Cosmic Orbital and Suborbital Microwave ObservationS

Ground based CMB experiments
4/5 March 2019

Antenna Systems and Characterization through UAV

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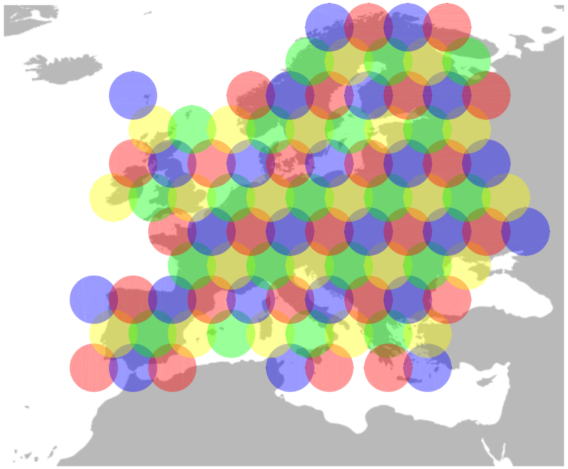
Antenna Systems for Space Applications

1. **Telecommunications**
   - Fixed Satellite Services (FSS)
   - Mobile Satellite Services (MSS) (Iridium, Iridium-Next)
   - Broadcasting Satellite Services (BSS)
   - Internet, multi-media applications, Voice over IP (VoIP), Video conference (KaSAT)
   - Military and governmental telecommunication services (Athena-Fidus)
   - ….
2. **Observation of the Earth**
   - Meteorology (MetOp, MetOp-SG)
   - Oceanography
   - Environmental disaster monitoring, seismic hazard analysis (COSMO-SkyMed)
   - …
3. **Navigation and Localization**
   - GPS
   - Galileo
   - …
4. **Cosmology and Fundamental Phisics**
   - Astrophysical surveys (Planck, WMAP)
   - …
5. **Space Exploration**
   - Planet exploration (ExoMars)

Antenna Systems for Space Applications

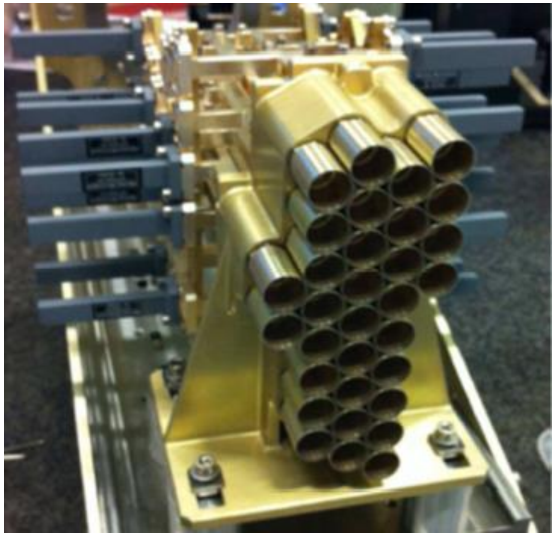
System Requirements

- High capacity (SatCom)
- Multi-frequency (SatCom, EO)
- On-ground coverage (SatCom, EO)
- High resolution (EO, Science)
- High sensitivity (EO, Science)



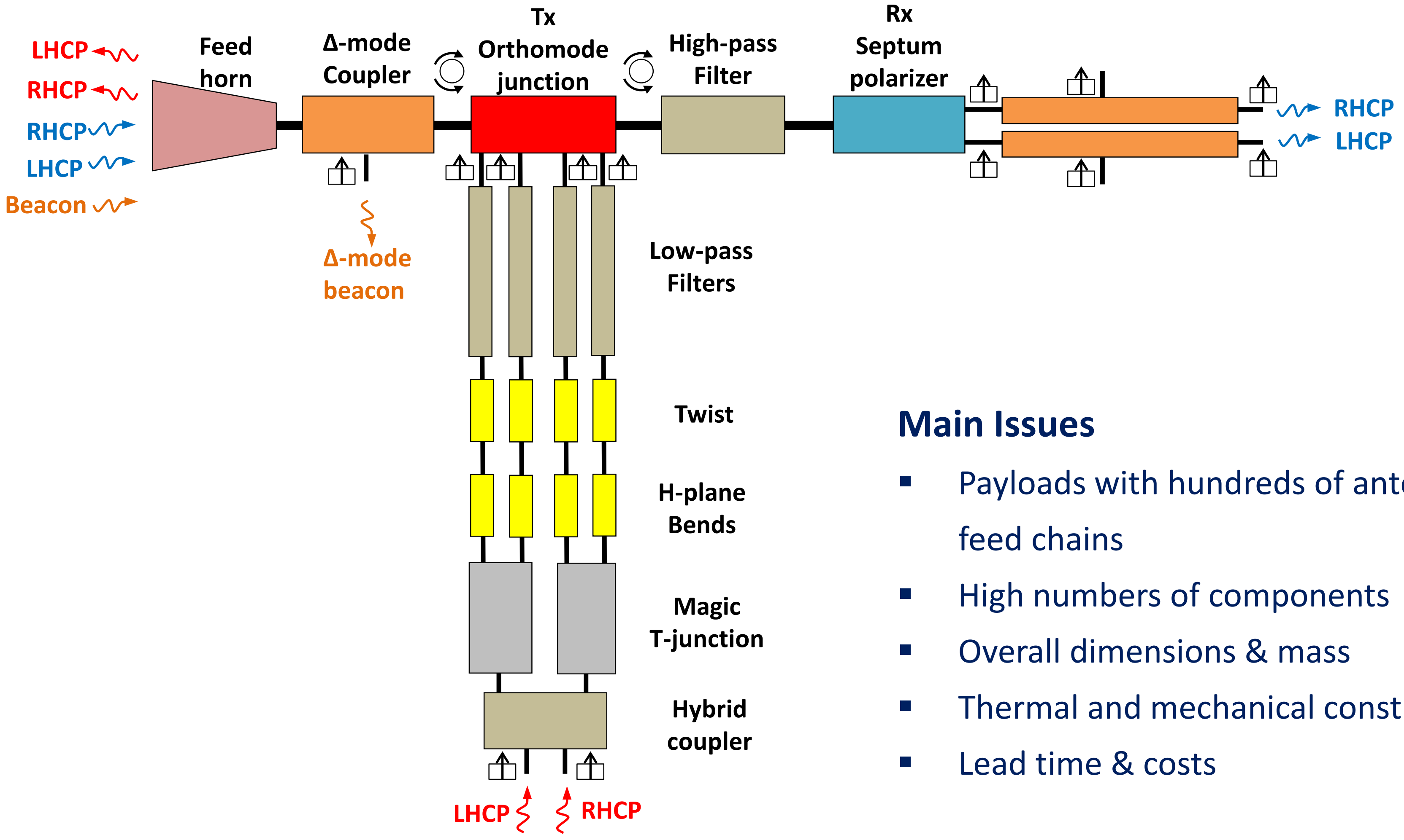
Antenna-feed cluster for SFB SatCom antennas

(Courtesy of Thales Alenia Space)



