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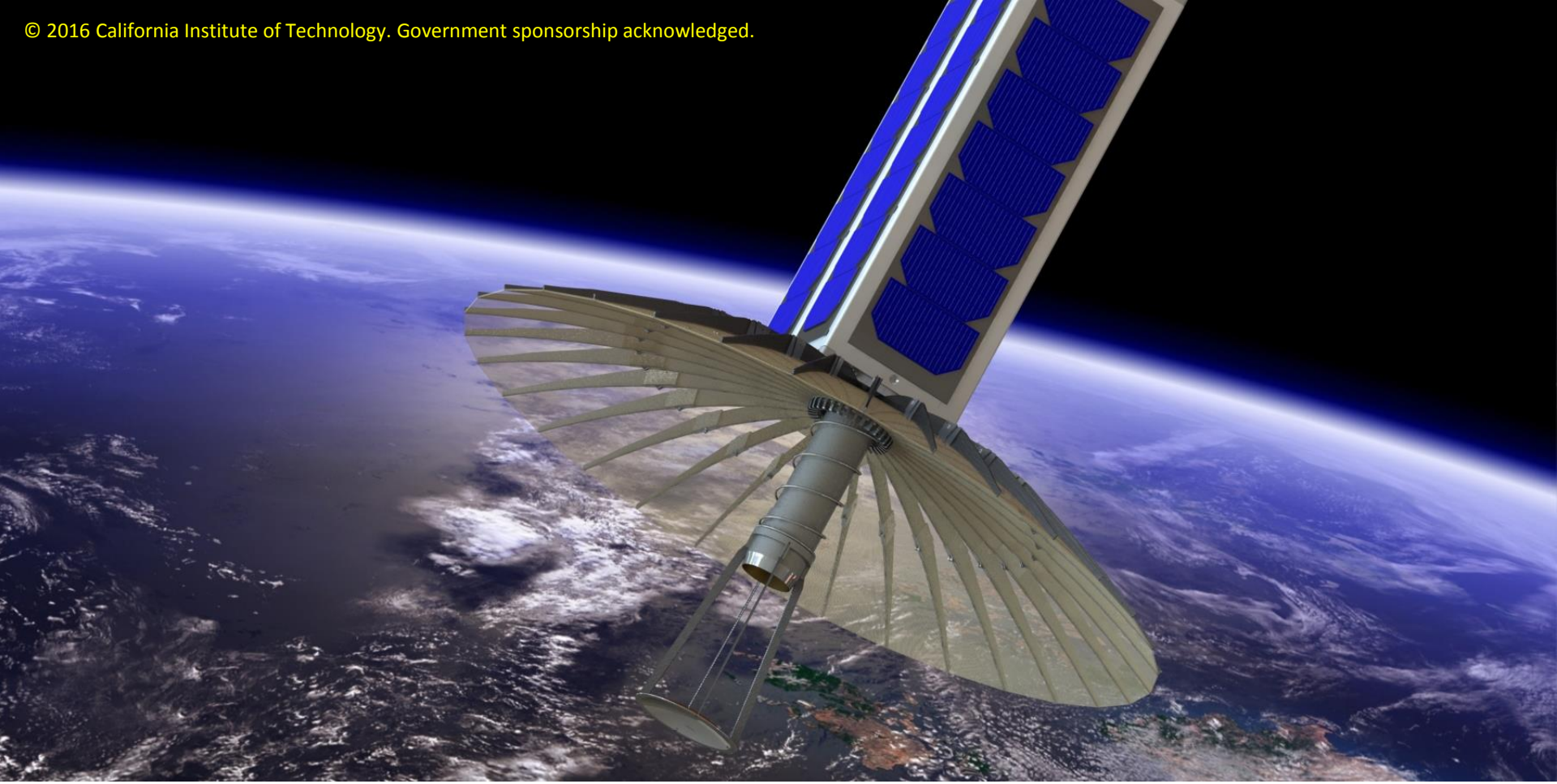

Ka-band High-Gain Deployable Reflector Antenna Enabling the first Radar in a CubeSat: RainCube

Nacer Chahat[1], Jonathan Sauder[1], Richard Hodges[1], Mark Thomson[1], Yahya Rahmat-Samii[2]

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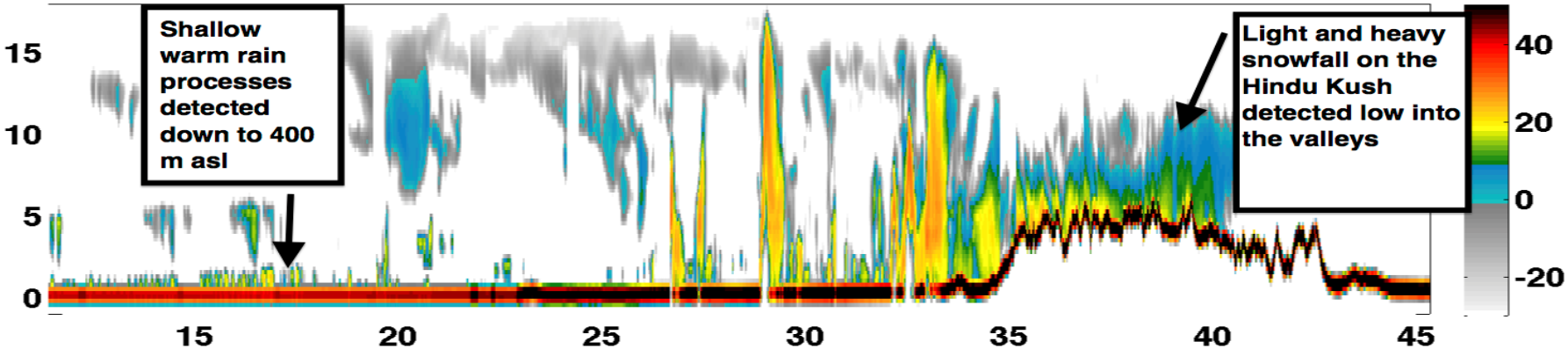
National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Introduction

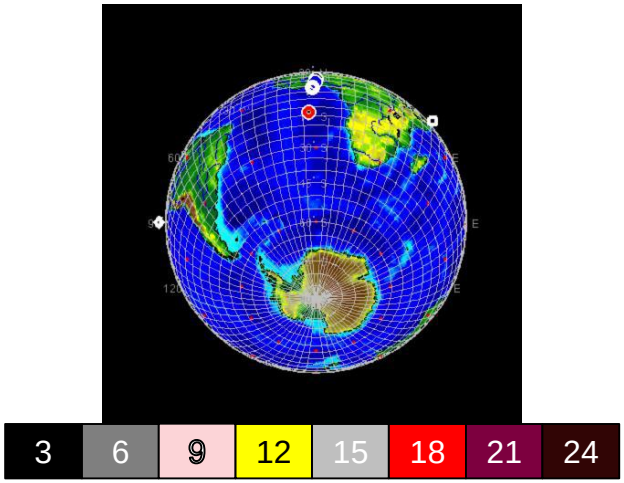
What is RainCube?

Constellation of Ka-band *Radar In CubeSat* that will *profile precipitation* down to near-surface, at all latitudes and at various sub-daily scales, to provide the temporal resolution in precipitation profiling that is necessary to *validate and improve weather and climate models*.



