Latest performance prediction of the single pixel feeds for the SKA1-mid array (J2-9)

Isak Theron* and Robert Lehmensiek

EMSS Antennas, iptheron@emss.co.za

SKA1-mid baseline

- 133 panelled dishes
  - Offset Gregorian
  - 15m projected diameter
- 5 single pixel frequency bands
  - 350 to 1050 MHz (3:1)
  - 950 to 1760 MHz (60%)
  - 1.65 to 3.05 GHz (60%)
  - 2.8 to 5.18 GHz (60%)
  - 4.6 to 13.8 GHz (3:1)

Driving requirement

- Sensitivity

$$A\downarrow e\ /T\downarrow sys\ = \eta A\downarrow p\ /T\downarrow sky + T\downarrow spill + T\downarrow rec$$

- Average over band, zenith to 30° elevation*
  - Band 1: 4.2 m^2/K
  - Band 2: 7.1 m^2/K
  - Band 3: 7.1 m^2/K
  - Band 4: 6.6 m^2/K
  - Band 5: 6.1 m^2/K

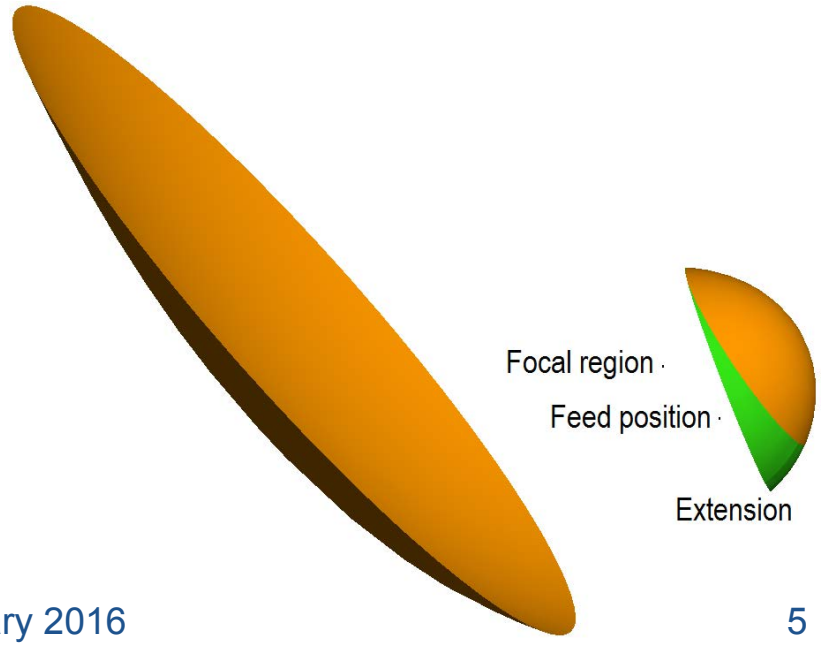
* Assuming perfect optics

Improve sensitivity

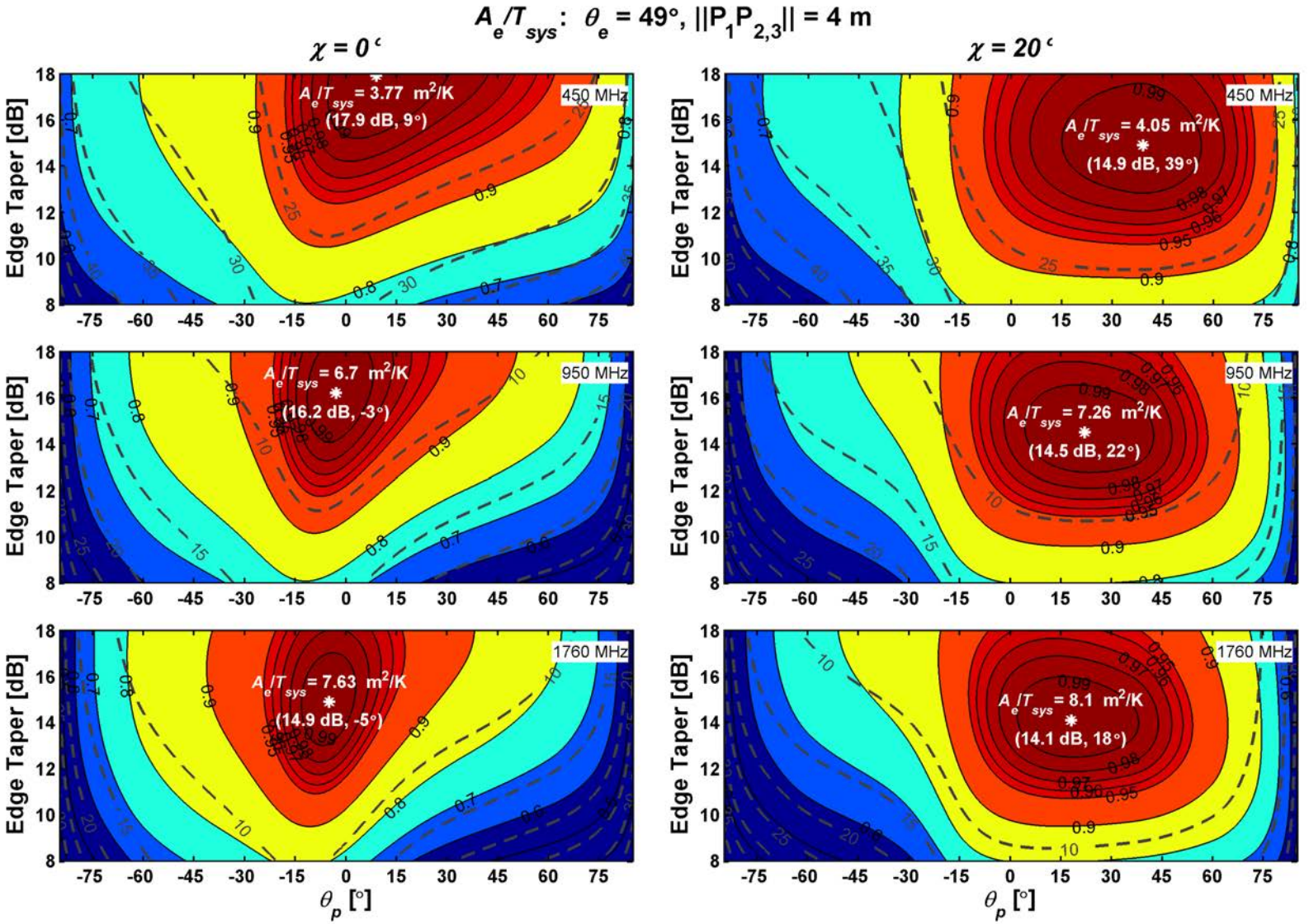
- Add effective area
  - More physical area is expensive (and locked)
  - Shaped optics to improve efficiency (some cost)
  - Difficult to improve more
- Reduce system noise temperature
  - Cooling as a fraction of total system cost
  - Cool as low as possible
    - Gifford-McMahon cooling
    - Both LNAs and lossy components

Optics configuration

- Shaped reflectors
- Extended sub-reflector (40° from feed point)
  - Allow high efficiency without increasing spill-over
  - Feed down configuration
- 58° feed half angle
  - Optimised suite of feeds
  - Similar to 49° unshaped
  - Similar to MeerKAT
- 5.2m sub-reflector



Gaussian feeds - sensitivity



Optimising the feeds

- Maximum sensitivity
  - Calculate “feed on dish” pattern to determine sensitivity
  - Optimum is dependent on the receiver noise
- Minimum reflection coefficient
  - Can reduce sensitivity
  - Cause frequency ripple if LNAs badly matched
- Limit cross-polarisation
- Some limit on side-lobes

Band 3, 4, 5 feed package

- Band 5 increased in priority during 2015
- Single feed package
  - Coordinated by Oxford University
    - Responsible for cryostat
  - Save power by using a single cold head
    - Provided it can lift the heat load (seems OK)
  - More complicated
    - Optimised multiple heat paths
    - Some feeds (and locations) not fully designed
    - May switch to wideband feeds

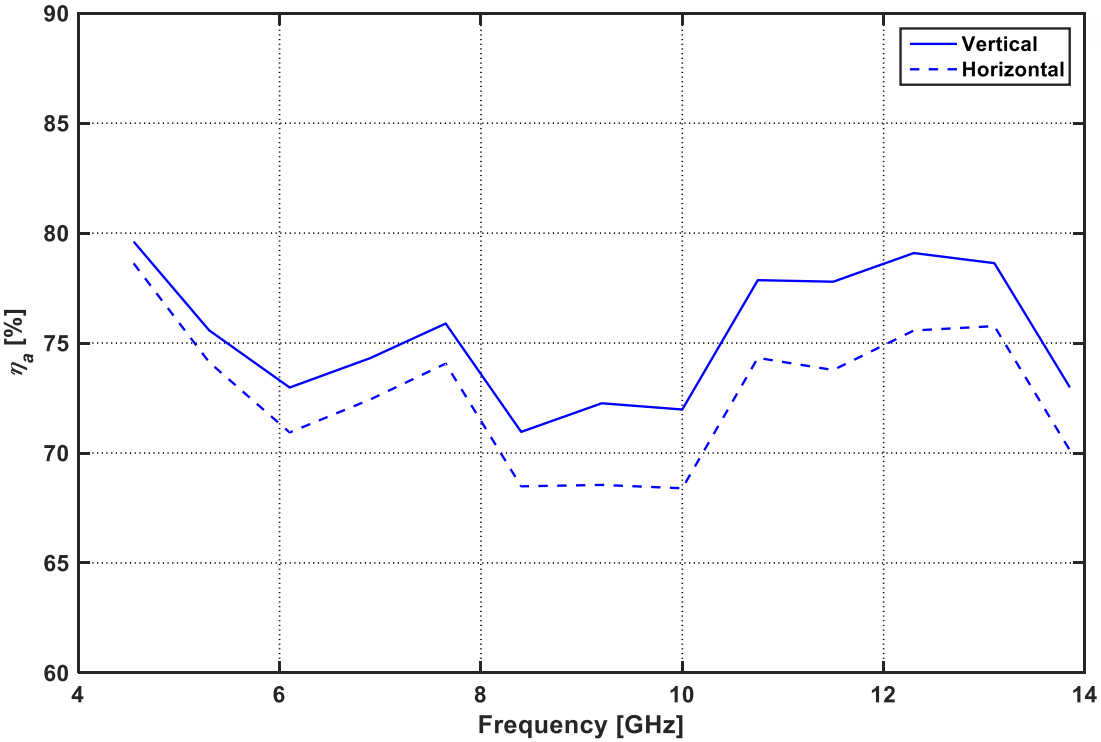
Noise temperature estimate

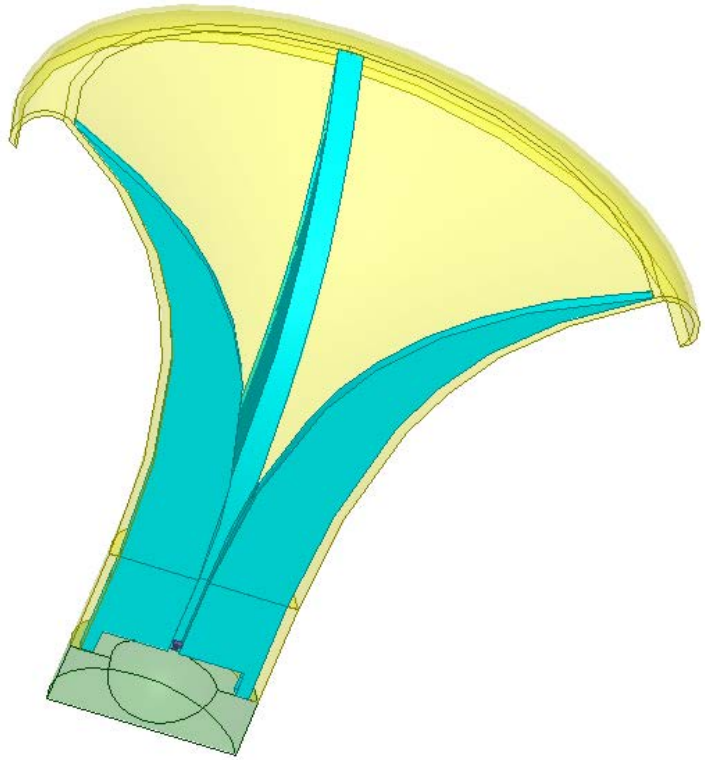
- Vacuum window provides thermal isolation
- Horn to LNA cable critical
- COTS Low Noise Factory LNA
- Reflector contributions larger
- Very preliminary!

