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High Data Rate Communications in CubeSat Swarms

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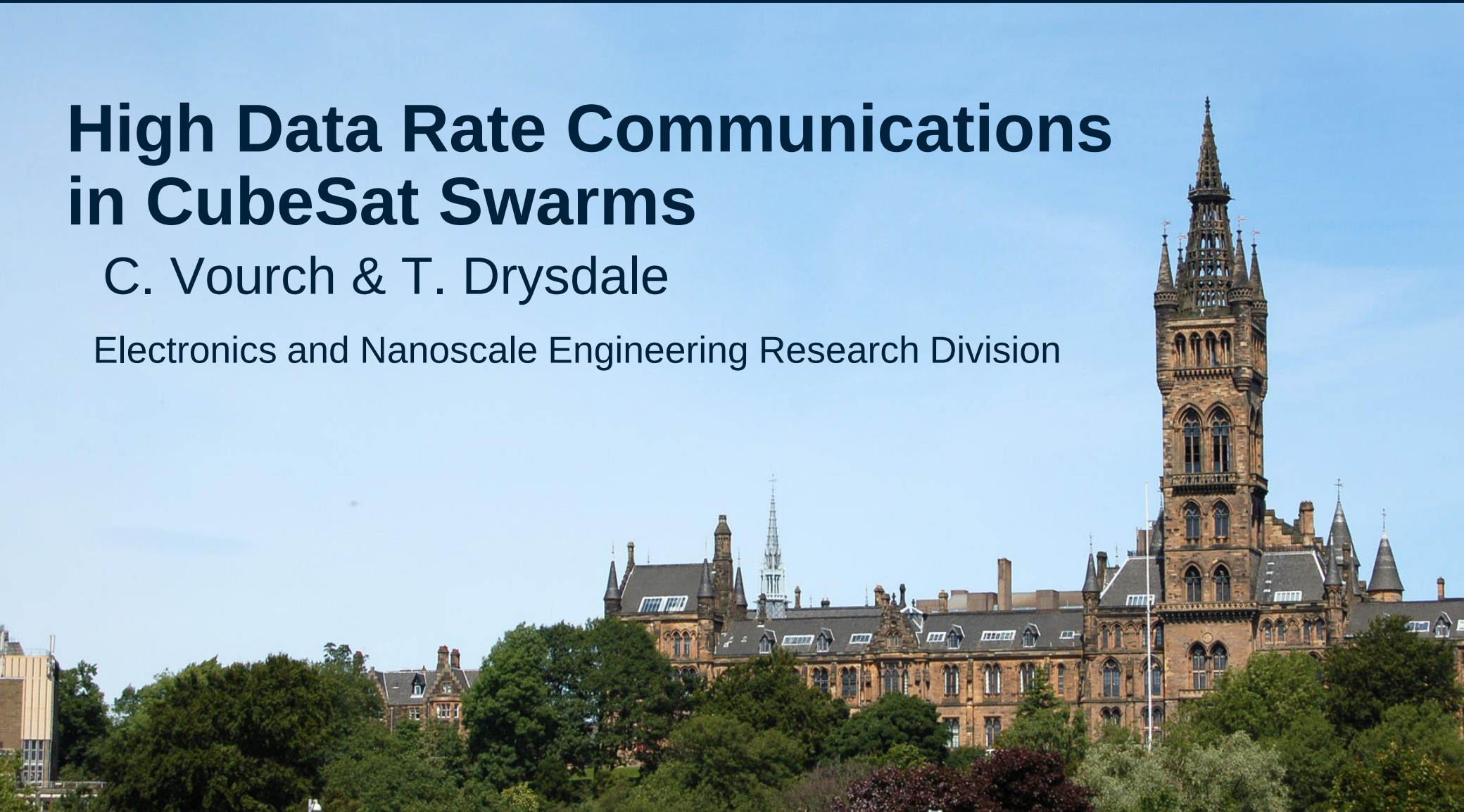

