A Q-Band Test-Source for UAV-Based Radiation Pattern Measurements

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on behalf of LSPE consortium

Summary

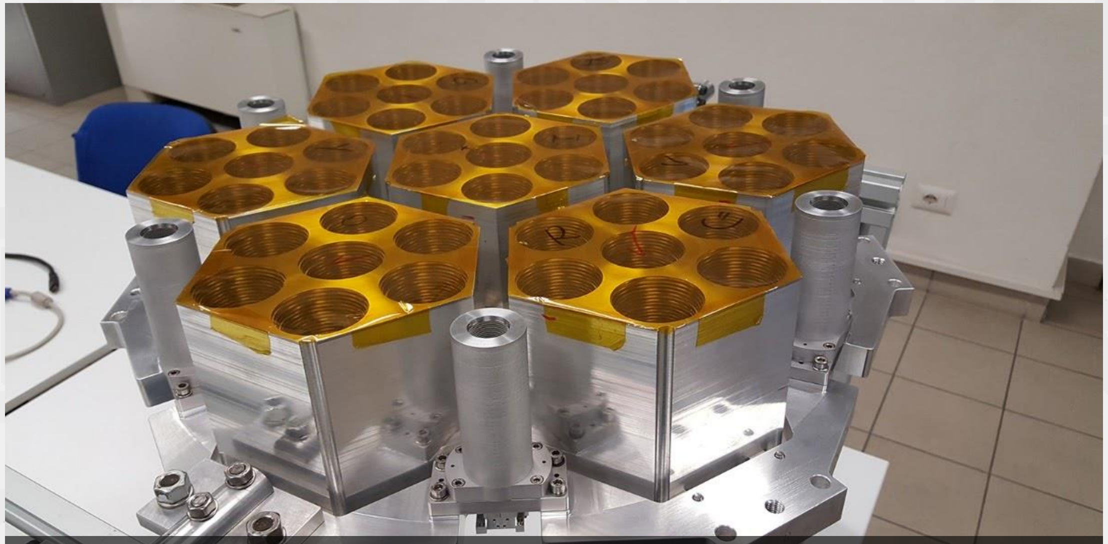
A Q-Band Test-Source for UAV-Based Radiation Pattern Measurements

- Context: the Large Scale Polarization Explorer
- Gained expertise in UAV-based antenna measurements: Square Kilometre Array
- Evolution of the system to Q-band
  - RF payload description
  - Indoor test (stability)
  - Outdoor test (pattern measurement)
- Underway work
  - system improvements
  - measurement campaigns definition

Context: The Large-Scale Polarization Explorer (LSPE)

- Dedicated to CMB polarization measurement (planned installation 2021)

- Within the LSPE project, the **Strip** instrument consists in a ground-based cluster of **49 coherent polarimeters working in Q-band (44 GHz)** for polarization measurements of the microwave sky on large angular scales (+ 6 receivers in W-band, 95 GHz, for atmospheric measurements)



The Strip focal plane

INFN ASI

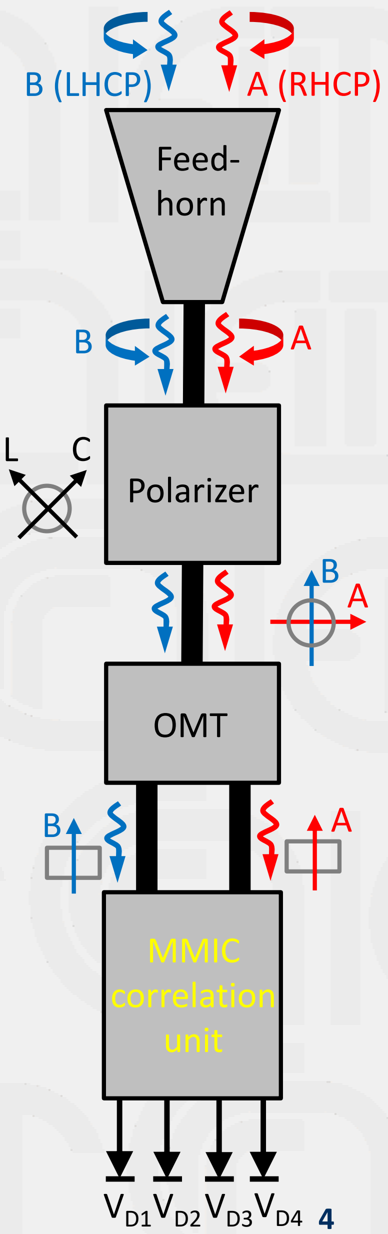
Context: The Large-Scale Polarization Explorer (LSPE)

<u>Detected signals</u>

$V_{D1} \propto \langle |A+B|^2 \rangle$
$V_{D2} \propto \langle |A-B|^2 \rangle$
$V_{D3} \propto \langle |A+jB|^2 \rangle$
$V_{D4} \propto \langle |A-jB|^2 \rangle$