4-6 CubeSats on 2-6 orbital planes in LEO

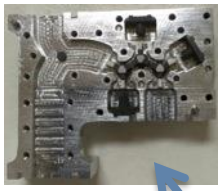
- Observe the same region at different times of the day during the same month
- Observe the same cloud at very short intervals (15-60 seconds)



Introduction

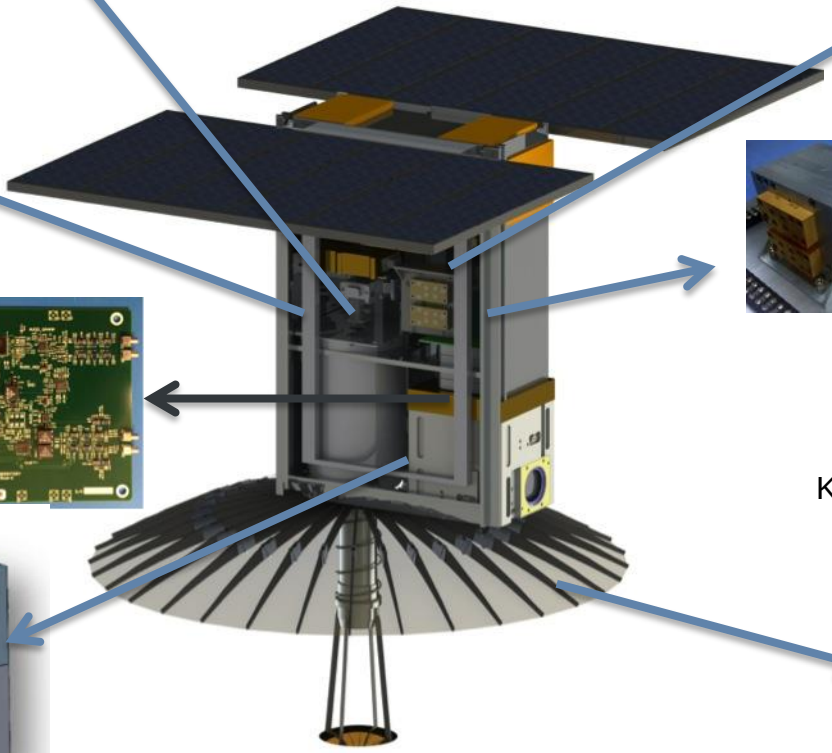
Payload System Architecture

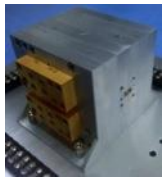
Front-end switch assembly (**FESA**)
Size: 5×5×1.9cm^3



The **UDA** performs conversion from/to baseband to/from Ka band and low noise amplification.
Size: 7.6×3.6×2.8cm^3

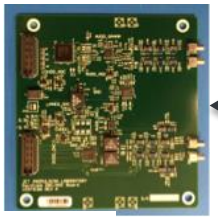
FESA driver
Size: 8.9×6.4×2.2cm^3



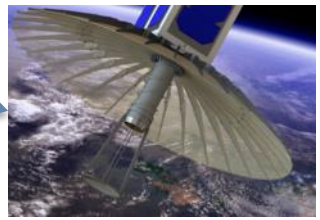


4-way waveguide power combiner **HPA**.
Size: 6.9×6.1×6.6cm^3

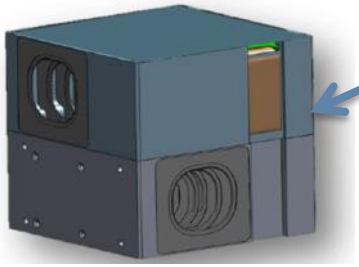
Digital assembly in PC104 form factor performs digital to analog and analog to digital conversion and digital signal processing



Ka-band deployable parabolic **antenna** stows in 1.5U



BCT Attitude Control Systems
Size:
10×10×10cm^3



Introduction

Project objectives

- **Problem**: RADAR in a 6U ($10\times20\times30cm^3$) CubeSat which requires a high-gain antenna (>42.0dBi)

- **Objective**: Enabling the first RADAR instrument in a CubeSat by developing the first Ka-band deployable high-gain antenna

- **Solution**: A Ka-band (35.75 GHz) Cassegrain mesh deployable antenna

- **Design Challenges**: Develop a low-cost 0.5 meter antenna stowed in a 1.5U ($10\times10\times15cm^3$) and deployed with 0.25 mm surface rms accuracy

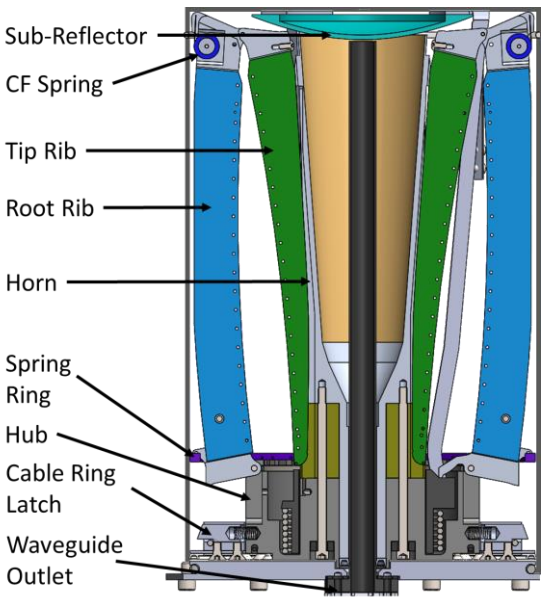
Antenna Requirements

Requirements

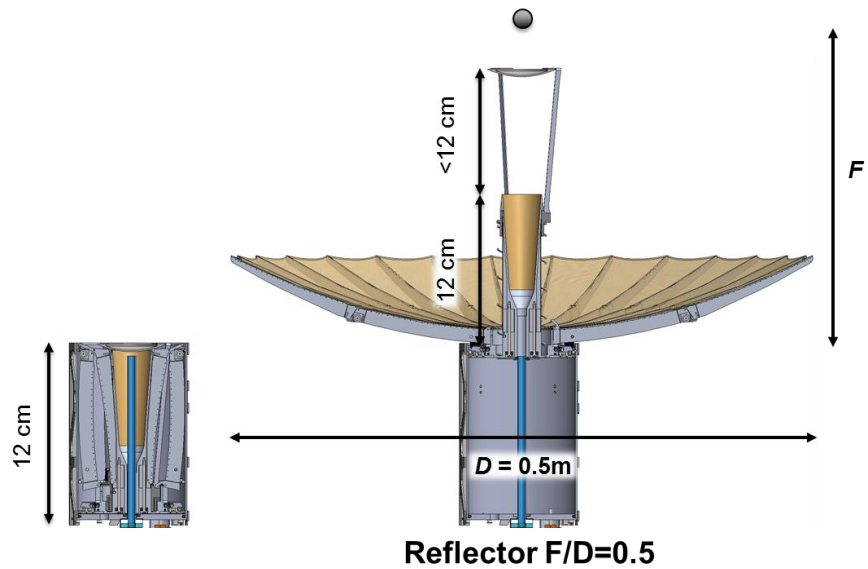
REQUIREMENT	Value
Frequency	35.75 GHz
Bandwidth	20 MHz (2 GHz)
Return Loss	14 dB
Feed Losses	< 0.3dB
Sidelobe Level	> 16.5dB
Polarization	linear
Antenna gain	42.0 dBi
Beamwidth	1.2°
Antenna input	WR-28
Stowage	10x10x15 cm^3
Mass	3kg (1.2kg)

Antenna design

Why a Cassegrain design?