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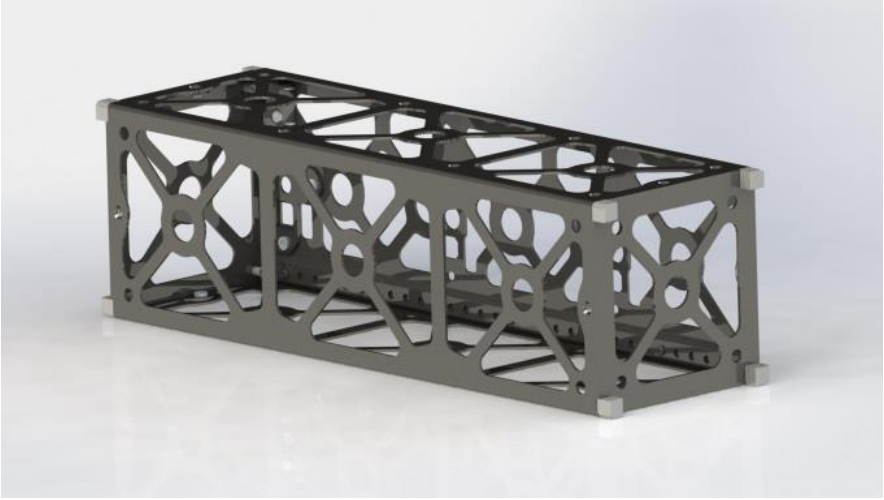
What are CubeSats?

- **Characteristics**
  - Small standardized satellites:
    - Chassis based on units (1U) of 10x10x10cm
    - 1U ~1Kg
    - Intensive usage of Commercial Off-The-Shelf (COTS) components



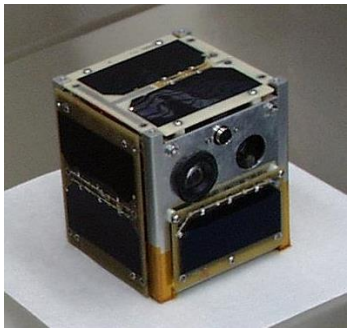
Credit: Pumpkin, Inc.

- **Main advantages**
  - Standardisation and cost reduction
    - COTS components
  - Cheaper and easier access to space

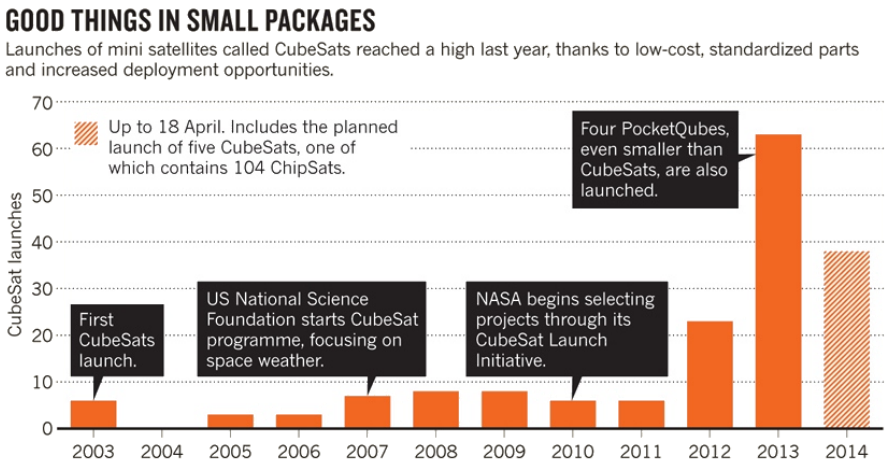
- **Drawbacks**
  - Limited payload
  - Higher risk of mission failure
    - Are COTS viable in a space environment? (space qualified?)