$Q_m \propto V_{D1} - V_{D2}$

$U_m \propto V_{D3} - V_{D4}.$



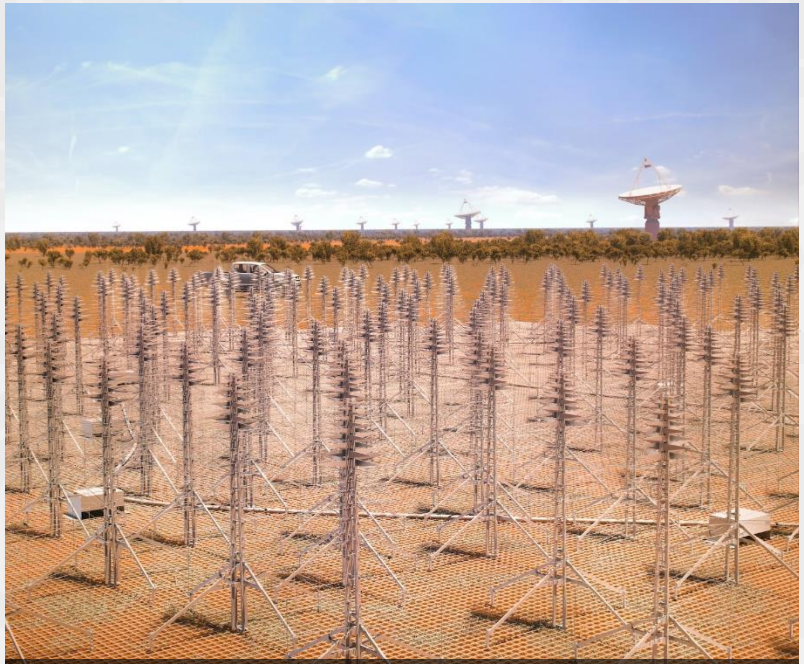
How to perform the in-situ characterization and instrumental calibration? (end-to-end verification)

Gained expertise: UAV-based measurements at low-frequencies

- Since 2013 the CNR-IEIIT gained experience in using UAVs to characterize and calibrate low-frequency arrays for radio astronomy (50–350 MHz) (SKA framework with INAF)

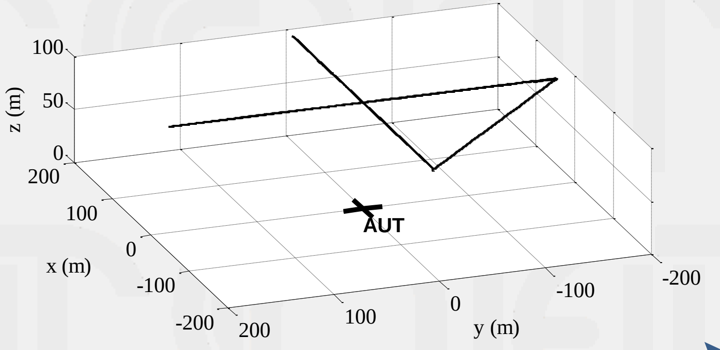
- Collaborations: Astron, Cambridge Univ., ICRAR …

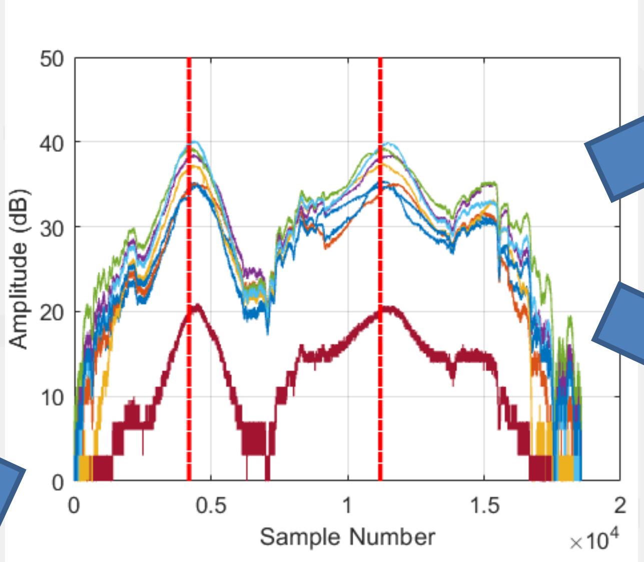
- Activities concerned: array calibration, embedded-element pattern measurement, array verification also in near-field



Artist's impression of SKA-Low in Australia (Credit: SKA Organisation)

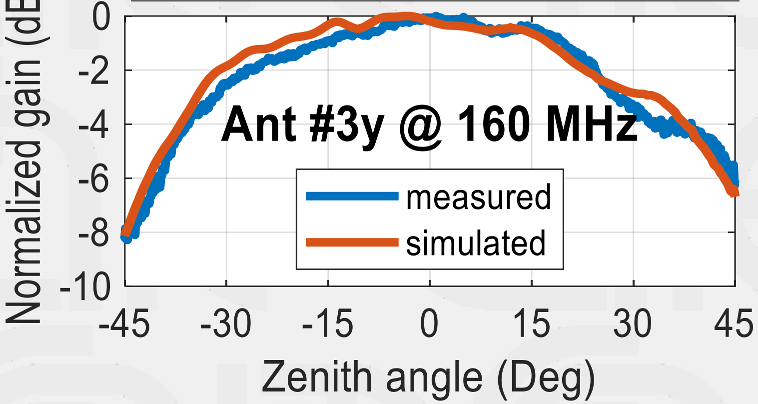
Gained expertise: UAV-based measurements at low-frequencies