Key KaPDA Components

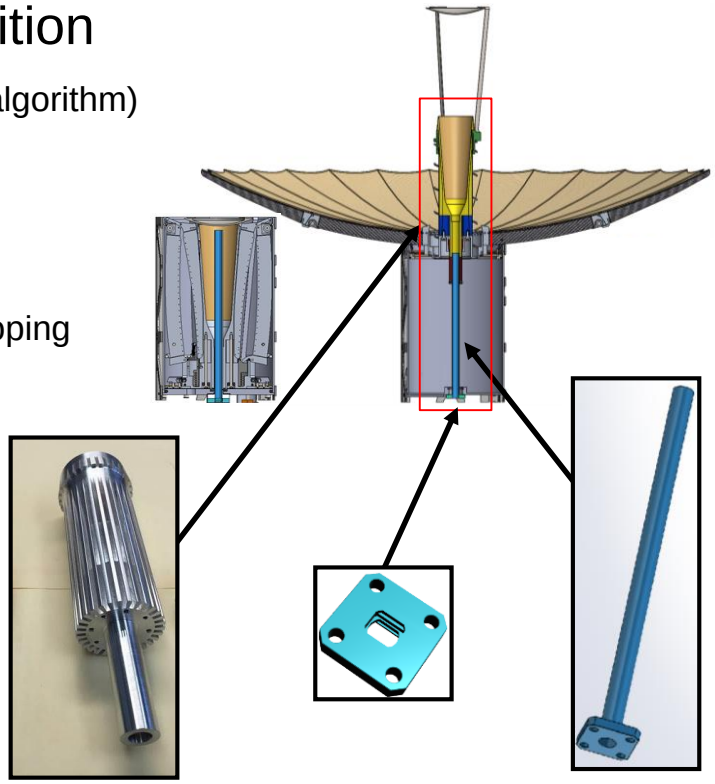


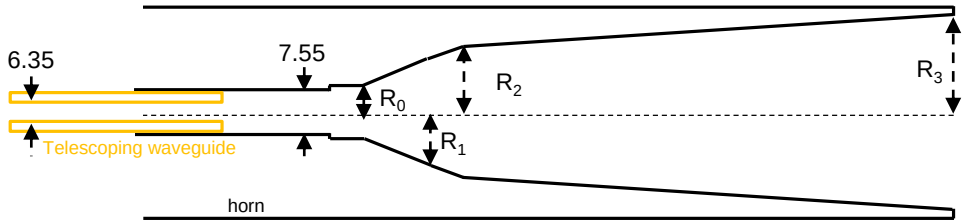
KaPDA Cassegrainian Configuration

Antenna feed horn

Feed horn, telescoping waveguide, and transition

- Multiflare horn antenna (optimized using BoR-MoM and genetic algorithm)
  - Linear and circular polarization can be obtained
  - good beam circularity
  - low cross-polarization
  - stable feed taper
  - Compatible with the deployment concept including a telescoping waveguide
- Minimization of taper and spillover loss
  - -10dB edge taper at 15.5°

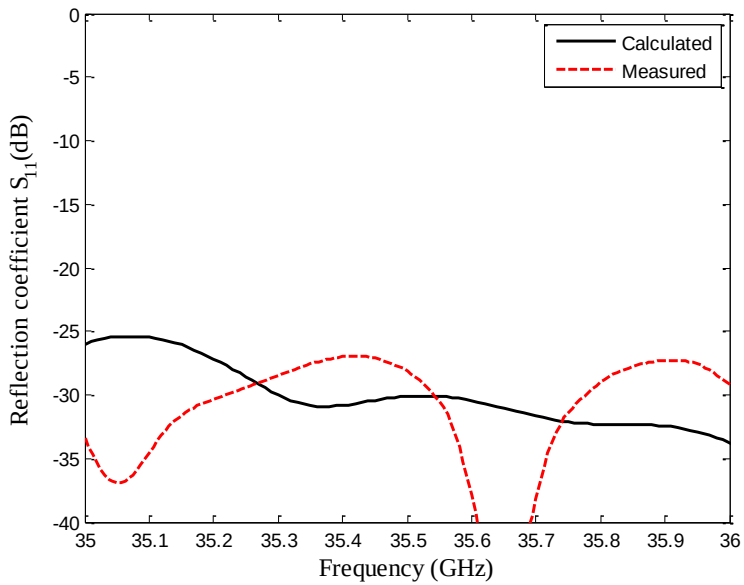




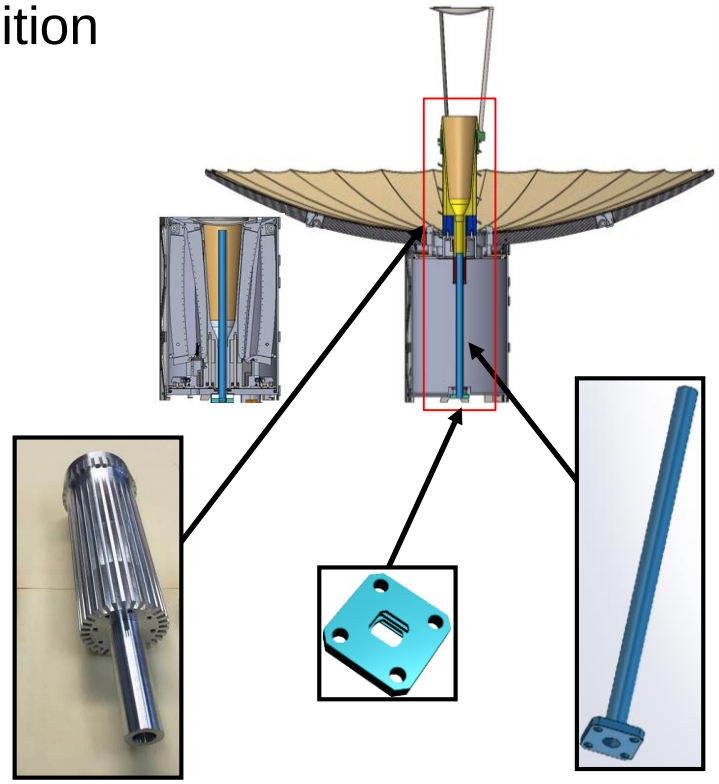
Flight horn including the telescoping waveguide (in mm)

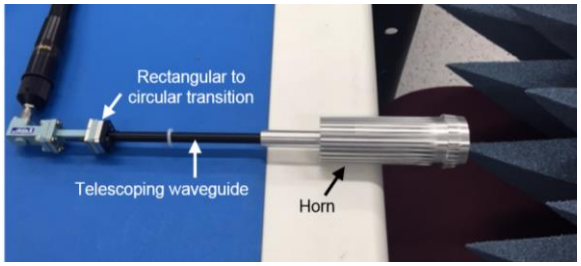
Antenna feed horn

Feed horn, telescoping waveguide, and transition



Feed horn reflection coefficient (includes the transition and telescoping waveguide)

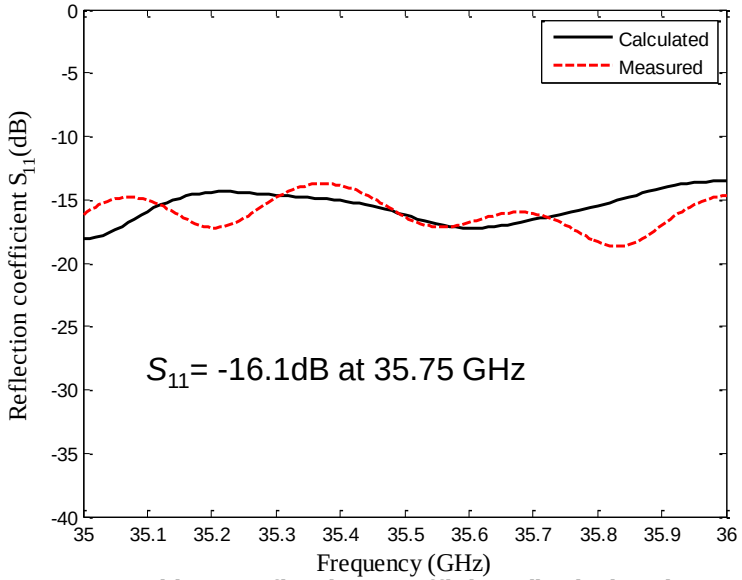




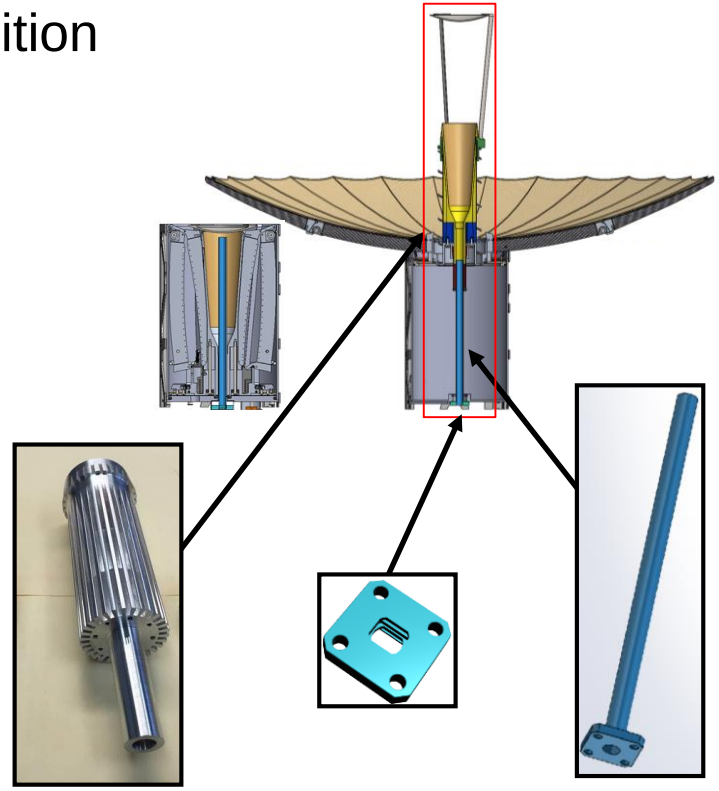
Measurement setup

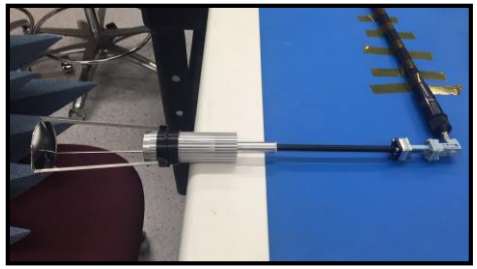
Antenna feed horn

Feed horn, telescoping waveguide, and transition



Feed horn reflection coefficient (includes the transition, telescoping waveguide, subreflector, and struts)

