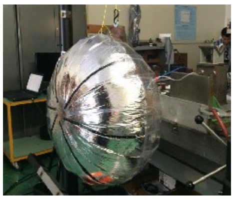
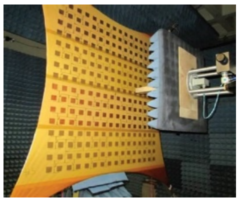


Figure 1.CubeSat standard and different specifications and sizes.

With the development of computer and micro electro mechanical technology, CubeSat has become a new research hotspot in the field of aerospace industry. In the past two years, CubeSat occupies nearly half of the total number of satellites deployed that year, and has become an significant part of the satellite system. However, in the past two decades, due to the lack of high-gain antennas for CubeSats, they are mainly used for simple missions in low earth orbit. The CubeSats equipped with a high-gain antenna can complete deep-space exploration relay missions, and can also quickly network with multi-satellite launching technology to provide uninterrupted high-precision observation and mobile communication services for specific areas. The development of high-gain antennas suitable for CubeSats has become an urgent need in the aerospace application field.

Gain is the main index of antenna performance. By deploying the antenna aperture and improving the accuracy of reflector, higher antenna gain can be obtained. The large aperture and high gain antenna must be light and foldable while CubeSat is small and light. Nowdays, The CubeSat high gain antennas mainly include four types: Reflection array antenna, cable net antenna, inflatable antenna and thin film antenna, as shown in Table 1. The reflective array antenna and cable net antenna have been used in orbit, but they have low aperture efficiency, low storage efficiency and complex deployable mechanism; Although inflatable antenna and thin film antenna have high storage efficiency, their shape and surface accuracy is poor, which is difficult to meet the requirements of engineering application. How to develop large-aperture and high-precision antennas under the strict volume and weight restrictions of CubeSats is a technical bottleneck that needs to be broken through in the application of CubeSats.

Table 1.Advantages and drawbacks of high-gain antenna for CubeSats

Antenna type	Reflectarray 	Mesh reflector 	Inflatable 	Membrane 
Advantages	Storage efficiency; Simple Deployment ; Low cost; High TRL.	Excellent efficiency; Infinite bandwidth; High TRL.	Storage efficiency; Infinite bandwidth; Simple deployment; Aperture >$1m^2$.	Storage efficiency; Medium cost; Compatible with 6U; Aperture >$1m^2$.
Deawbacks	Low efficiency; Max aperture <$1m^2$; Narrow bandwidth; Thermally affected ; Tx only.	Low storage efficiency; Complex deployment; Max aperture <$1m^2$.	Poor surface accuracy; High sidelobe level ; Low TRL.	Low efficiency; Complex deployment; Poor surface accuracy; Low TRL.

Through the analysis of the existing CubeSat high-gain antenna configuration, it can be found that in the face of the CubeSat volume and mass limitation, the antenna reflector should adopt a lightweight and foldable structure with a high surface-to-quality ratio. The cable net structure and the membrane structure are two types of deployable structures with high surface-to-quality ratio. The membrane structure as a reflecting surface is difficult to ensure the shape accuracy of the antenna, and the technology maturity is low. The cable net structure is more mature as a reflecting surface technology, but its support structure is generally a peripheral truss or radial rib, the structure is complicated to deploy, and the storage efficiency is low. Aiming at the problems existing in the existing CubeSat high-gain antenna structure, this design proposes a new inflatable cable net reflector antenna concept. This new antenna combines the advantages of the cable net antennas and the gas-filled antennas. The inflatable ring is used as the deployable support structure of the tension cable net system. This improves the storage efficiency of the cable net antenna, reduces the structural weight and the complexity of the deployment mechanism. It is a very promising CubeSat high-gain antenna configuration.

1.2 Antenna design

The new inflatable cable net reflector concept is shown in Figure 2. This new type of antenna reflector mainly includes three parts: an inflatable ring, a tension cable net structure and a metallic mesh. The reflective surface of the antenna is a metal reflective net attached to the tension cable net structure. The tension cable net structure includes front net, tension ties and rear net. Both the front net and the rear net are in a rotating parabolic configuration, and the corresponding nodes of the two are connected by front nets. The tension cable net structure is supported by an inflatable ring structure, and the cable net reflecting surface antenna is deployed by inflating it, and provides tension for the reflecting surface to maintain the profile.

