X/Ka-band One-Meter Deployable Mesh Reflector for Deep Space Network Telecommunication

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***Abstract*— A deployable one meter mesh reflector compatible with 12U-class CubeSat is introduced for telecommunication. It is compatible with NASA's deep-space network (DSN) at X-band (i.e., uplink: 7.145-7.19 GHz; downlink: 8.4-8.45 GHz) and Ka-band frequencies (i.e., uplink: 34.2–34.7 GHz; downlink: 31.8–32.3 GHz). Three right-handed circularly polarized (RHCP) antennas, both transmit and receive, are introduced here: X-band only, Ka-band only, and X/Ka-band.**

***Index Terms*—antenna, array, stripline, waveguide, dual frequency, DTE, DFE, telecommunication, patch.**

I. INTRODUCTION

In the past few years, growing interest for CubeSats carrying science experiments in Low Earth Orbit and Deep Space has exploded. The National Aeronautics and Space Administration (NASA), in particular, has launched multiple pioneering missions such as Mars Cube One [1] and Radar in a CubeSat (RainCube) [2],[3], which were enabled by innovative deployable antennas. MarCO, has two twin 6U CubeSats on their way to Mars. They are the first CubeSats to travel into deep space and they carry a deployable X-band reflectarray designed to enable 8kbps bent pipe relay communication from the Insight spacecraft at Mars (~1AU) during the critical Entry Descent and Landing of Insight. The RainCube mission, deployed successfully in Low Earth Orbit (LEO), a 0.5-m mesh reflector from a 6U CubeSat to measure rain and snow precipitation [3]. They could pave the way for a new generation of small spacecraft that would make interplanetary space science and Earth Science much more accessible.

To further improve the capabilities of CubeSats for interplanetary missions, there is an outstanding need for larger RF aperture. Additional research continues for larger deployed antenna apertures [3]-[5] that will produce high gain for telecommunications applications, or are needed to produce narrow beamwidths for Earth science needs. For deployable antennas, the deployed precision for the frequency of operation, as well as stowed volume during launch, are critical parameters.

One approach for an RF deployed aperture is a reflectarray where the panels are held against the side of the spacecraft bus during launch and deployed in a hinged

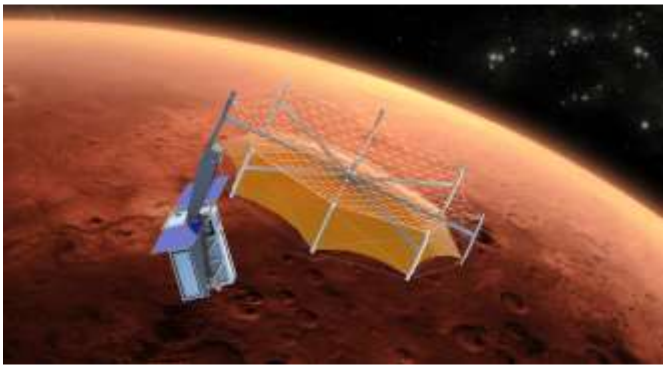


Fig. 1. An artist's concept of the X-band one-meter deployable mesh reflector antenna.

system on-orbit. A first application of this approach integrated solar panels with the reflectarray antenna (ISARA) operating at Ka-band, combining the two functions and resulting in small additional mass and volume increase over the solar panels themselves [5]. This flight system was built, tested on the ground, and demonstrated in LEO.

Later on, this work was extended to an X-band telecommunication system using a reflectarray deployed from a 6U CubeSat: MarCO. It was launched with the NASA InSIGHT Mars lander mission to provide near-real-time bent-pipe relay during the entry descent and landing portion of that mission. The project OMERA at the Jet Propulsion Laboratory demonstrated a Ka-band one meter reflectarray compatible with a 6U-class CubeSat [6],[7].

This paper propose an alternative to reflectarrays to provide an effective aperture of one meter compatible with 12U-class CubeSat as a 3U volume is required to fold the mesh reflector. Please note that the boom of this antenna deploying the reflector away from the bus is still under development. The mesh reflector is a commercially available mesh reflector invented and commercialized by Tendeg LLC [8].