K/Ka-band	
Tx band (GHz)	17.7 – 21.2
Rx band (GHz)	27.5 – 31.0

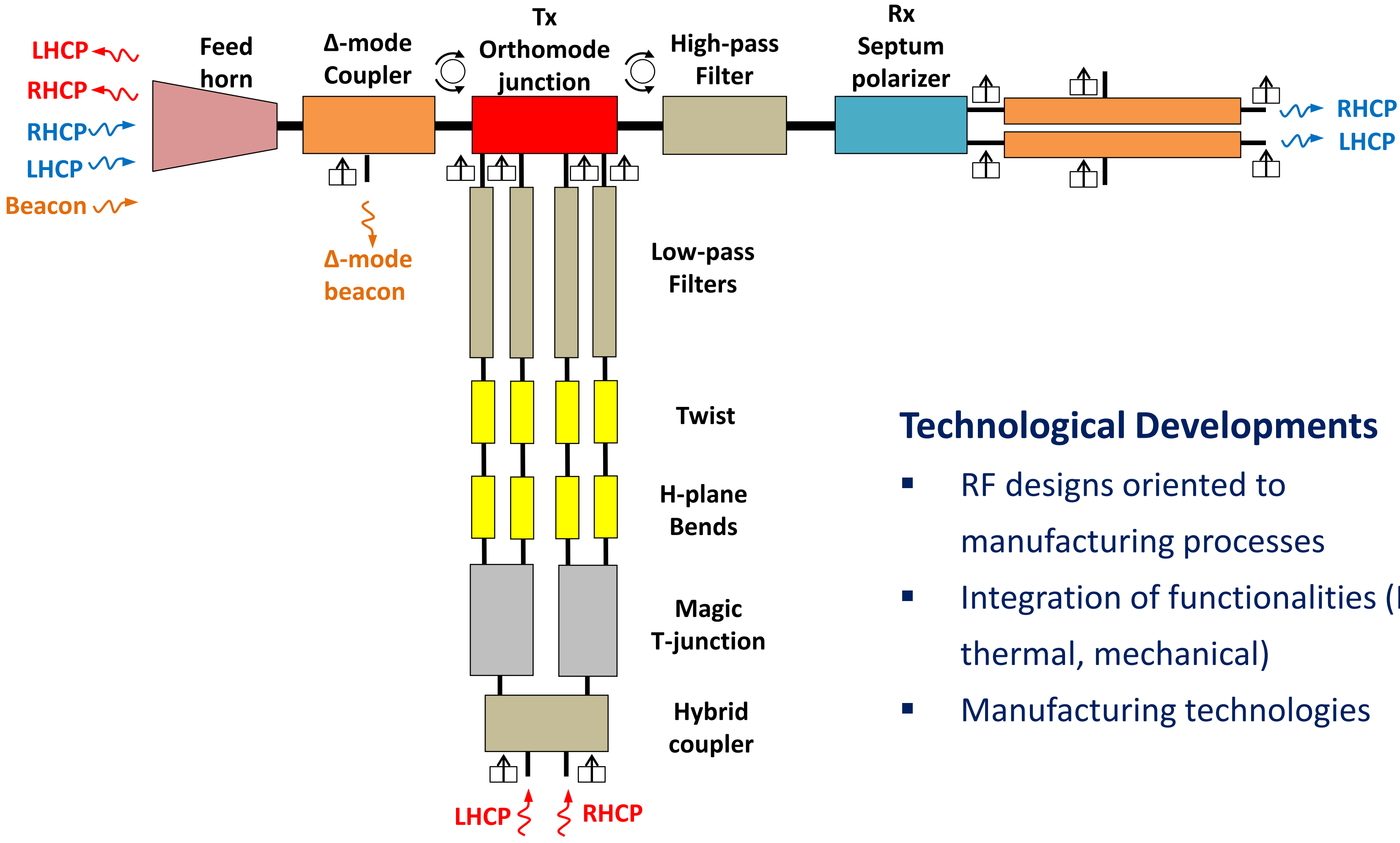
Multi-Beam & Multi-Band Antenna-Feed Systems



Main Issues

- Payloads with hundreds of antenna-feed chains
- High numbers of components
- Overall dimensions & mass
- Thermal and mechanical constraints
- Lead time & costs

Multi-Beam & Multi-Band Antenna-Feed Systems

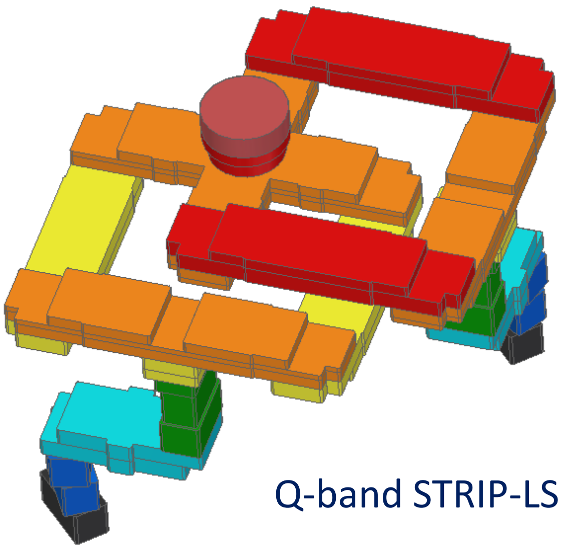


Technological Developments

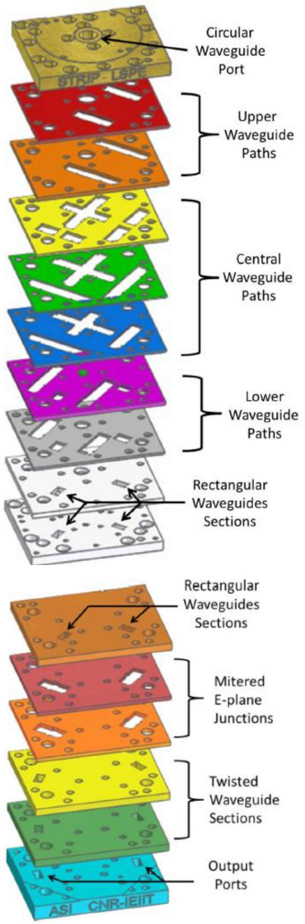
- RF designs oriented to manufacturing processes
- Integration of functionalities (RF, thermal, mechanical)
- Manufacturing technologies

RF Designs Oriented to EDM Platelet Manufacturing

- Multi-layer layout with standard-thickness metal layers
- Manufacturing process parallelization (wire EDM)
- Symmetric design ⇔ channel equalization
- Plumbing to match the correlation unit flange



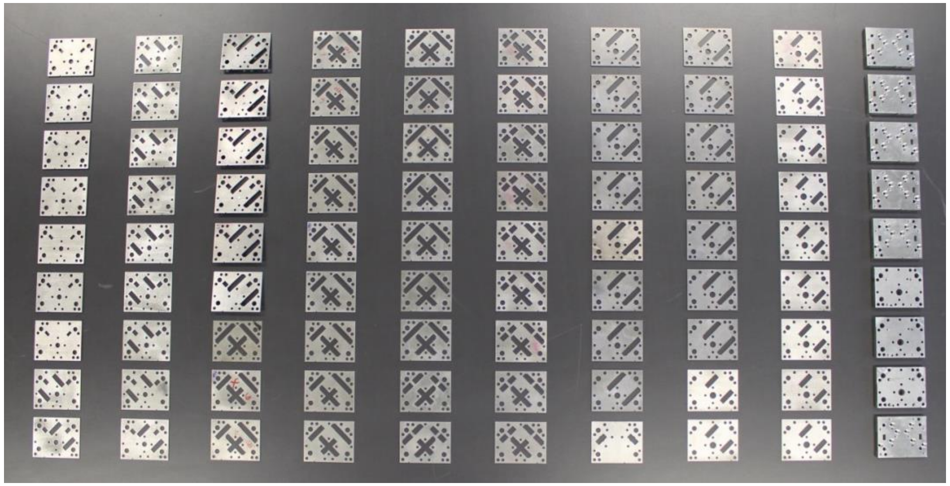
Q-band STRIP-LSPE OMTs



ASI project N. I/038/09/0 “Sviluppi tecnologici nel millimetrico per missioni di polarizzazione”

ASI project N. I/038/09/0 “Large Scale Polarization Explorer”

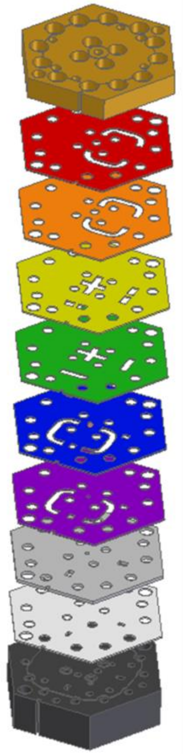
RF Designs Oriented to EDM Platelet Manufacturing

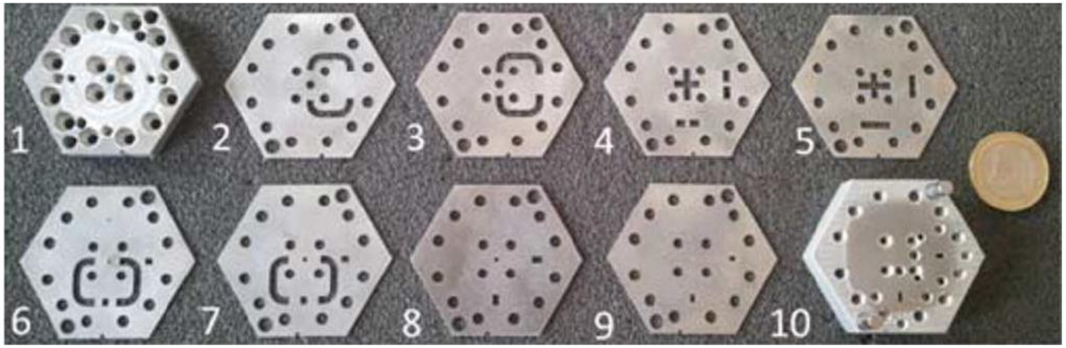


Q-band STRIP-LSPE OMTs

Measured Performance	
Band (GHz)	39 – 48 (nominal) (21%) 29 – 50 (enlarged) (53%)
Return loss (dB)	> 22 (> 5)
Insertion loss(dB)	< 0.6 (< 0.3 silver-plated)
Cross-coupling (dB)	< -50
Isolation (dB)	> 50