History

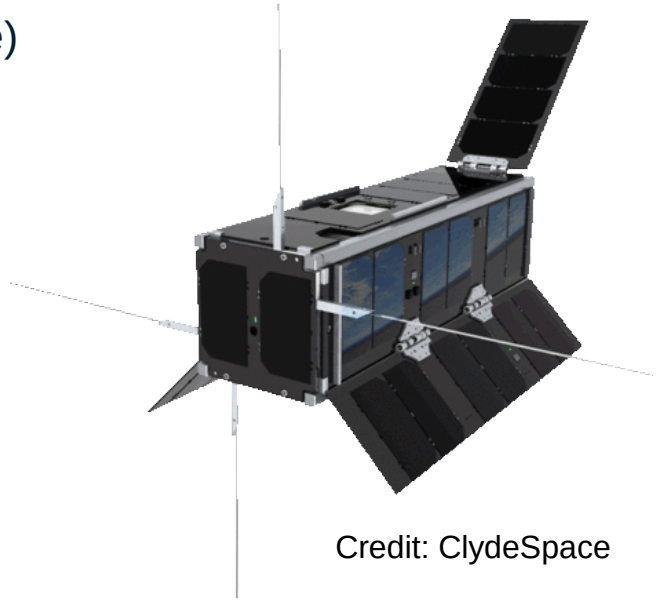
- **From the first CubeSat…**
  - First specifications of CubeSats: **1999** (Cal Poly & Stanford)
  - First launch of a CubeSat: **2003**
- **… to the first UK Space Agency's CubeSat**
  - UKube-1: 8th July 2014:
    - 3U CubeSat designed and built in Scotland (ClydeSpace)



Credit: UTIAS



Credit: Nature, Vol. 508, 16 April 2014



Credit: ClydeSpace

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And now?

Future of CubeSats

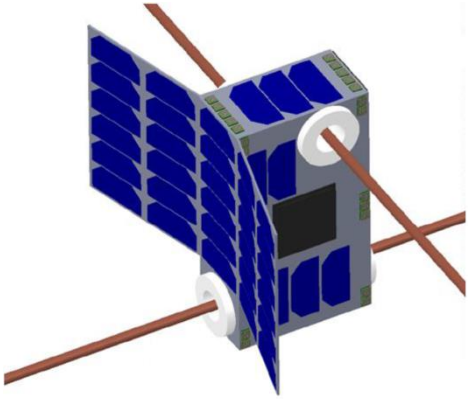
- **First generation of CubeSats already demonstrated viability**
  - The “shelf” of the available components is already well furnished and still growing
  - Current CubeSat EO missions provide useful data
  - Physical limitations for specific missions

- **Next generation of CubeSats**
  - Move toward distributed platforms: swarms of CubeSats
    - Take the most out of the small size of CubeSats
    - Possibility of large aperture

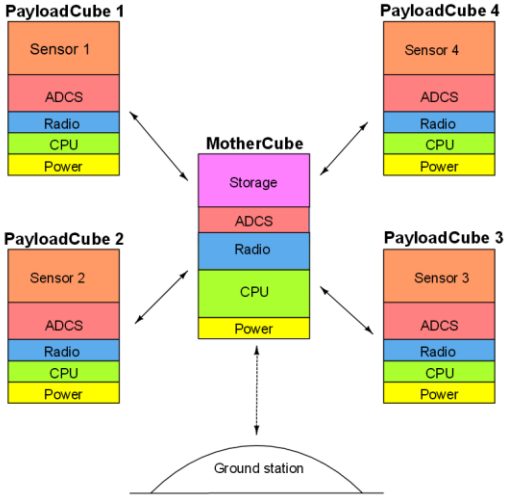
Current projects involving swarms of CubeSats

- SOLARA/SARA (MIT)
  - Solar Observing Low-frequency Array for Radio Astronomy/Separated Antennas Reconfigurable Array (30kHz – 30MHz)
  - 16 to 20 6U-CubeSats in circular formation with a diameter between 10 and 100 km

- Mothercube (Aurora Flight Sciences)
  - CubeSat-based Synthetic Aperture Radio Telescope
  - Technology demonstrator for CubeSat cluster
  - 3U-CubeSats