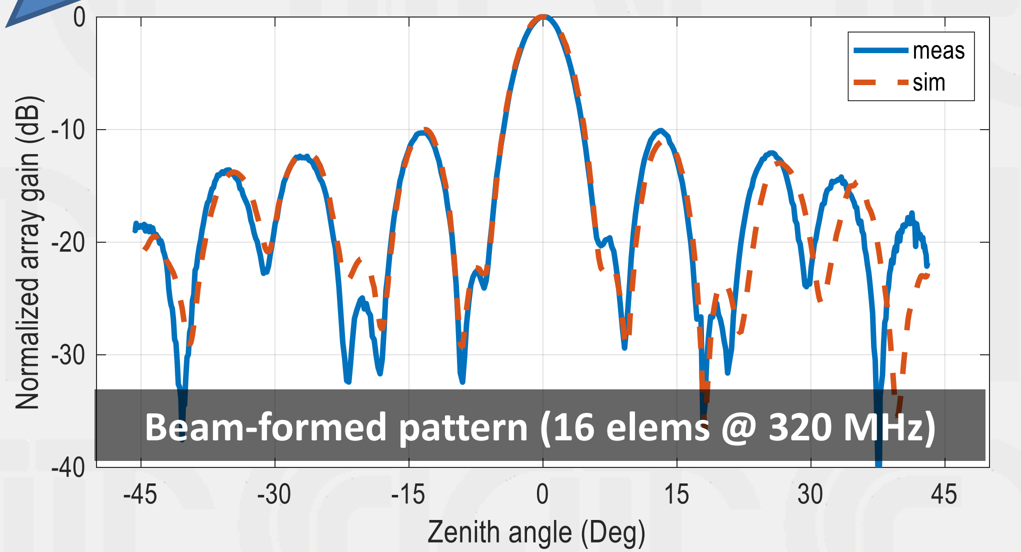




Example of raw data (power) collected from 8 antennas during 2 subsequent rectilinear flights (E-/H-plane)

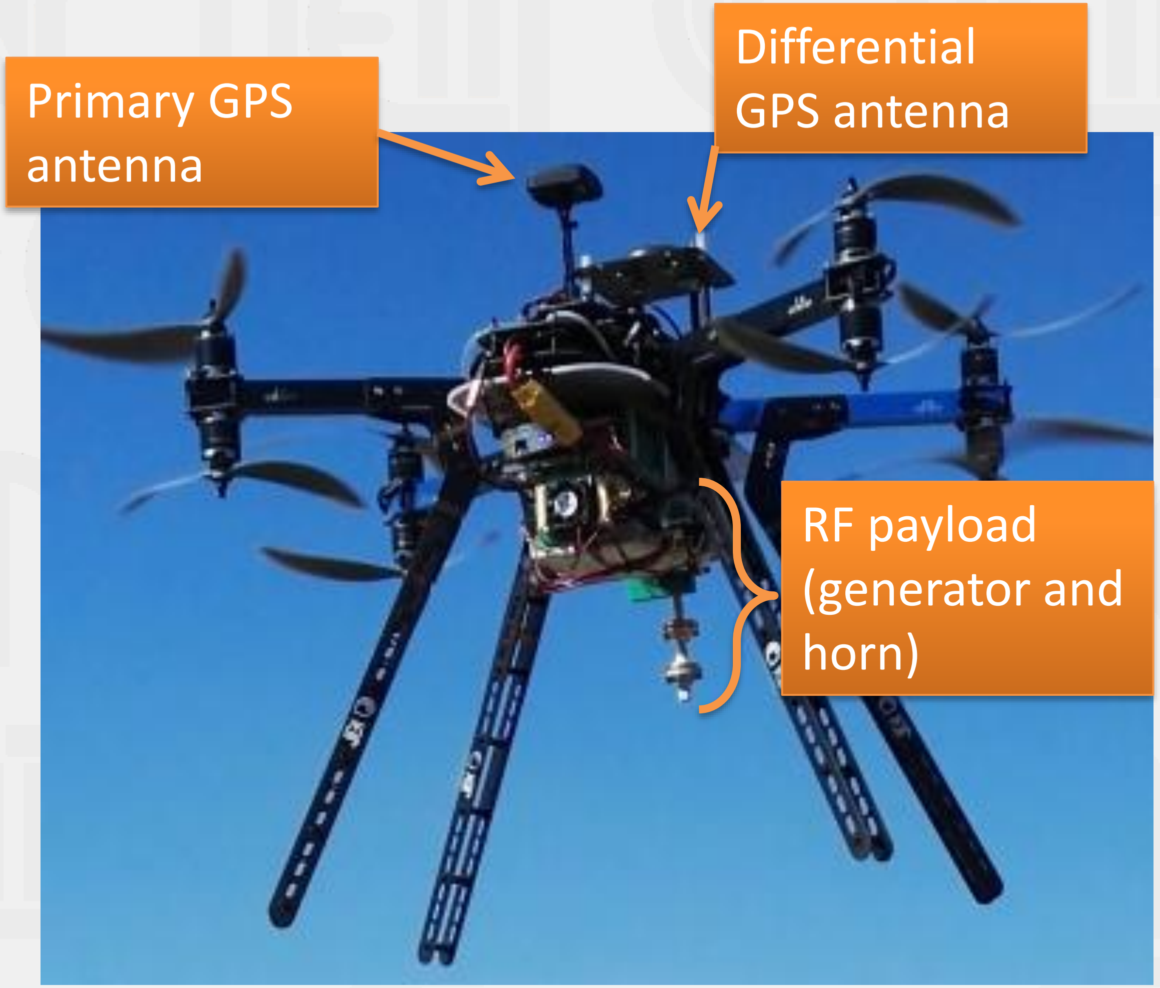
Embedded-element pattern





Beam-formed pattern (16 elems @ 320 MHz)