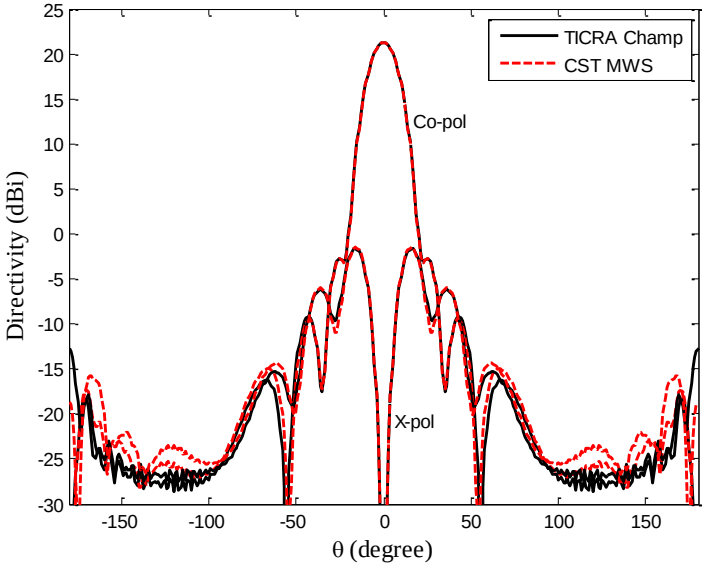




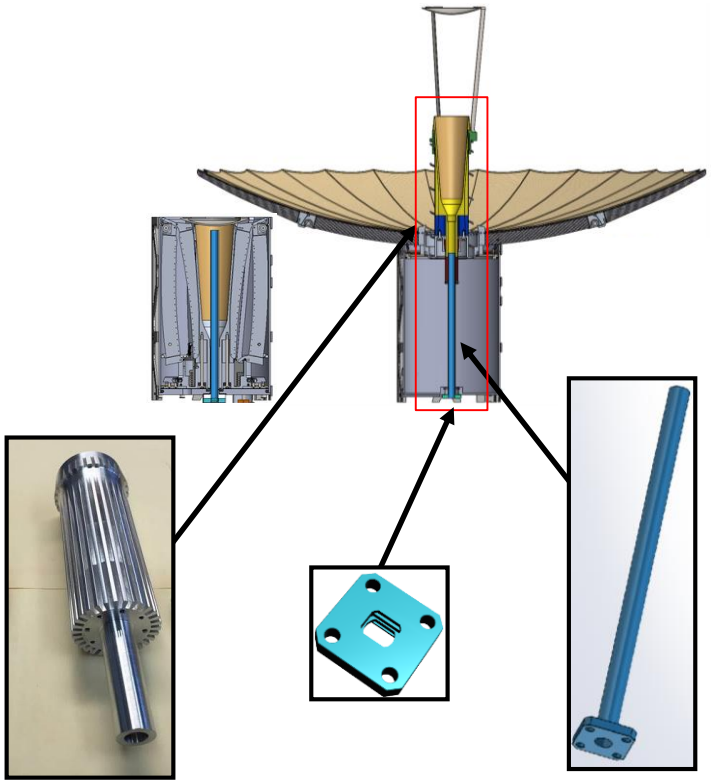
Measurement setup

Antenna feed horn

Feed horn radiation pattern

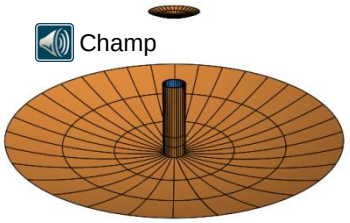


Radiation pattern of the optimized multiflare horn feed at 35.75GHz (φ = 45°).

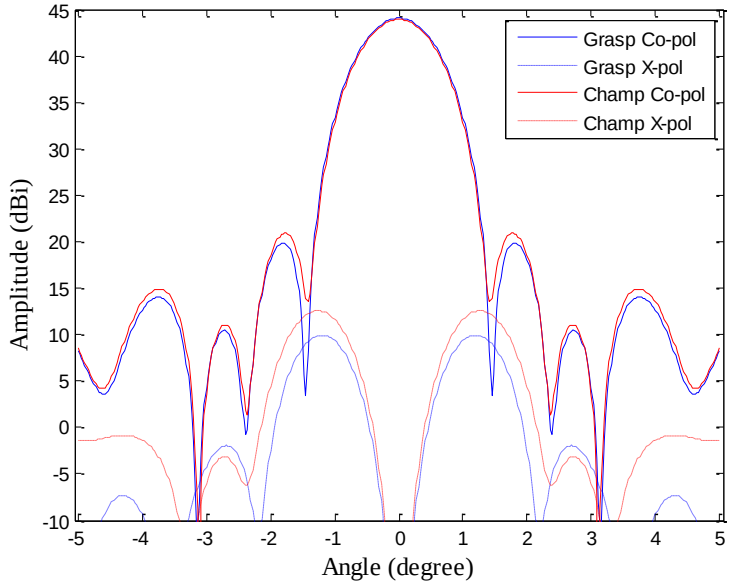


Reflector Antenna Optimization

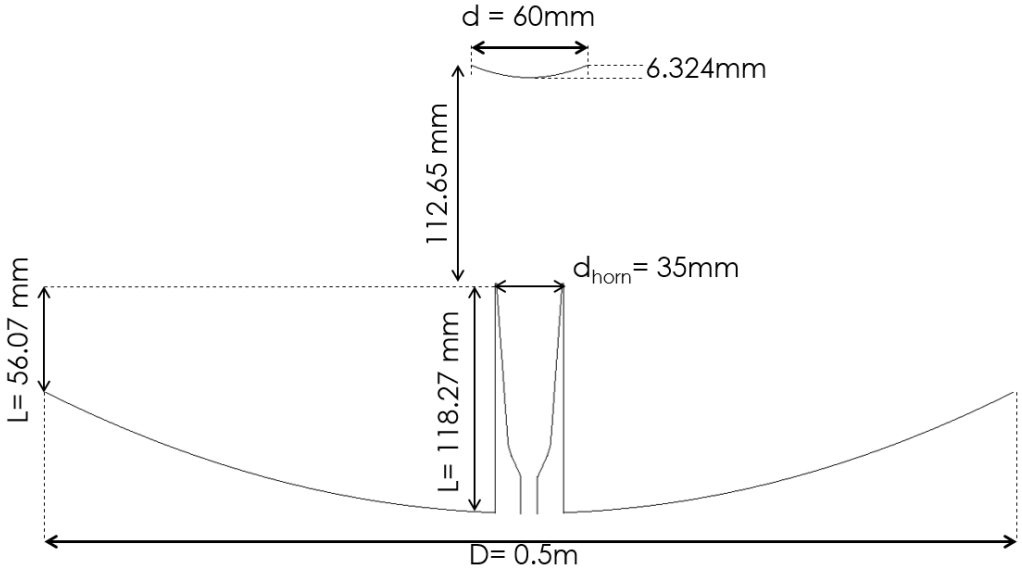
Step 1: Ideal parabolic reflector optimization



- Optimization of the Cassegrain design without including:
  - Ribs
  - Struts
  - Mesh