W-band Platelet Ortho-Mode Transducer





Measured Performance & Envelope	
Band (GHz)	81 – 109 (30%)
Return loss (dB)	> 21
Insertion loss(dB)	< 0.25 (@ room temperature)
Cross-coupling (dB)	< -40
Isolation (dB)	> 40
Waveguide structure dimensions	22 mm x 22 mm x 24 mm
External lattice step	42 mm

RF Designs Oriented to 3D Printing

Main Advantages

- Manufacturing of parts with complex geometries ➡ integration of several RF functionalities in a single block, minimization of flanges and screws (SFB, MFB)
- Design flexibility ➡ novel layouts of waveguide components
- Near-net shapes ➡ reduction of mass and waste
- Reduction of lead time and cost ➡ more efficient component development

Main Issues

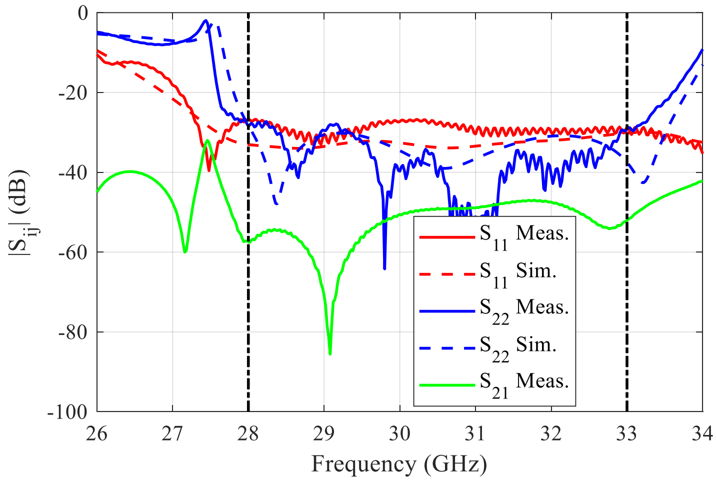
- Manufacturing accuracy and repeatability ➡ impact on RF performance @ high frequencies
- Maximum part size ➡ applicability limits to low frequency applications (C, X bands)
- Surface roughness ➡ high insertion losses
- Qualification and quality assurance ➡ standardization of new processes

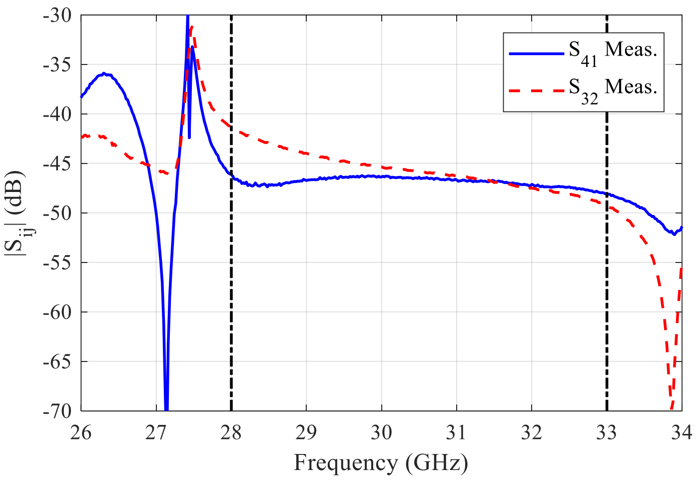
ESA project AO/1-9376/19/NL/HK "Evaluation and consolidation of Additive Manufacturing processes and materials for the manufacturing of RF hardware"

ESA project AO/1-8876/17/NL/CRS "3D printing of high-frequency components"

RF Designs Oriented to 3D Printing: OMTs

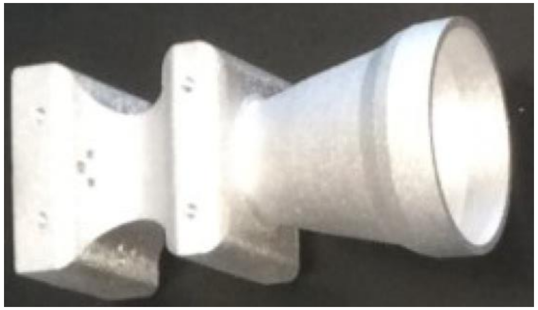
Parameter	Value
Operative Band	28.5 – 31.2 GHz (10%)
Return Loss	≥ 25 dB
Insertion Loss	≤ 0.2 dB
Isolation	≥ 50 dB
Cross-Polarization	≤ -40 dB

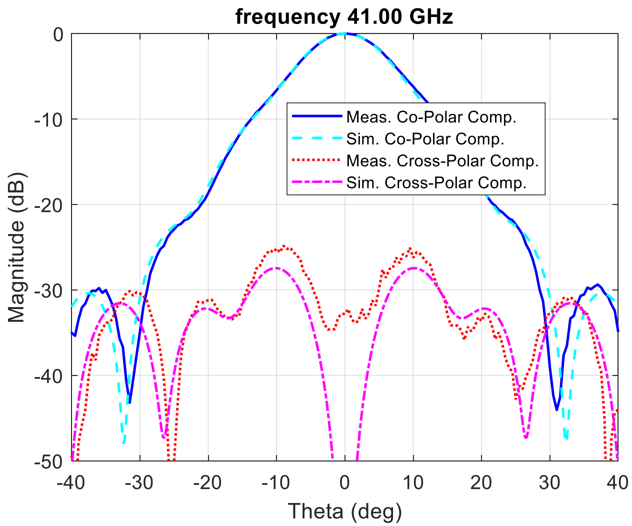


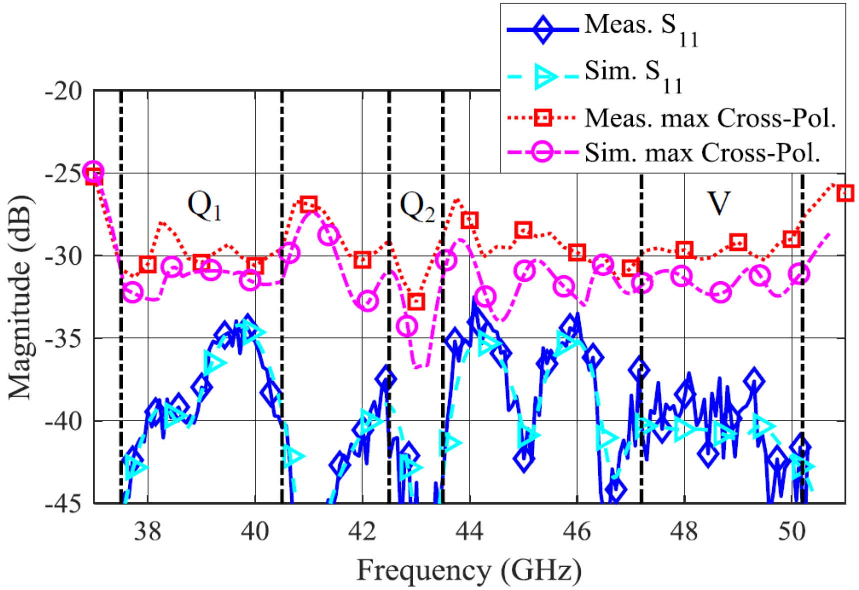


RF Designs Oriented to 3D Printing: Smooth-Wall Feed-Horns

Parameter	Value
Operative Band	Q1 = [37.5, 40.5] GHz (7.7%) Q2 = [42.5, 43.5] GHz (2.3%) V = [47.2, .50.2] GHz (5.5%)
Return Loss	≥ 30 dB
Illumination Angle	22 deg
Cross-Polarization	≤ -30 dB
Gain	> 25 dB

