# Ka-band Parabolic Deployable Antenna (KaPDA) Enabling High Speed Data Communication for CubeSats

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## Introduction/Background

CubeSats are at a very exciting point as their mission capabilities and launch opportunities are increasing. But as instruments become more advanced and operational distances between CubeSats and earth increase communication data rate becomes a mission-limiting factor. Improving data rate has become critical enough for NASA to sponsor the Cube Quest Centennial Challenge where one of the key metrics is transmitting as much data as possible from the moon and beyond[1]. Currently, many CubeSats communicate on UHF bands and those that have high data rate abilities use S-band or X-band patch antennas. The CubeSat Aneas, which was launched in September 2012, pushed the envelope with a half-meter S-band dish which could achieve 100x the data rate of patch antennas. A half-meter parabolic antenna operating at Ka-band would *increase data rates by over 100x that of the Aneas antenna and 10,000x that of X-band patch antennas*.

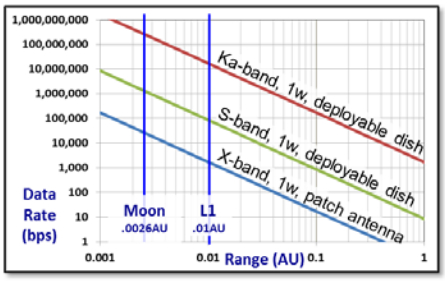


**Figure 1. A Ka-band dish antenna provides higher data rates than S-band dish or X-band patch antennas**

A number of deployable parabolic and parabolic like antennas have been developed in the past for CubeSats. Concepts have included a gore-wrap composite reflector[2], a reflector transformed from the CubeSat body[3], an inflatable parabolic reflector with reflecting material on one side and transparent material on the other[4], a mesh reflector supported by ribs[5,6], and a reflectarray[7]. While these designs provide unique solutions, they are all designed to operate at S-band (with the exception of the reflectarray). A Ka-band antenna would have much greater gain, which translates to greater data rate, but requires a much higher surface accuracy than S-band. It should be noted are several other high gain, high frequency antennas under development, such as the DaHGR[8] but thus far additional data has not been published on them.

**Figure 2. KaPDA Fully Deployed**

Two knit mesh antennas have been developed for CubeSats, but both were designed for S-band operation. They were a spiral stowed rib design[6] and the Aneas parabolic deployable antenna (APDA) folding rib design that was flown on USC/ISI's Aneas spacecraft[5]. The spiral stowed rib design, while very compact, would be challenging to extend to Ka-band as the ribs could not apply adequate force required to stretch Ka-band mesh to achieve the required surface accuracy. The APDA architecture would work well for Ka-band, as it uses straight folding ribs, which

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can apply more force and allow for greater surface accuracy. In addition, the APDA is the only CubeSat parabolic deployable antenna to have flown. Therefore, it was decided to use the APDA as a starting point for the Ka-band parabolic deployable antenna (KaPDA) design.

## Design Challenges and Solutions

There were three key categories of design challenges for developing KaPDA: surface accuracy, stowed space, and ability to deploy. Solutions for these requirement areas often conflicted with each other, making the design process challenging. For example, greater surface accuracy could be obtained by using ribs with a larger cross-section, but a larger cross-section required more stowage space.

The surface accuracy of an antenna directly influences its gain. An ideal 0.5-meter antenna would produce about 45 dB of gain at Ka-band frequencies used for satellite communications. The specific design point for KaPDA was the frequency bands reserved for the deep space network; 34.2 GHz to 34.7 GHz for uplink (earth to space) and 31.8 GHz to 32.3 GHz for downlink (space to earth). The design goal was 50 % efficiency, or losses of only 3dB, achieving a gain of 42dB. According to initial RF estimations, surface distortions must be below 0.57 mm RMS (root mean squared) to achieve the desired efficiency (this number was later increased to 0.4 mm and the 0.2 mm RMS). As a comparison, the APDA was measured to have surface distortions at the rib tips of 2.54 mm RMS. Therefore, a Ka-band design using the APDA architecture needed to improve the surface accuracy by an order of magnitude and required significant component redesign. Deeper ribs made of aluminum will be used to improve surface accuracy, as deeper ribs increases the cross-section which results in less deflection.