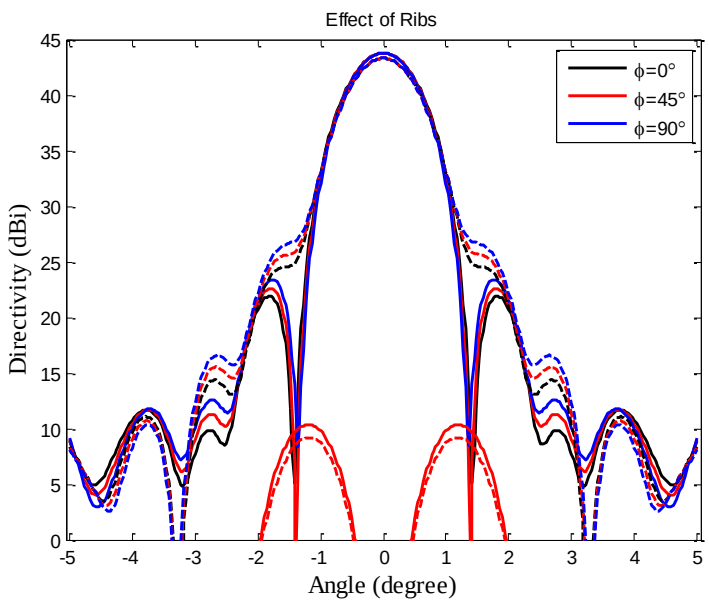
Radiation pattern of the ideal parabolic reflector at 35.75 GHz using different simulations methods at φ = 45°.



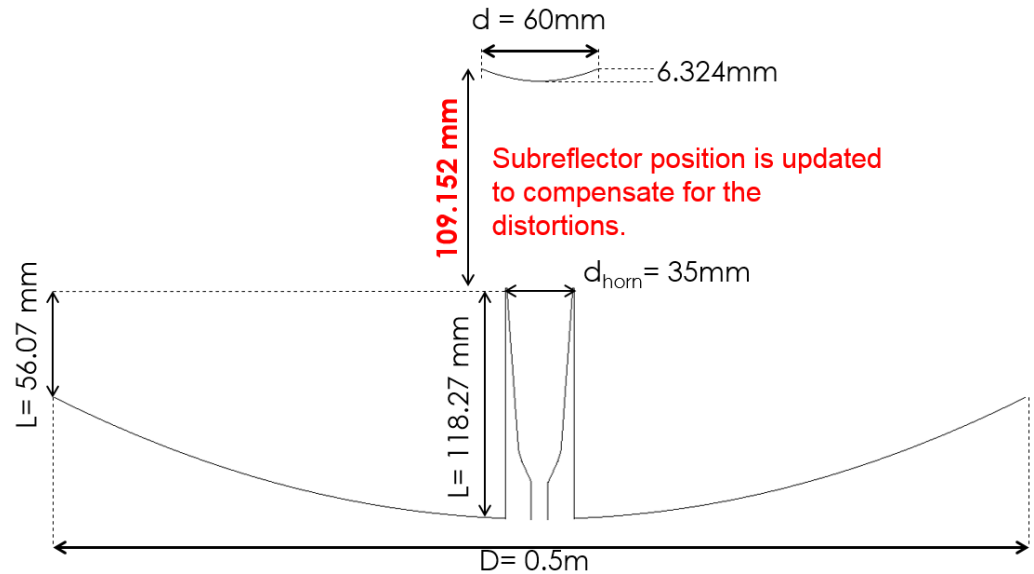
Reflector Antenna Optimization

Step 2: Unfurlable paraboloid

- De-focusing effect caused by the ribs distortion
- The subreflector is refocused
- $Gain_{refocused}$=43.9dBi and $Gain_{defocused}$=43.4dBi ➔ +0.5dB decreased



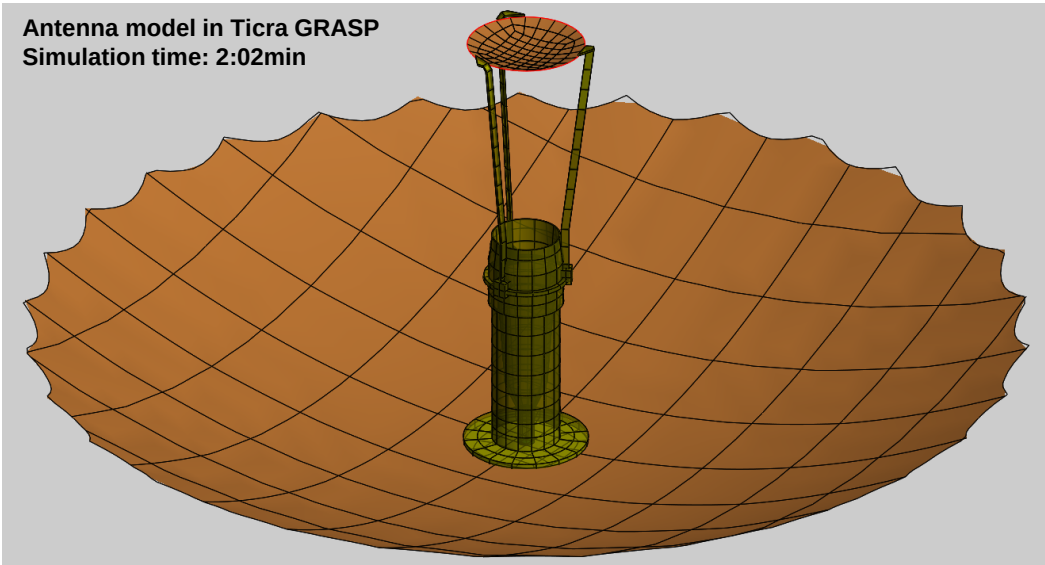
De-focusing effect using 30 ribs. The subreflector is re-focused to compensate the ribs effect.
Dash line: before correction. Solid line: after correction.



Reflector Antenna Optimization

Solid reflector antenna

- Ticra GRASP is employed:
  - MoM for the feed, struts, and subreflector.
  - PO + PTD for the main reflector
  - The horn is a BoR object
  - The 3 struts are represented using a tabulated mesh
  - Mesh is represented by a Wire mesh object
- The reflector is represented by an unfurlable surface with 30 ribs, and a focal length of 0.25m
- Rim is defined using tabulated rim
- CST MWS is used to calculated the feed insertion loss and S_{11}.

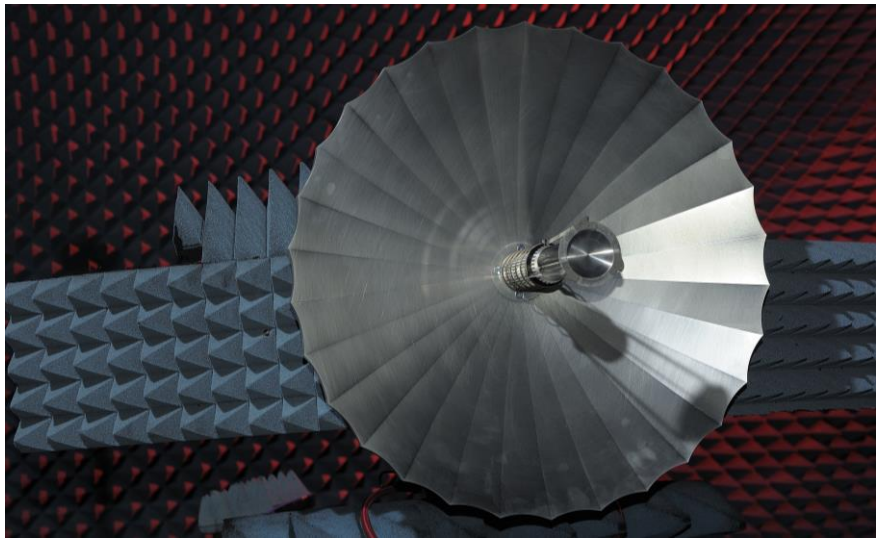


	Gain (dBi)	Loss (dB)	Peak SLL (dB)
Ideal directivity	45.45	-	-
Spillover + Taper	44.3	1.15	23.1
Blockage	43.97	0.33	22.1
Surface ribs (30)	43.90	0.07	20.7
Struts	43.60	0.3	17.7
Surface mesh* (40OPI)	43.35	0.25	17.4
Surface accuracy** (±0.22mm)	42.88	0.47	16.8
Feed loss / telescoping waveguide / transition	42.76	0.12	-
Feed mismatch (RL=15dB)	42.62	0.14	-
Overall performance	42.62	2.83	16.8