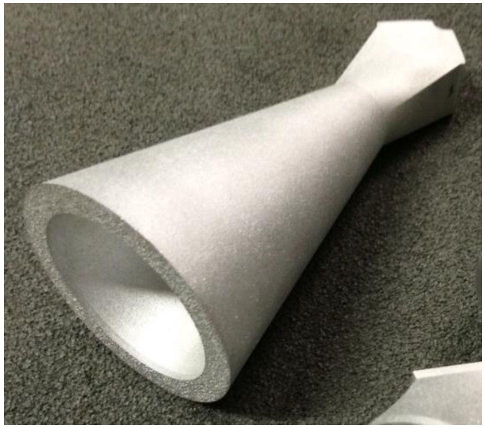


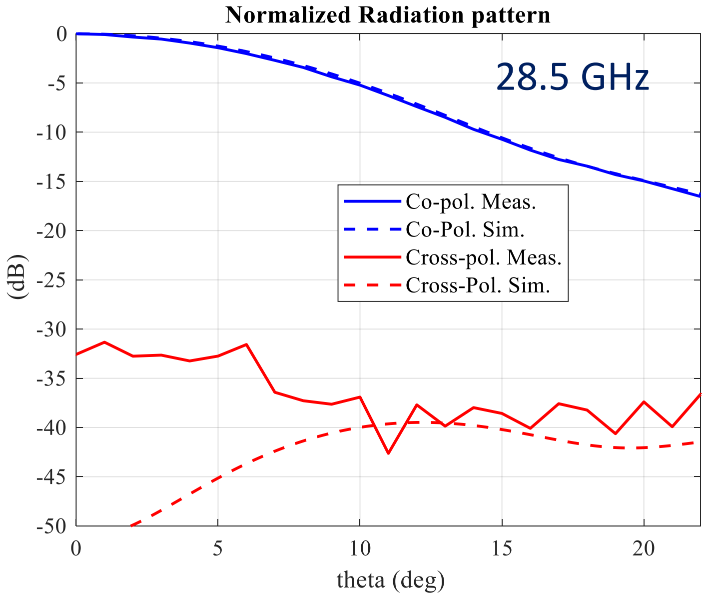


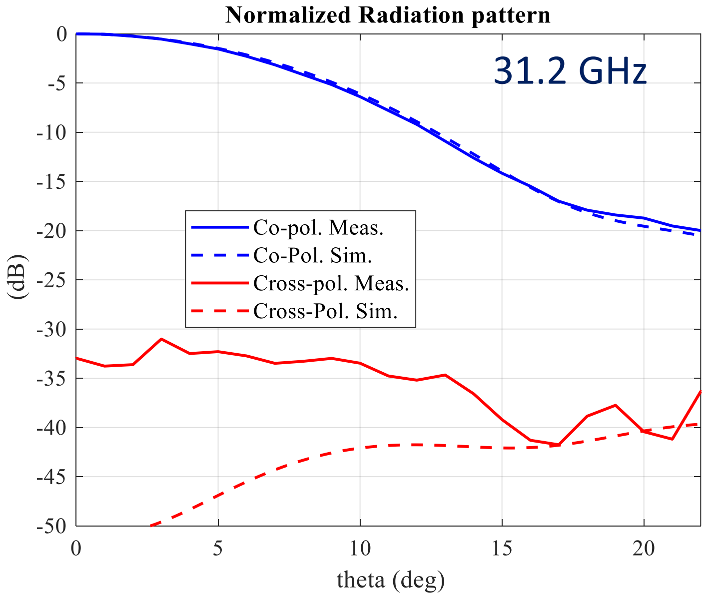


RF Designs Oriented to 3D Printing: Septum Polarizer + Feed Horn

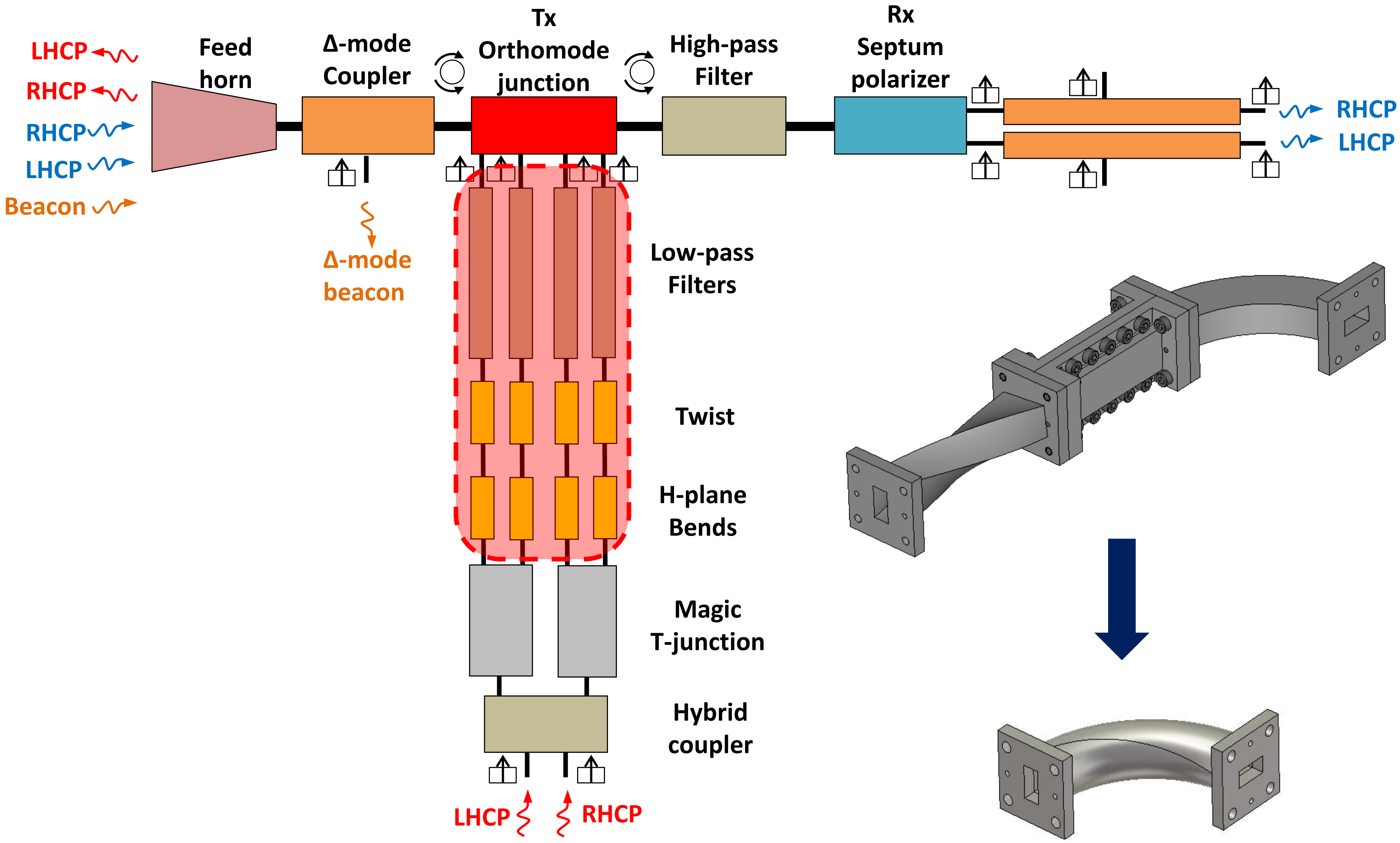
Parameter	Value
Operative Band	28.5 – 31.2 GHz (10%)
Return Loss	≥ 25 dB
Isolation	≥ 30 dB
Cross-Polarization	≤ -38 dB
Illumination Angle	22 deg
Taper at Illumination Angle	[16, 20] dB





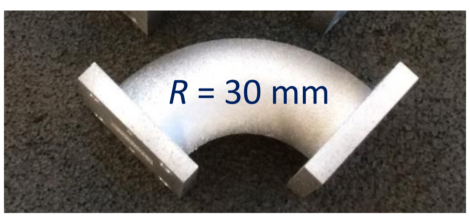


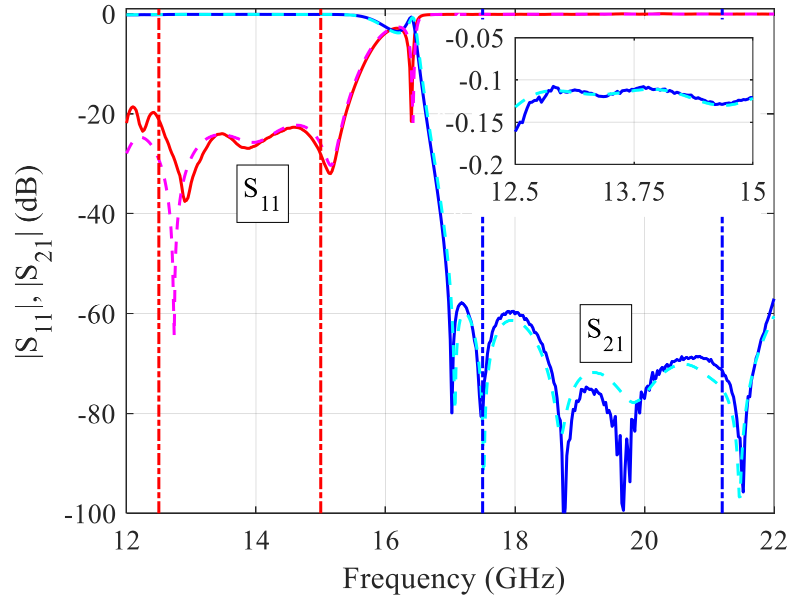
RF Designs Oriented to 3D Printing: H-Plane Bend + Twist + Filter



