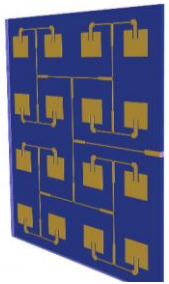
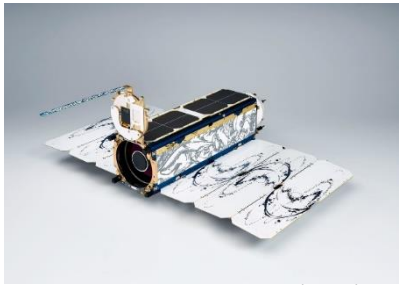
Design of open source, millimetre-wave calibration CubeSat





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24th September 2018

Outline:

- 1. Introduction on CMB measurement
- 2. Open source calibration of detectors
- 3. CubeSat overview
- 4. Payload design
    - 4.1. Horn antennas
    - 4.2. Patch array antennas
- 5. Conclusions
- 6. Future work

3 month ESAC traineeship: Jun – Sep 2018

- Project supervisors: **Marcos Lopez-Caniego**, **Xavier Dupac**, **Jorge Fauste**
- Other supervisors: **Julio Gallegos**, **Fernando Martin-Porqueras**
- Contributing students: **Jesus Mendia** (Universidad Europea, Madrid)
- Also helped by: **Dr Genova Santos** (QUIJOTE, IAC), **Dr Dunner** (ACTPol, PUC)

1. Introduction on CMB measurement

- Inflation Gravitational Waves
- B-mode polarised signal
- Sources of inaccuracies:
  - Foreground contamination
  - Instrument systematics

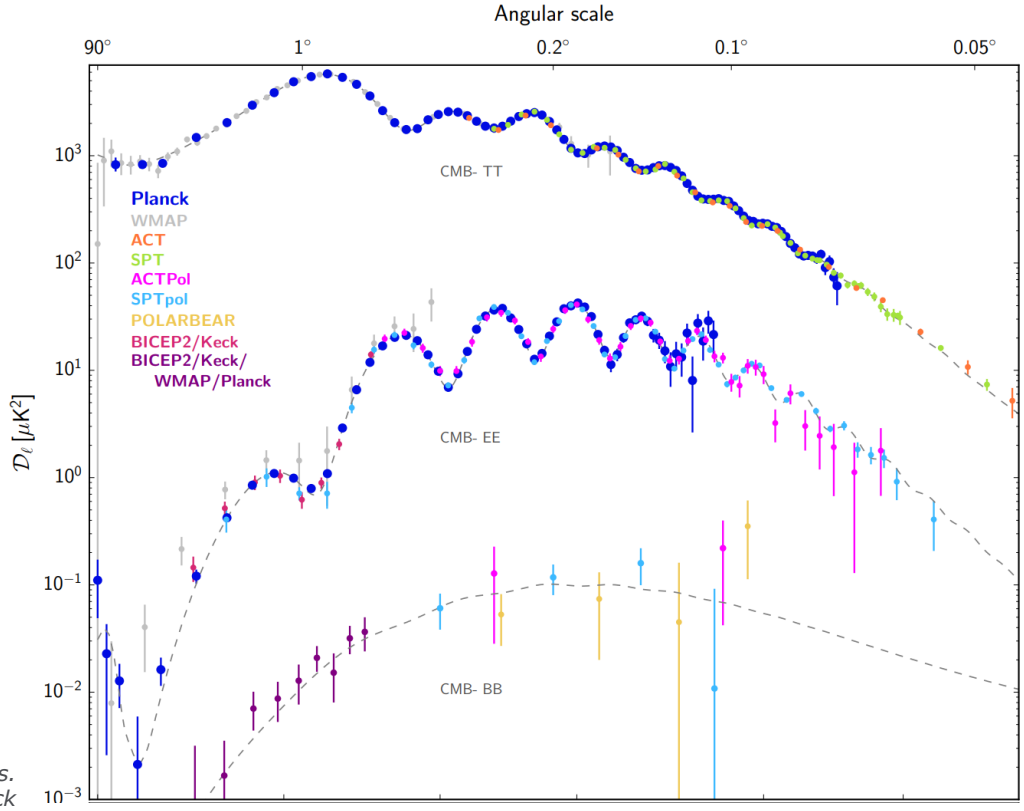
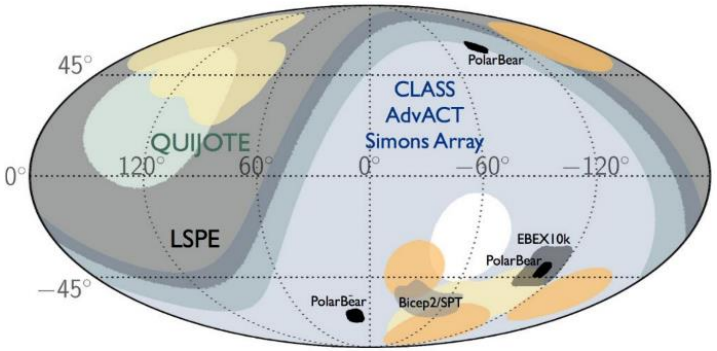


