



# Antenna Pattern Calibration of Radio Telescopes using an UAV-based device

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Solar-Terrestrial  
Centre of Excellence

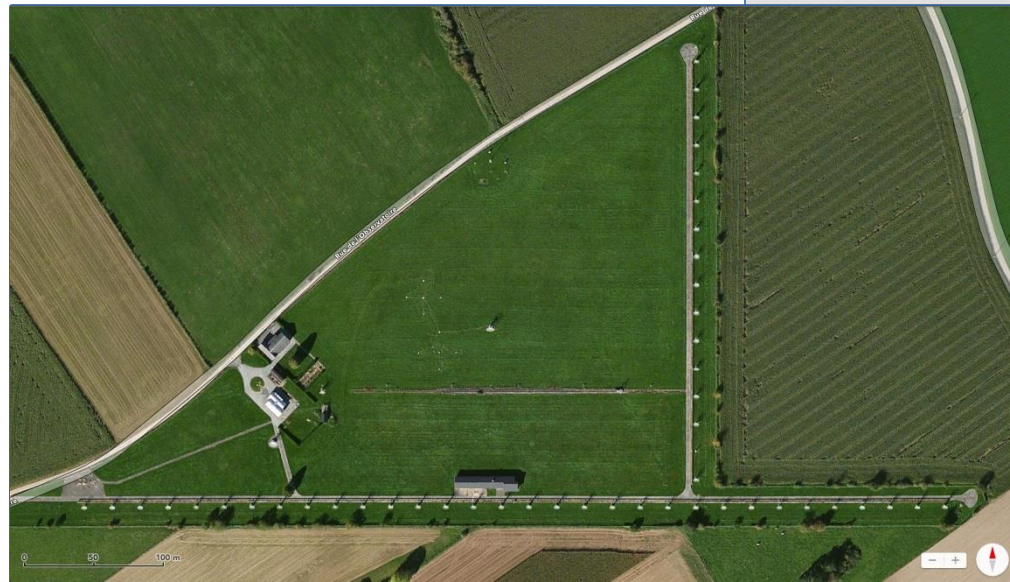


Belgian Institute for  
Space Aeronomy



Royal Observatory  
of Belgium

# The Humain Radio-Astronomy Station

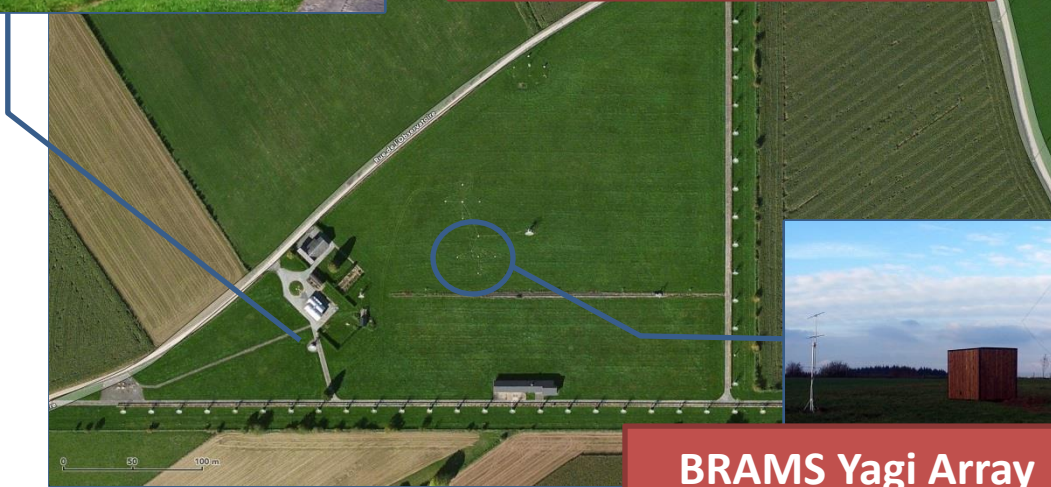
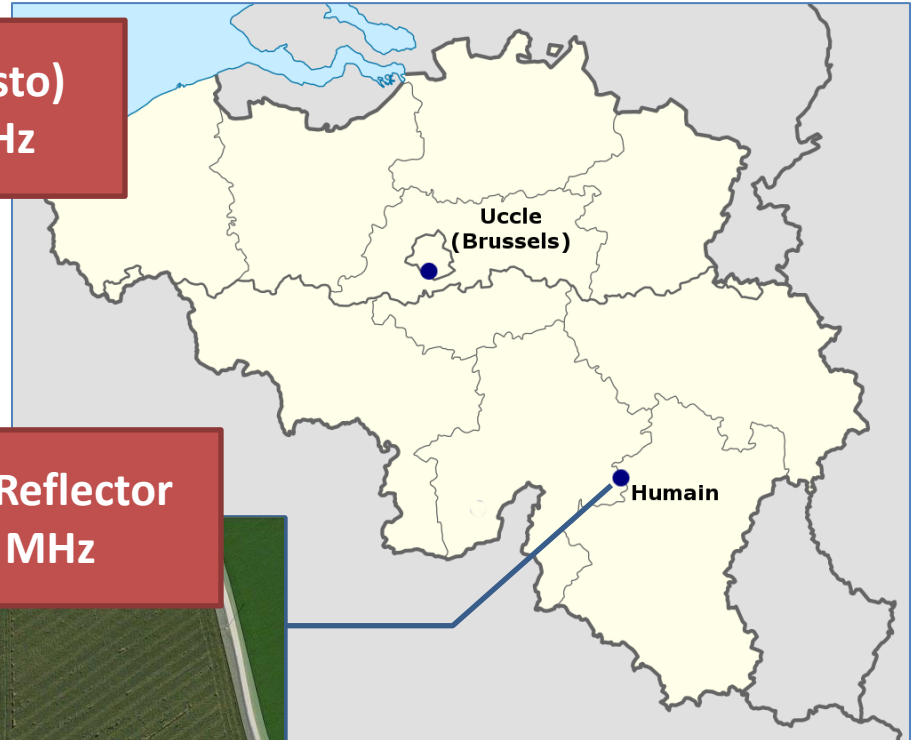


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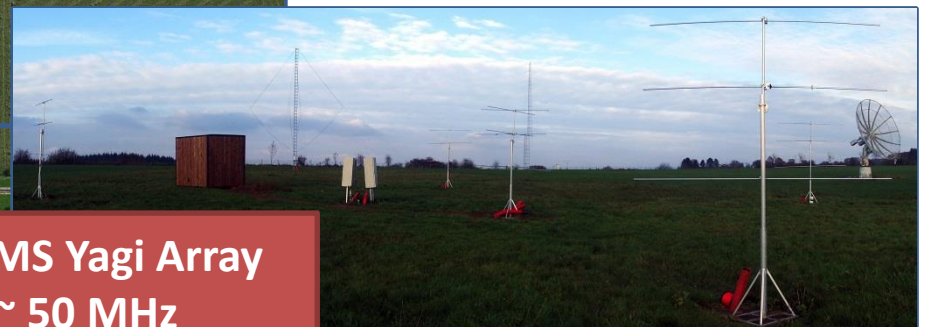