	Band 5
Vacuum window	1.5 K
Quad-ridge feed horn	0.7 K
Horn to LNA cable	4.0 K
LNA	6.5 K
Dish structure and digitiser / back end contributions	3.0 K
$T_{Receiver}$	15.7 K

Band 3, 4, 5 feed package

- Band 5 most likely a QRFH similar to Band 1
  - JLRAT in China



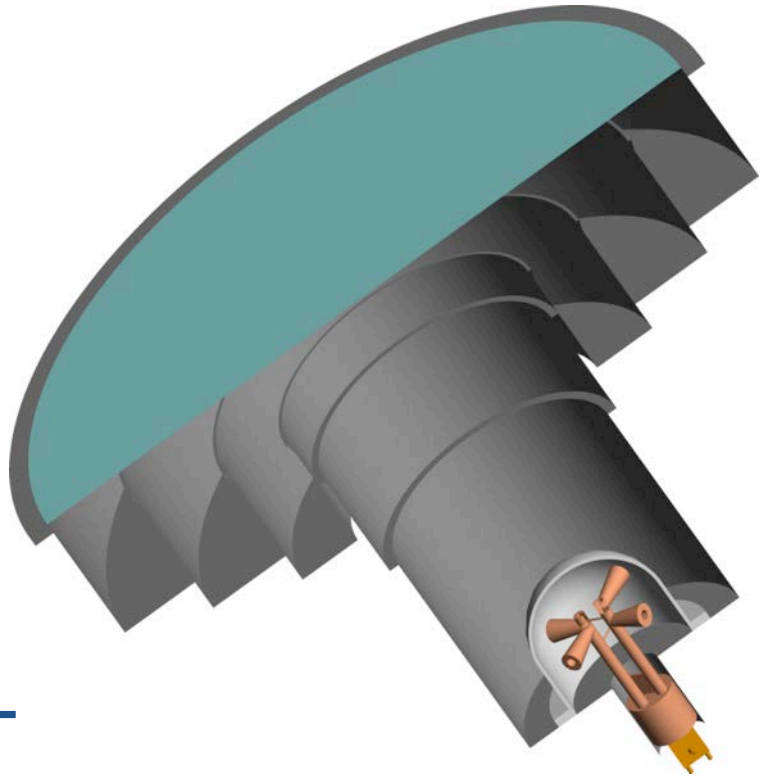


Band 5 sensitivity

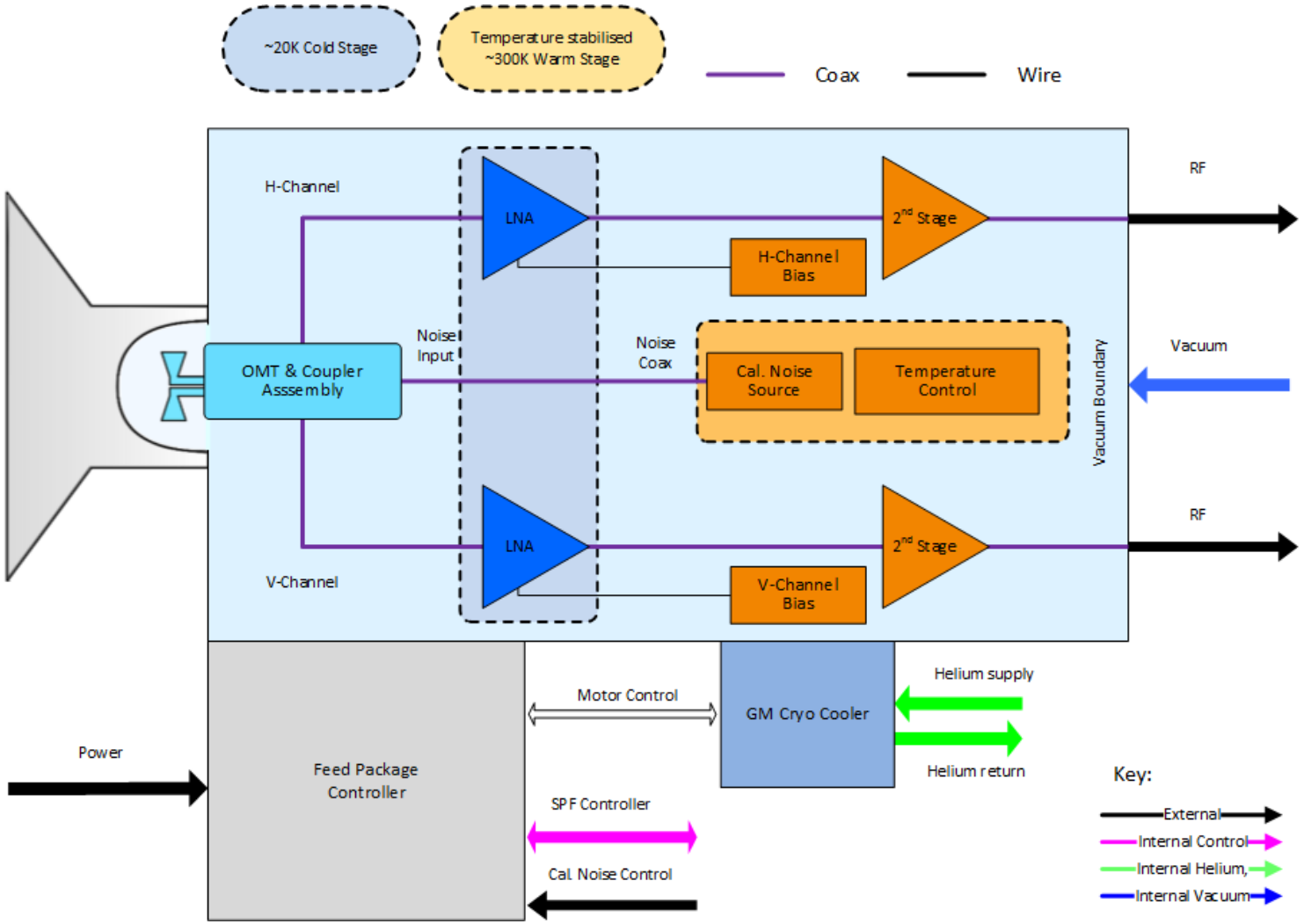
- Average Band 1 efficiency slightly higher
  - Assume an efficiency of 75%
- At 13.8 GHz the sky contribution ≈ 7 K
- Even with no spill-over
  - Sensitivity ≈ 5.8 m^2/K
  - Need to reduce receiver temperature to achieve specified 6.1 m^2/K

Band 2 feed package

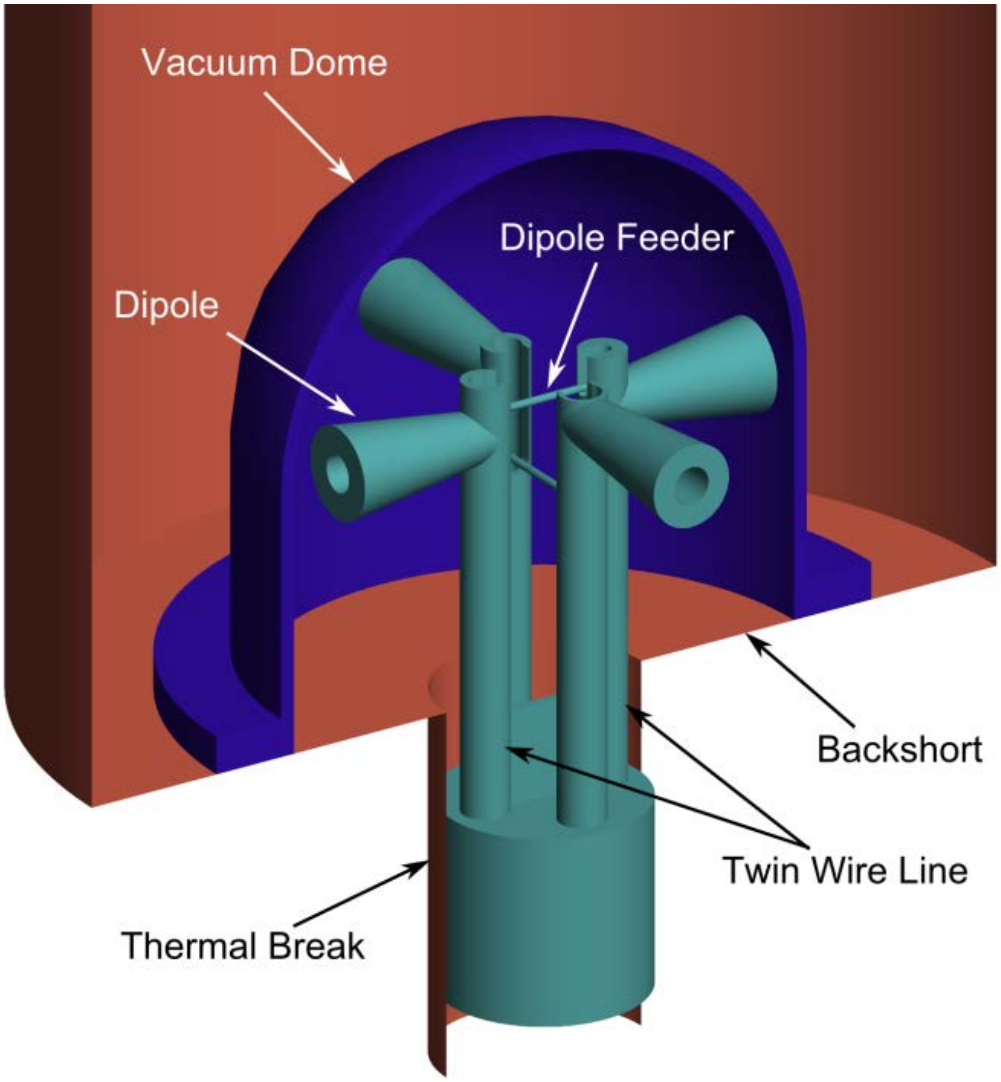
- Clone of MeerKAT L-band “receiver”
  - EMSS Antennas
- Axially corrugated feed
- Dipole OMT cooled
  - Back short ambient
- HDPE dome vacuum boundary
- Coupler integrated in OMT
  - Part of the thermal break