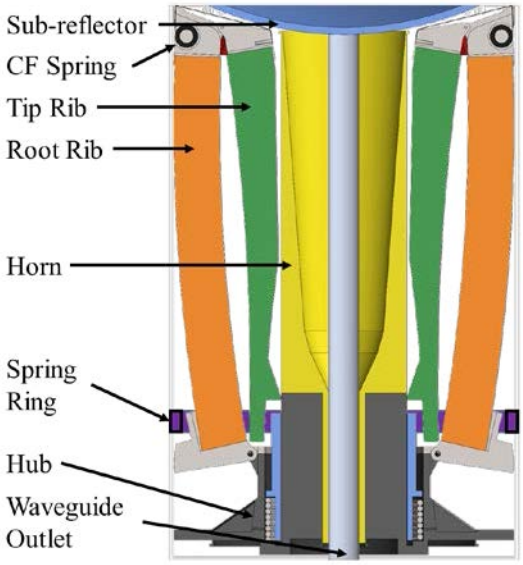


**Figure 3. Key KaPDA Components**

KaPDA is targeted for use on 6U and 3U CubeSats. To make KaPDA practical for both sizes, the maximum space it could consume was determined to be 1.5U (10 cm x 10 cm x 15 cm). The actual dimensions for KaPDA were required to be slightly smaller, as the antenna assembly must slide into a CubeSat chassis. To fit within the 15 cm height constrain, the ribs were required to fold in half. Unlike the APDA or spiral stowed rib design, where the receiver was mounted on the feed, a sub-reflector/horn/waveguide combination must be used for Ka-band operation. These additional components must all stow within the volume. To find the smallest stowed size, a number of antenna configurations were explored, including Gregorian and Cassegrainian. The Cassegrainian configuration was found to best balance stowed volume and achievable gain (see figure 3 highlighting stowed state), as the secondary reflector was mounted below the focal point.

The final challenge was to develop a mechanism to deploy the antenna from 1.5U to the 0.5-meter diameter and maintain the required surface accuracy. To keep an accurate surface the mesh will be tensioned to 0.17 N per centimeter, which requires 9 N applied to each rib after mandated factors of safety. For a 30 rib reflector, a total of 270 N is required to hold the ribs in place at the end of deployment. One of the greatest deployment challenges was finding a mechanism which could slowly apply 270 N to the antenna during the deployment while avoiding whiplash effects, which could break components and impair surface accuracy. While traditionally springs would be used, they deploy too rapidly. Using a damper to slow the deployment was not possible due to space constraints. Therefore, the best deployment mechanism was found to be a gas powered deployment, which can tension the mesh with approximately ten time the force springs would supply, eliminating creases in the mesh. Gas slowly pushes the combination piston/hub upwards, slowly deploying the antenna.

To deploy the antenna, the hub is driven upwards by compressed gas pushing on a piston (images A to B), formed by the bottom of the hub. As the hub starts to get close to the top, the spring ring, which is attached to the root rib base hinges, catch on a snap ring in the top of the CubeSat canister, and the ribs begin to deploy (B-C). The tip ribs reach a point where they become free of the horn interference, and the constant force springs deploy them (Image C). The hub continues to travel upwards until the root ribs have fully deployed (image D). As the ribs fold


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outwards, the sub-reflector is released by the root rib hinges and telescopes along the horn, pushed upward and held in place by a spring (C to D). After the hub is fully deployed, it is locked into place by spring loaded latches.