**LPDA (e-Callisto)**  
45 – 400 MHz

**6m Parabolic Reflector**  
300 – 800 MHz

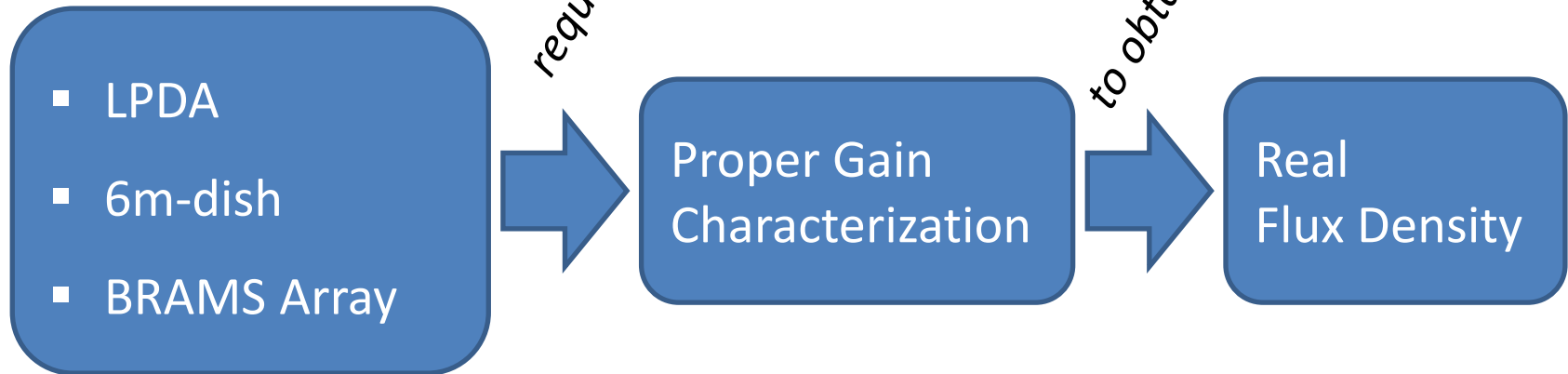


**BRAMS Yagi Array**  
~ 50 MHz



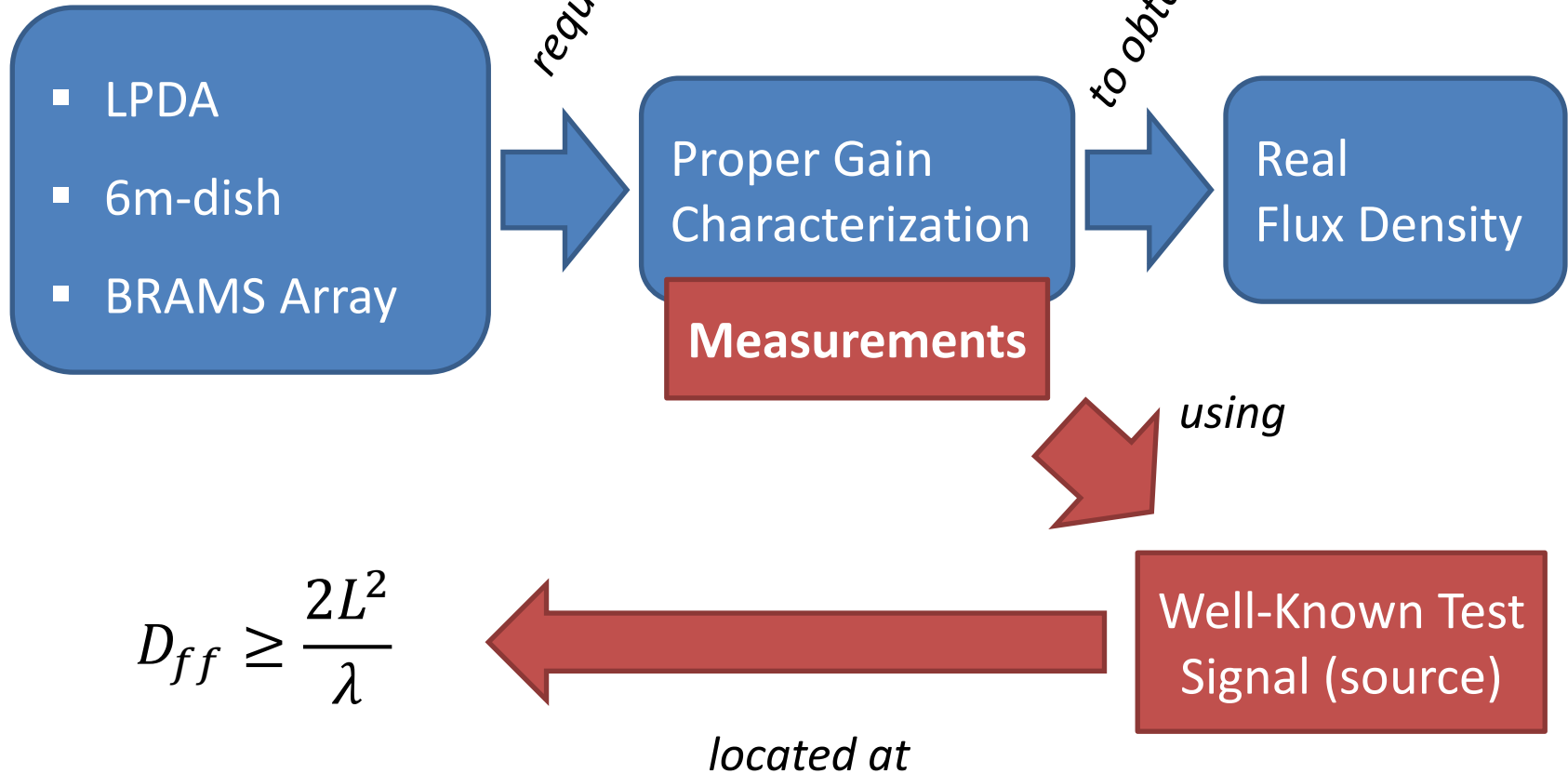
# Antenna Pattern Characterization

Human Antenna Systems