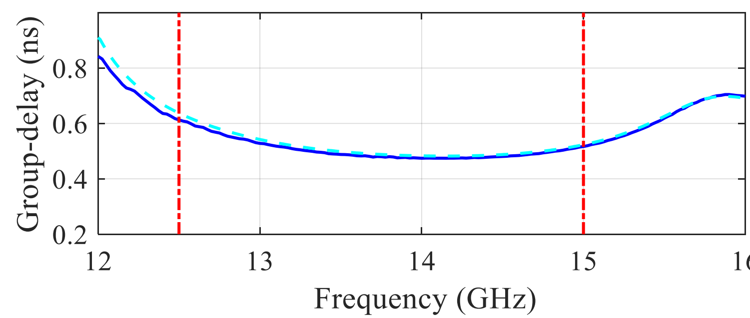
RF Designs Oriented to 3D Printing: H-Plane Bend + Twist + Filter

Parameter	Value
Pass-band	12.5 - 15.0 GHz
Stop-band	17.5 - 21.2 GHz
Return loss	≥ 22 dB
Insertion loss	≤ 0.13 dB
Rejection	≥ 60 dB
Twist/bend angle	90 deg
Twist/bend radius	30 mm





(a)

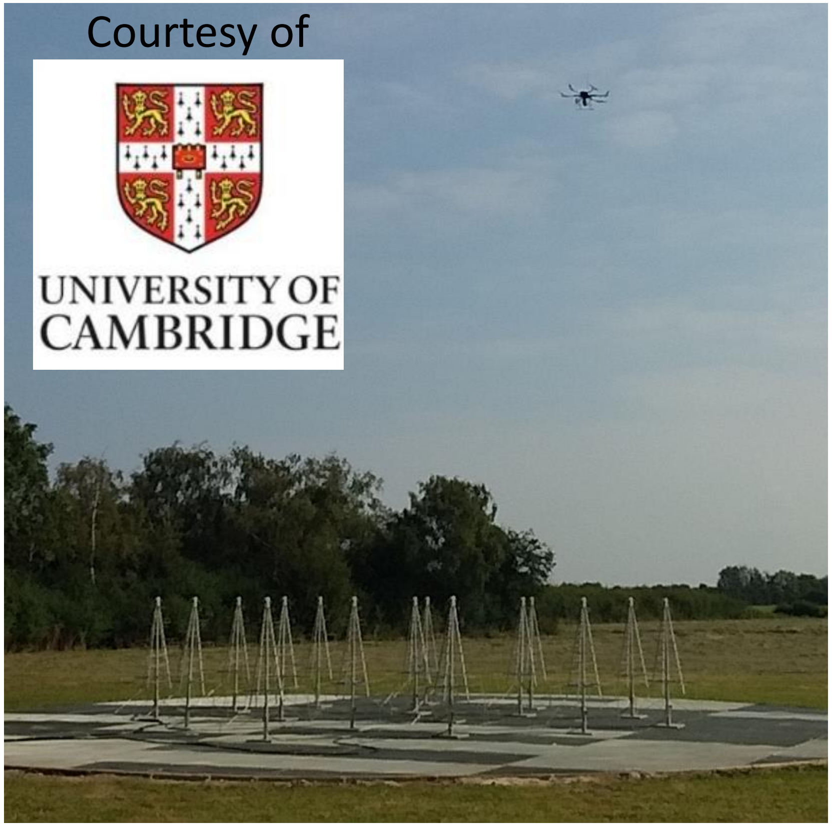


(b)

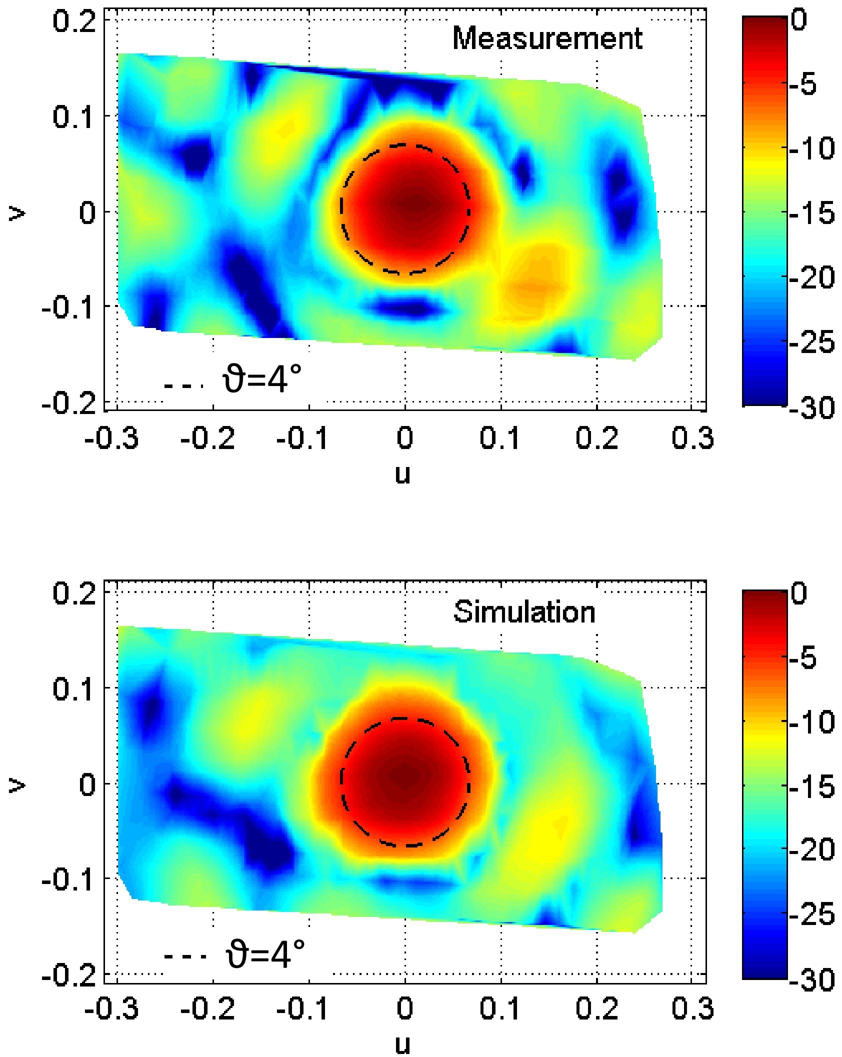
SKA AAVS0.5 Array pattern at 350 MHz

Cartesian Raster measurement in FF

Mullard Radio Astronomy Observatory (UK)

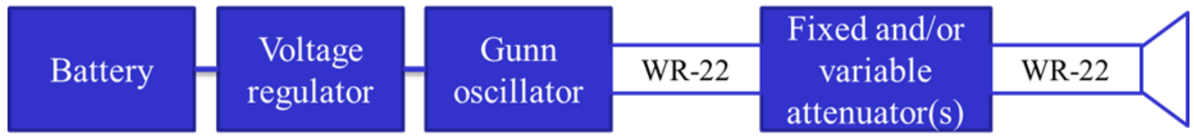


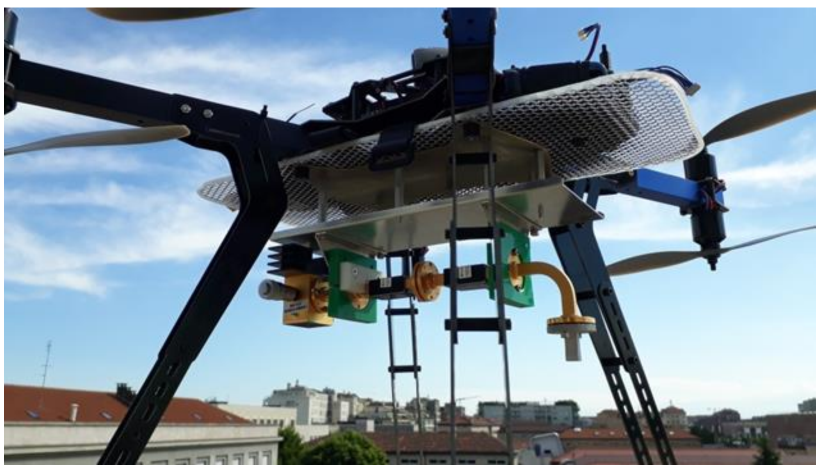
Normalized array pattern at 350 MHz
uv plane, 150 m height