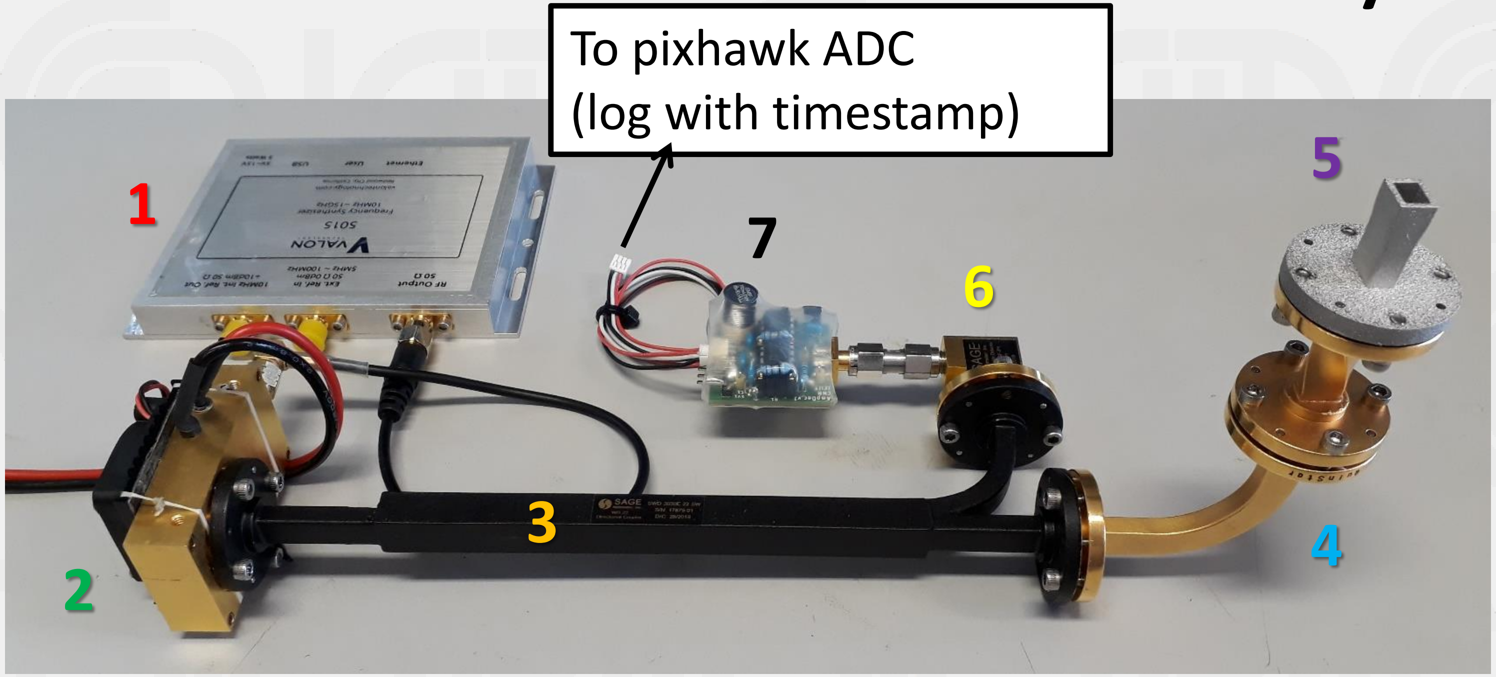
UAV-based system as far-field point source



- Based on a commercial multicopter with open-source autopilot
- RF payload (generator and horn)
- Real-time differential GPS (RTK) for improved flight performance
- Fully automatic flight with planned mission
- Possibility to control the UAV heading during the flight

Position accuracy (<u>knowledge</u>): < 5 cm
Attitude accuracy (<u>knowledge</u>): ~ 2°
Sampling rate: 5 Hz

Q-band Payload



F. Paonessa et al., "Design and Verification of a Q-Band Test Source for UAV-Based Radiation Pattern Measurements," IEEE Transactions on Instrumentation and Measurement, vol. 69, no. 12, pp. 9366-9370, Dec. 2020.

1) tunable CW frequency synthesizer (<=15 GHz)

2) active x4 multiplier (33-50 GHz out)