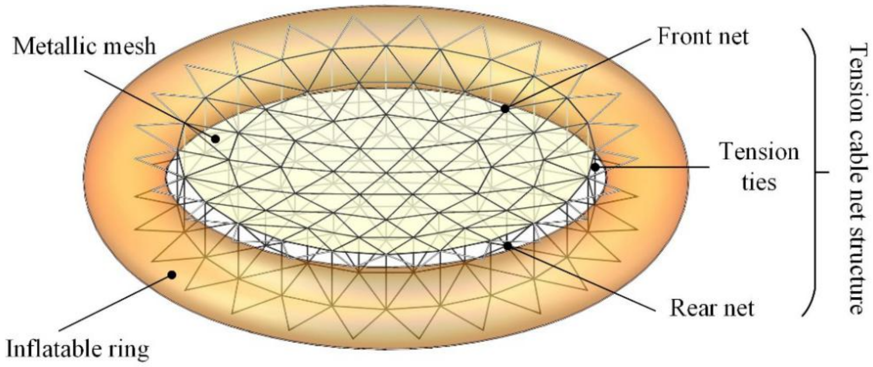


Figure 2.The structure of the cable net reflector.

Based on the concept of inflatable cable net reflector, a new high-gain antenna suitable for CubeSat is further proposed. The antenna adopts a central-feed Cassegrain mirror structure, which mainly includes a main reflector, a sub-reflector, a horn and a storage chamber, as shown in Figure 3. The main reflector includes a support cylinder, a liftable tray, an inflatable ring, a tension cable net structure and a metal reflecting net. The supporting cylinder is a thin-walled cylindrical structure, fixed to the liftable tray. The liftable tray is embedded on the four guide screws through four threaded ear sleeves. The inflatable ring is a membrane inflatable structure. When the inflatable ring is inflated and deployed, it is a circular cross section (diameter 20cm) with an inner diameter of 1m and an outer diameter of 1.4m. The tension cable net structure includes front net, rear net and tension ties. When the tension cable net structure is deployed, the reflecting surface cable net is in the shape of a circular curved surface, which is divided into an inner cable net and a boundary cable net. The inner cable net is composed of triangular cable net units. The center of the cable net is connected to the support cylinder. The net is used to connect the edge nodes of the inner cable net and the inflatable ring. The inner cable net nodes are all located on a paraboloid of revolution; when the tension cable net structure is deployed, the rear net and the front net are symmetrical about the center plane of the inflatable ring; When the cable net structure is deployed, the front net is located between the front net and the inner cable net corresponding node of the rear net. The metal reflective mesh is a gold-plated molybdenum wire mesh, and the gold-plated molybdenum wire mesh is attached to the inner wire mesh of the reflective surface wire mesh.

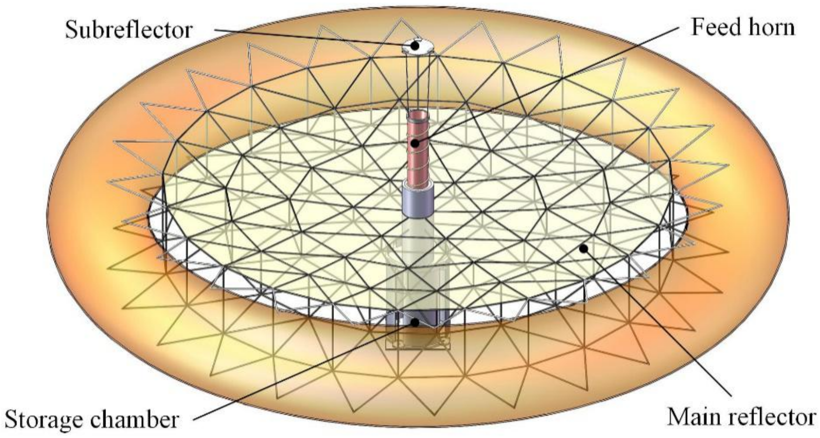


Figure 3.The structure of the inflatable cable net antenna.