The performance obtained using this offset mesh reflector at X-band and Ka-band are excellent with more than 60% efficiency.

Fig. 2. Deployment of the one-meter deployable mesh reflector antenna.

II. ANTENNA PERFORMANCE AT X-BAND

A. *Antenna configuration*

The mesh reflector is an offset reflector to accommodate the deployment of the reflector away from the feed. The feed remains fixed on the CubeSat bus and the reflector is deployed by a boom as shown in Fig. 2.

The antenna is simulated using TICRA Grasp using Physical Optics (PO) and method of moment (MoM) / multilevel fast multipole method (MLFMM) solver. The CubeSat and boom are described as a MoM object to assess the scattering from boom and CubeSat bus. The feed is designed and analyzed using a full wave software (CST MWS). The field of the feed is imported as a tabulated feed where the pattern is described on a full sphere on a set of equidistantly spaced points in θ and φ. The phase center of the feed is located at the focal point of the reflector to optimize performance.

B. *X-band antenna feed design*

The X-band feed needs to operate at X-band uplink (7.145-7.19 GHz) and downlink (8.4-8.45 GHz) frequency bands. The antenna needs to survive harsh temperature and potentially high radiation levels. The X-band feed should be left handed circularly polarized (LHCP) at both uplink and downlink frequency bands. An innovative RHCP antenna, capable of operating in harsh environment was proposed in [9] for the Europa Lander mission. This antenna operates at both uplink and downlink frequency bands. A 2×2 patch array with LHCP was designed to illuminate the one meter mesh reflector. The antenna is shown in Fig. 3. The unit cell is fed at a single point and is entirely made of metal. This element is single-fed thereby simplifying the feeding network and the antenna assembly. The calculated and measured reflection coefficients of the antenna are in good agreement (Fig. 4).

C. *Antenna reflector performance at X-band*

The standard directivity $D_{max}=(\pi \cdot D/\lambda)^2$ of the reflector is 37.5dBic and 38.9dBic at 7.1675GHz and 8.425GHz, respectively, assuming an effective area of one meter. The taper and spillover loss are slightly higher than ideal as the edge taper is about -8dB. The mesh OPI loss and surface accuracy loss are negligible (i.e. <0.05dB). The feed loss and mismatch loss are around 0.5dB.

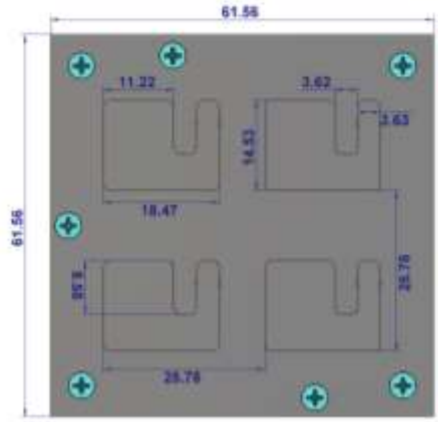


Fig. 3. Dual-band X-band feed with LHCP. Dimensions in mm.

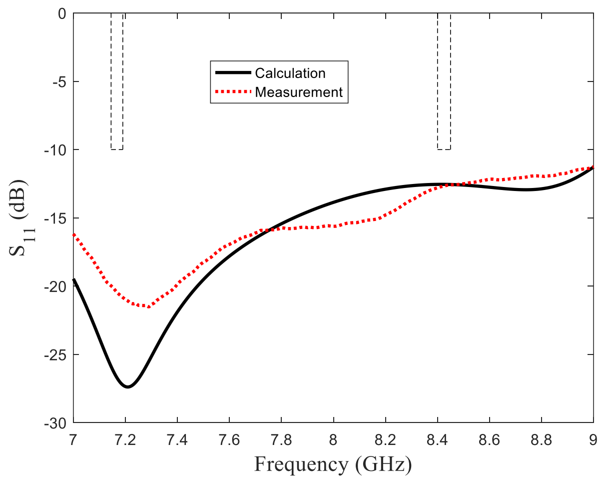


Fig. 4. Calculated and measured reflection coefficient of the X-band feed.