Figure 18 from Planck Collaboration (2018) *Planck 2018 results. I. Overview, and the cosmological legacy of Planck*

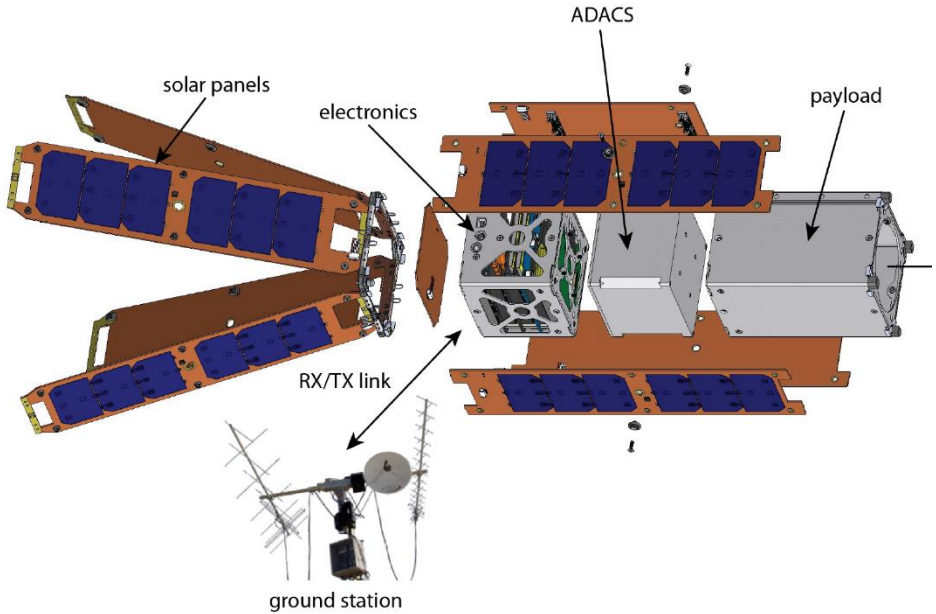
2. Open source calibration of detectors

- Instrument-induced polarisation rotation (IPR)
- Known linearly-polarised source
  - Point-like in detector beam
  - Brightness: high SNR but avoid saturation
  - Orientation of source on sky known to <0.2°
- Current calibration
  - Zero correlations, ground based, physical sources in sky