The antenna storage chamber and the deployable structure are shown in Figure 4, where the storage chamber includes a motor, a gear set, a guide screw, a bed plate and four thin-walls. The motor is fixed on the bed plate, the gear set includes four small-diameter gears and one large-diameter gear. The large-diameter gear is installed in the center of the bed plate, four small gears are installed at the four corners of the bed plate, and the guide screw is coaxial with the four pinions. Storage chamber size: 10cm×10cm×15cm. The retractable feed includes a feed horn, a retractable waveguide and a spring. The outer wall of the feed horn is cylindrical, and the inside is a variable-angle column cone horn; the retractable waveguide is a two-section slender sleeve structure, one end is connected to the feed horn, and the other end is connected to the radio signal transmitter or receiver; the spring is sleeved inside the central cylinder to provide power for the ejection of the feed horn. The retractable sub-reflector includes a sub-reflecting surface, a support rod and a spring. The reflecting surface is a hyperboloid thin shell structure; the support rod is composed of three thin rods, one end is connected to the upper edge of the sub-reflector, another end is connected to the ring embedded in the feed horn, and the three thin rods are distributed at 120 degrees, and the spring is sheathed on the feed horn providing power for the ejection of the sub-reflector.

Figure 5 shows the deployment process of the new antenna: (a) The antenna is stored in the CubeSat before launch; (b) After launching into the orbit, the motor drives the four guide screws to rotate synchronously through the gear set and slowly push the antenna out of the storage chamber; (c) After the antenna is fully pushed out, the inflatable ring self-inflate and deploy through powder sublimation, then the tension cable net structure of the main reflector and the metallic mesh of the main reflector deploy simultaneously. When the main reflector inflatable ring is inflated, the main reflector tension cable net structure and the main reflector metallic mesh reach the design shape; (d) After the main reflector is fully deployed, the spring compressed by the feed horn is released and push out the feed horn; (e)) Finally, the spring compressed by the support rod is released and push out the sub-reflector. So far, the entire deployment process of the antenna is complete. The working status of the CubeSat inflatable cable net antenna is shown in Figure 6.

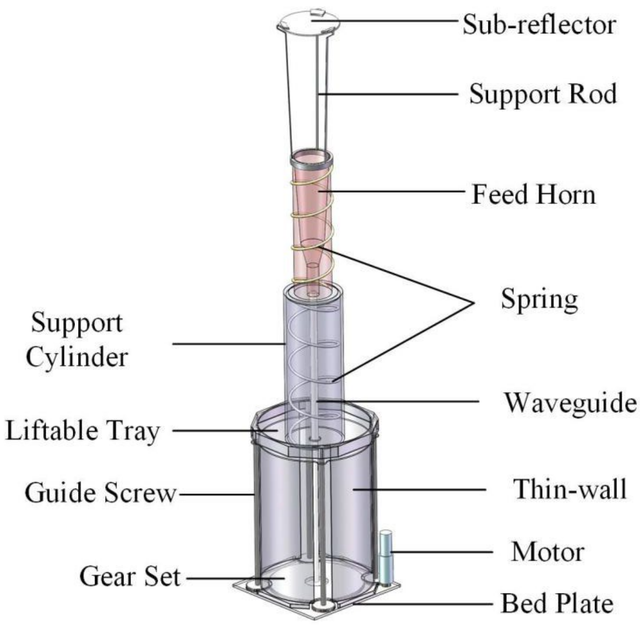


Figure 4.The structure of the storage chamber and retractable sub-reflector.