3) directional coupler

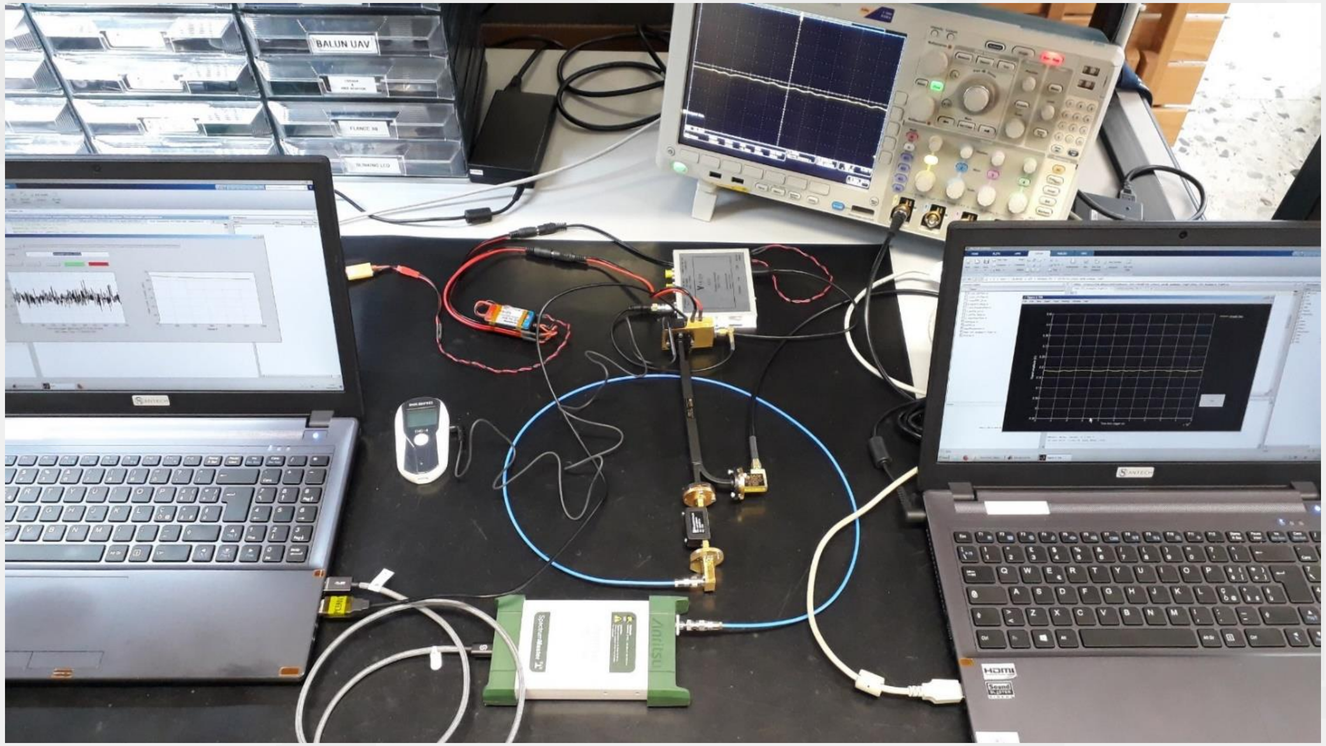
4) bend and twist

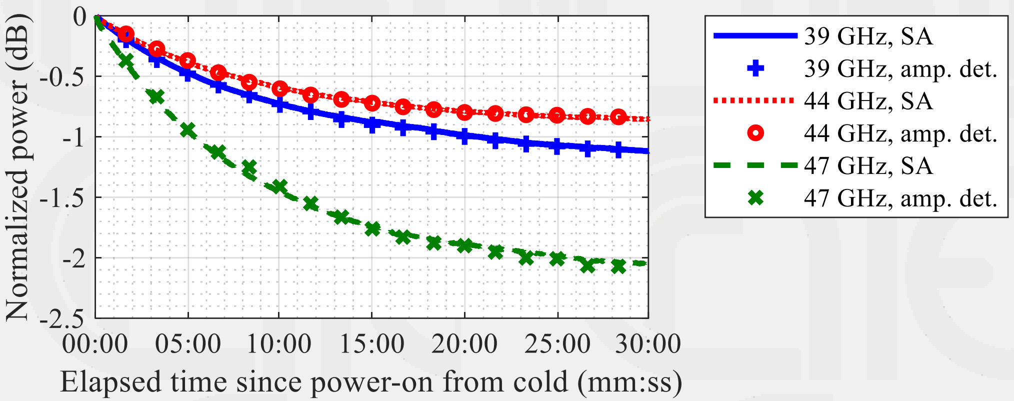
5) rectangular horn

6) amplitude detector

7) precision V amp → output to autopilot ADC input

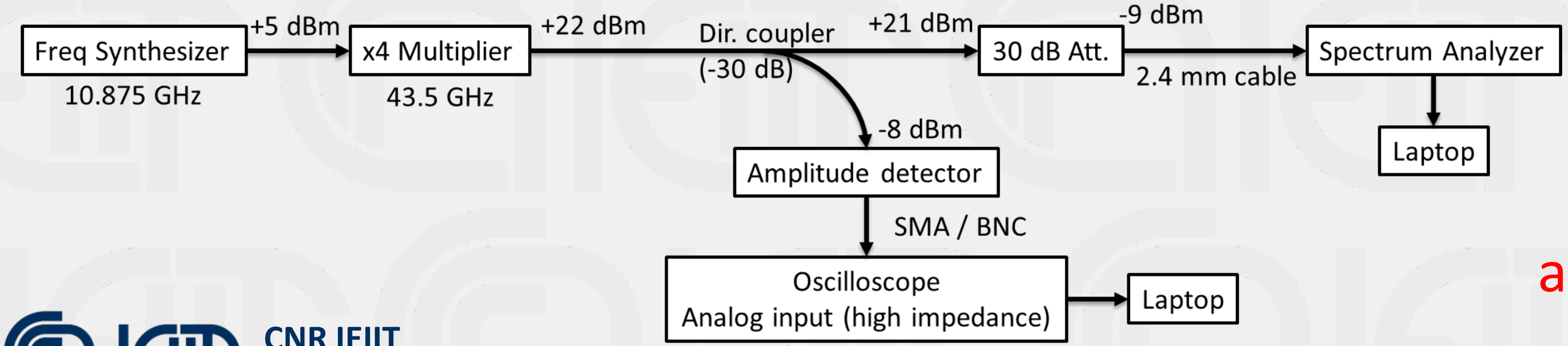
Tests in laboratory: output stability





Power stability during 30-minutes warm-up: comparison between the amplitude detector readings (markers) and the spectrum analyzer measurements (lines). Curves normalized to their initial value.