Baccigalupi, C. (2017) *Polarised Low Frequency Foregrounds,* CMB Workshop 2017

3. CubeSat overview



B.Johnson. (2015) *CalSat,* Columbia University, New York

- OBC, Comms, Power, ADCS
- Open source operations

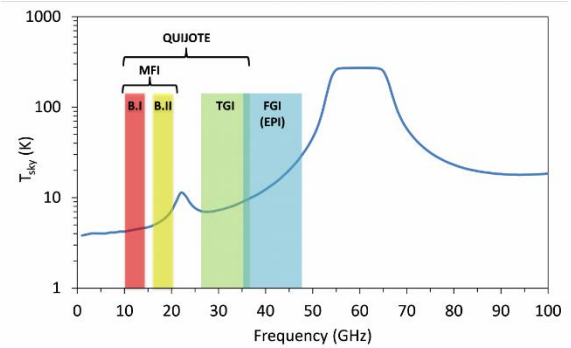
CubeSpace (2018) *Cube ADCS Specification*

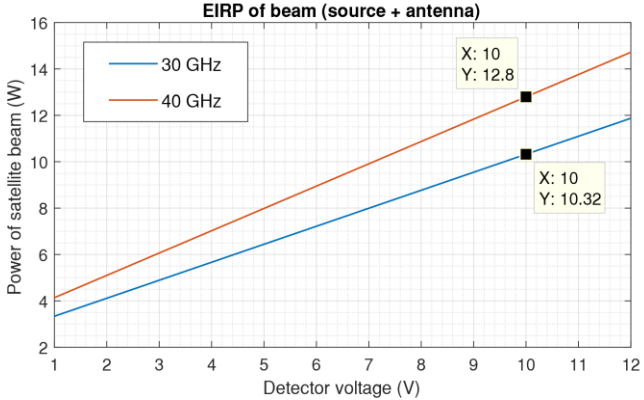
4. Payload

- CMB experiment requirements
  - Sources at **30**, **40** and **90 GHz** for QUIJOTE, CLASS, ACTPol and future STRIP, CMB-S4

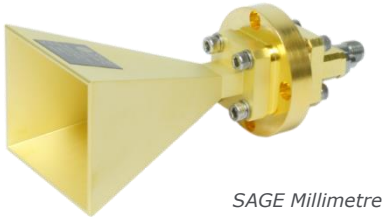
- EIRP beam power required
  - QUIJOTE parameters:
    10.3W (30GHz), **12.8W** (40GHz)
  - Estimated for 90GHz: **0.98W** (noise not factored)

EPI-Consolider (2018) *FGI*





4.1 Horn antennas



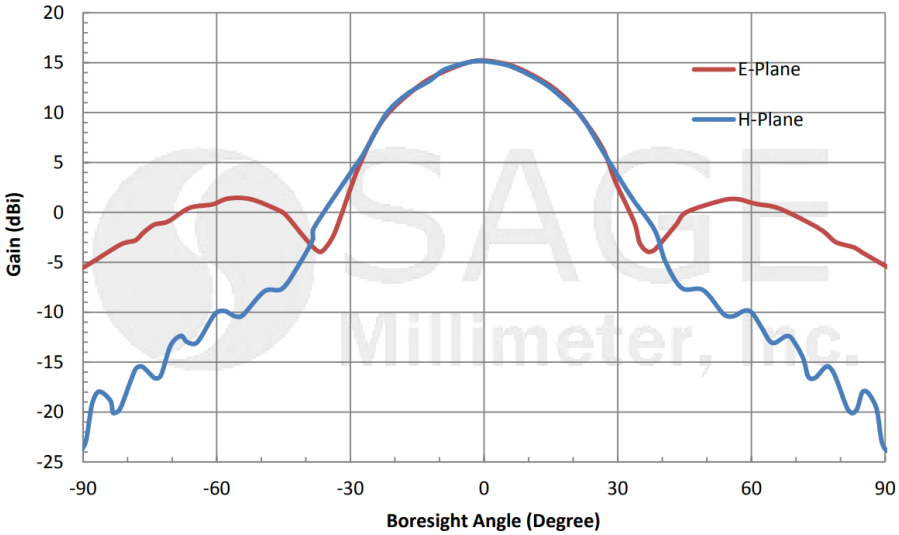
SAGE Millimetre

- Easily-characterisable radiation pattern

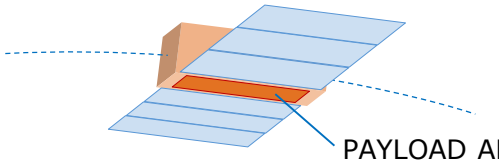
- Polarisation orientation measurement fully from ADCS