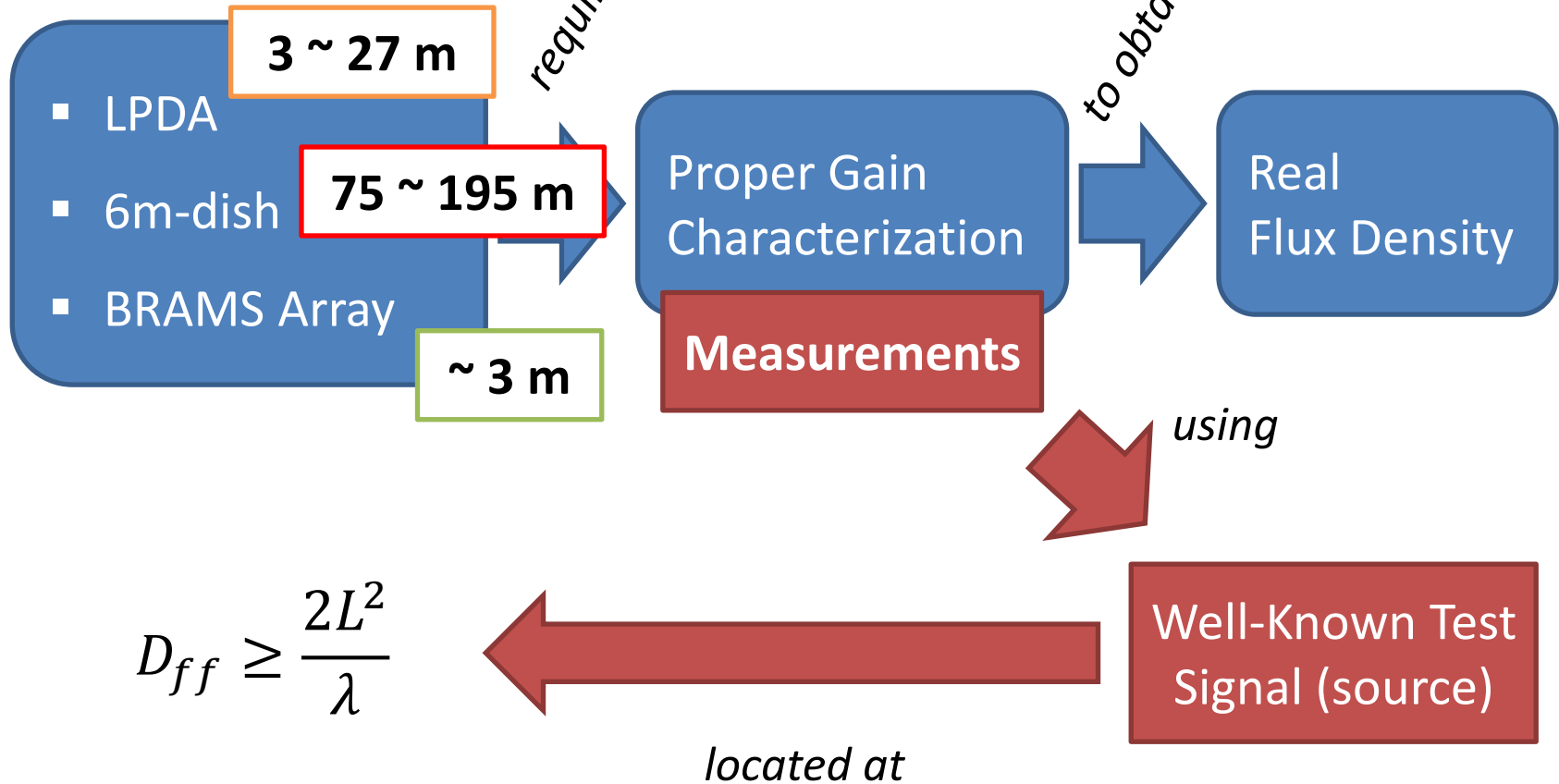
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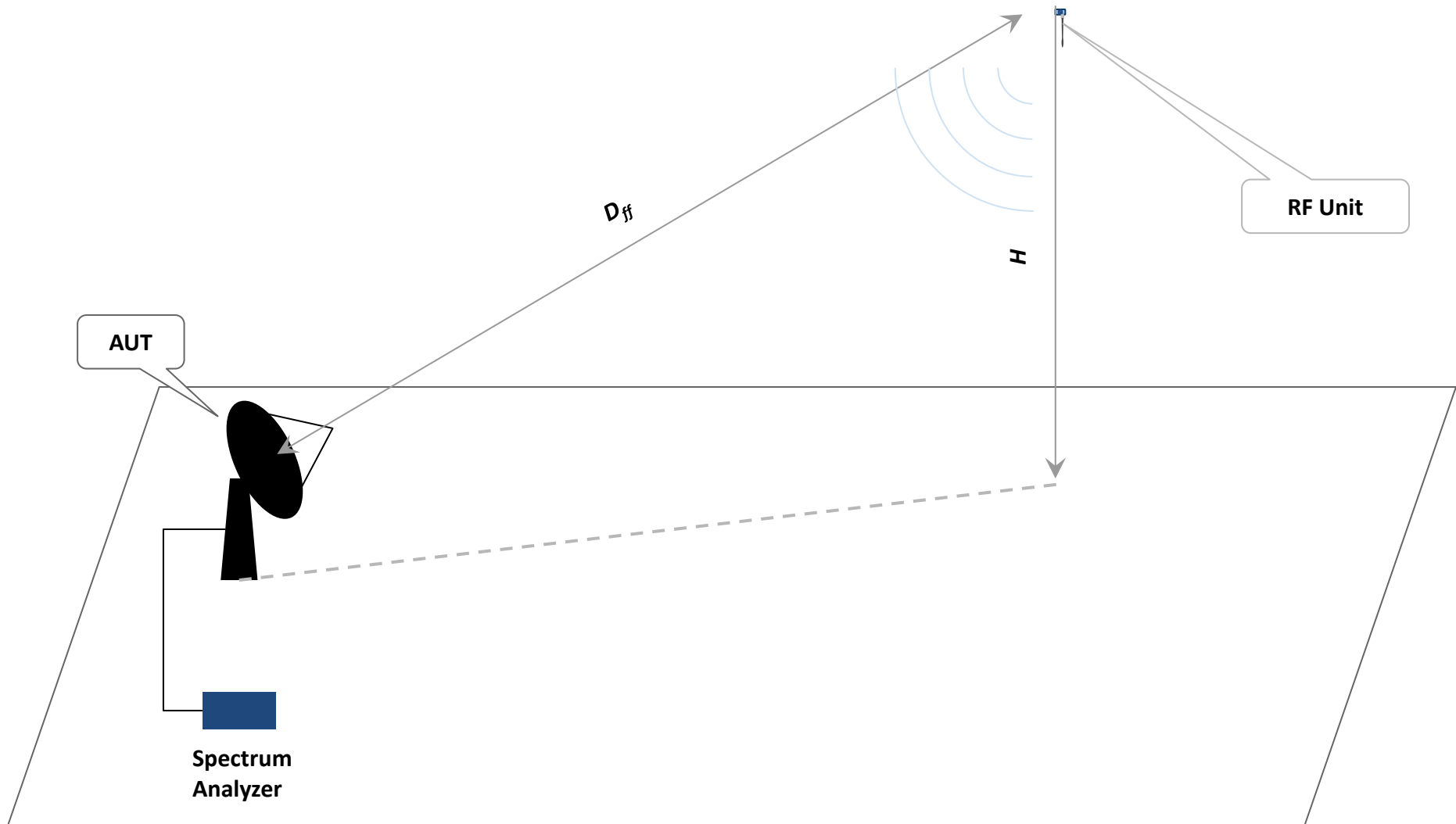


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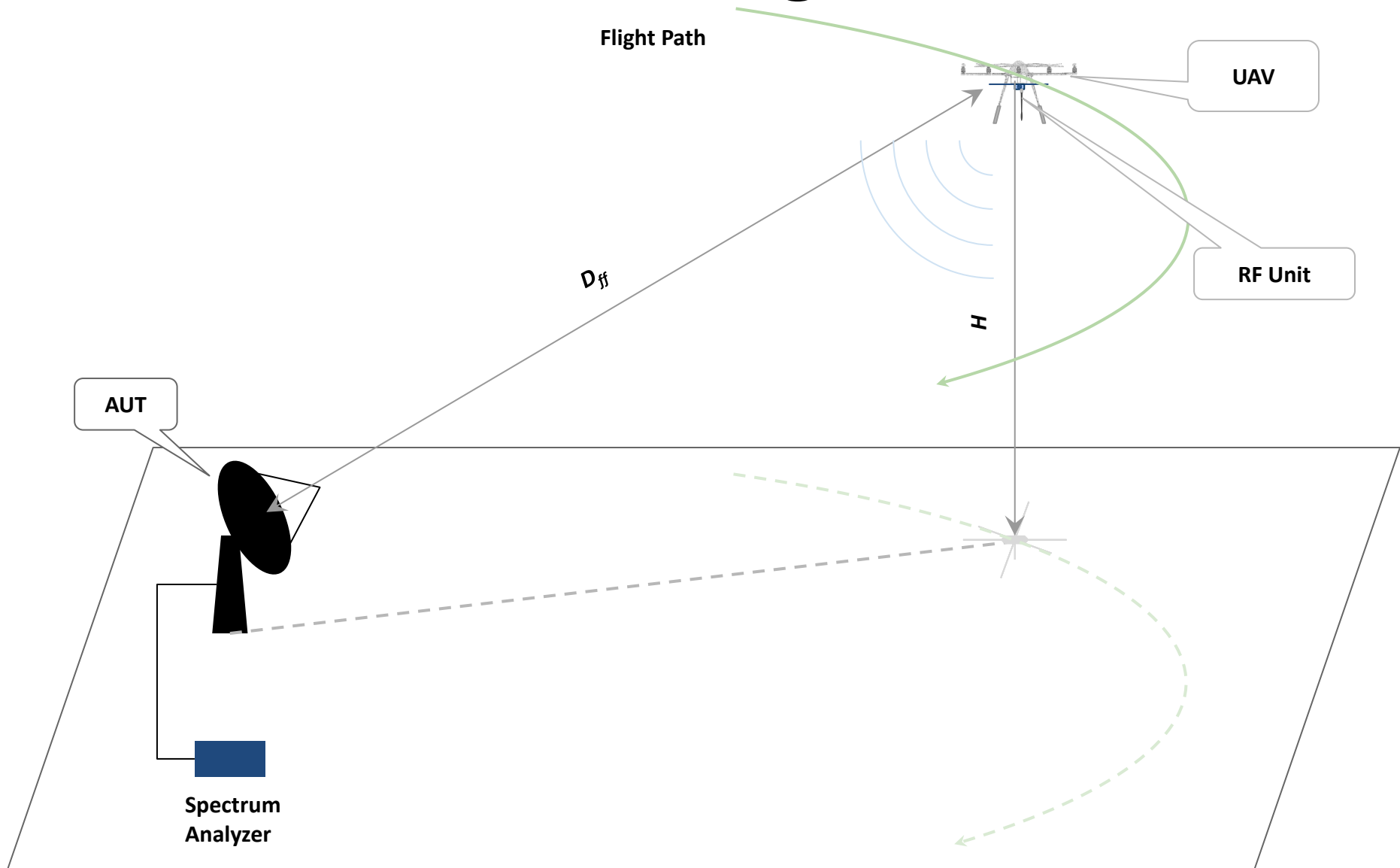
Human Antenna Systems