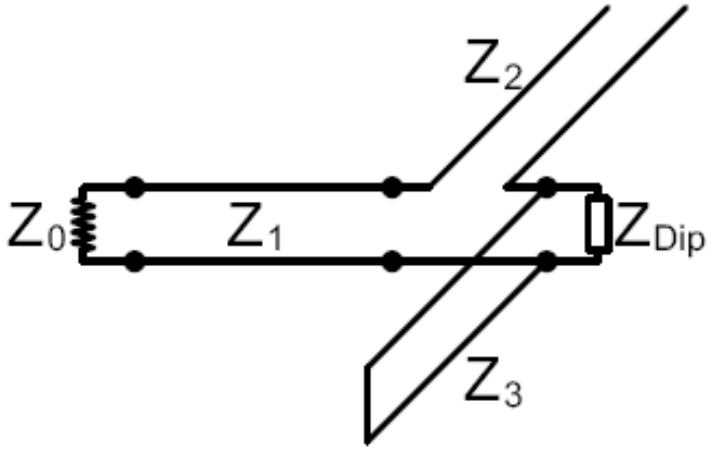


Band 2 feed package

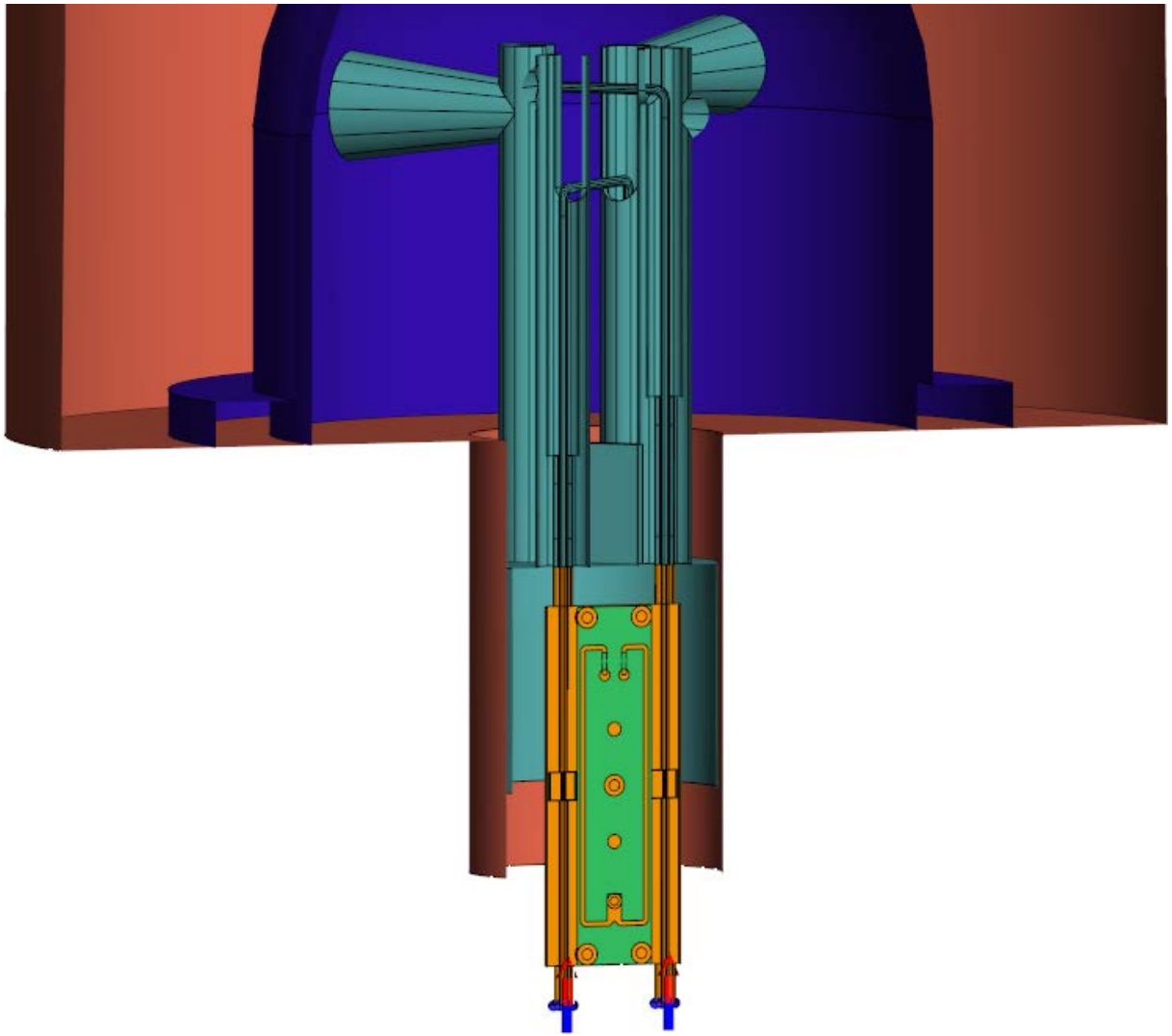


Ortho mode transducer



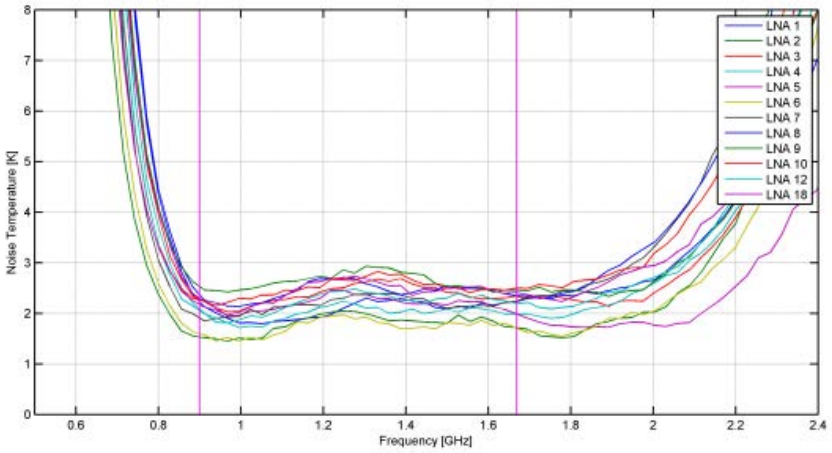


Calibration noise coupler



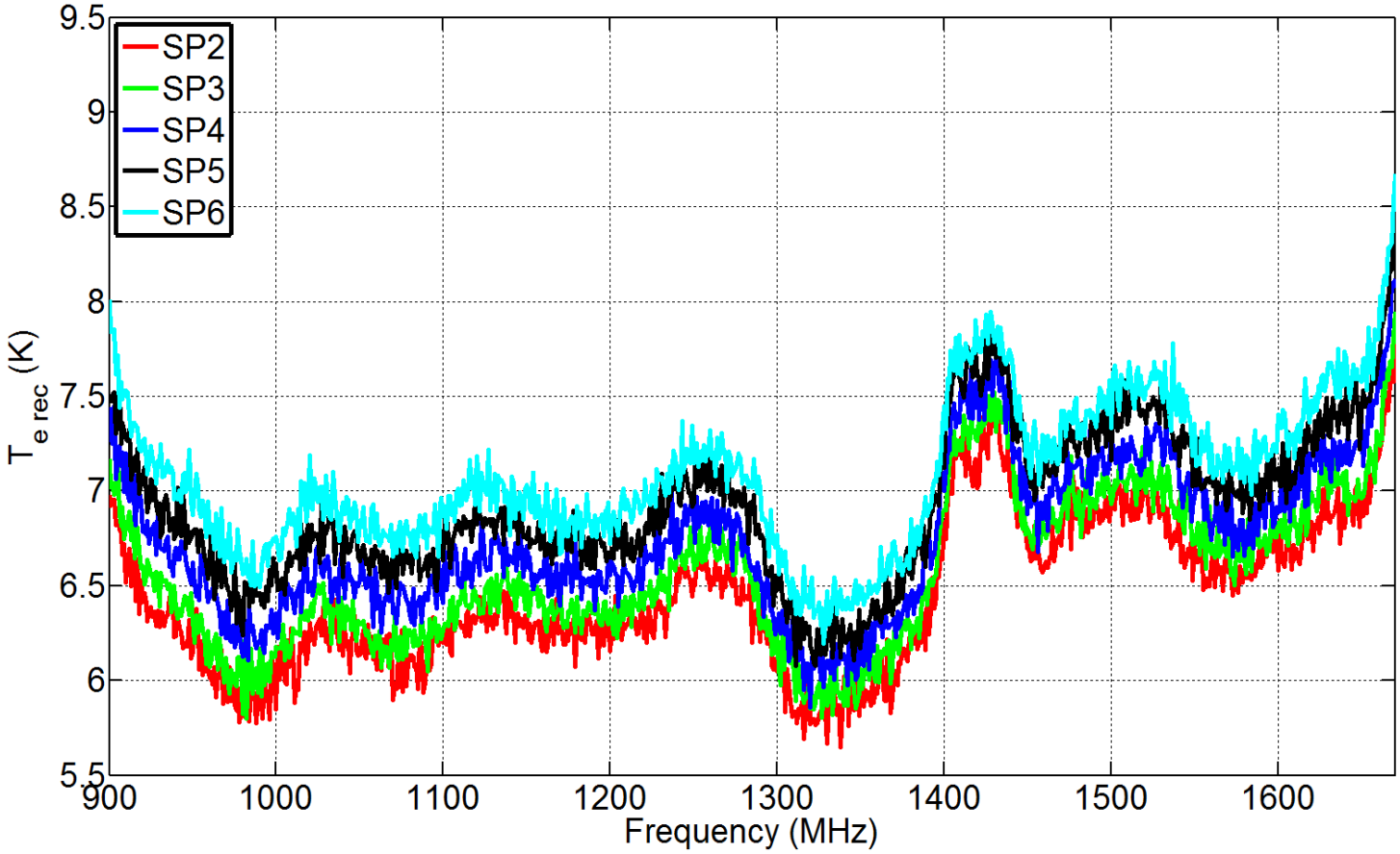
Noise temperature estimate

	950 MHz	1760 MHz
Horn and radome	0.1 K	0.1 K
Vacuum window, OMT, Coupler	1.1 K	1.3 K
Coupler to LNA thermal isolation	1.0 K	1.5 K
Coupler output connector	0.5 K	0.5 K
LNA	3.0 K	3.0 K
Post-LNA RF	0.5 K	0.5 K
Dish structure and digitiser / back end contributions	2.0 K	2.0 K
$T_{Receiver}$	8.2 K	8.9 K