- Horn gain required
  - QUIJOTE and COTS sources: **20dBi** (30GHz), **18dBi** (40GHz)
  - Estimated for 90GHz: **2dBi**

SAGE Millimetre



- Horn antenna subsystem



10V input from CubeSat bus

30 GHz 100mW output P, 3.8W input P

40 GHz 199mW output P, 5.6W input P

90 GHz 39.8mW output P, 2W input P

Gunn oscillators
69.9 x 45.5 x 25.4

Waveguides

WR28 | WR22 | WR10

Horns

58.4 | 50.8 | 25.4

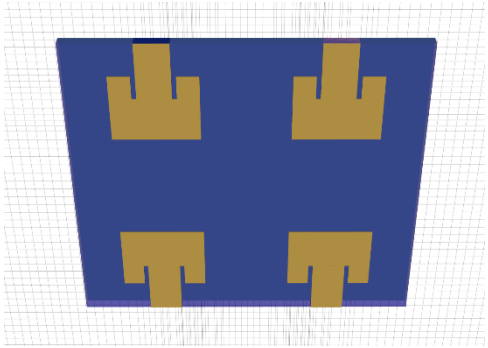
19.6dBi, 16° HPBW | 19.8dBi, 16° HPBW | 14.6dBi, 32° HPBW