# Measurements using a test signal



# Measurements using an UAV





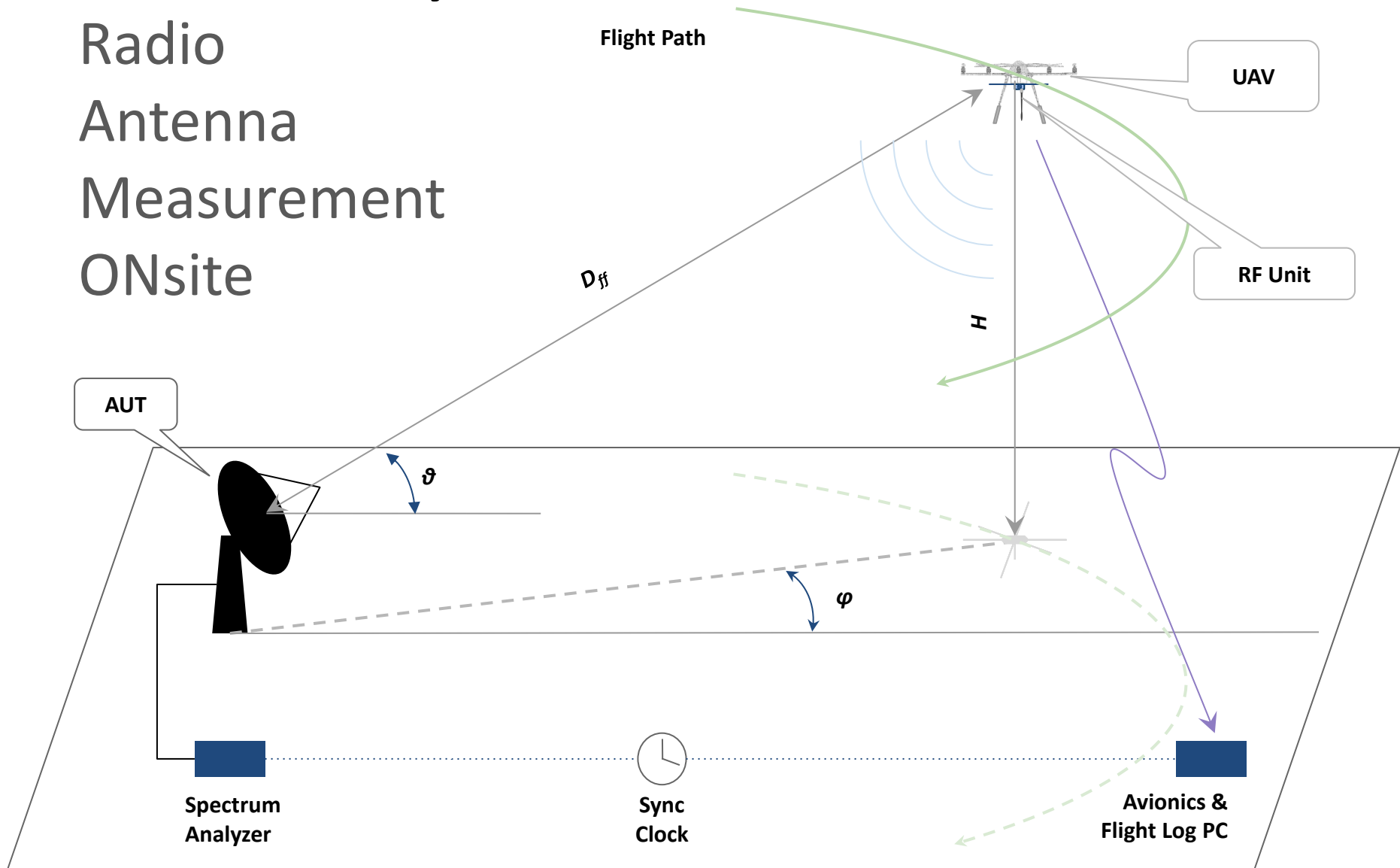
# RAMON System

Radio

Antenna

Measurement

ONsite



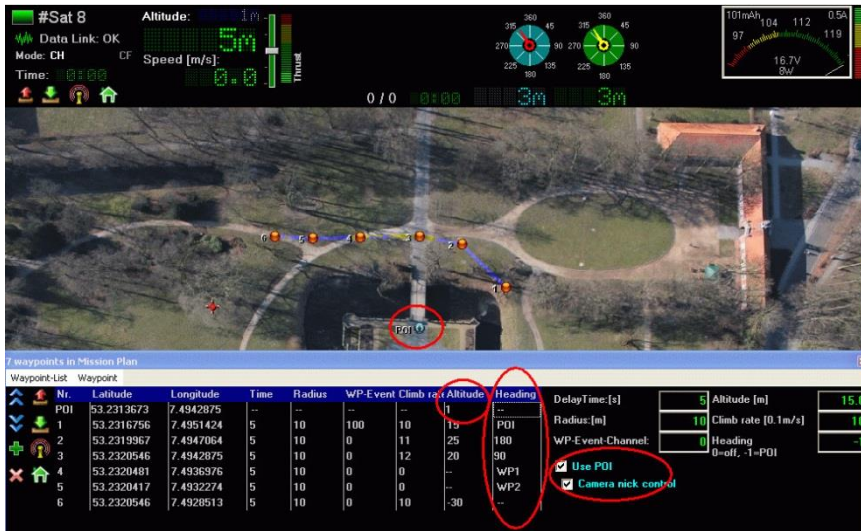
# Unmanned Aerial Vehicle (UAV)

## OktoXL – Mikrokoopter

- Payload: 2.6 kg (max)
- Range: 500 m
- GPS-aided navigation
- Barometric altimeter
- ~ 15 min autonomy



# Unmanned Aerial Vehicle (UAV)



- Predefined waypoints-based autonomous flight path
- Position and hold mode with heading control (3°)
- 5 satellites (min): ~3 m accuracy

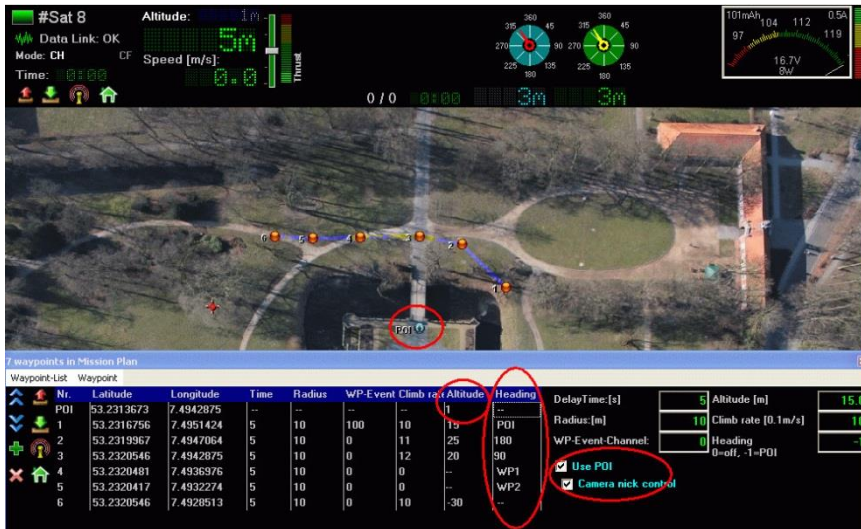
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# RF Unit