Reflector Antenna validation

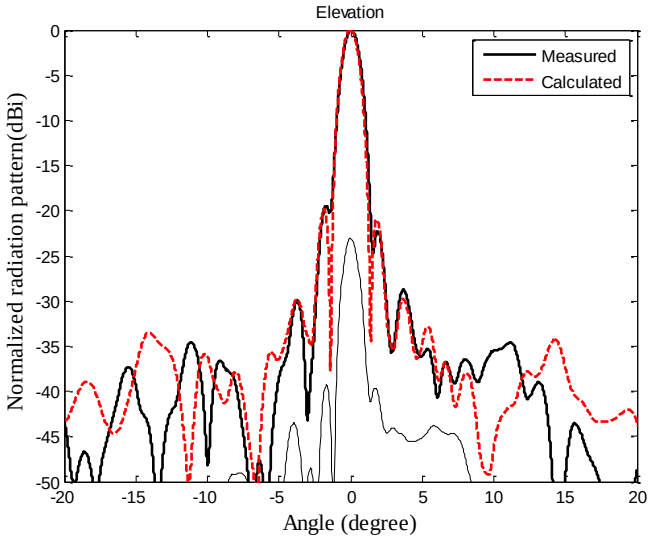
Solid reflector antenna

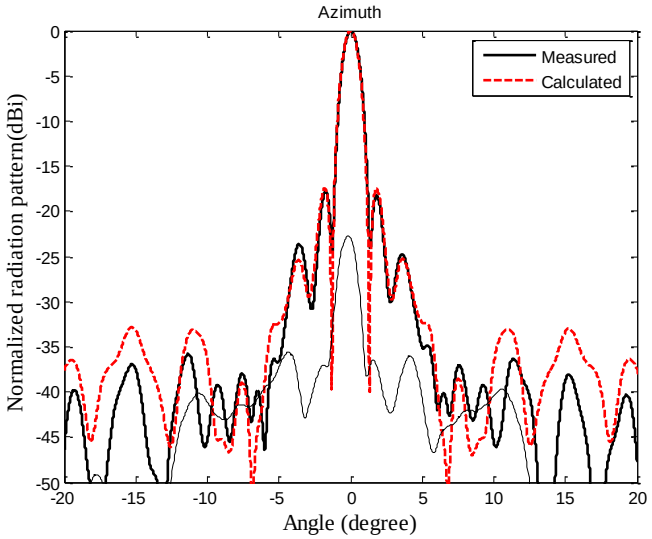
- Validate the design using a solid reflector
- Allows to assess the mesh loss accurately



Directivity (dBi)		Gain (dBi)		Loss (dB)*		Peak SLL (dB)	
Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.
43.6	43.55	43.3	43.24	0.3	0.31	-17.45	-17.75

***feed, transition, telescoping waveguide, mismatch losses are included**

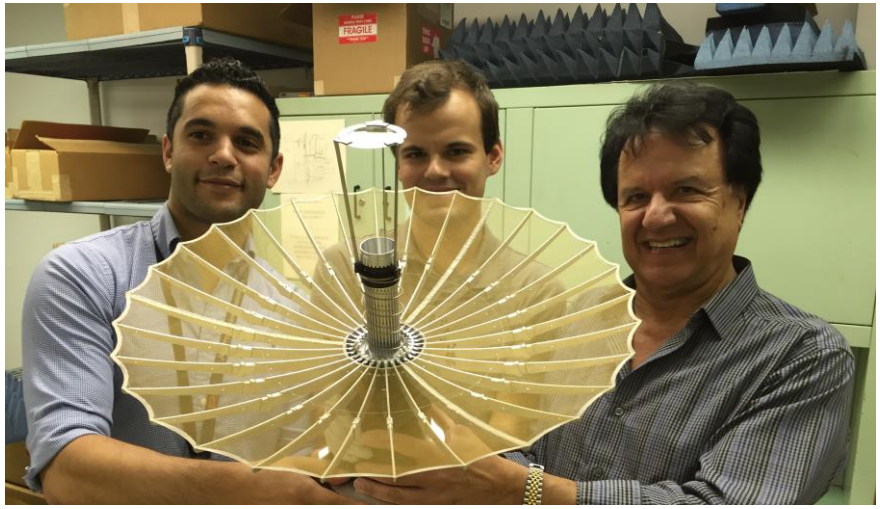


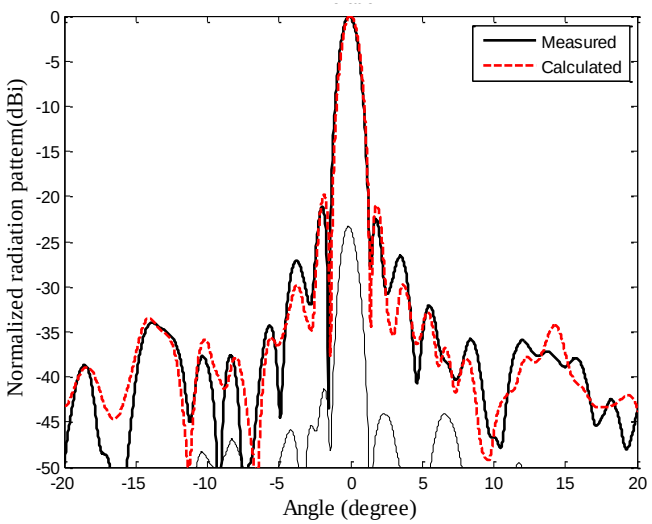


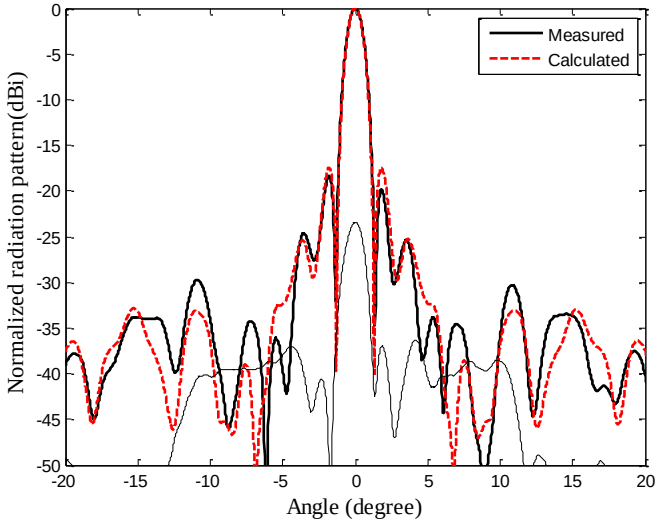
Reflector Antenna Validation

Mesh reflector antenna results before deployment

- Performed a first measurement before deployment
- Surface accuracy measure as ±0.2mm