<= 0.05 dB agreement



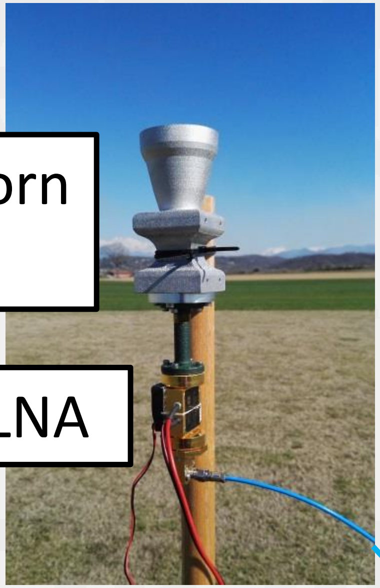
Further validation tests on freq. stability (vibrations, temperature) also with different oscillators (Gunn)

Outdoor test: radiation pattern measurement @ 44 GHz

Rectilinear scan @ constant altitude (20 m) → E-plane measurement

Reference horn @ 44 GHz

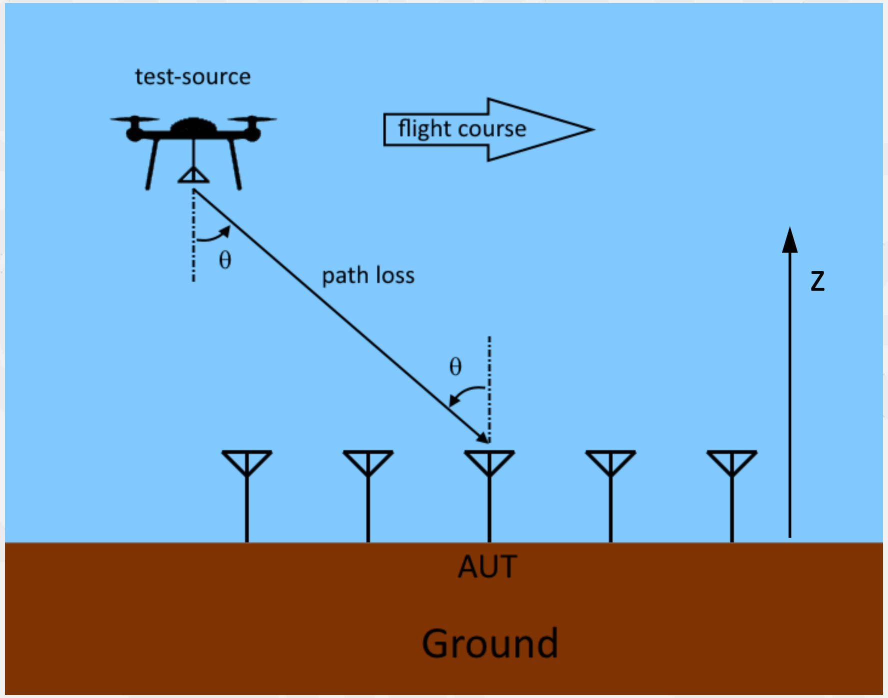
30 dB LNA



GPS-triggered portable spectrum analyzer

Laptop for data acquisition

Outdoor test: Extraction of the antenna pattern



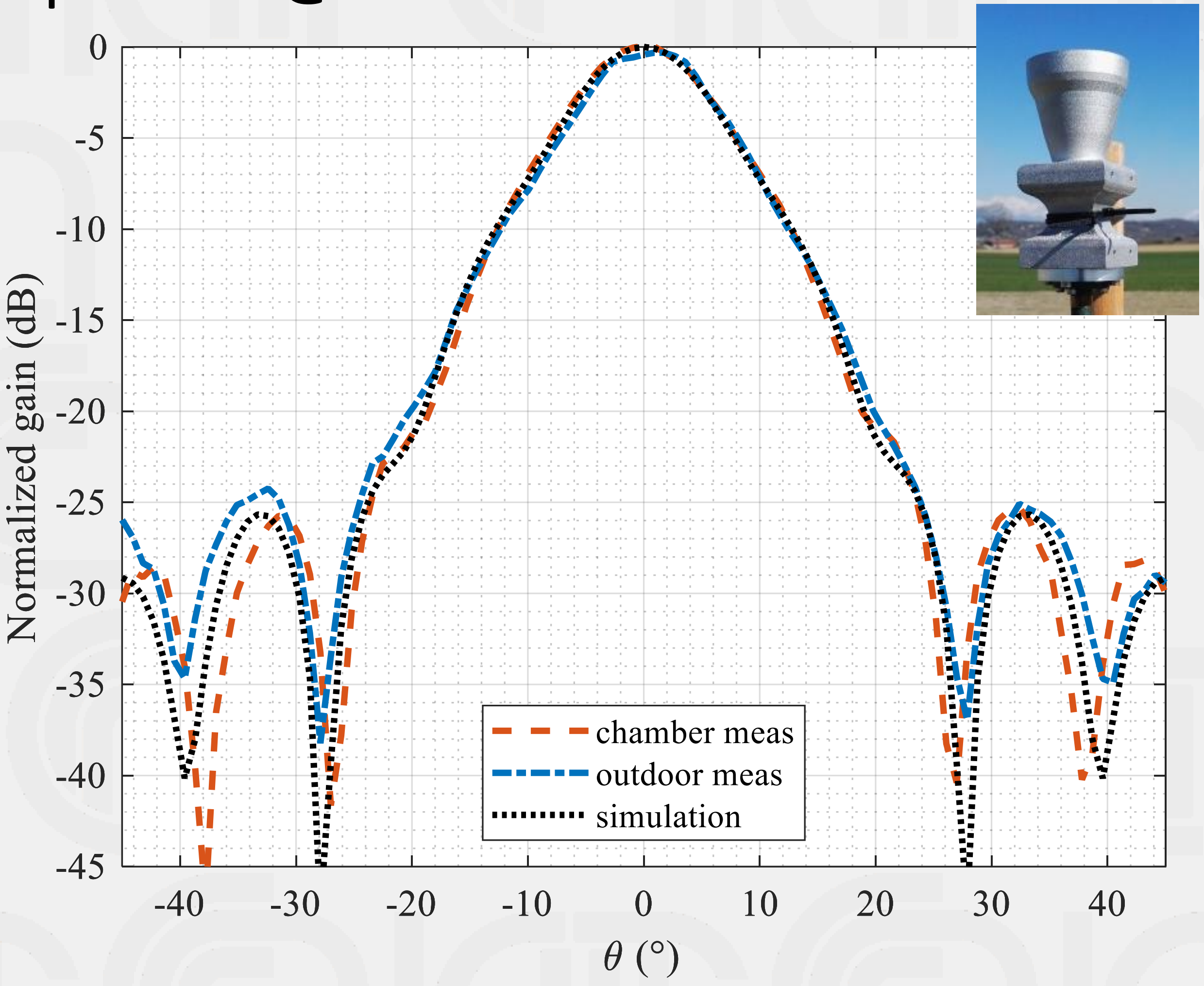
- AUT pattern along the flight trajectory is computed from received power pattern (Friis equation in far-field)