42.5 | 34.2 | 8.6

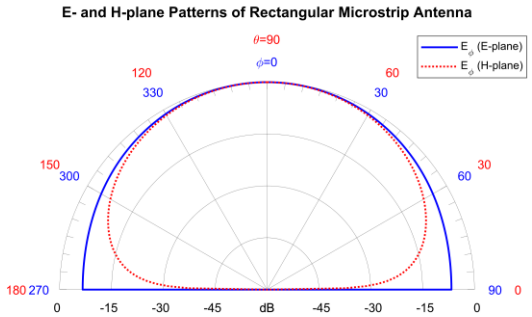
Filters for harmonics

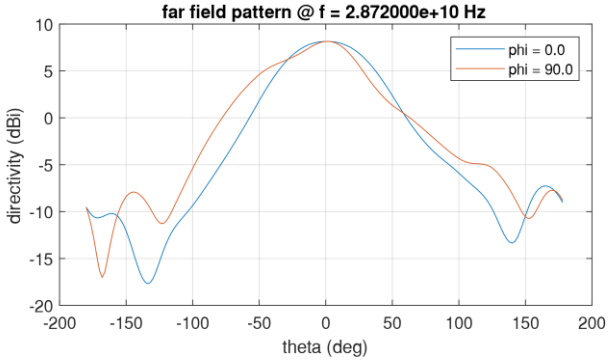
Polariser

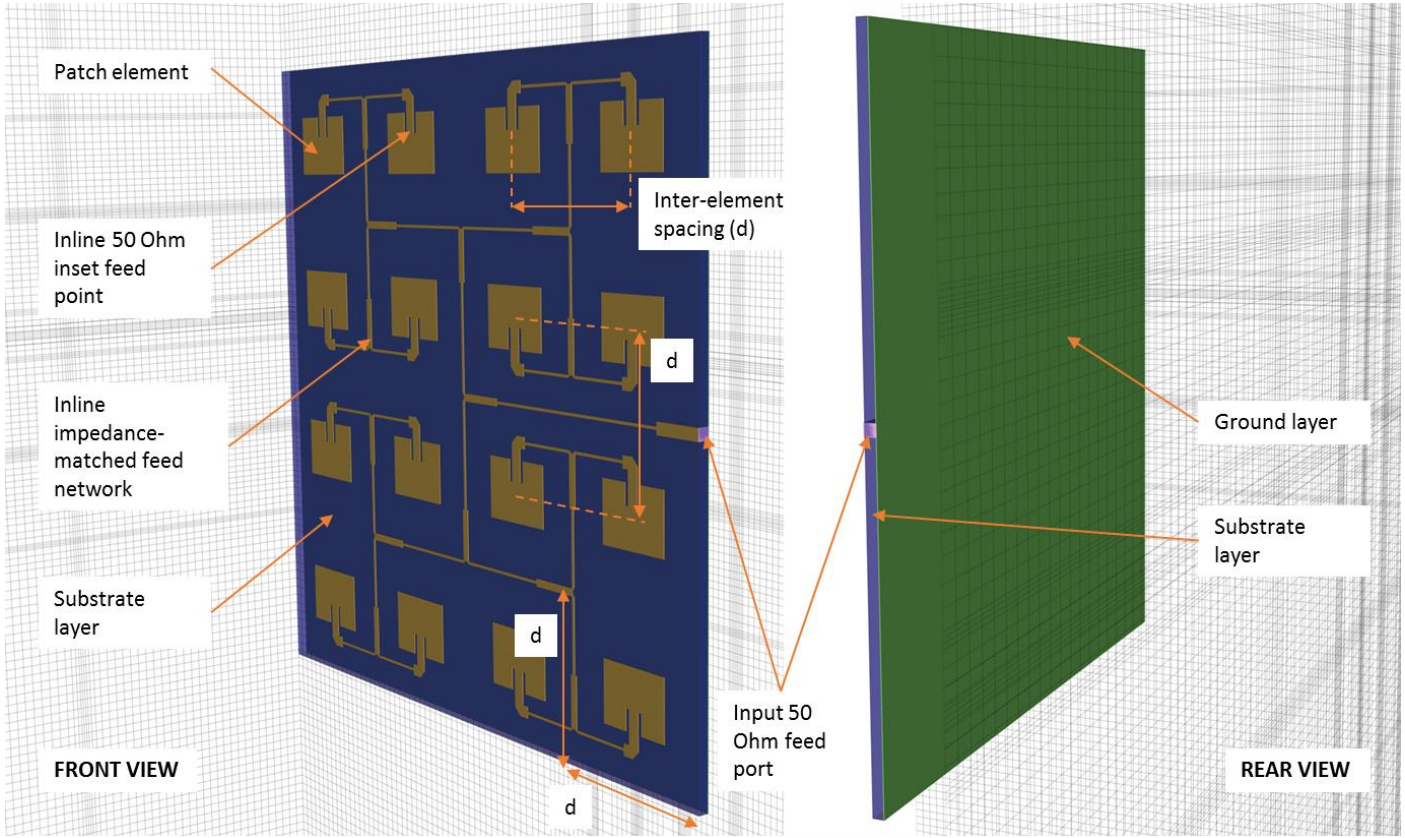
4.2 Patch phased array antennas



- Array focuses radiation of elements
- Beam steering with progressive phase shift
- Reduces constraints on CubeSat internal volume





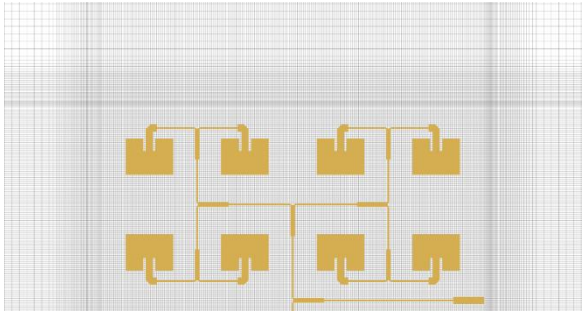

Patch element
Inline 50 Ohm inset feed point
Inline impedance-matched feed network
Substrate layer
FRONT VIEW
Inter-element spacing (d)
d
d
d
Input 50 Ohm feed port
Ground layer
Substrate layer
REAR VIEW