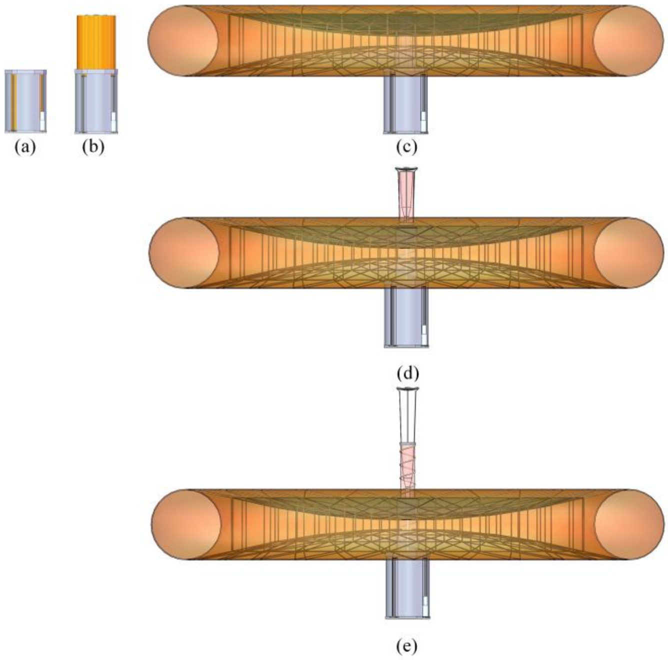


Figure 5. The deployment process of the proposed inflatable cable net reflector antenna.

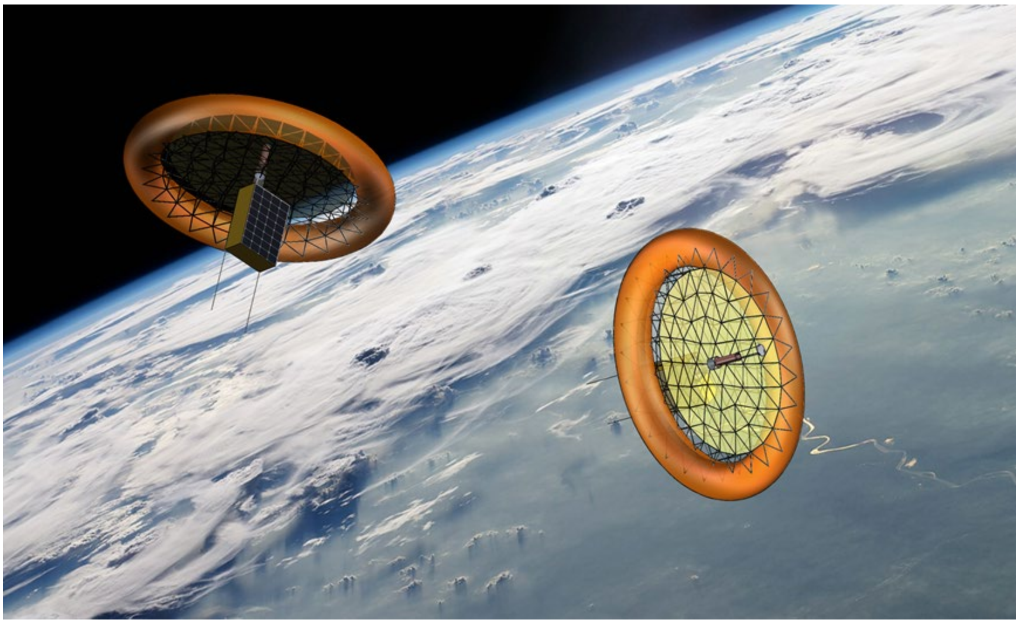
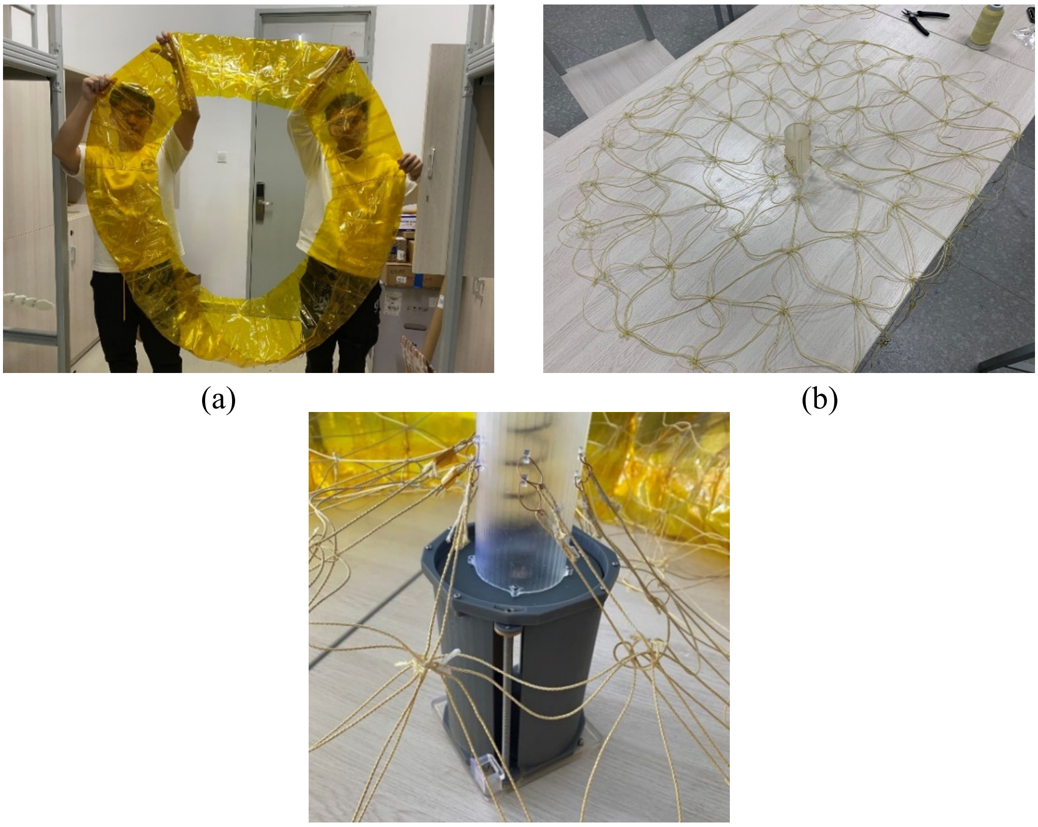