Credit: MIT/JPL



Credit: Aurora Flight Sciences

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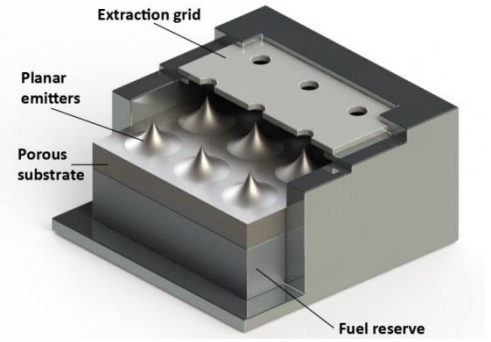
Two main challenges for swarms of CubeSats

1/ Pointing and positioning systems

- **Available now: Altitude and Determination Control System**
  - Allows accurate pointing for CubeSats
  - Better capabilities than a simple “tumbling” CubeSat

Credit: Maryland Aerospace, Inc.

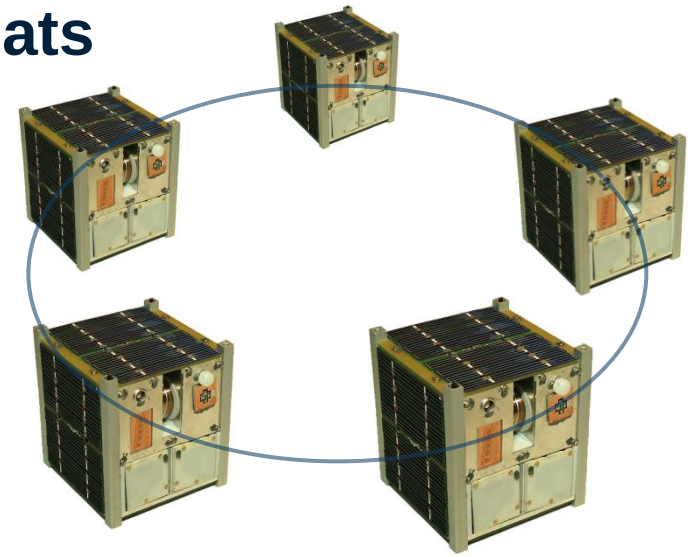
- **Current limitation: Propulsion systems (Thrusters)**
  - Propulsion system for relative positioning of CubeSats within the swarm
  - Current research on ion/plasma thrusters



Credit: Dan Courtney, MIT

Two main challenges for swarms of CubeSats

2/ Communication systems



Our requirements:

- Small and versatile antenna

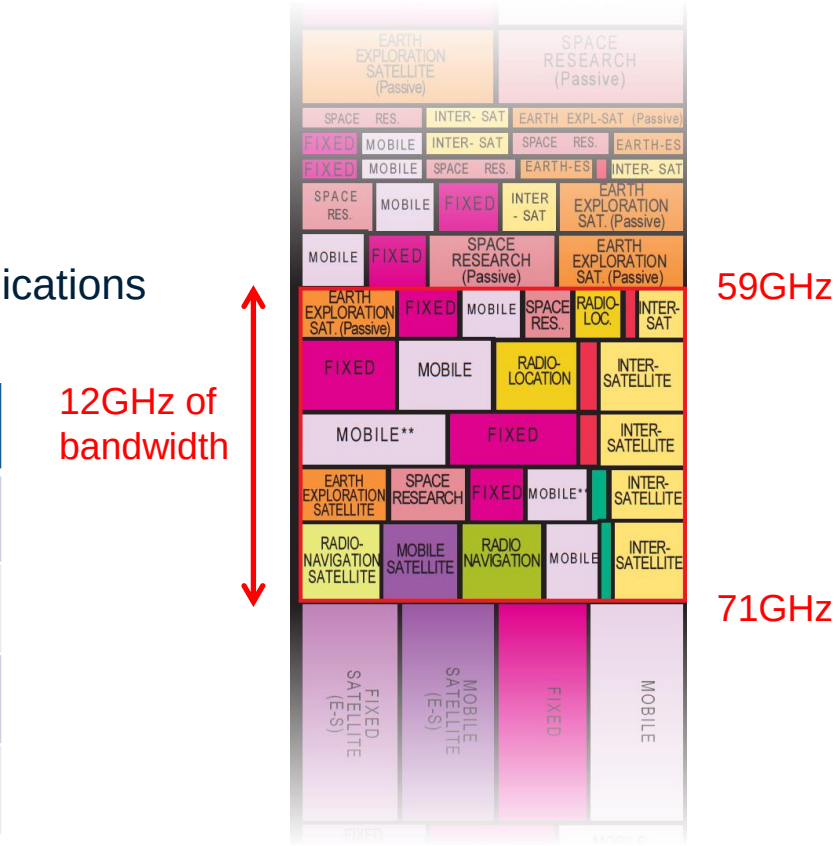
- Directive antenna
  - Do not waste energy with omnidirectional radiation pattern
  - Larger communication range within the swarm
  - Avoid interferences between communication paths