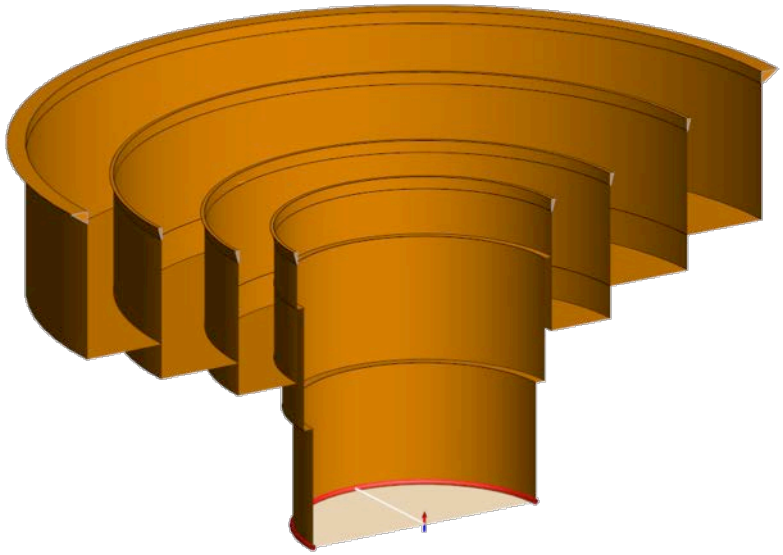
MeerKAT receiver temperature

- Physical 15.7, 17.7, 19.6, 21.6, 23.4 K



Optimising the horn

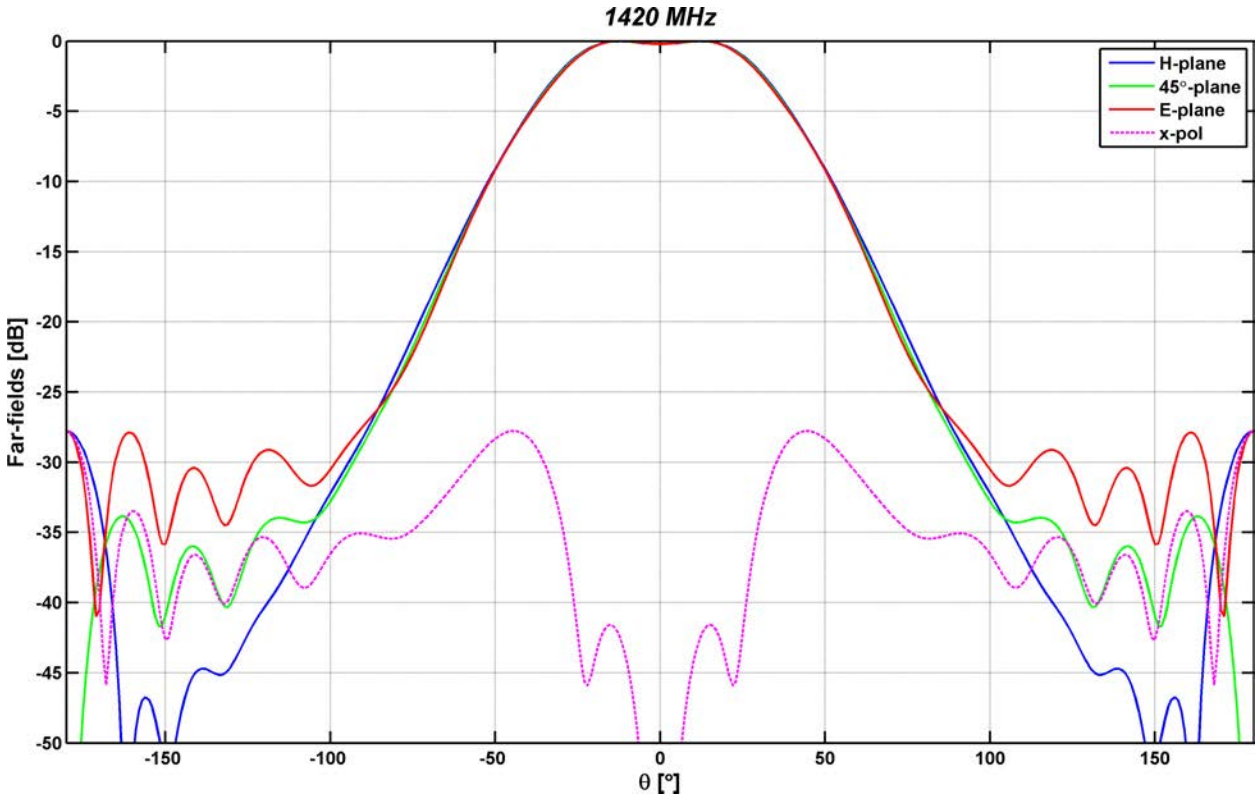
- Wide flare axially symmetric corrugated horn
  - Good pattern symmetry
  - Good cross-polar performance
  - Low loss
- Optimisation parameters
  - Corrugation width, depth and offset
  - Step radius and length
  - Phase centre

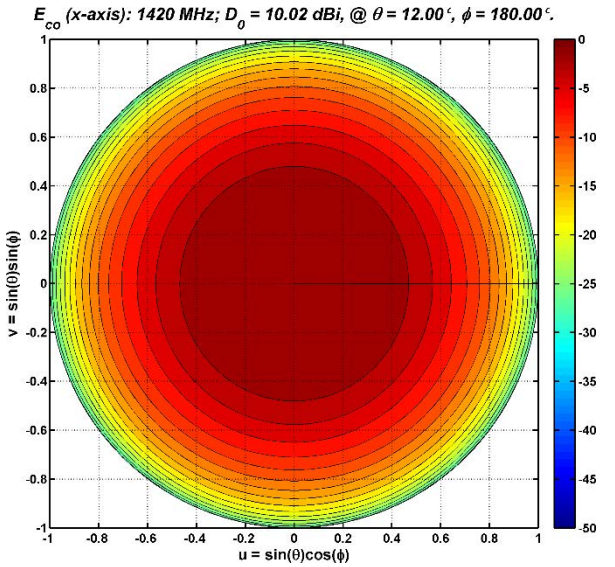


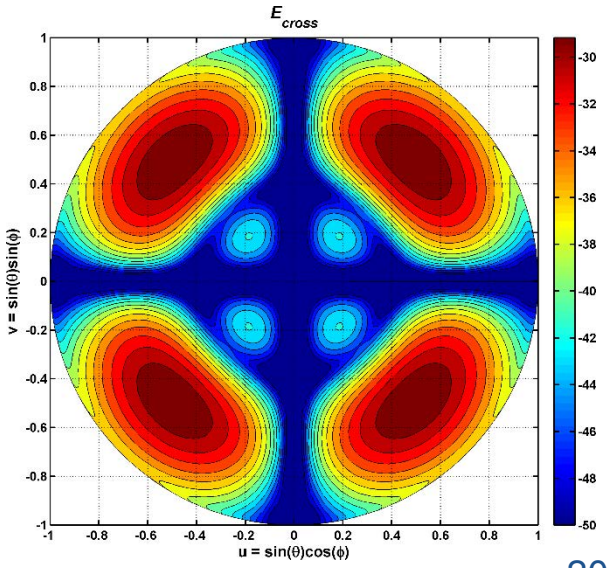
EM analysis

- Horn analyses in FEKO
  - Full wave (Method of Moments)
  - 2 planes of symmetry
  - TE_{11} mode reflection coefficient into free space
  - Spherical mode expansion of radiation pattern
- Dish analyses in GRASP
  - High frequency (Physical Optics with diffraction)
  - Reflector far field from spherical modes
  - Integrate with brightness to get $T_{antenna}$