The calculated overall gain of the mesh reflector antenna is about 35.85dBic and 36.95dBic at 7.1675GHz and 8.425GHz, respectively. This translates into an efficiency of 68% and 64% at 7.1675GHz and 8.425GHz, respectively.

The radiation pattern is measured in a planar near-field anechoic chamber at NASA's Jet Propulsion Laboratory, Pasadena, CA, USA where the feed is mounted onto a bus simulator as can be seen in Fig. 5. The radiation pattern of the mesh reflector antenna is shown in Fig. 6. A good agreement is obtained. The XPD is lower than 3dB within the downlink frequency band and lower than 4.5dB within the uplink frequency band.

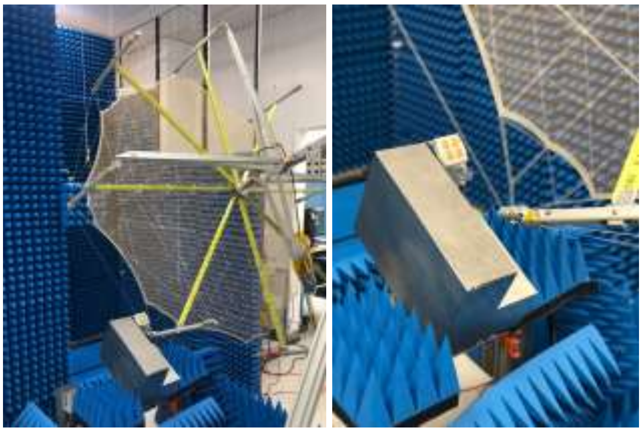
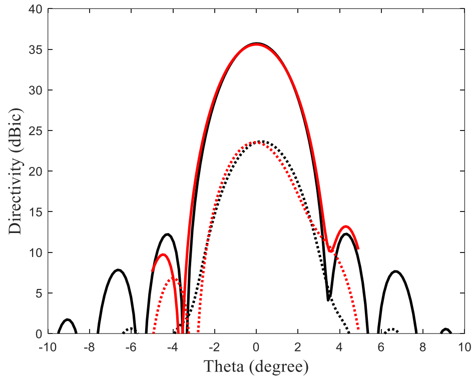


Fig. 5. X-band mesh reflector in the near field anechoic chamber with its off-load structure. Note that the boom is not included. The CubeSat bus is included.



(a)

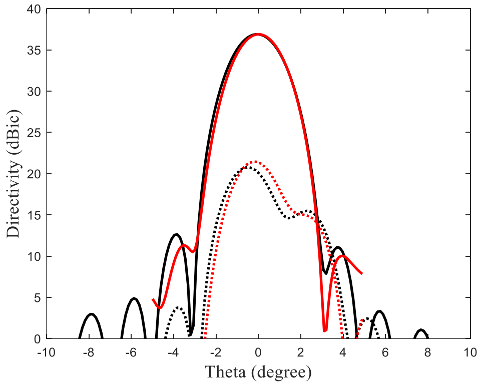


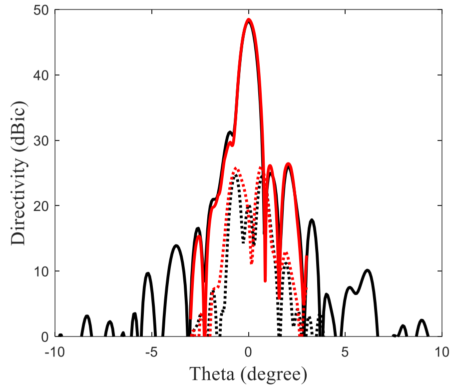
Fig. 6. X-band mesh reflector radiation pattern at (a) 7.1675GHz and (b) 8.425GHz. — RHCP. --- LHCP. Calculation in black and measurement in red.