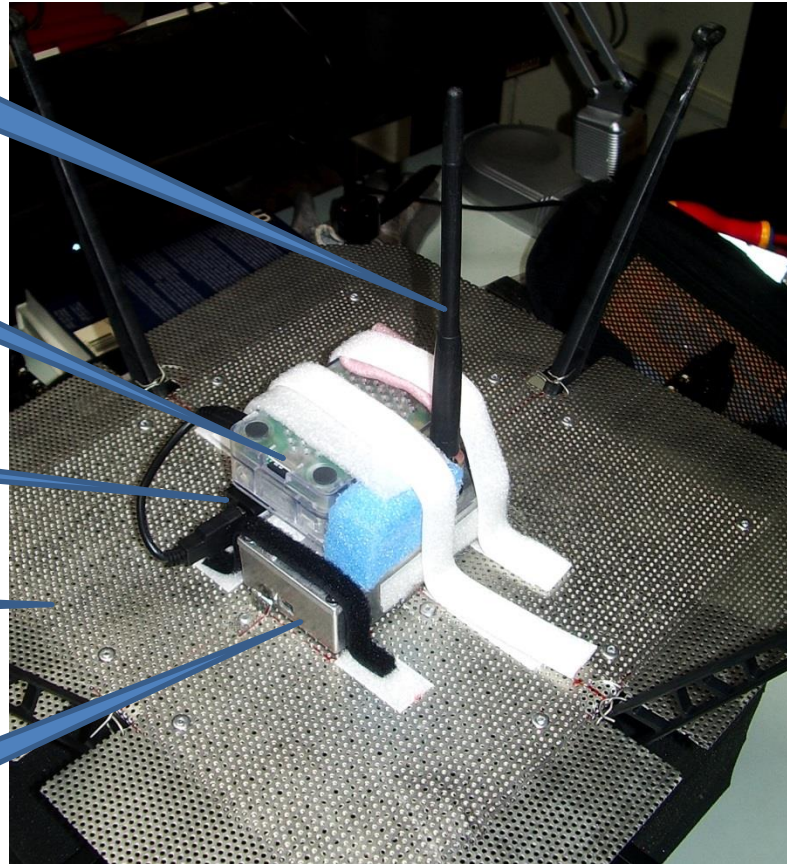
Short Monopole  
Antenna

SBC  
(Raspberry Pi)

Battery Bank

Metallic Mesh

RF signal  
generator



# RF Unit

$Z = 50 \Omega$

Short Monopole  
Antenna

Freq Control

SBC  
(Raspberry Pi)

+6h autonomy

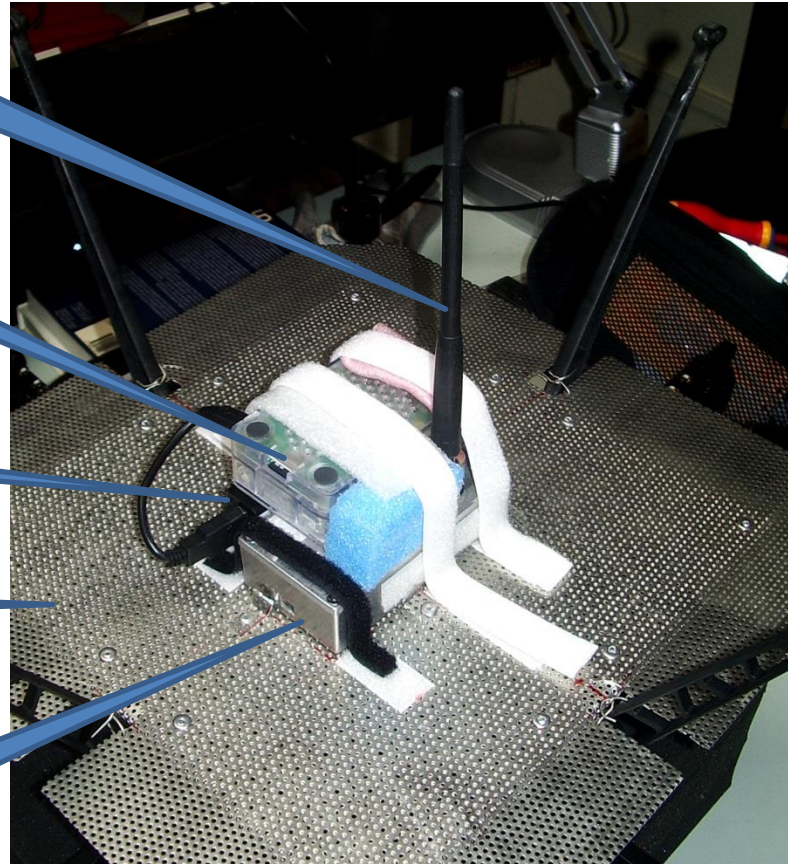
Battery Bank

Metallic Mesh

EM isolation

RF signal  
generator

-6 dBm (max)





# Receiver / Data Logger

Spectrum Analyzer

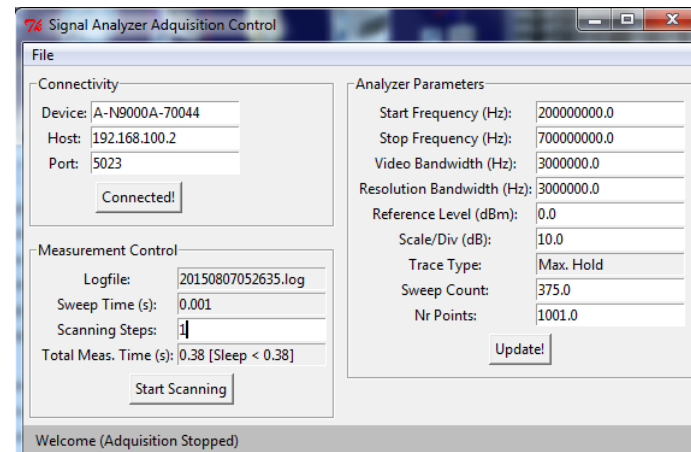


AUT

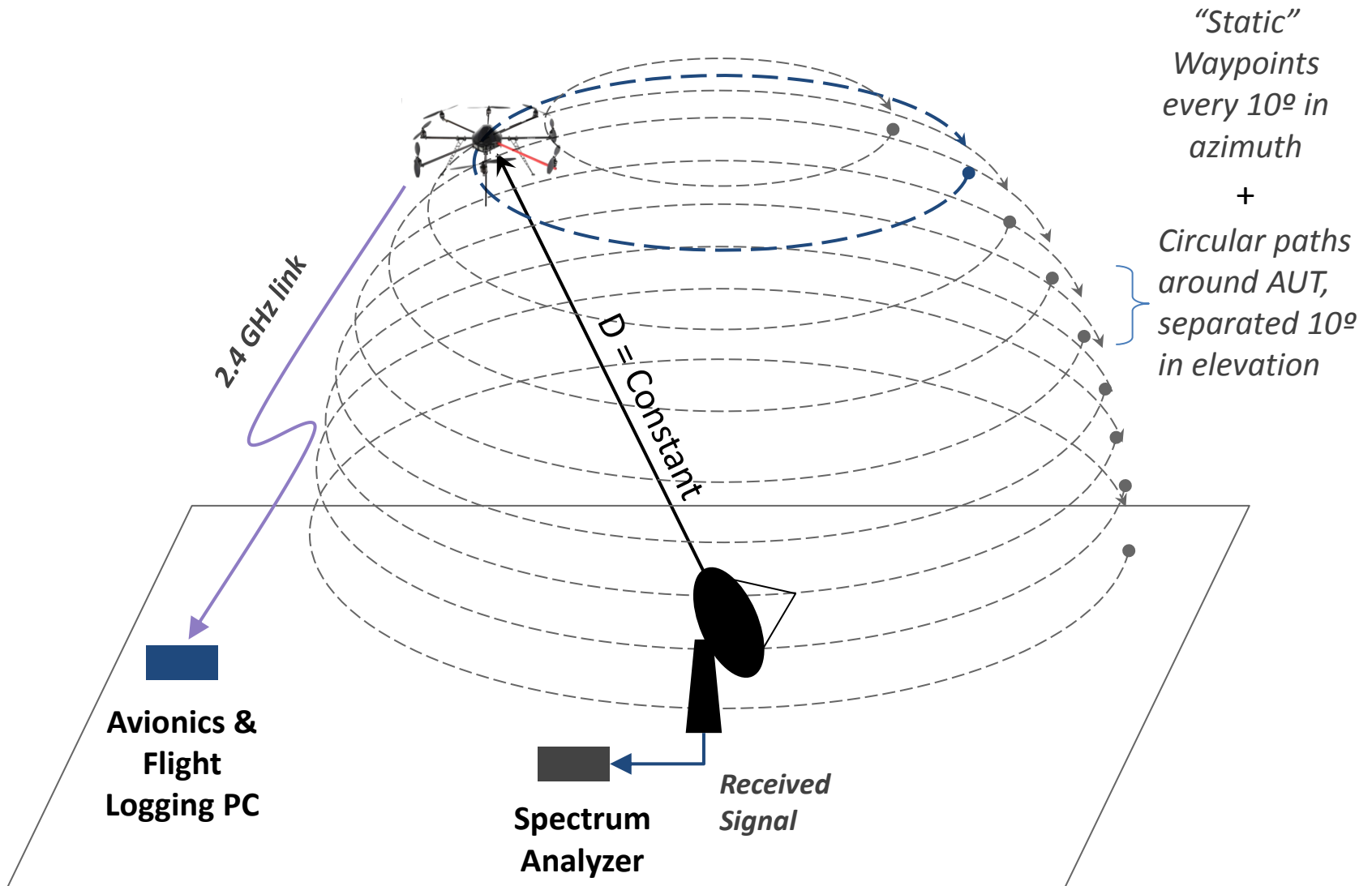
- Python script (GUI)
- SCPI commands over FTP
- Max Hold mode
- Output: received power & timestamps