- Large bandwidth for high-data rate
  - Enable distributed tasks amongst CubeSats or synthetic aperture swarms
  - No need for processing units

Choice of the V-band

- **Our choices**
  - **V-band** provides:
    - larger bandwidth than current used bands
    - is available for communication within satellites
    - components already existing for terrestrial applications

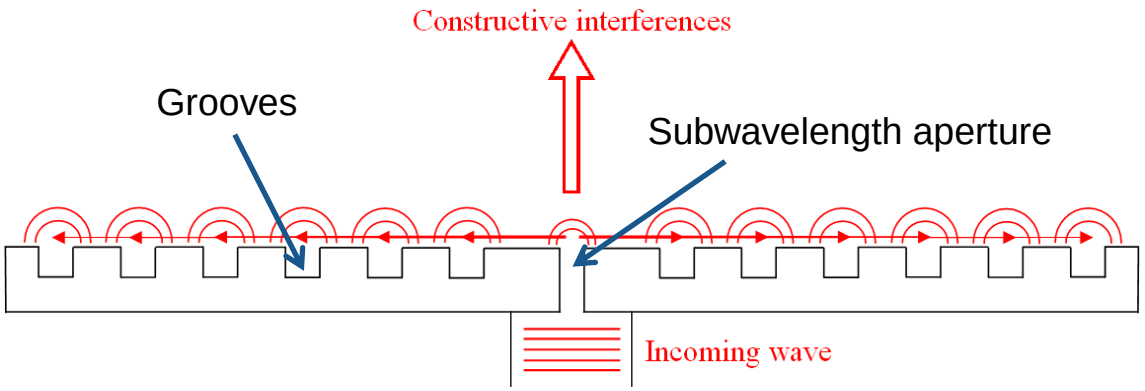
Band	Frequency	Available BW
UHF	435/915 MHz	30 MHz
S-band	2.45 GHz	100 MHz
K-band	23.05 GHz	1GHz
V-band	**60 GHz**	**12 GHz**



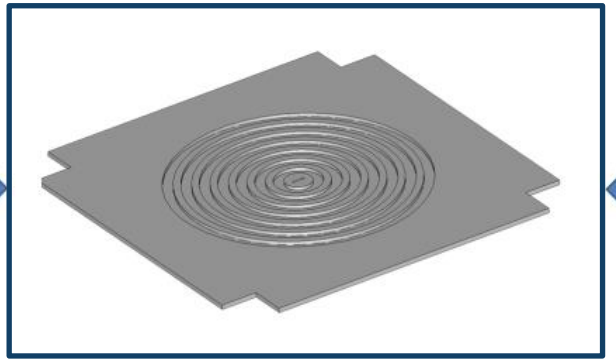
Choice of the V-band

- **Our choices**
  - **"Bull's eye" antenna**
    - Very-low profile (few millimetres)
    - Directive antenna (gain>15dBi)
    - Easy to manufacture at 60 GHz

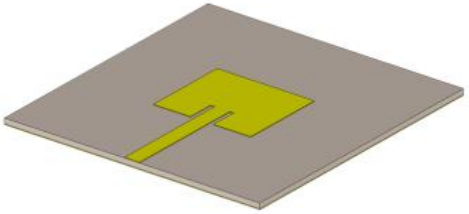
    (CNC milling machine)