Example horn pattern

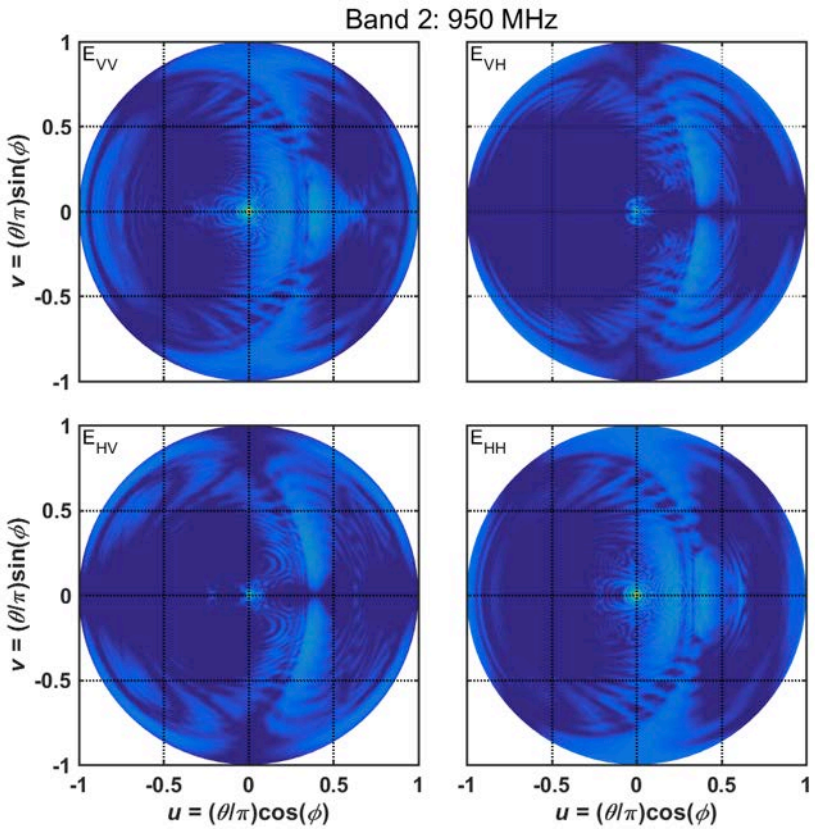


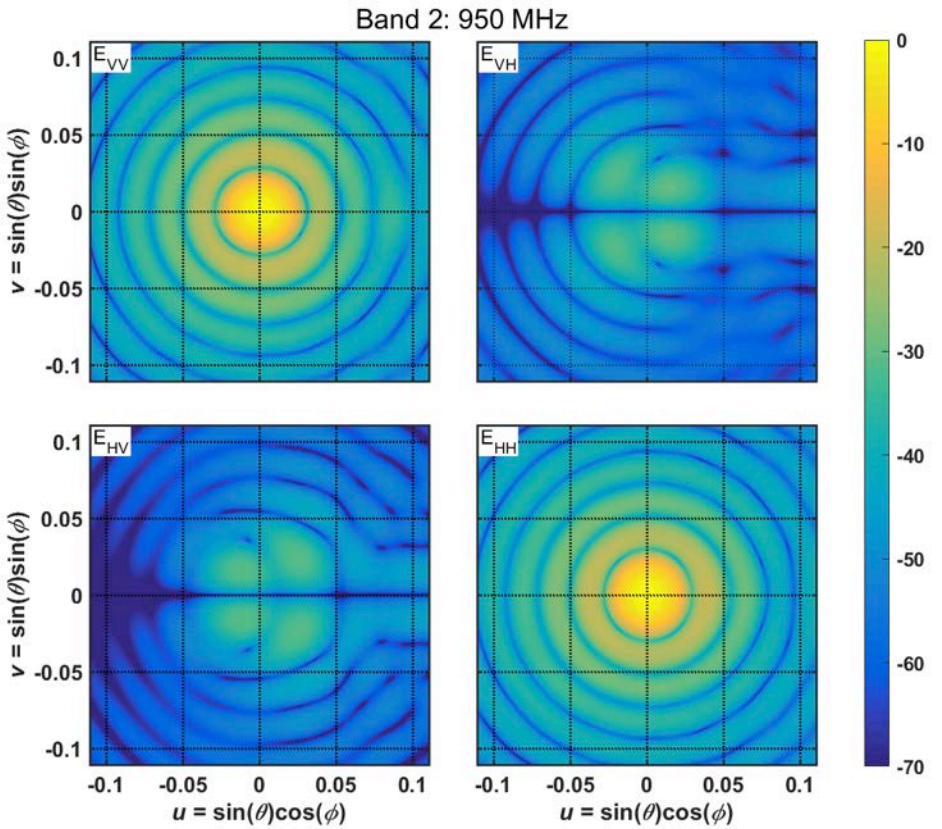




Optimised feed, dish pattern

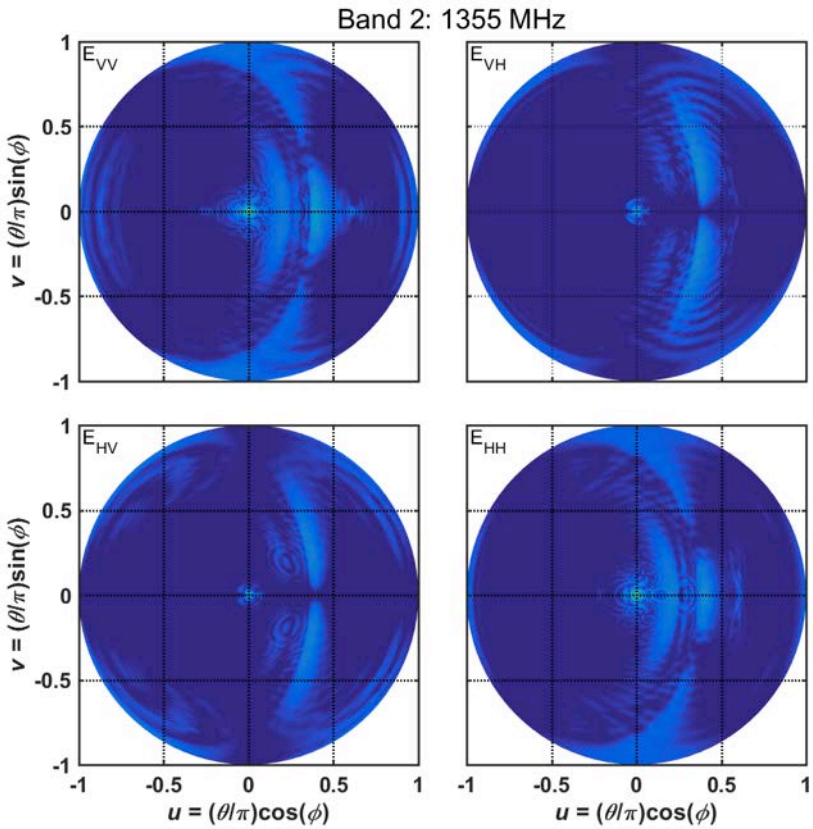
- 950 MHz

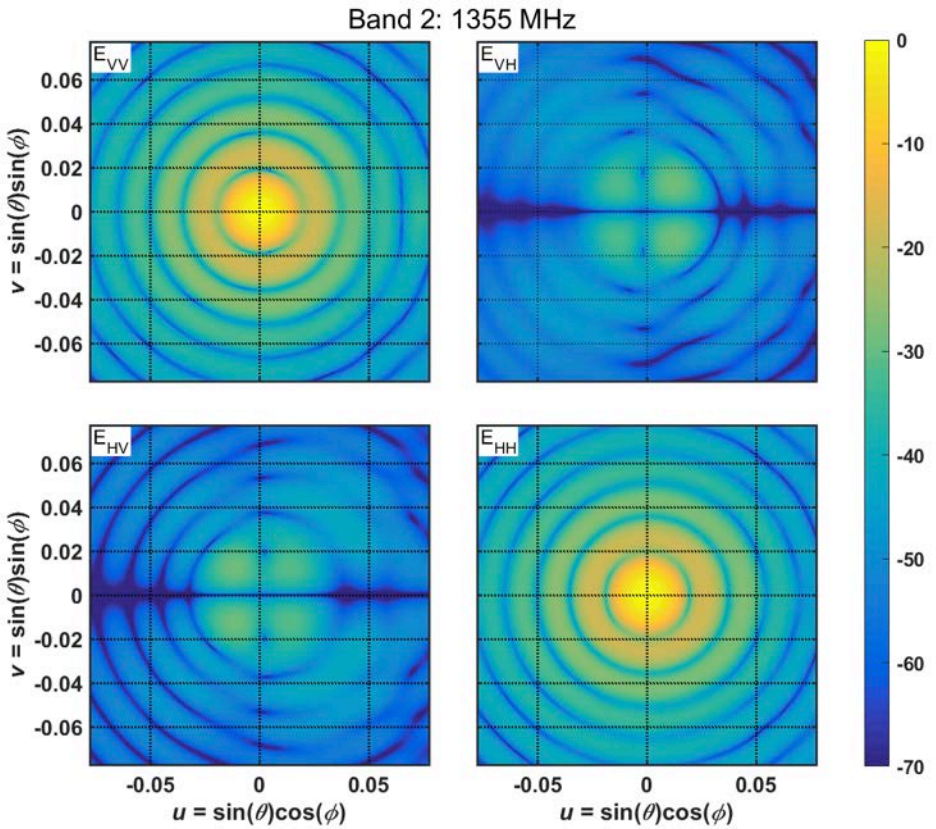




Optimised feed, dish pattern

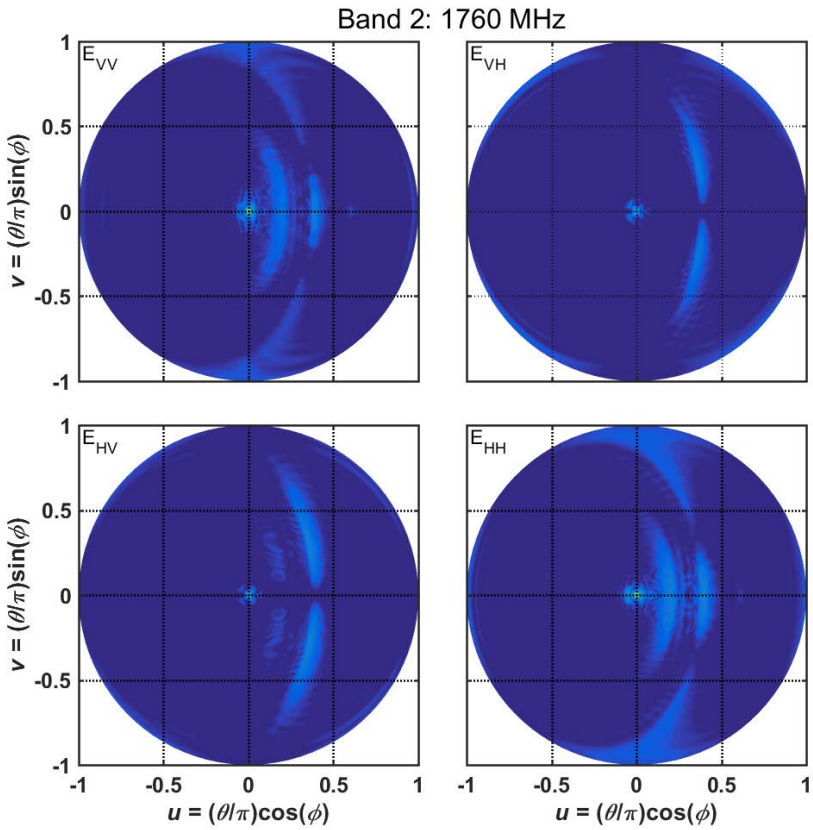
- 1335 MHz

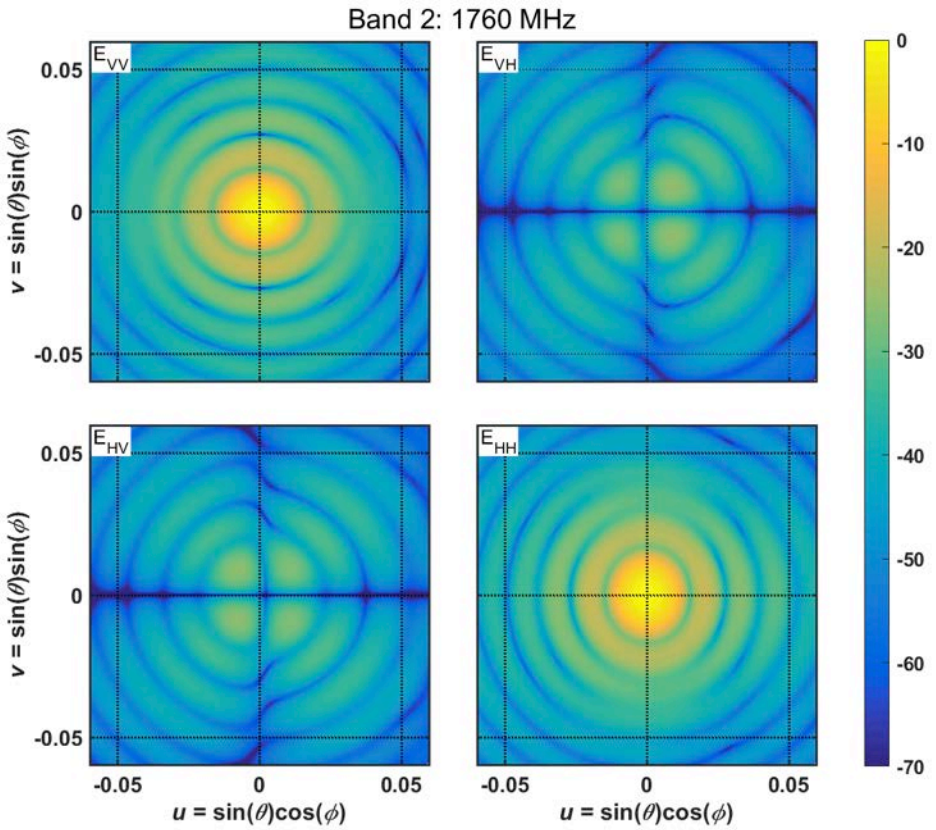