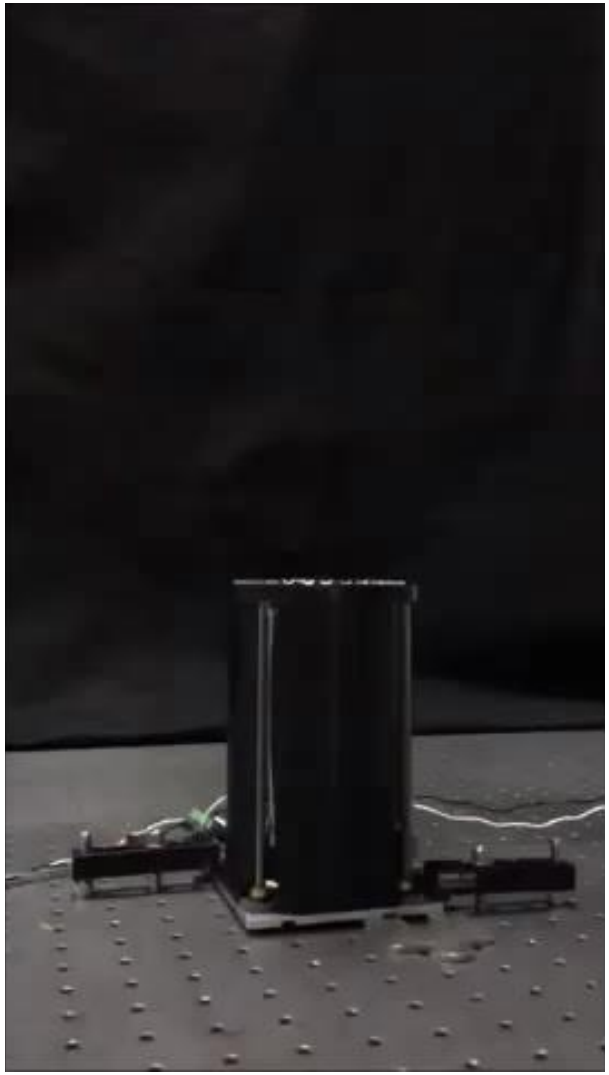


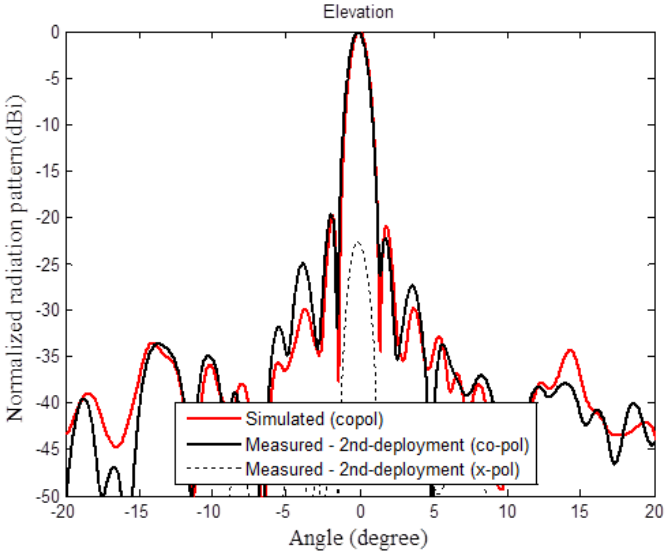
	Directivity (dBi)		Gain (dBi)		Loss (dB)*		Peak SLL (dB)	
	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.
Solid	43.6	43.55	43.3	43.24	0.3	0.31	-17.45	-17.75
Mesh	-	43.28	42.61	42.48	-	0.8	-16.8	-18.33

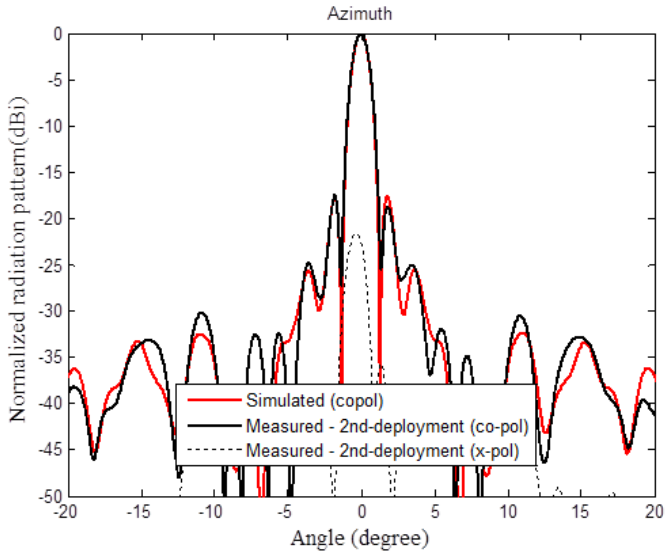
***feed, transition, telescoping waveguide, mismatch losses are included**

Deployment and RF Test

Mesh reflector antenna results after deployment







Conclusion

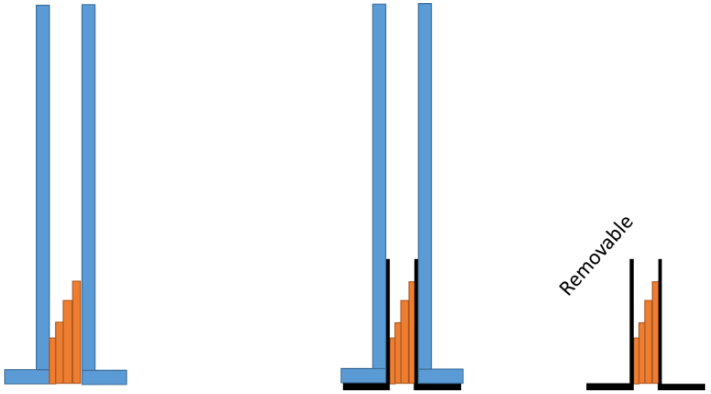
REQUIREMENT		Value	Compliance
Frequency	GHz	35.75	35.75
Bandwidth	MHz	20	>500
Return Loss	dB	14	16
Feed Losses	dB	<0.3	<0.15
SLL	dB	>16.5	>16.5
Polarization		linear	linear
Antenna gain	dBi	42.0	>42.5
Beamwidth	degree	1.2	1.2
Antenna input		WR-28	WR-28
Stowage	cm^3	10x10x15	10x10x15
Mass	kg	3	1.2
Thermal	˚C	-17 to 35	-26 to 62

Impact of this work

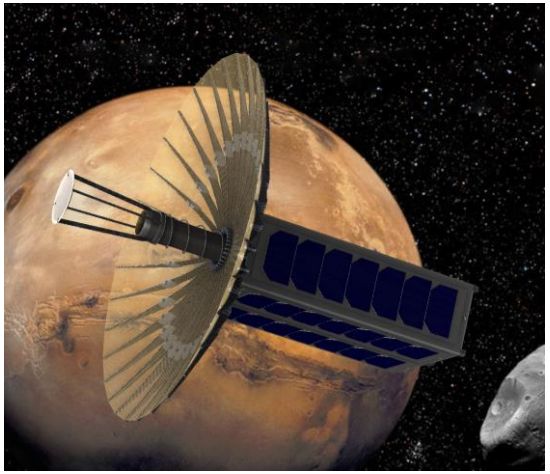
RainCube Mission will be flying this antenna in 2017.

Conclusion

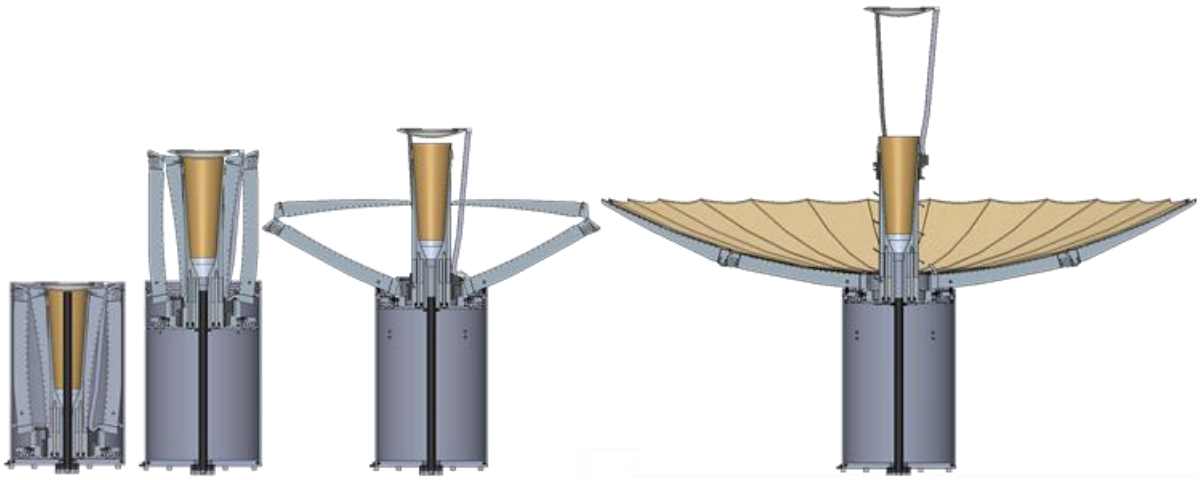
- New design in progress for Deep Space and LEO Telecommunication
  - RHCP (compact polarizer)
  - DSN bands:
    - Uplink: 34.2-34.7 GHz
    - Downlink: 31.8-32.3 GHz

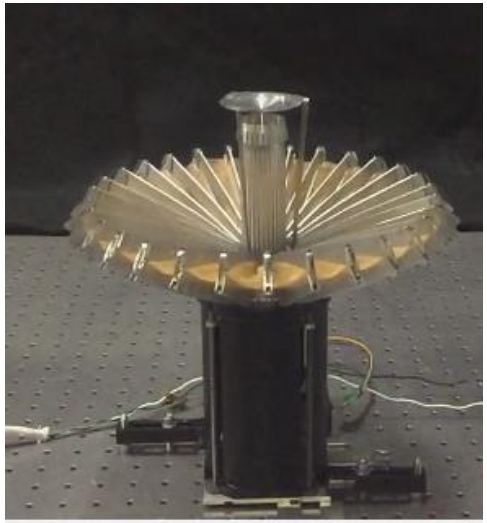


Polarizer integrated in the telescoping waveguide



Questions?