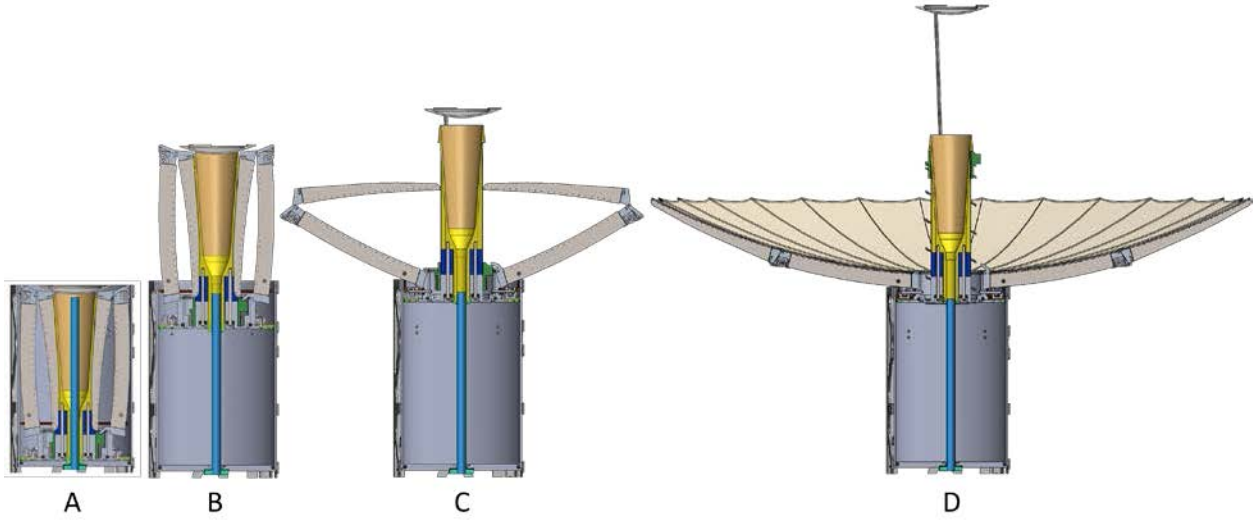


**Figure 4. The KaPDA antenna has a specific deployment sequence**

## Construction and Testing

After the design of the antenna was completed, prototype construction began. Two different prototypes were constructed, a solid non-deploying RF prototype which was used to check the RF simulations, and a mechanically deploying prototype used to check the mechanics of the antenna deployment. The solid non-deploying prototype had a primary reflector which was hogged out of aluminum, and had a surface accuracy tolerance of 0.05mm, which represented a perfectly constructed antenna. The horn and secondary reflector were interchangeable with the mechanical deploying prototype, so only one copy of the horn and secondary reflector required machining. The mechanical deploying prototype consisted of multiple machined aluminum parts. While most of the components could simply be assembled after machining, the ribs and secondary reflector assemblies were bonded together on precision bonding fixtures. Then the mesh was stretch over a mold, and stitched to each of the antenna ribs, which had multiple small holes along the edge. Over 2000 stitches were required to attach the mesh to the ribs. The edges of the mesh were secured with Solithane, to prevent the mesh from unraveling when it was cut. After completion, the antenna was removed from the mold.

**Figure 5. Solid Non-Deploying RF (left) and Mechanical Deploying (right) Prototypes**

| Measure | Units | Goal | Analytical | Tested |
|---|---|---|---|---|
| **Stowed Size** | U (10x10x10cm^3) | 1.5 | 1.54 | 1.54 |
| **Deployed Diameter** | m | 0.5 | 0.51 | 0.51 |
| **Gain** | dB | 42 | 42.6 | 42.5* |
| **Beam Width** | degrees | 1.2 | 1.2 | N/A |
| **RMS Surface Accuracy** | mm | 0.40 | N/A | 0.22* |
| **Mass** | Kg | 3.0 | 1.9 | 1.2 |
| **Thermal** | °C | -17 to 35 | -26 to 62 | -- |

*Pre-deployment Test Results

**Table 1: KaPDA Exceeds Performance Goals**

The first test conducted was an RF test of the solid reflector, which produced a gain for 43.2 dB, aligning with simulations and performing well above the goal. Next, a deployment test of the mechanical prototype without the mesh was performed. After a successful deployment, and the mesh was attached, the antenna was removed from the mold and measured to find an initial surface accuracy. The ribs were found to match the desired parabolic shape to within an error of 0.22 mm RMS, which aligned with specifications. Next, the mechanical antenna was taken to the RF range, and found to produce a gain of 42.5 dB, as predicted. The reason for the loss in gain was because of the non-solid


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surface and predicted surface imperfections (0.2mm tolerance instead of 0.05mm which could be achieved with a machined surface). It was important to take initial RF and surface accuracy measurements before stowing and deploying antenna, to fully characterize its original state and understand how stowing and deployment influence performance. This is the testing which has been completed to date.

The future testing sequence of the antenna will first consist of stowing the fully meshed antenna for the first time, and then deploying it. Next, the antenna will be measured again to check surface accuracy and RF performance. This cycle will be repeated until the RF performance significantly degrades, to characterize how many times the antenna could undergo deployment testing.

## Conclusion

RF analysis of the antenna design predicted after losses due to the ribs, sub-reflector blockage, and mesh, the antenna would have a gain of 42.6 dB, giving 0.6 dB of margin above the 42dB goal. The solid reflector performed at 43.2 dB, and the mechanical prototype which had the actual mesh performed 42.5 dB, aligning with simulations and surpassing goals. In addition, all other goals for the antenna have been surpassed (see Table 1), especially mass which is almost 1/3$^{rd}$ of the original design goal. The next step is to deploy the antenna with mesh, which will prove if the design is fully functional. After this future long term testing will be focused on raising the TRL of the antenna by thermal-vacuum and vibration testing. As the detailed design for KaPDA has been constructed and there is a clear path forward, it is expected the first flight model will be completed by the end of 2015.

KaPDA would create opportunities for a host of new Cubesat missions by allowing high data rate communication which would enable using data intensive instruments or venturing further into deep space, including interplanetary missions. It would increase current data communication rates by 100 times to 10,000 times. Additionally KaPDA provides a solution for other small antenna needs, like radar and the opportunity to obtain Earth science data.

## Acknowledgments

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