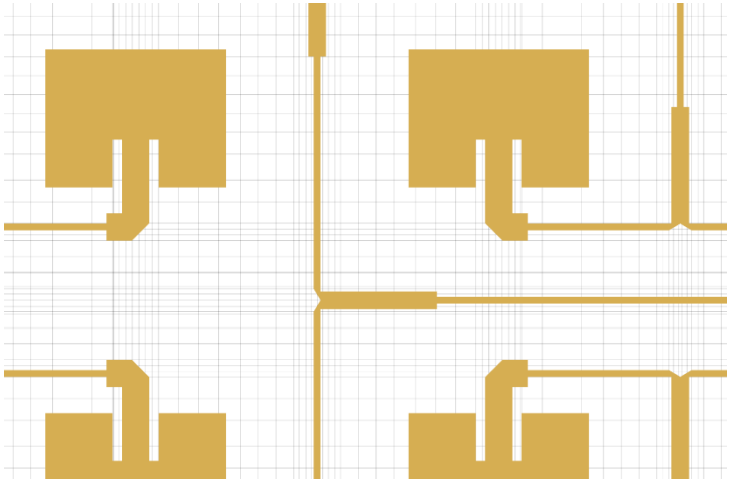
- OpenEMS Finite-Difference Time-Domain electromagnetic solver