Bulky, directive horn antenna



"Bull's eye" antenna

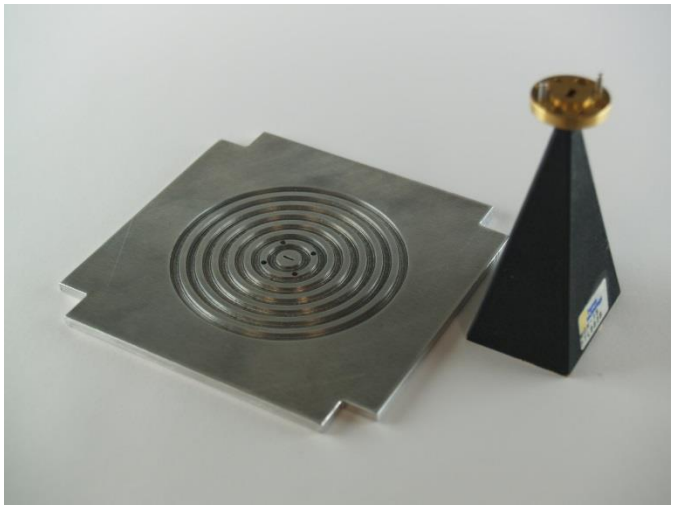


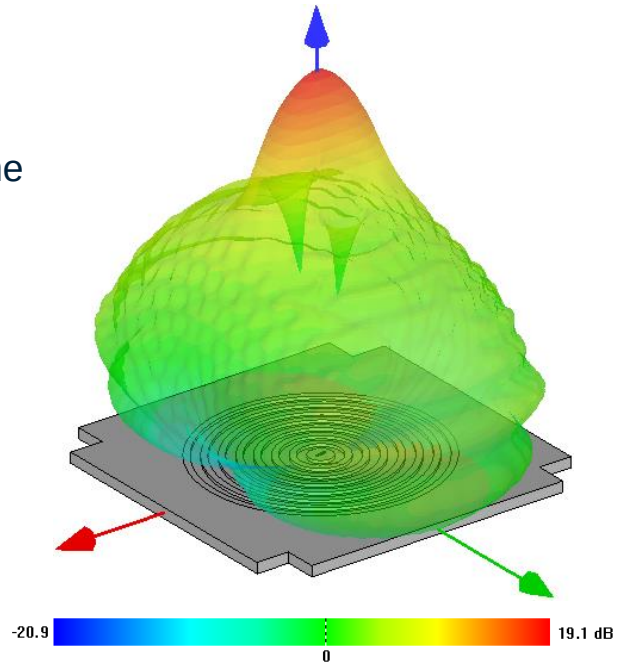
Low-profile, omnidirectional patch antenna