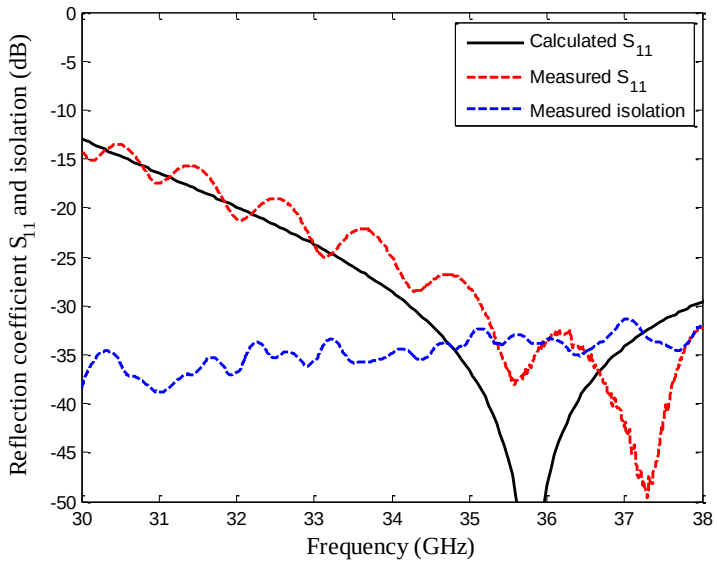


Backup slides

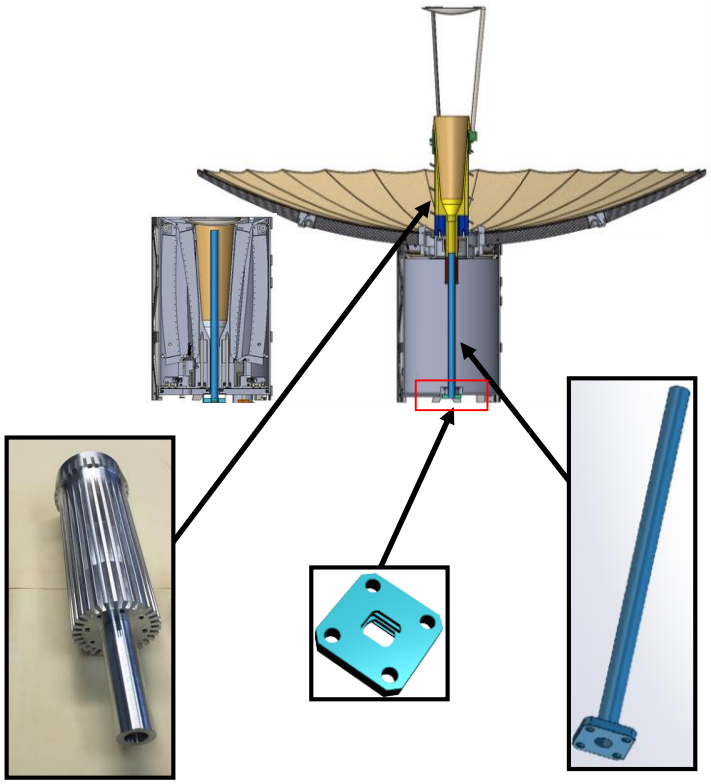
Antenna Design

Rectangular to circular transition

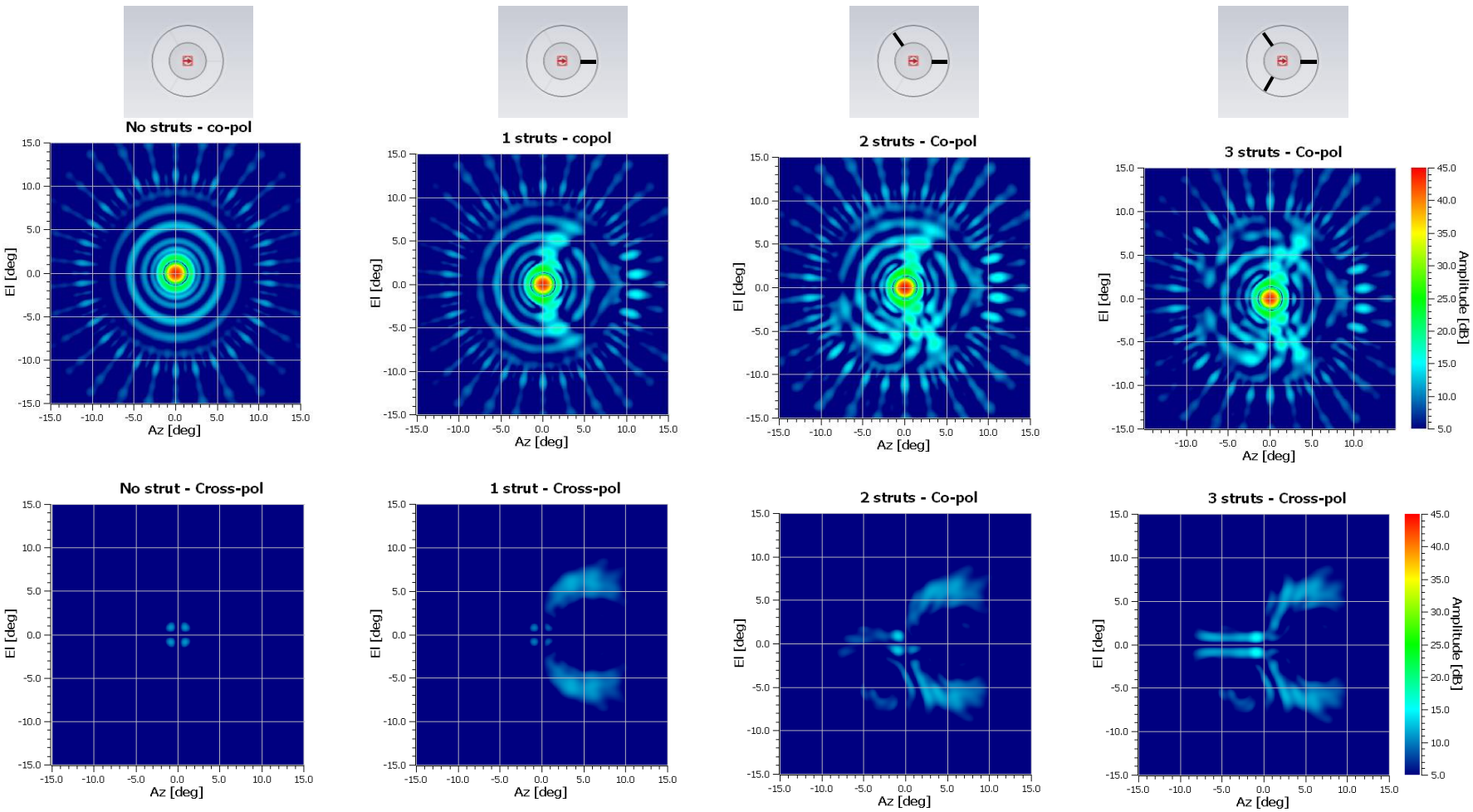
- Rectangular to circular waveguide transition
  - WR-28 to 6.35mm diameter circular waveguide
  - Custom made (using Mode Matching code)
  - Total length of 3.65mm
  - Measured S_{11} = -37dB at 35.75 GHz
  - Insertion loss < 0.05dB



Rectangular to circular waveguide transition performance



Antenna Optimization

Step 2: Unfurlable paraboloid

No strut | 1 strut | 2 strut | 3 strut