- Inline non-phased patch array antenna with inset-feeds

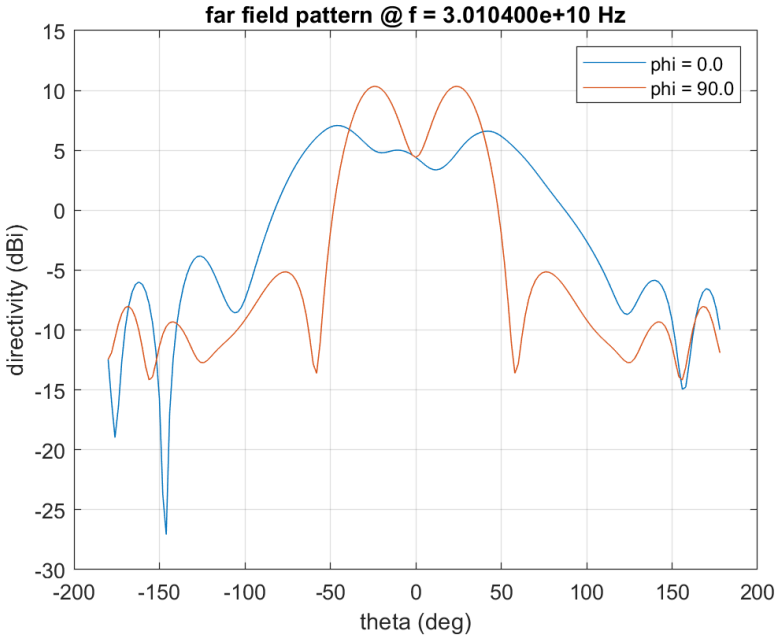
- Impedance matching, mesh definition

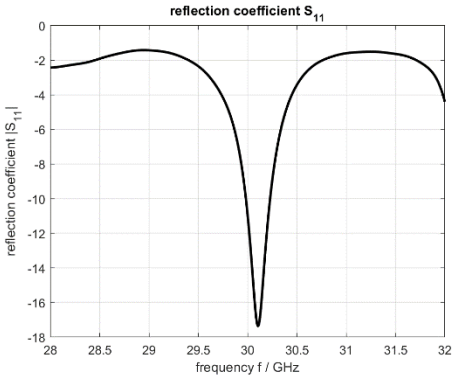
- 2x2, 4x4 and 8x8 arrays simulated

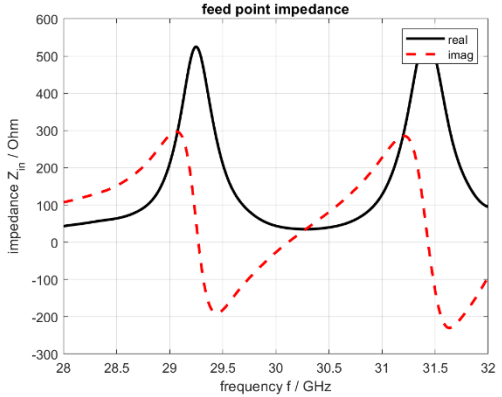


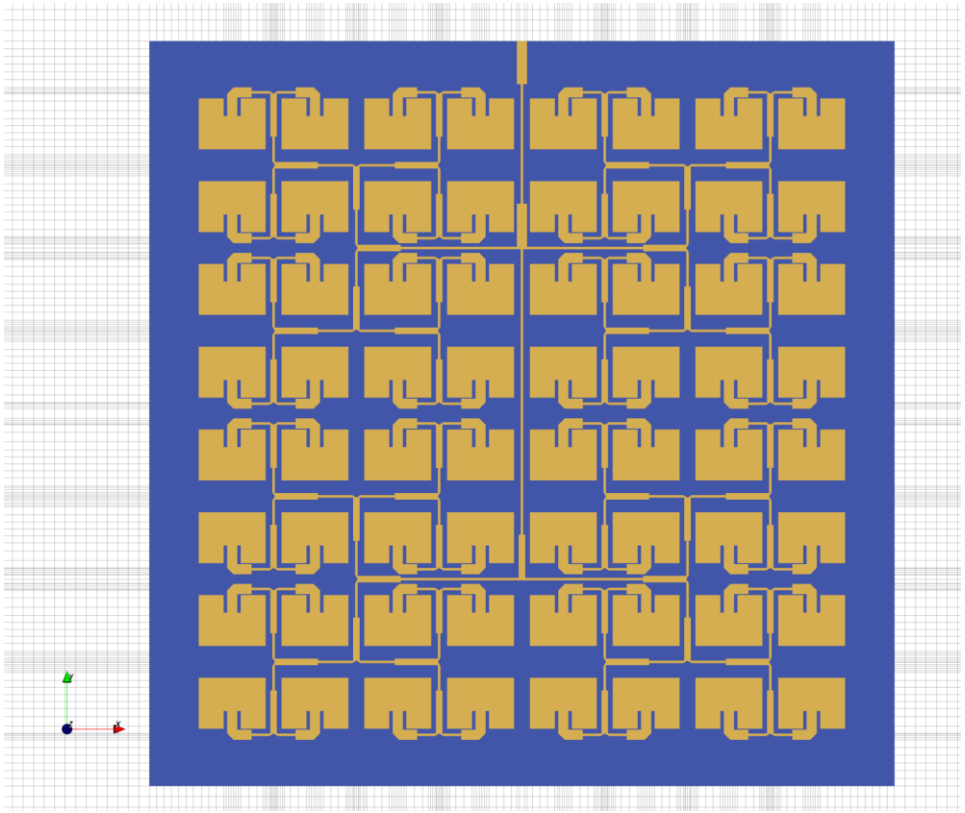


- d = 0.5*lambda, 4x4 array, designed for 30GHz
- Results: radiating f=30.1GHz, max. directivity=10.4dBi, radiating efficiency=88.0%









- Issues with array simulations:
  - Inline feed network not compatible with small element spacing
  - Interference of feed network not yet quantified
  - Unwanted interaction of grating lobes with large element spacing

5. Conclusions

- Horn antenna preferred for calibration, patch arrays need more research
  - Requires active ADCS with ‘point and track’ operation
- Power system structured to separate solar panels from CubeSat buses
- Planet Dove solar panel deployment
  - Orbit averaged power over year: max = 22W, min = 14W
- Orbit-lifetime extension results by Jesus Mendia
- Drone-based prototypes
  - ACTPol in Atacama, Chile

6. Future work

- Patch array antenna
  - Feed network for small element spacing, input power, feed network interference, probe feed
  - Prototype array, multi-layer phase control for beam steering

- Power system
  - Battery sizing and simulating storage during eclipse times
  - More accurate modelling of sub-system consumption

- CAD for configurations
- Experimental licence for frequency allocations