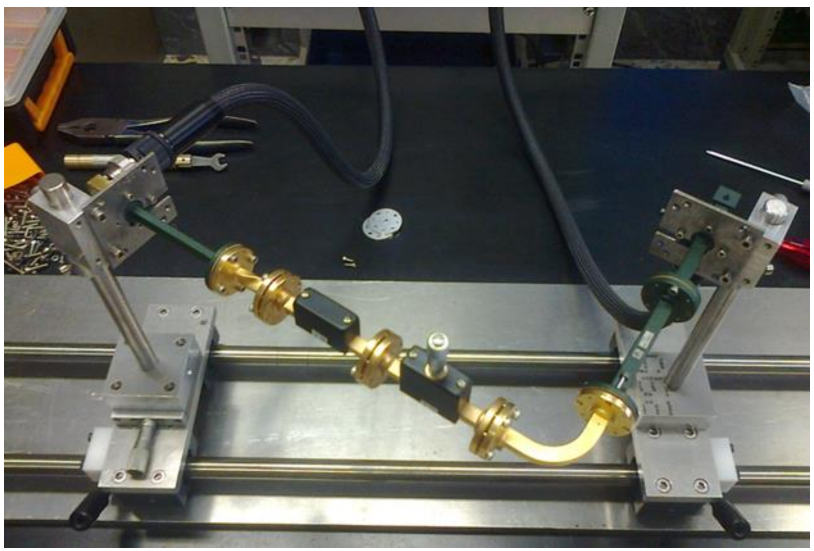
Gunn-based Development of Q-band payload for UAV

RF chain





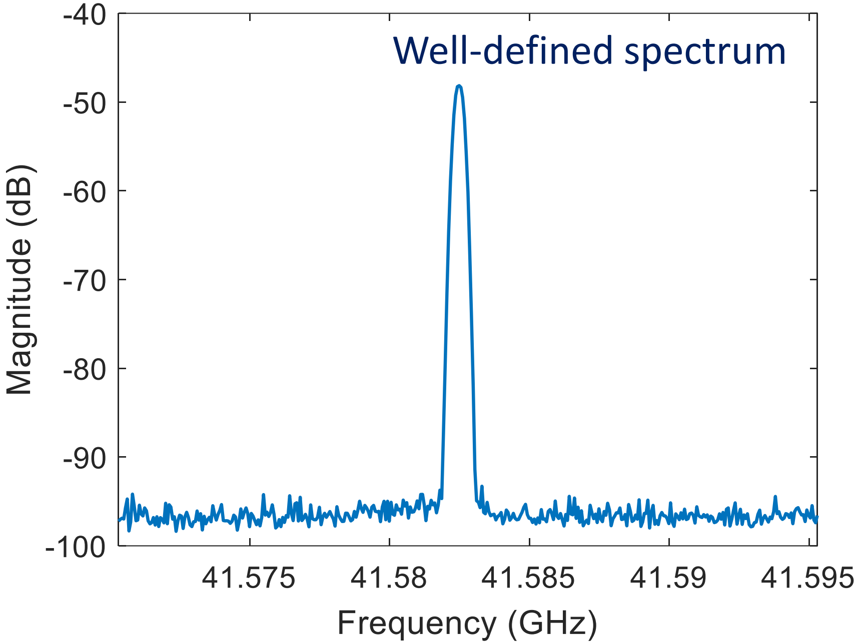
Payload mounted on the UAV



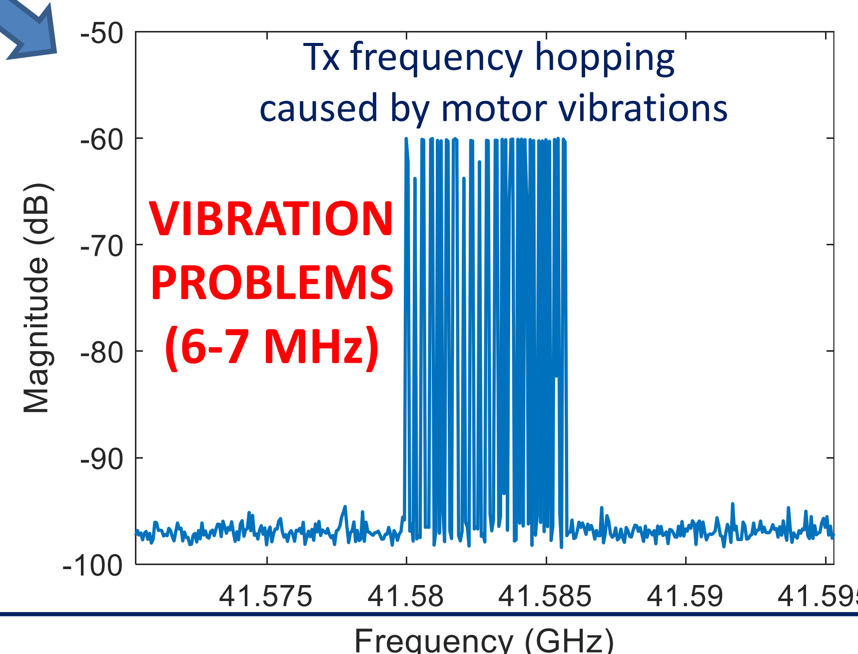
Passive components measured at the VNA

Vibration Problems

UAV not flying and close to the Rx

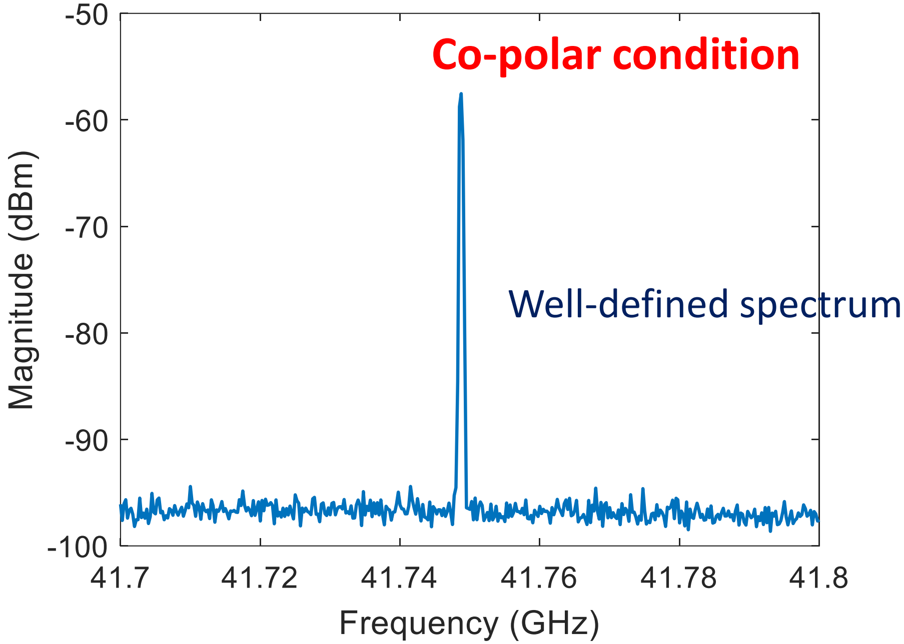


UAV flying at the zenith

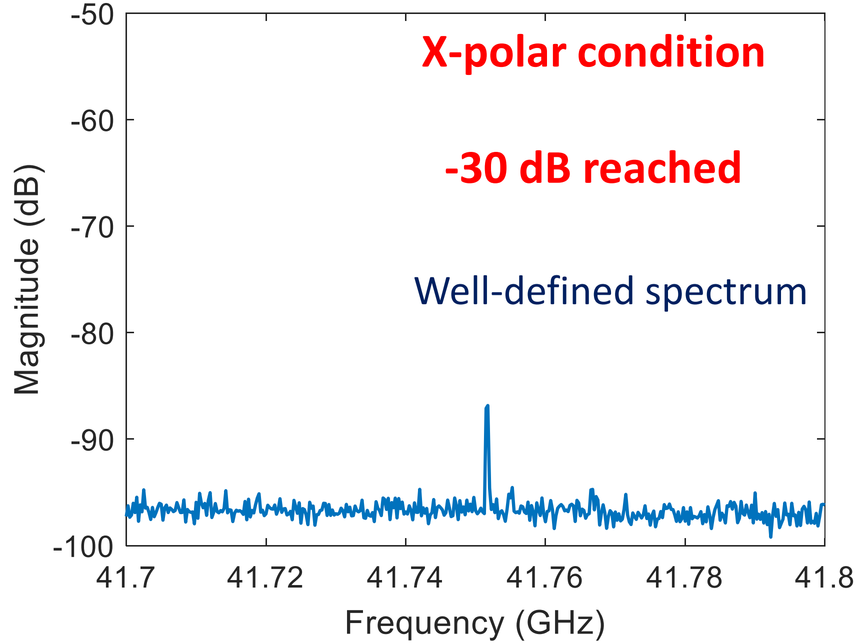


Vibration Problems: after damping

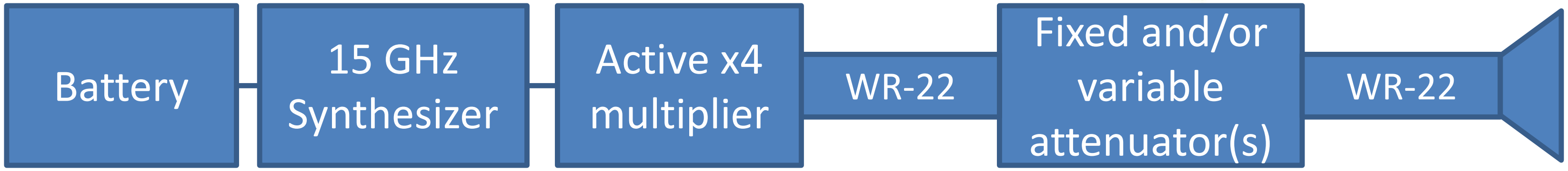
UAV flying at 25 m height
and spinning around zenith