- For quasi-rectilinear flights @ constant altitude:
  - Source *distance, orientation & gain* are not constant
  - *Path loss* & *source gain* must be computed and kept into account when AUT pattern is computed

- Data needed:
  - UAV position: d*ifferential GPS (DGPS/RTK)* provides centimeter-level accuracy
  - UAV orientation: *Inertial Measurement Unit* (IMU) accuracy within 2 degrees
  - Test-source gain: comes either from simulation or reference measured data
  - Test-source power: amplitude detector
  - Data synchronization is important (position, orientation, **and RF**)

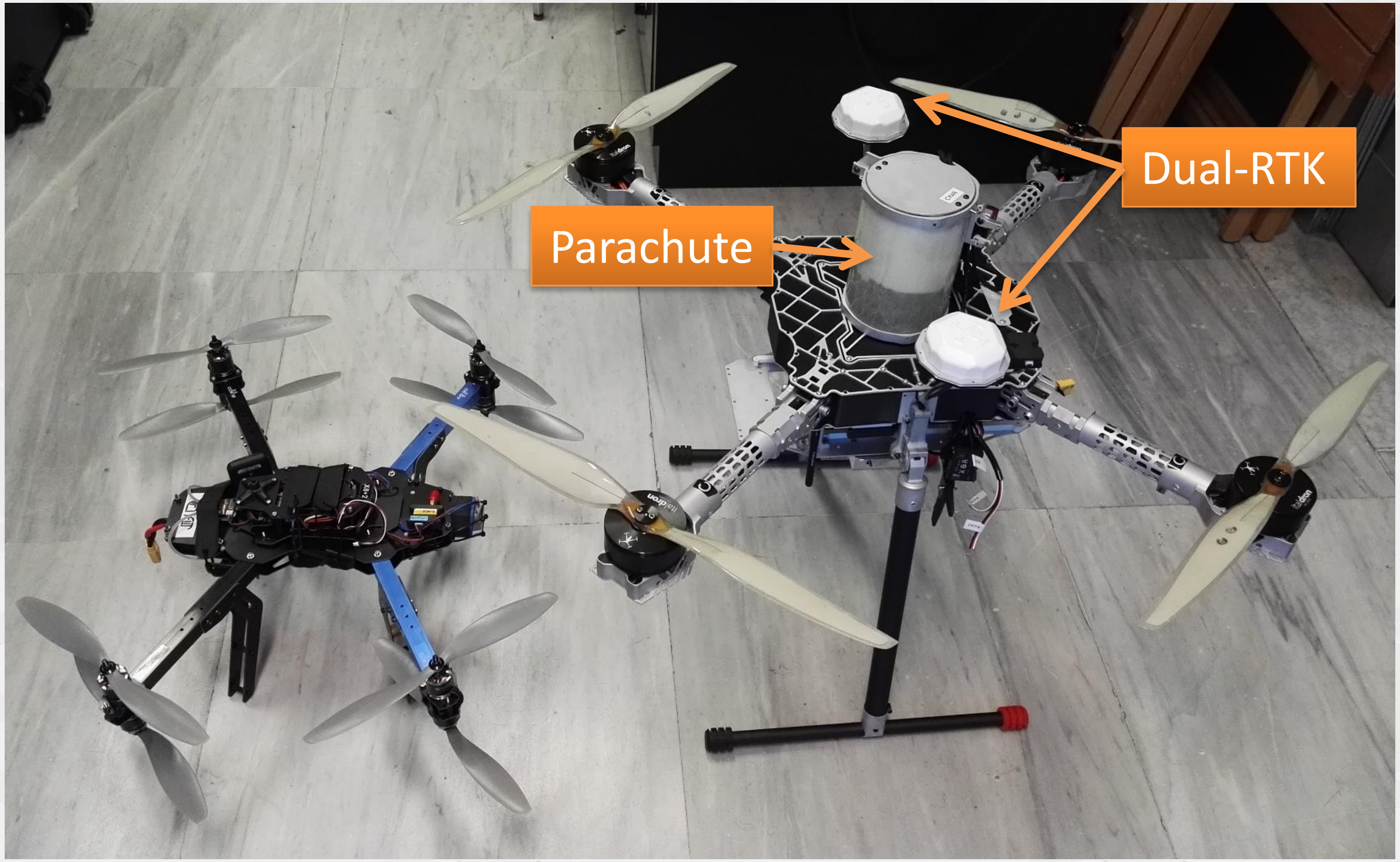
Outdoor test: radiation pattern measurement @ 44 GHz