Figure 6. An artist's rendering of 6-U CubeSat($10\times20\times30cm^3$)using the proposed inflatable cable net reflector antenna in orbit around the Earth.

1.3 Antenna prototype

In order to test the structure design of the proposed inflatable cable net antenna, a principle prototype antenna with a diameter of 1.4m was fabricated. The inflatable ring of this prototype antenna is spliced by polyimide film. Because the ring is a non-developable curved surface, there are many difficulties in the splicing process, so the ring is divided into 24 cylinders for splicing. The completed inflatable ring is shown in Figure 7(a). The cable net system is fabricated by Kevlar fibers and the nodes are fixed with epoxy resin. The completed cable-net system is shown in Figure 7(b). The main components of the storage chamber and deployment mechanism are made by 3D printing, and the assembly is shown in Figure 7(c). The completed principle prototype antenna is shown in Figure 8. Besides, according to the test, the main reflector can be fitted in 1.5U ($10\times10\times15cm^3$) as shown in figure 9.



(a) (b)

(c)

Figure 7.The fabrication process of the antenna prototype.

Figure 8.The completed inflatable cable net antenna principle prototype with a diameter of 1.4m。

Figure 9.The main reflector can be fitted in 1.5U (10×10×15cm^3)even when it is not fully evacuated.

1.4 Innovations of this project

In view of the problems existing in the current CubeSat high-gain antennas, this project proposes a new inflatable cable net reflector antenna design. The main innovation lise in the use of an inflatable ring as the peripheral support structure of the cable net reflector, which can not only improves the storage efficiency and deployment reliability of the antenna, but also achieves higher surface accuracy. Compared with inflatable reflector antennas and membrane antennas, the main reflector of this project is supported by a cable net structure, which has a higher technological maturity and can achieve better reflector surface accuracy. Compared with traditional cable net reflector antennas, this project uses an inflatable ring as the main reflector deployable support structure, which can effectively reduce the complexity of the deployment mechanism; the main reflector of this antenna is mainly composed of a cable-membrane structure, and the sub-reflector is designed with a retractable structure, which makes it lighter and has a greater storage efficiency. It is a very promising high-gain antenna configuration for CubeSats.

2.References

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