*Ethernet*

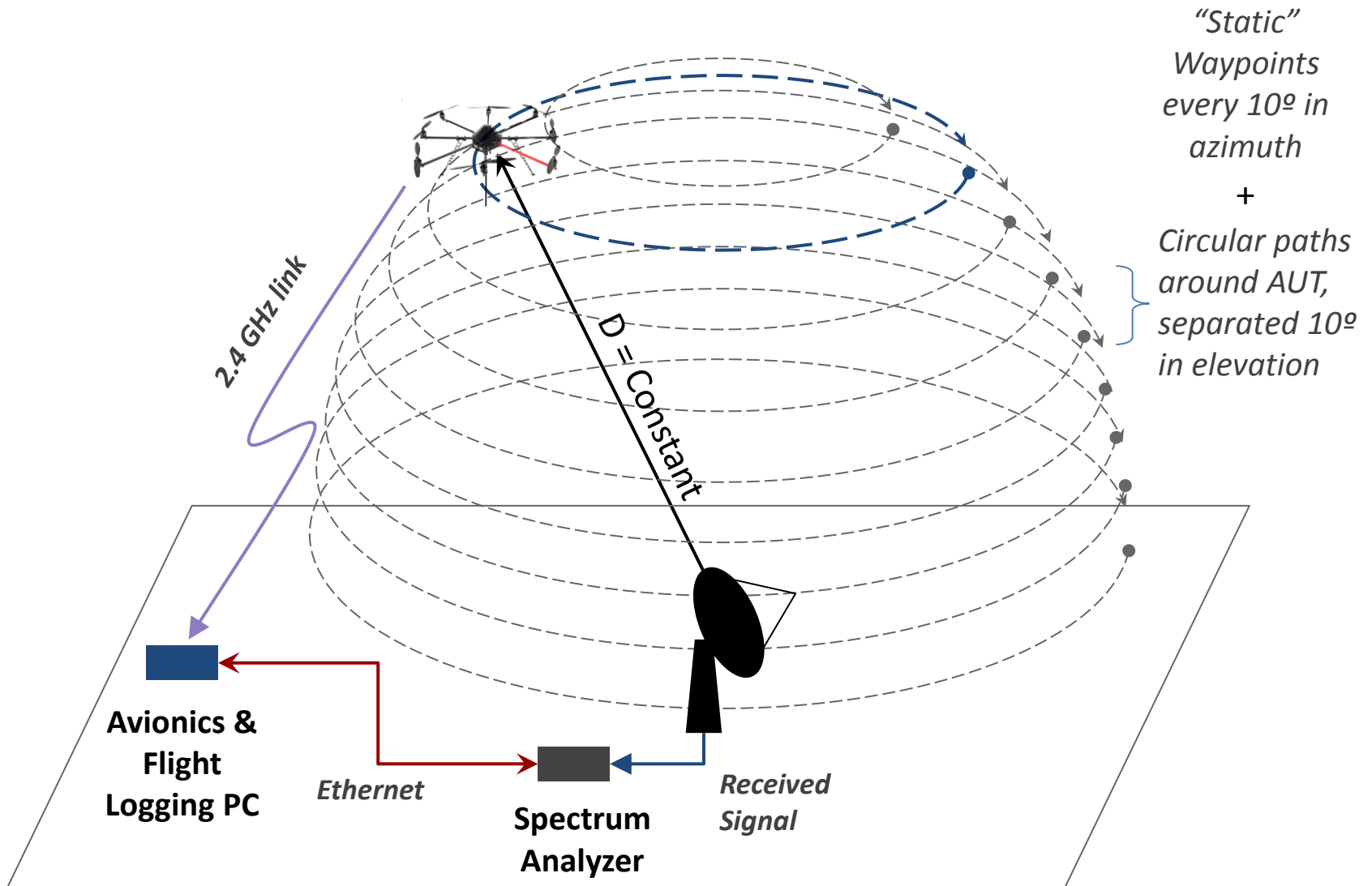


# Measurement Strategy





# Measurement Strategy



# Measurement Strategy

Imagesize (1366x567) Position 50.192723 : 5.250526

File GPX Log Data Link WayPoints Display GPS coordinates

#Sat 8 Altitude: 5m Waypoint 36/36 P37  
 Data Link: OK Mode: CH CF Speed [m/s]: 0.0 Thrust 0:00 [s] 3 [m/s] 118 [m] 3 [m/s]

7812mAh 139 149 0.5A  
 130 158  
 14.5V 7W  
 GPX-Log: stopped

Signal Analyzer Acquisition Control

File

Connectivity  
 Device: A-N9000A-70044  
 Host: 192.168.100.2  
 Port: 5023  
 Connected!

Analyzer Parameters  
 Start Frequency (Hz): 275000000.0  
 Stop Frequency (Hz): 525000000.0  
 Video Bandwidth (Hz): 3000000.0  
 Resolution Bandwidth (Hz): 3000000.0  
 Reference Level (dBm): 0.0  
 Scale/Div (dB): 10.0  
 Trace Type: Max. Hold  
 Sweep Count: 375.0  
 Nr Points: 1001.0  
 Update!

Measurement Control  
 Logfile: 20150807055130.log  
 Sweep Time (s): 0.001  
 Scanning Steps: 1  
 Total Meas. Time (s): 0.38 [Sleep < 0.38]  
 Start Scanning

Stopped

37 waypoints in Mission Plan

Nr.	Time	Radius	WP-Event	Climb rate	Altitude	Heading	Speed	CAM-Nick	Prefix	Latitude	Longitude
19	12	10	100	30	118	P1	30	AUTO	P	50.1915012	5.253313
20	12	10	100	30	118	P1	30	AUTO	P	50.1914956	5.253213
21	12	10	100	30	118	P1	30	AUTO	P	50.1915012	5.253113
22	12	10	100	30	118	P1	30	AUTO	P	50.1915179	5.253016
23	12	10	100	30	118	P1	30	AUTO	P	50.1915451	5.252926

Altitude [m]: 4.0  
 Climb rate [0.1m/s]: 30  
 Heading: 0=off, -1=P01: 315  
 CAM-Nick [°]: 0