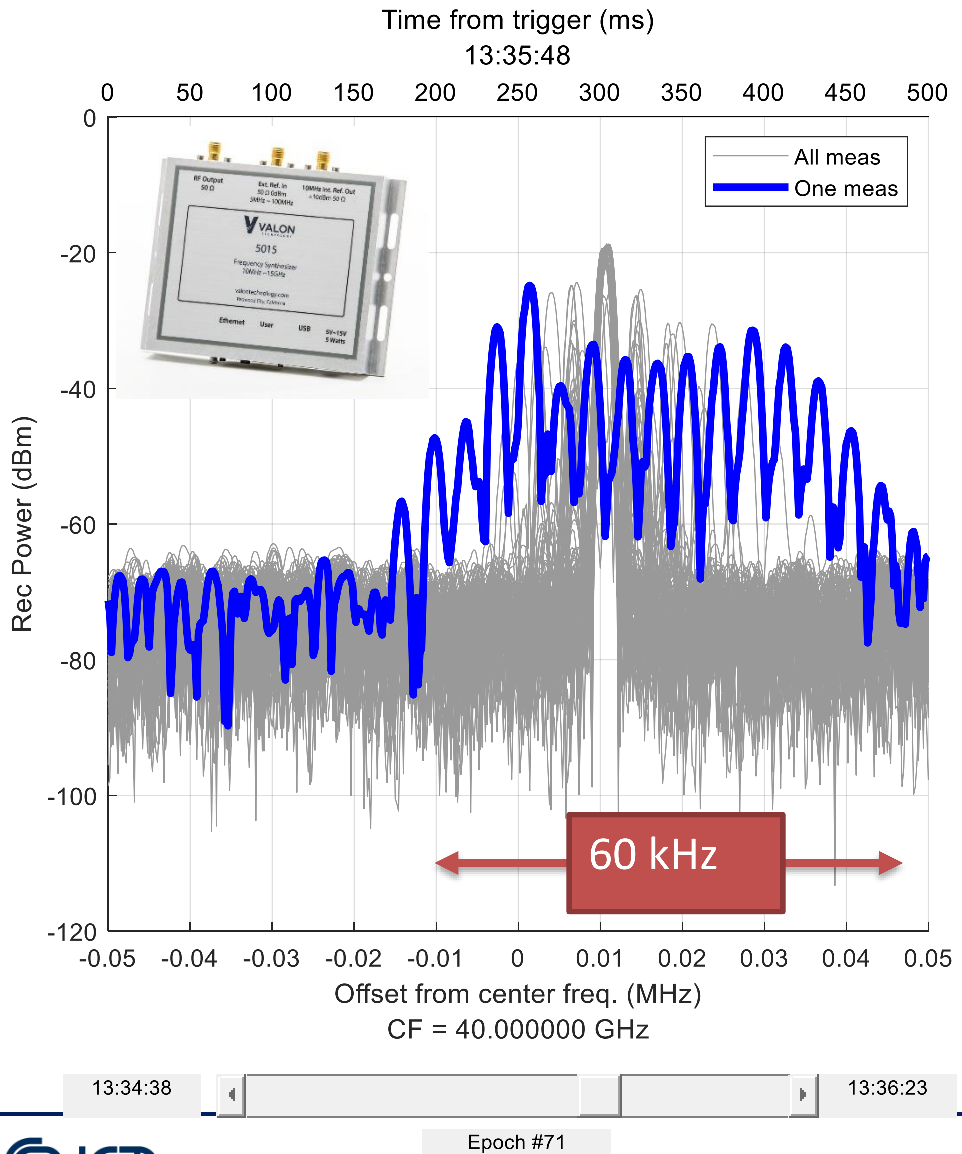
UAV flying at 25 m height
and spinning around zenith



PLL-based Development of Q-band payload for UAV



PLL oscillator + multiplier on the UAV, no vibration damping



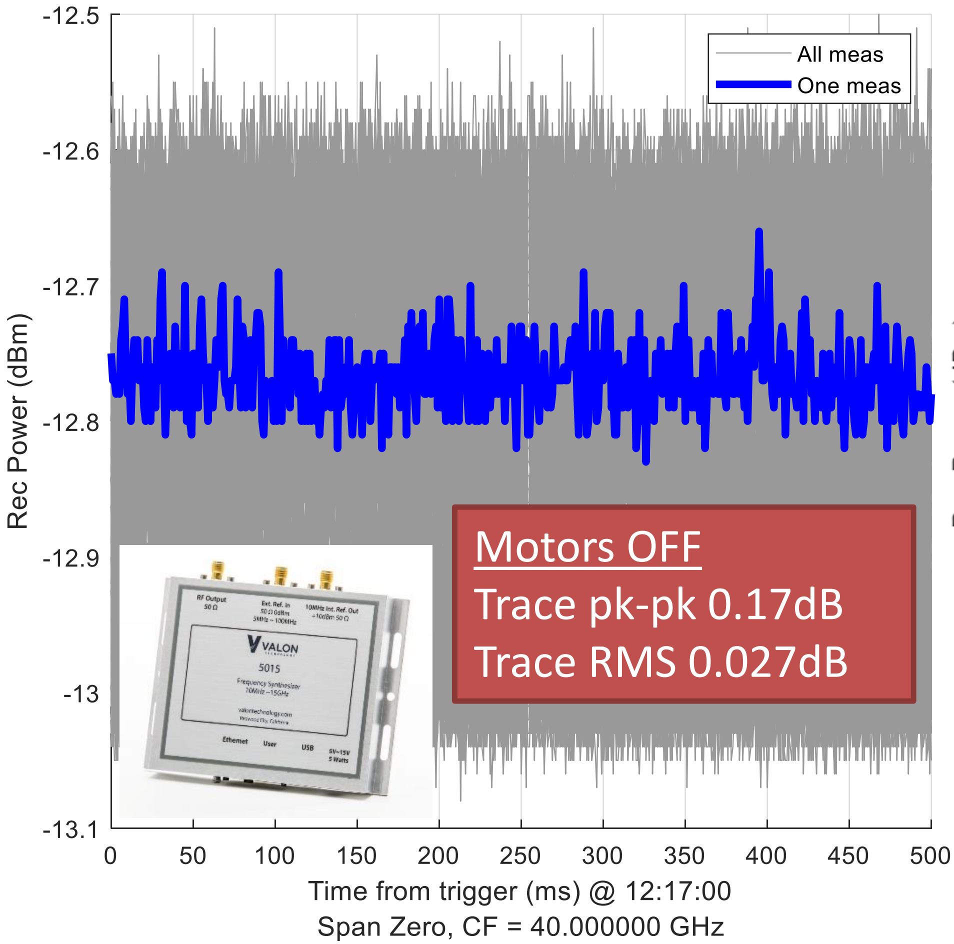
Generator on the UAV: vibrations impact on the spectrum shape

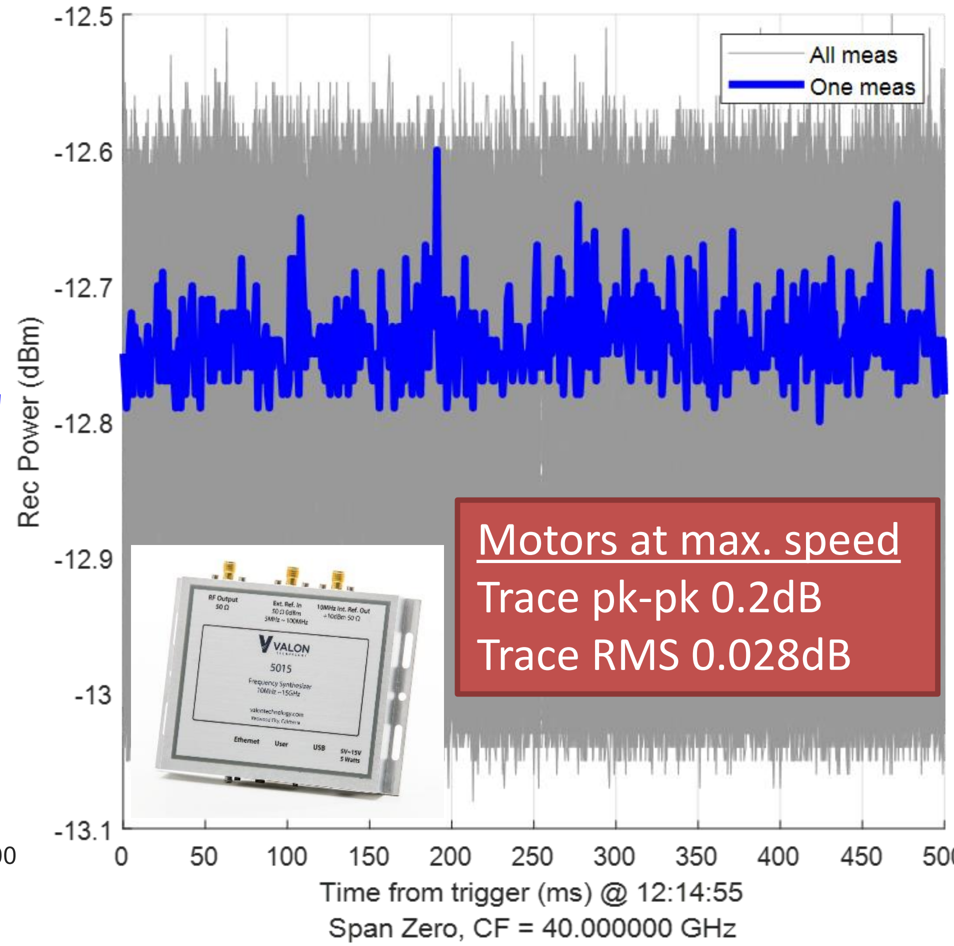
Occupied bandwidth is increased and side-peaks overpower the carrier