A gain of 36.1-dBic and 36.8-dBic is measured at uplink and downlink frequency bands, respectively. This translates into an efficiency of 72% and 62%, respectively.

III. Antenna Performance at Ka-Band

A. *Ka-band antenna feed design*

At Ka-band, the feed design is much easier. The feed is a multiflare horn demonstrating low cross polarization, low side-lobe level, good return loss, and excellent beam circularity. It is also easy to fabricate. It was optimized to provide an edge taper of -10dB following the methodology described in [10]. A polarizer was also designed to provide RHCP at the DSN uplink and downlink frequency bands.



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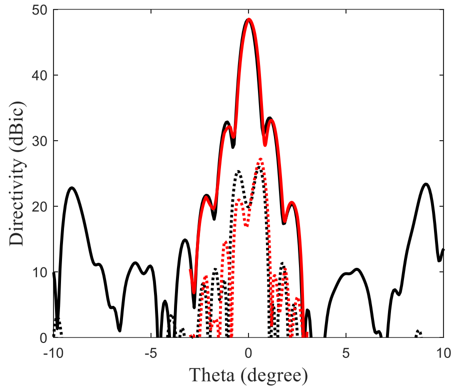

(b)

Fig. 7. Radiation pattern of the Ka-band mesh reflector. — RHCP. --- LHCP. (a) φ = 0 degree. (b) φ = 90 degree. In black: calculated with the measured surface. In red: measured.

B. *Antenna reflector performance at Ka-band*

The feed horn phase center is located at the focal point of the reflector. The surface mesh and surface accuracy loss are obviously much larger than at X-band (0.25dB and 1.1dB, respectively). The surface rms was measured to be 0.38mm which is a lot at Ka-band. Such surface rms is impacting the gain and the side lobe levels. The total calculated loss due to the mesh is about 1.35dB at 32GHz (i.e. 1.1dB due to the surface rms and 0.25dB due to the mesh OPI).

The surface of the mesh was measured and included into the calculation allowing to obtain an excellent accuracy between calculation and measurement. The calculated and measured radiation pattern at Ka-band is shown in Fig. 7. A measured gain of 48.4dBic and 48.7dBic is obtained at 32GHz and 34.35GHz, respectively. This translates into an efficiency of 64% and 57%, respectively.

IV. X/Ka-Band Antenna Performance

The two feeds can be used simultaneously with the one meter reflector while fitting in the stowage volume. However, as the co-located feeds are not placed at the focal point of the reflector, the pointing is different in azimuth. The antenna efficiency and gain are also affected. The pointing is less of an issue. Typically, X- and Ka-band are expected to be used simultaneously with X-band receiving commands from and Ka-band transmitting telemetry to the DSN. In this case, maximum gain should be obtained at Ka-band (i.e. >47.5dBic) while a reduced gain at X-band (i.e. > 20dBic) is needed.

When co-located, the X-band antenna demonstrates a gain of 35.2dBic and 36.8dBic, at uplink and downlink frequency band, respectively. The Ka-band antenna has a gain of 47.8dBic and 47.6dBic, at uplink and downlink frequency band, respectively.

The X-band antenna demonstrates a gain of 20.5dBic at +0.6degree in azimuth which is meeting the requirement to provide simultaneous X/Ka-band communication.

V. Conclusion

This paper provides a detailed description of a novel, highly constrained deployable mesh reflector antenna which is currently the largest antenna compatible with 12U-class CubeSat operating at X- or Ka-band.

At X-band, a gain of 36.1-dBic and 36.8-dBic is achieved at uplink and downlink frequency bands, respectively. This translates into an efficiency of 72% and 62%, respectively. For the Ka-band only antenna, a gain of 48.4-dBic and 48.7-dBic is obtained at downlink and uplink frequency bands which translates to a 62% and 72% efficiency.

The performance of the antenna is also given when both X-band and Ka-band feeds are collocated. The antenna efficiency at X-band is higher than 55% and higher than 50% at the Ka-band downlink frequency band.

Acknowledgment

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