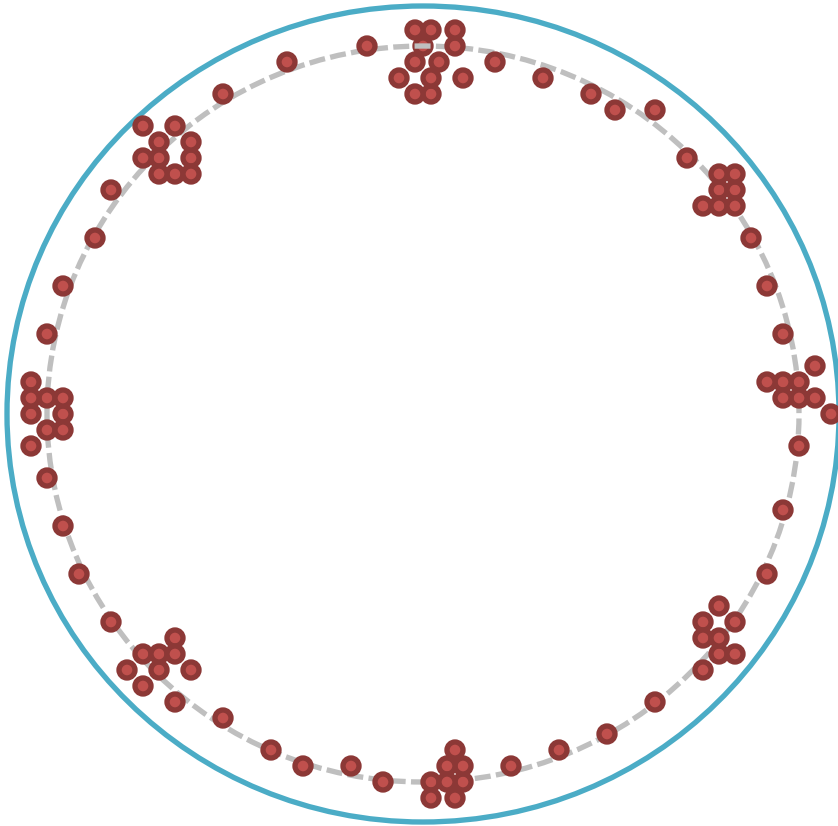
BL1: 39°C 0A  
 BL2: 39°C 0A  
 BL3: 42°C 0A  
 BL4: 41°C 0A  
 BL5: 42°C 0A  
 BL6: 41°C 0A  
 BL7: 42°C 0A  
 BL8: 41°C 0A

Google

8:05 AM 8/7/2015

Spectrum Analyzer

# Data Processing



Flight Track

$t_1 : \rho_1[f_1], \rho_1[f_2], \rho_1[f_3], \dots, \rho_1[f_m]$   
 $t_2 : \rho_2[f_1], \rho_2[f_2], \rho_2[f_3], \dots, \rho_2[f_m]$   
 $t_3 : \rho_3[f_1], \rho_3[f_2], \rho_3[f_3], \dots, \rho_3[f_m]$

$\vdots$

$t_x : \rho_x[f_1], \rho_x[f_2], \rho_x[f_3], \dots, \rho_x[f_m]$

$\vdots$

$t_y : \rho_y[f_1], \rho_y[f_2], \rho_y[f_3], \dots, \rho_y[f_m]$

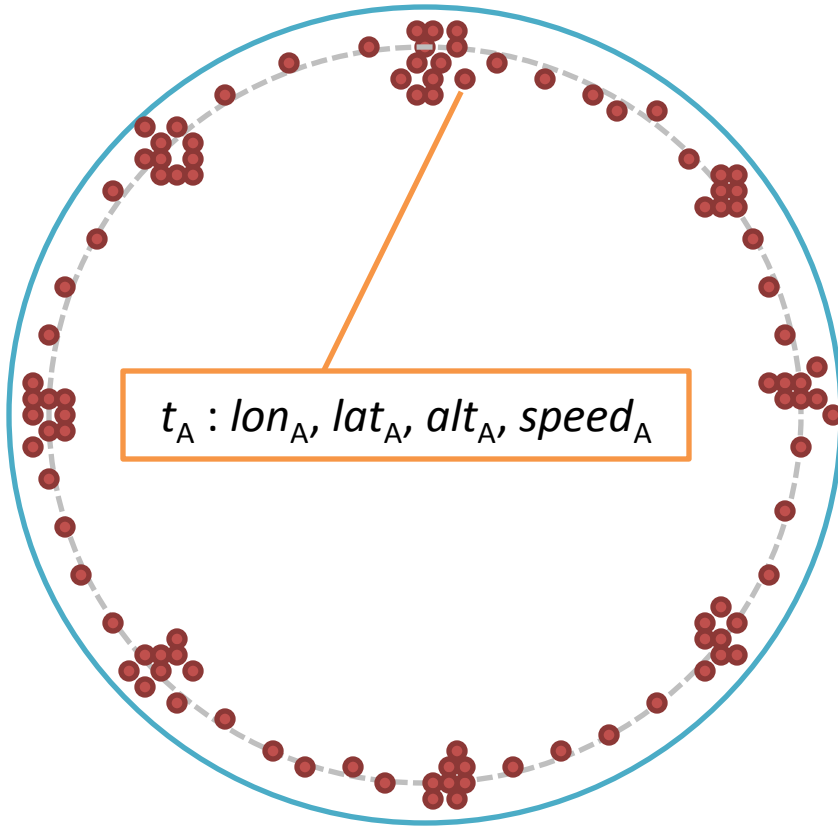
$\vdots$

$t_{n-1} : \rho_{n-1}[f_1], \rho_{n-1}[f_2], \dots, \rho_{n-1}[f_m]$

$t_n : \rho_n[f_1], \rho_n[f_2], \rho_n[f_3], \dots, \rho_n[f_m]$

Received Power Log

# Data Processing



Flight Track

$t_1 : \rho_1[f_1], \rho_1[f_2], \rho_1[f_3], \dots, \rho_1[f_m]$   
 $t_2 : \rho_2[f_1], \rho_2[f_2], \rho_2[f_3], \dots, \rho_2[f_m]$   
 $t_3 : \rho_3[f_1], \rho_3[f_2], \rho_3[f_3], \dots, \rho_3[f_m]$