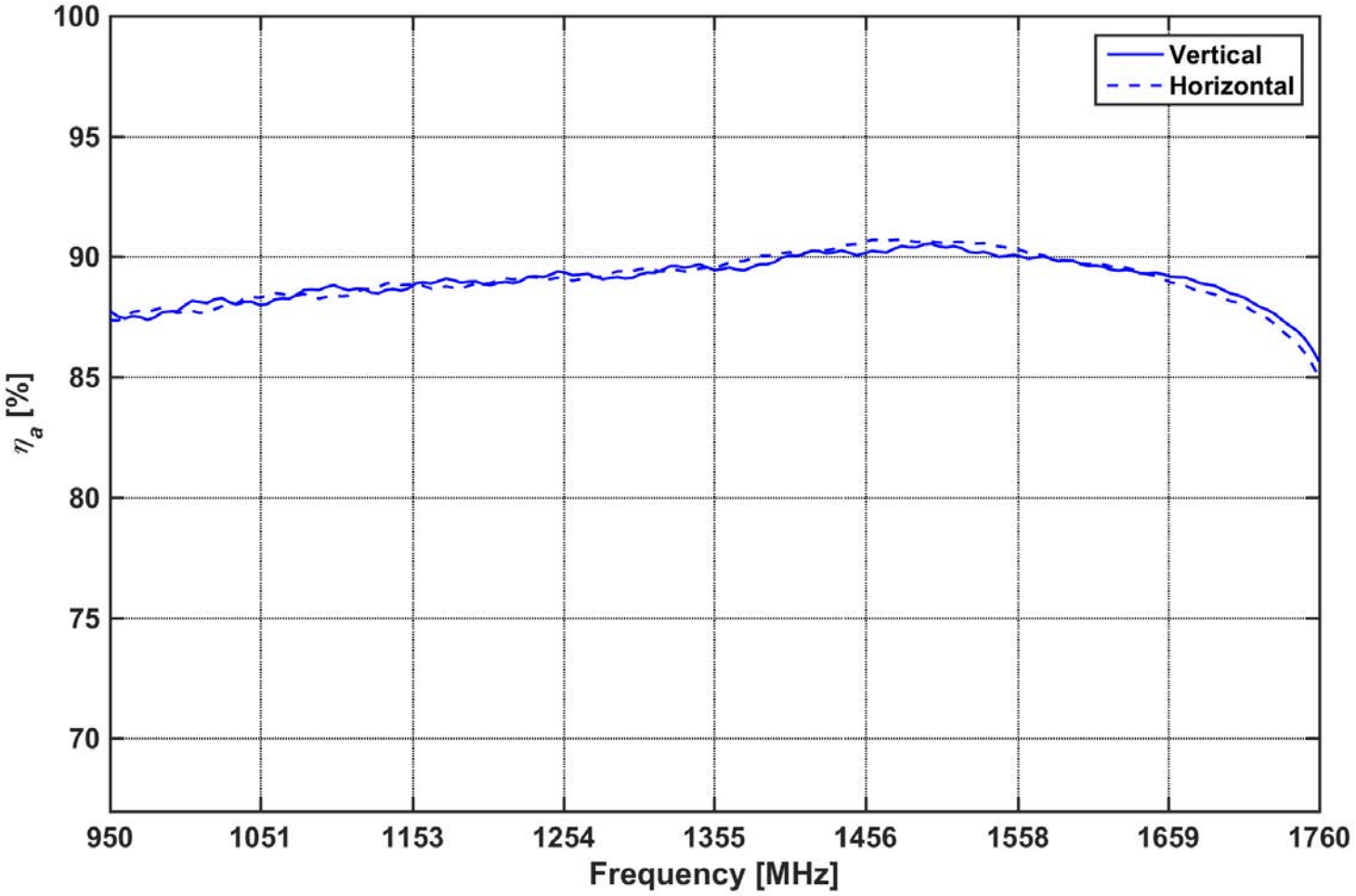
Optimised feed, dish pattern

- 1760 MHz

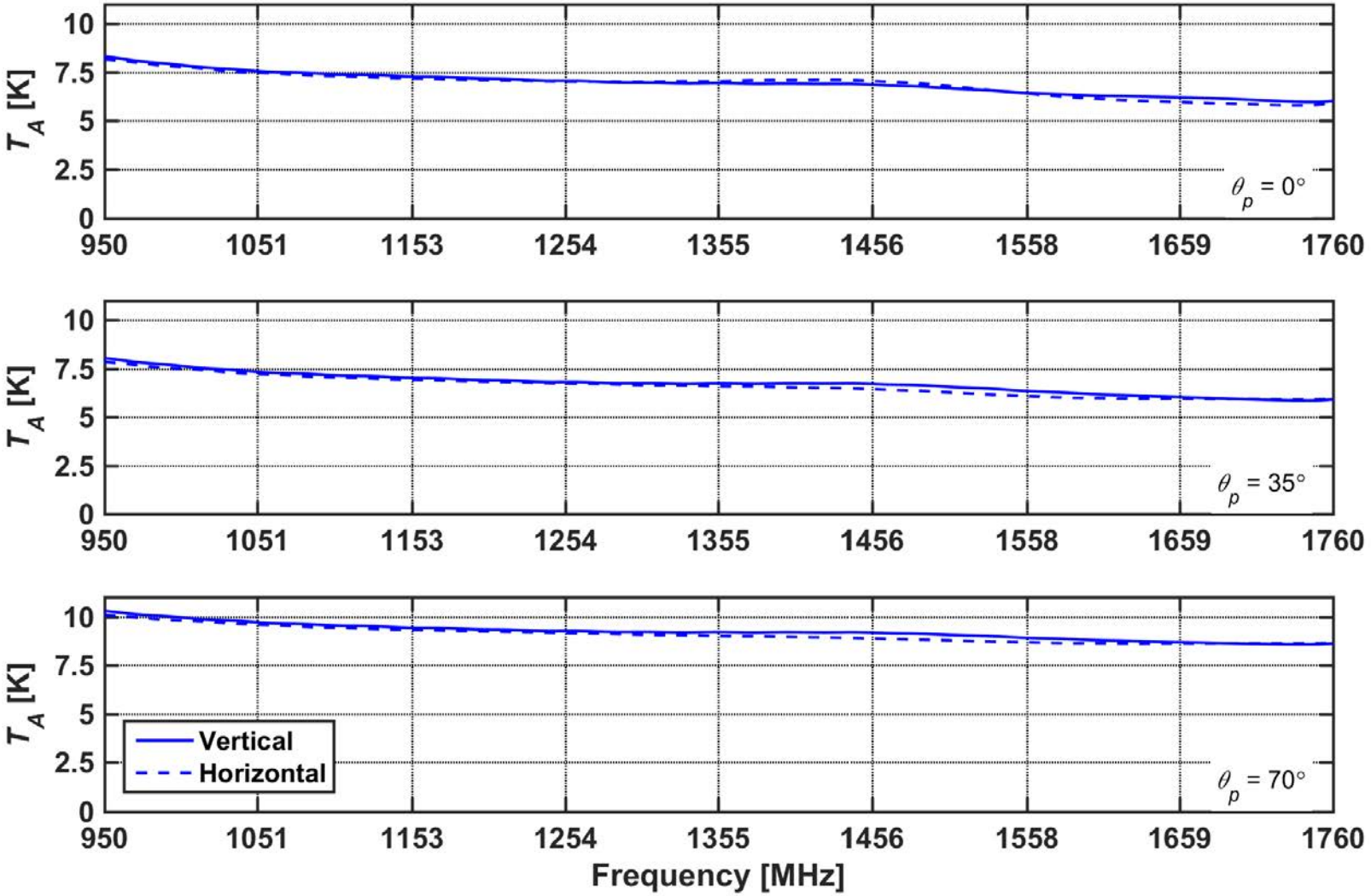




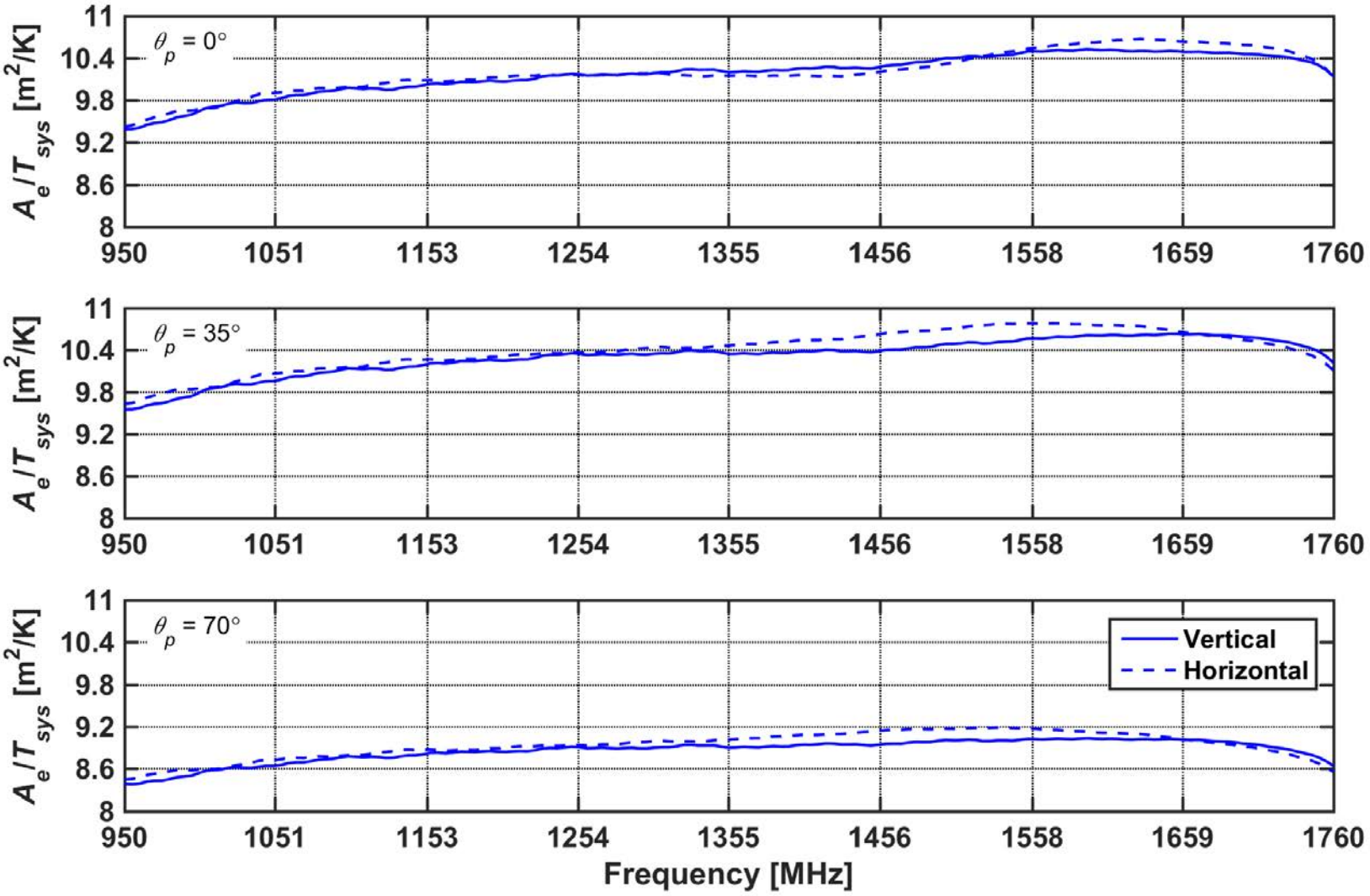
Band 2 efficiency



Band 2 antenna temperature

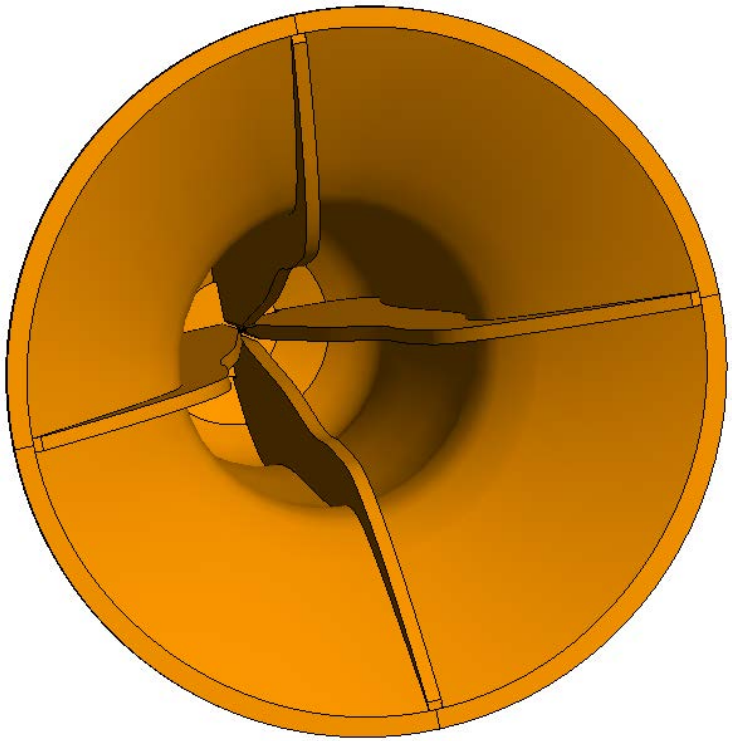


Band 2 sensitivity



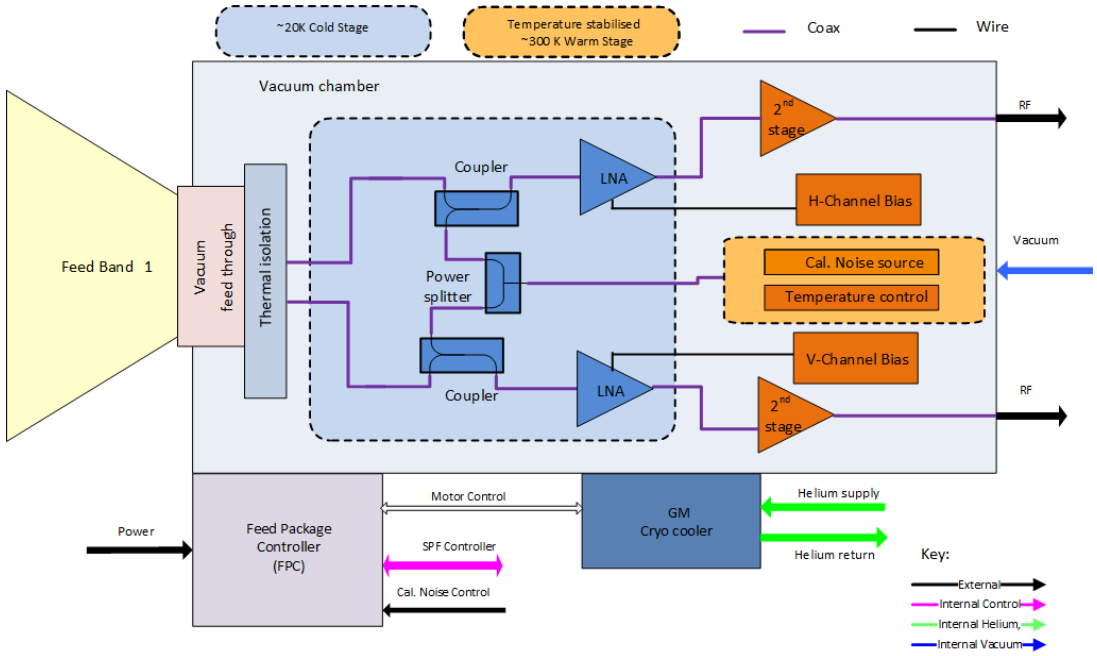
Band 1 feed package

- Band 1
  - Chalmers University in Sweden