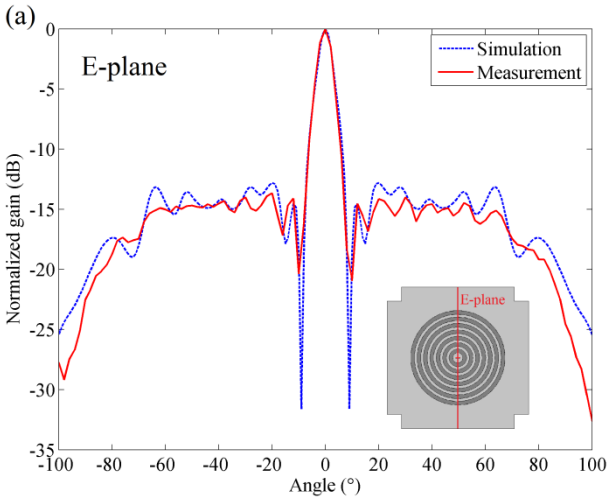
Our “Bull’s eye” design and performance

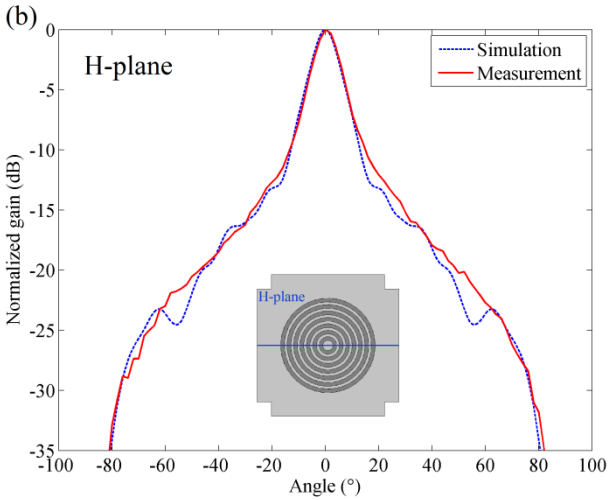
Features:

- Dimensions: 100x100x3mm
- 7 indented rings
- Gain: 19.1dBi
- Bandwidth: ~5GHz
- Fabricated with CNC milling machine









C. J, Vourch and T. D. Drysdale, ‘V-Band "Bull's eye" antenna for CubeSat applications,’ *IEEE Antennas and Wireless Propagation Letters*, 13 . pp. 1092-1095. 2014

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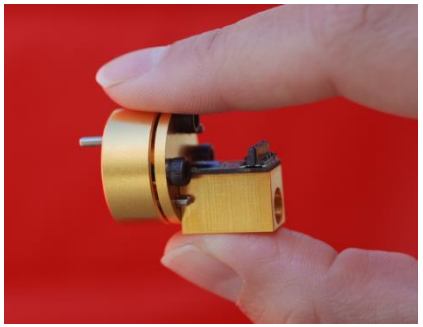
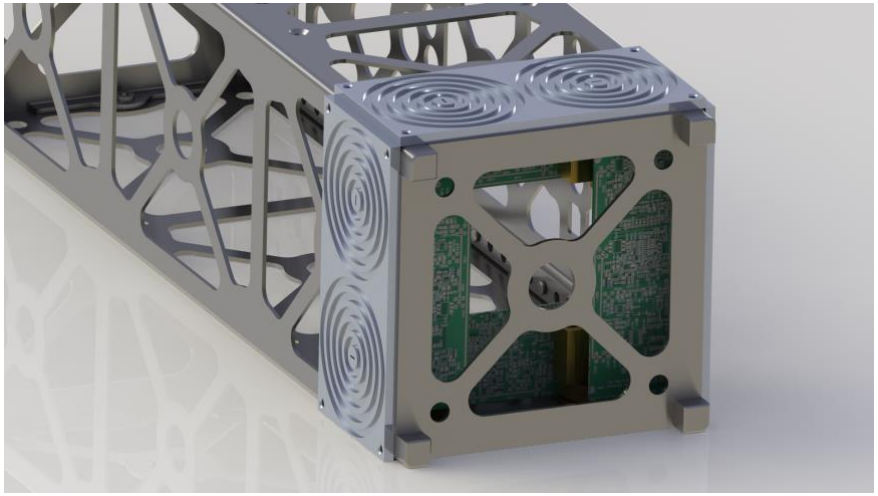
Future work: integration

- **Integrated RX/TX V-band module**
  - Provides a standardised solution with integrated RX/TX antennas
  - Module size: 50x100x40mm (0.5U)
  - Commercial VubiQ modules:
    - Output power: 10mW
    - Frequency: 57 to 64 GHz
    - 1.5 GHz of modulated bandwidth



Credit: VuBiQ, Inc



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Conclusion

- For physical reasons, CubeSats will never have the same capabilities than conventional satellites. We need to work on the type of mission for which they are more appropriate: there is a an opportunity for swarms of CubeSats

- Efficient communication systems are necessary for distributed task-based swarms
  - Swarms development is driven by recognized strategic importance of the CubeSat platform
  - V-band “Bull’s eye” antenna communication module addresses the problem of high-data rate communication within a swarm CubeSats
    - 12GHz of available bandwidth
    - Very-low profile, highly-directive and cheap “Bull’s eye” antenna
    - Commercially available V-band communication module for terrestrial applications