Zero Span Acquisition with 1 MHz RBW

Span zero & 1 MHz RBW

RBW sufficient to account for spectrum distortion (e.g. between 100 kHz and 1 MHz)

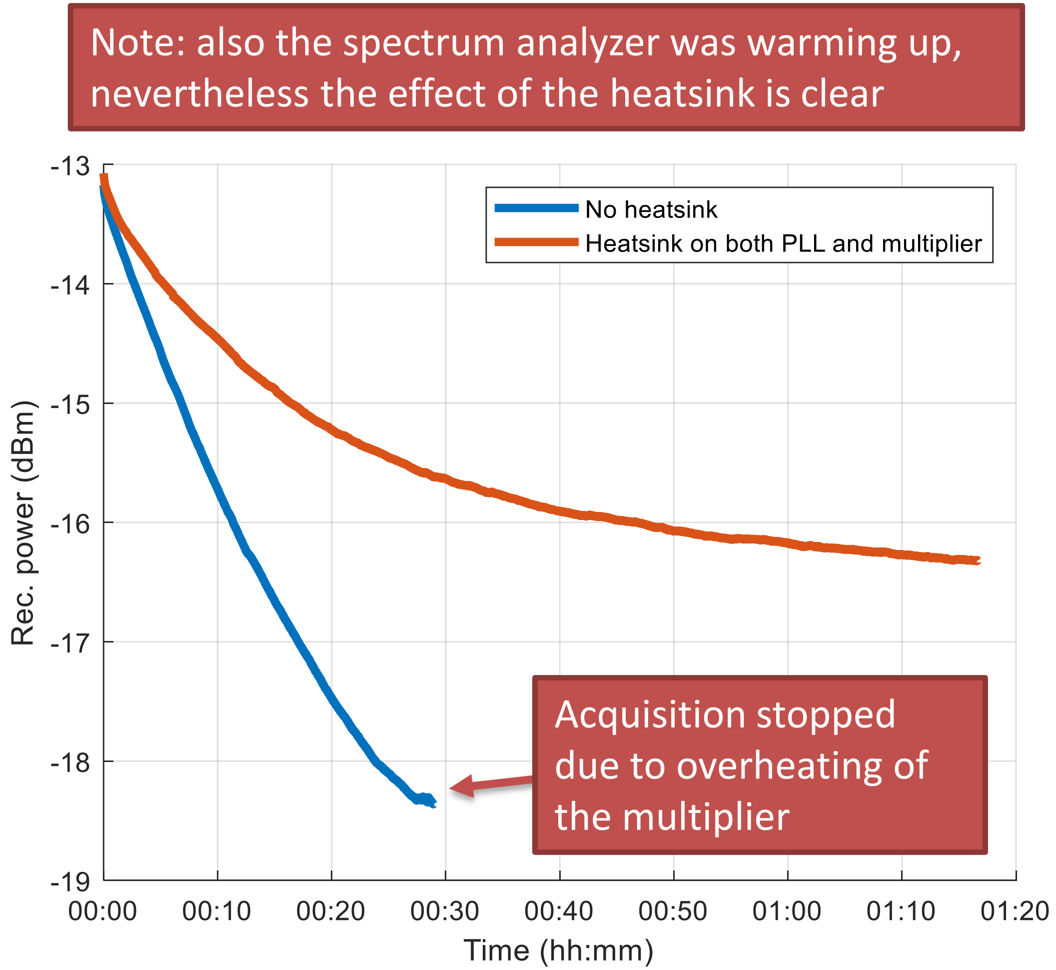




PLL-based Development : power stability issue

2 measurements, output power vs. time, without and with heatsink, in laboratory (room temperature ~21°C, no forced air-flow on the devices)

The plot highlights a variation of the output power due to the temperature (cumulative effect of PLL and multiplier) (… and spectrum analyzer)



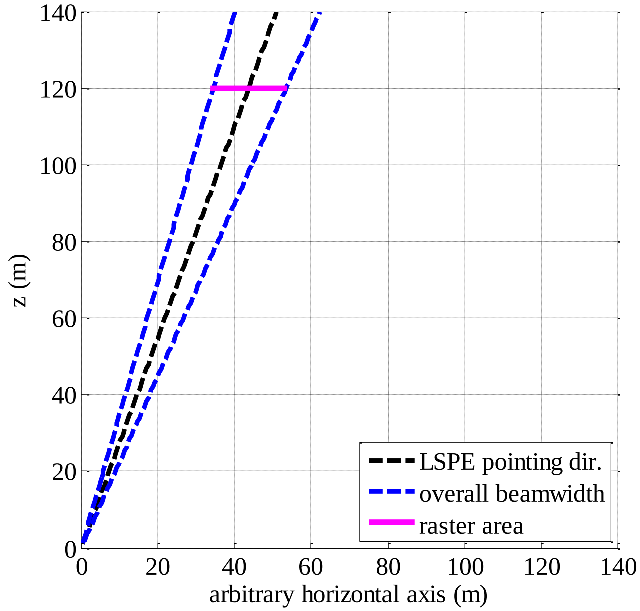
Scan strategies and accuracy

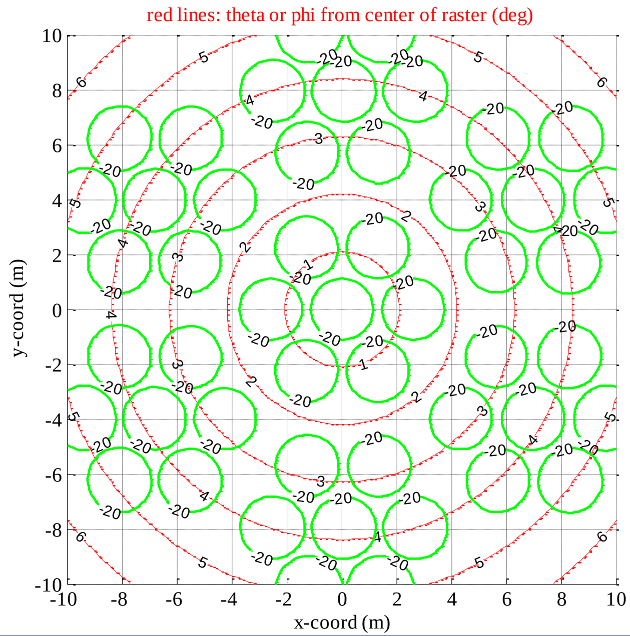
Flight strategy example

- LSPE pointing angle from zenith: 20°
- Raster measurement @ 120 m flying height above the ground (*quasi*-far-field)
- Size of raster flight: ±10 m (±4 Deg)
- It will be covered in multiple flights

Positioning accuracy and related measurement uncertainty

- RTK GPS accuracy (horizontal): ±2 cm
- Resulting angular accuracy @ flying location: ±0.0084°
- RTK GPS accuracy (height): ±5 cm
- Resulting angular accuracy @ flying location: ±0.0077°
- <u>Combined worst-case angular accuracy: ±0.0161° (60 arcsec)</u>
- <u>Uncertainty on path loss (spatial attenuation): <0.01 dB</u>





Conclusion

Sources

- PLL has better frequency stability
- Gunn has better power stability (not enough)
- A power measurement device is needed onboard

Flight Strategy

- Near-field beam verification
- UAV with longer flight duration is valuable
- Coupling with star tracker for enhanced accuracy (absolute pointing), ref. Michele Maris