  - Wideband – Quad ridge feed horn
    - No logical thermal break
  - Low frequency
    - Large aperture
    - Cannot cool entire feed



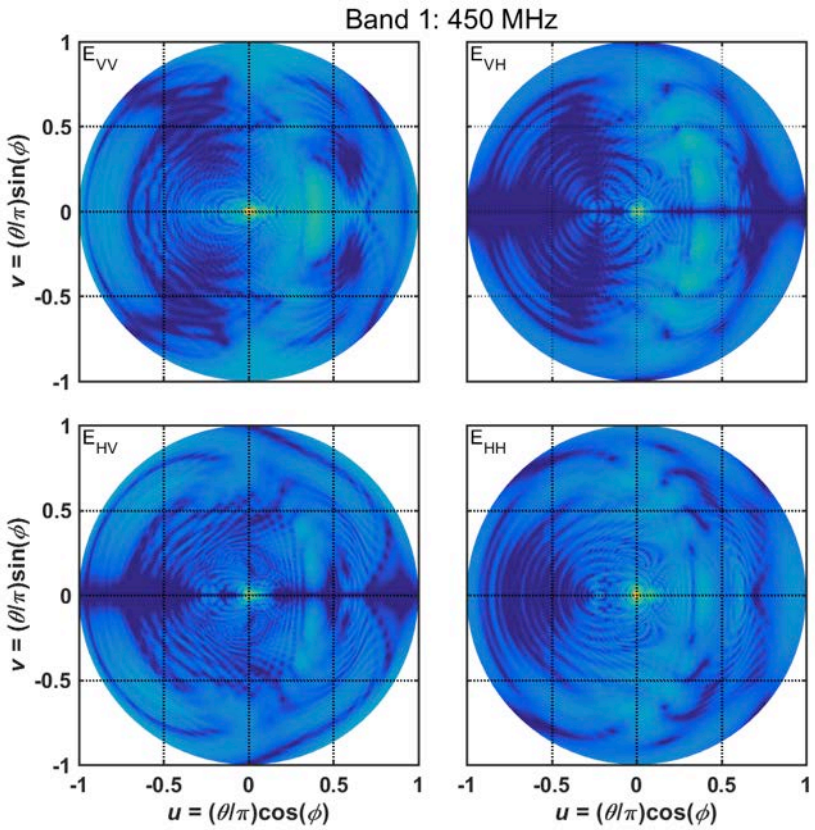
Band 1 cryogenics

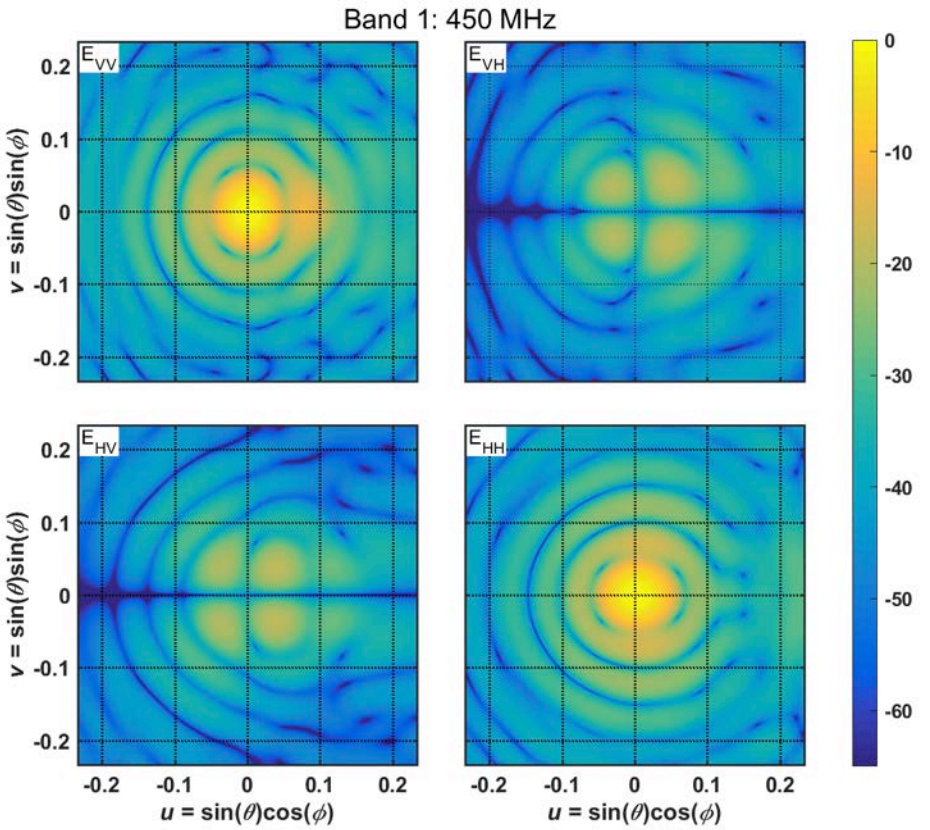
- Cool only LNAs
  - Ambient loss between feed and LNAs
  - Optimised as much as possible
  - Receiver noise
    12.9K @ 350 MHz
    18.3K @ 1050 MHz