E-plane pattern @ 44 GHz



- Comparison both with anechoic chamber measurement and simulation
- weighted logarithmic difference (weight function = simulation)
  - RMS = 0.15 dB (outdoor – sim)
  - RMS = 0.11 dB (chamber – sim)
  - RMS = 0.21 dB (outdoor – chamber)

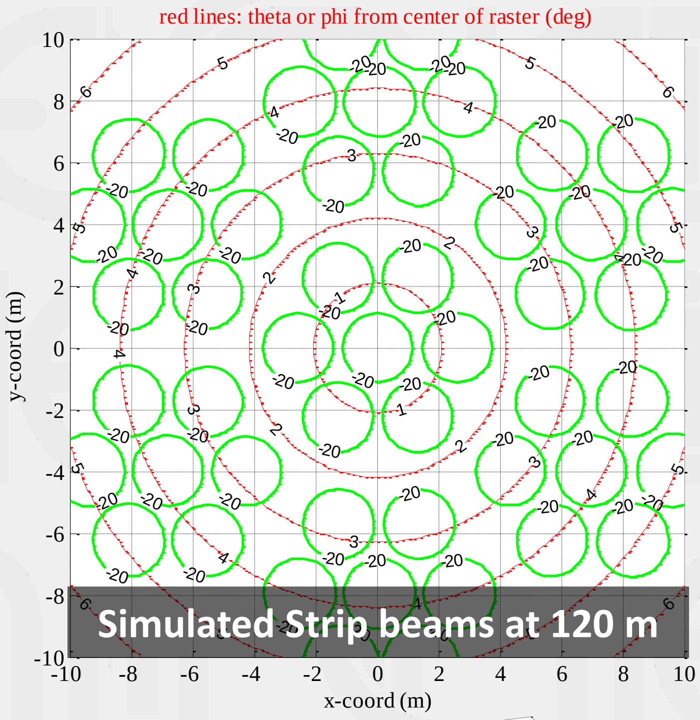
Underway work: new UAV with improved performance for polarization measurements

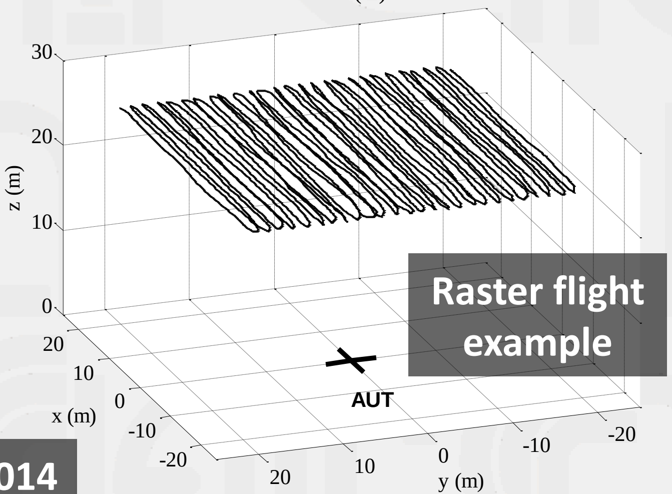


- Aluminum frame
- Propellers: either fiberglass or carbon fiber
- Payload: 1.5 kg vs. 0.8 kg
- Parachute
- <u>**RTK: 2 receivers vs. 1 (for yaw estimation)**</u>

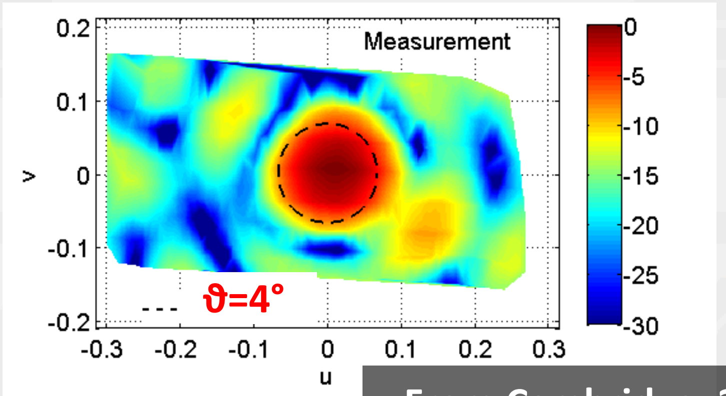
Underway work: future tests planning

- Tests of the updated double-RTK system for improved polarization measuremens
- Measurement campaigns definition:
  - Strip
  - Quijote
  - Definition of operation modes of the telescope (scan strategies, dynamic range)





First step co-polar pattern (including sidelobes), then polarization measurements



From Cambridge, 2014