Optimised feed, dish pattern

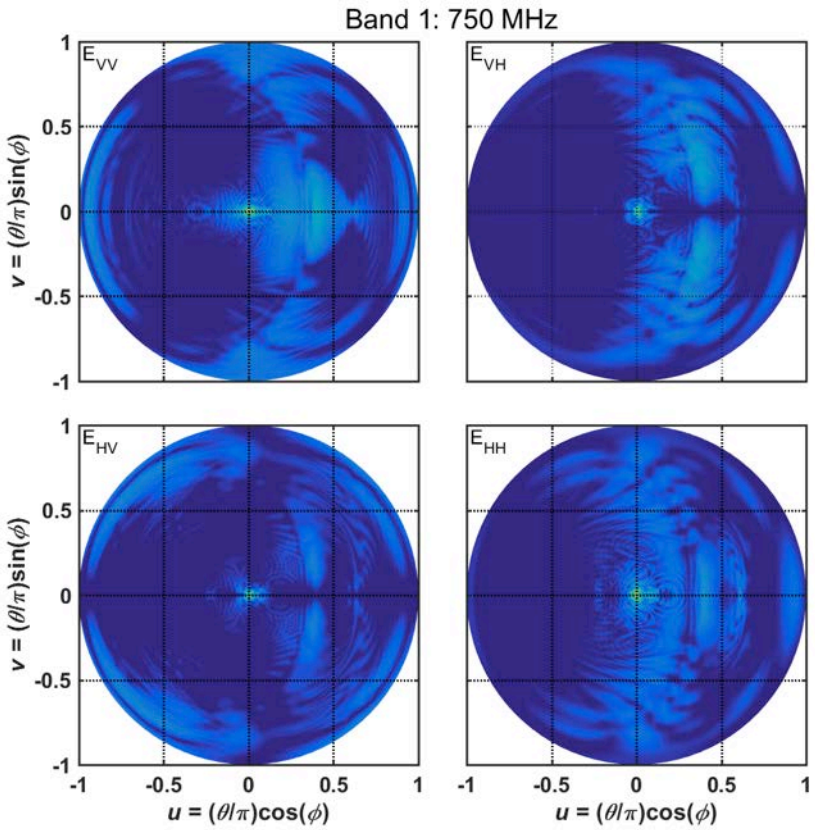
- 450 MHz

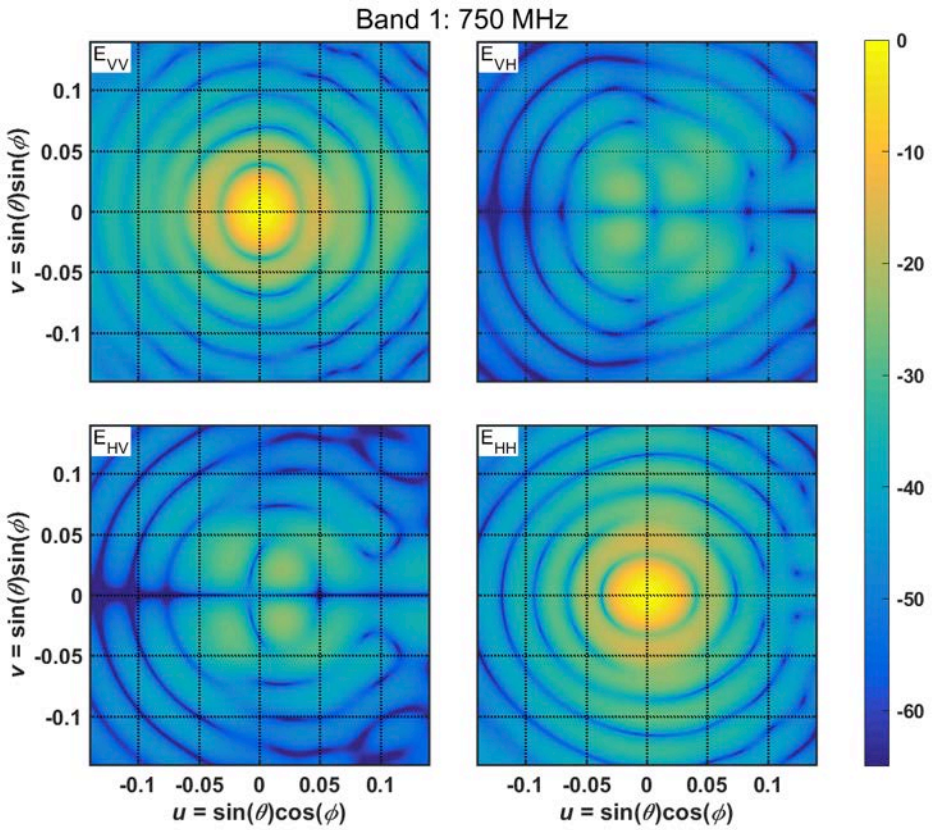




Optimised feed, dish pattern

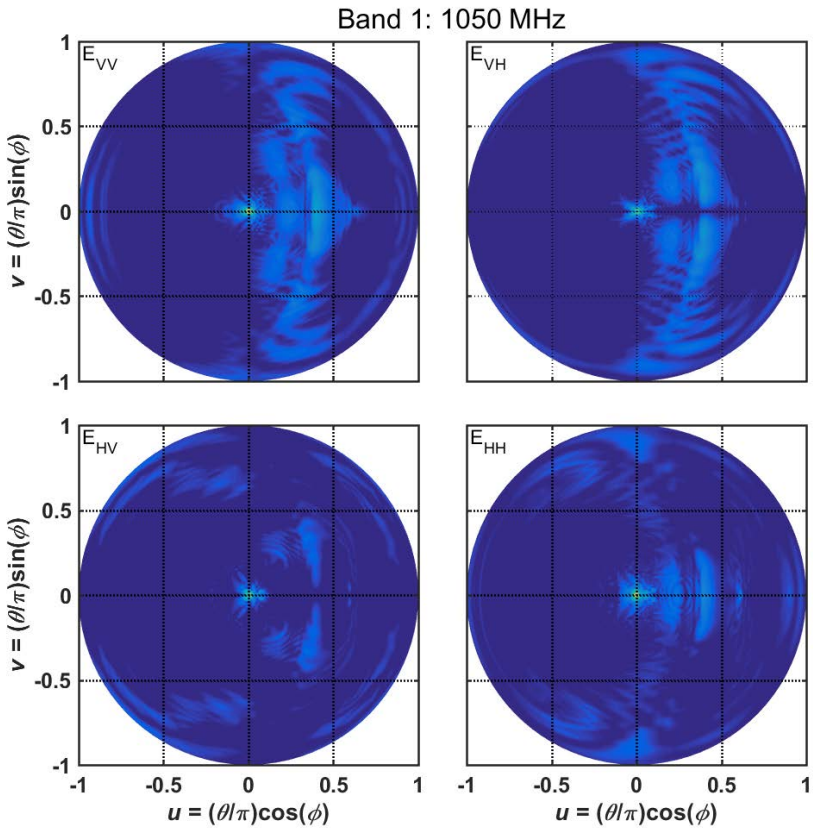
- 750 MHz

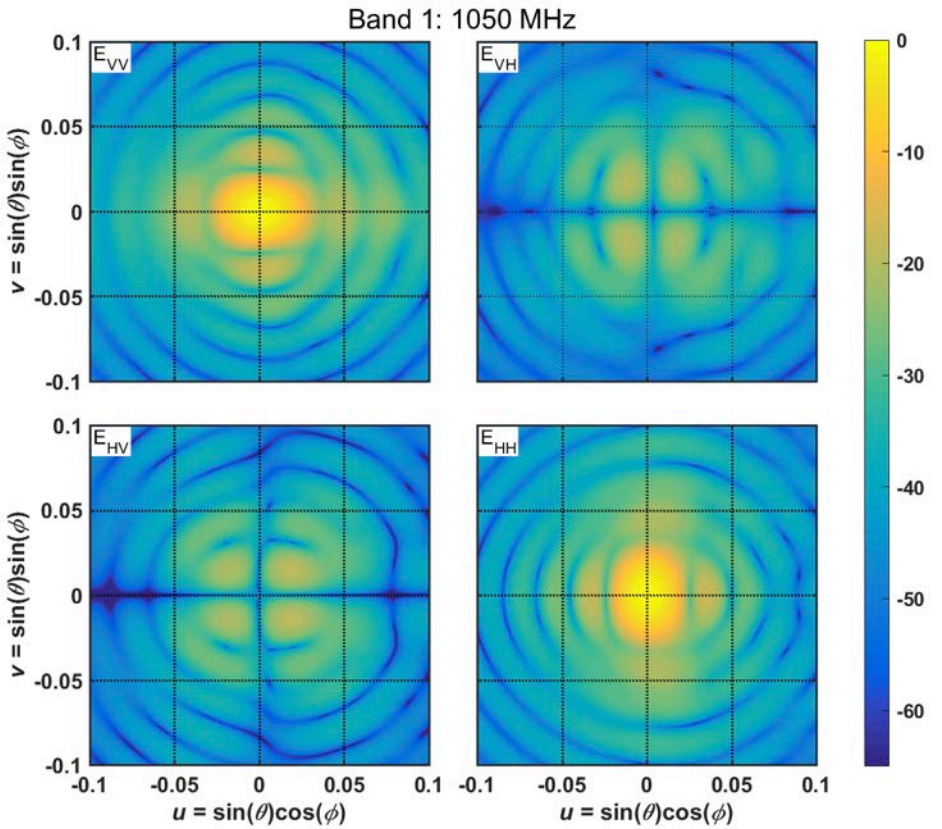




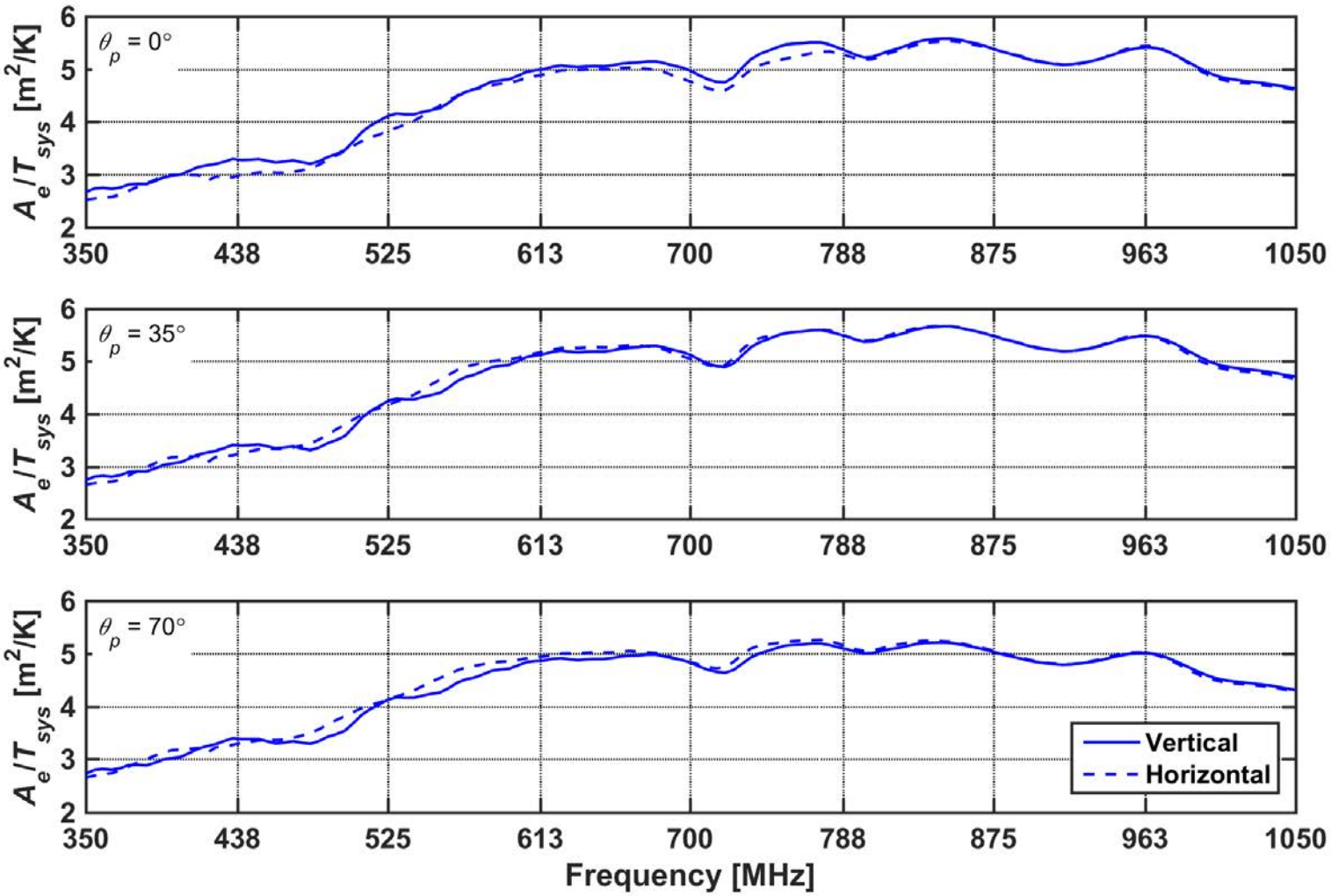
Optimised feed, dish pattern

- 1050 MHz





Band 1 sensitivity



Questions?