⋮

$t_x : \rho_x[f_1], \rho_x[f_2], \rho_x[f_3], \dots, \rho_x[f_m]$

⋮

$t_y : \rho_y[f_1], \rho_y[f_2], \rho_y[f_3], \dots, \rho_y[f_m]$

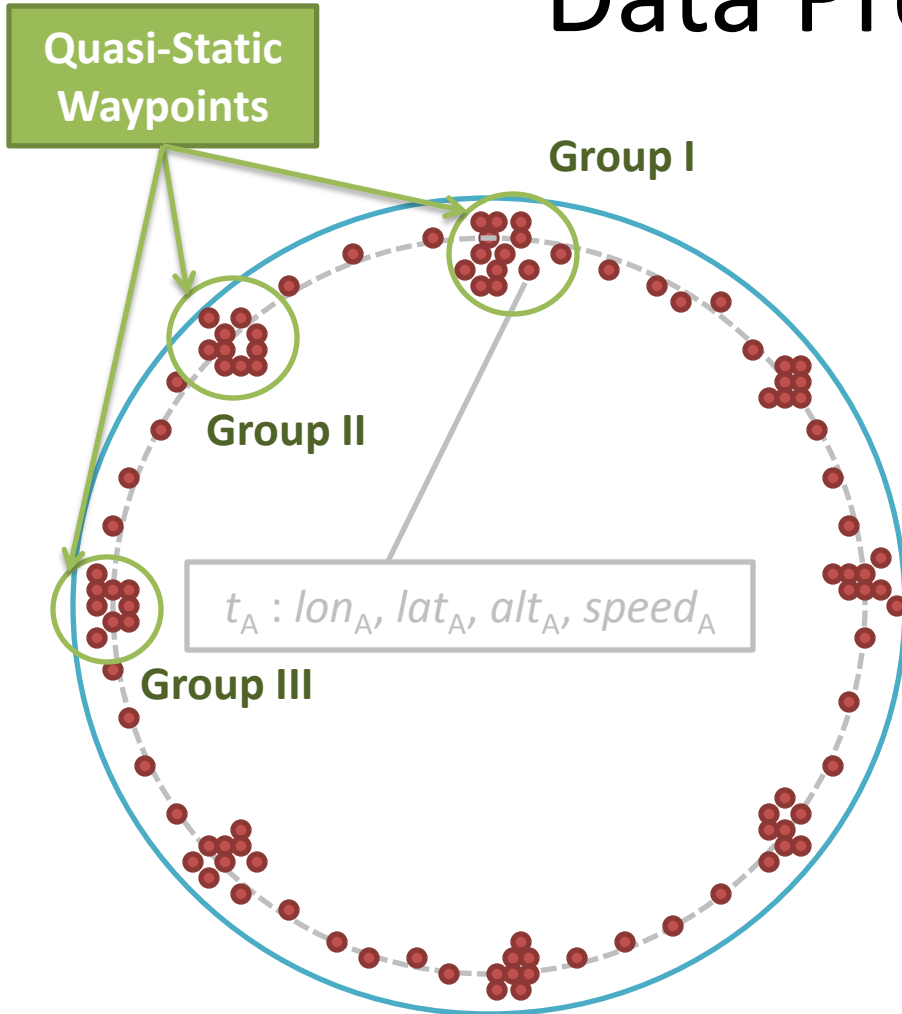
⋮

$t_{n-1} : \rho_{n-1}[f_1], \rho_{n-1}[f_2], \dots, \rho_{n-1}[f_m]$

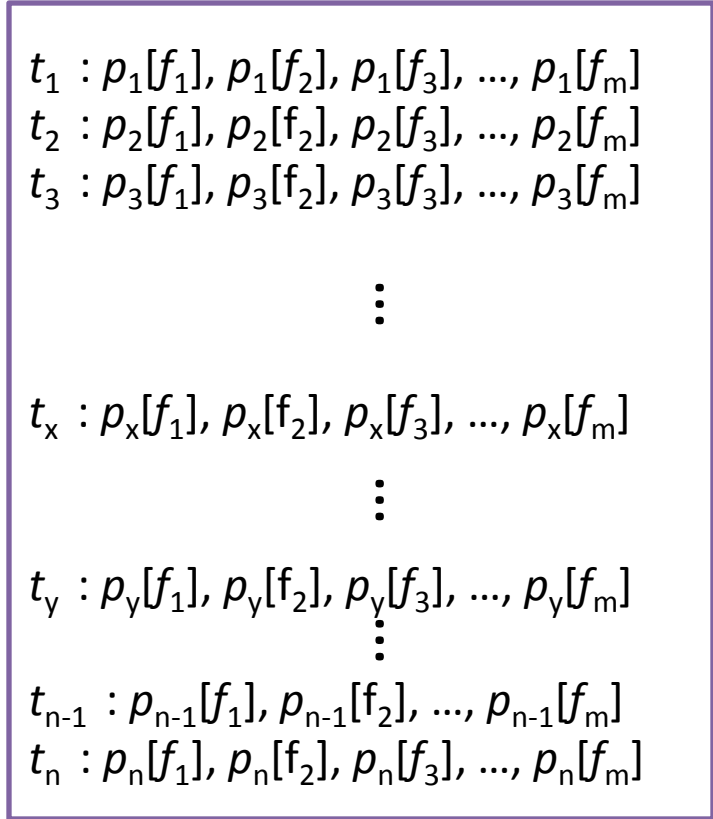
$t_n : \rho_n[f_1], \rho_n[f_2], \rho_n[f_3], \dots, \rho_n[f_m]$

Received Power Log

# Data Processing



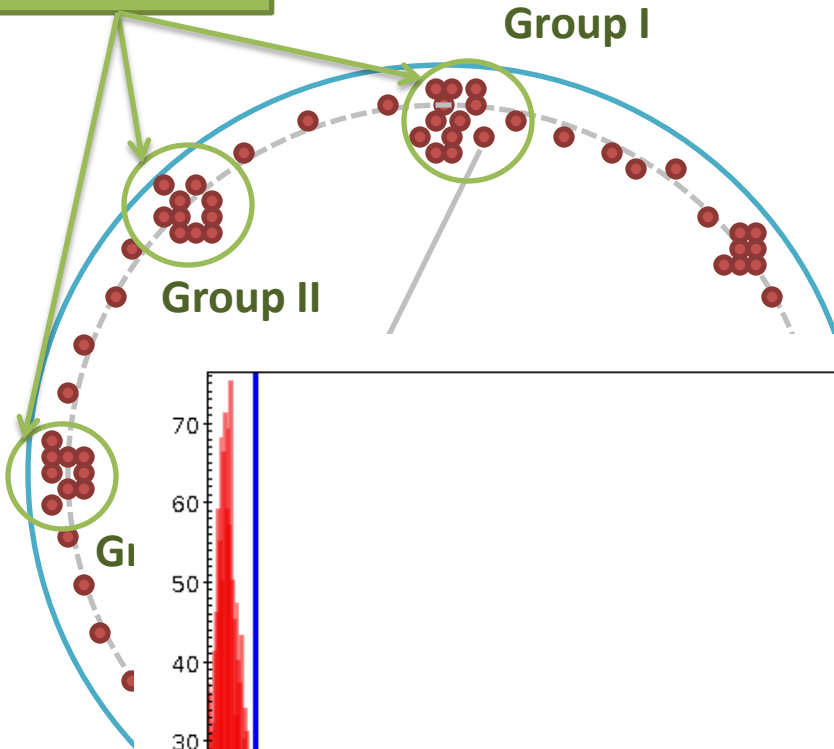
Flight Track



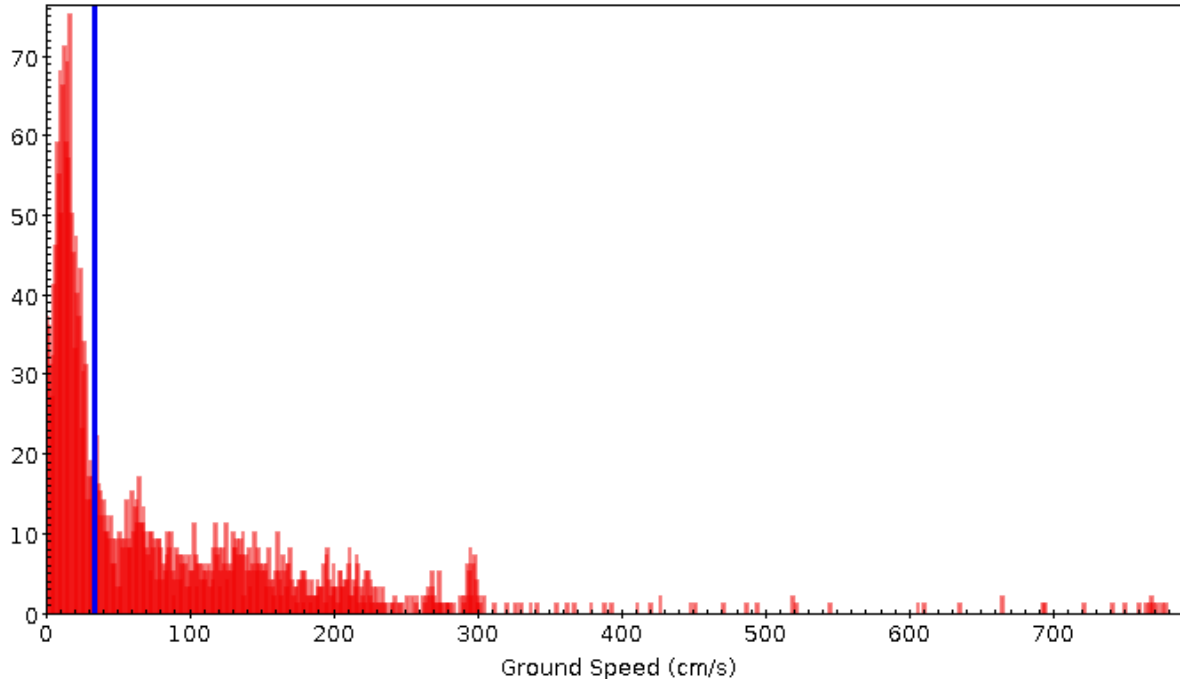
Received Power Log

# Data Processing

Quasi-Static Waypoints



$$\begin{aligned}
 t_1 &: \rho_1[f_1], \rho_1[f_2], \rho_1[f_3], \dots, \rho_1[f_m] \\
 t_2 &: \rho_2[f_1], \rho_2[f_2], \rho_2[f_3], \dots, \rho_2[f_m] \\
 t_3 &: \rho_3[f_1], \rho_3[f_2], \rho_3[f_3], \dots, \rho_3[f_m]
 \end{aligned}$$



$f_3], \dots, \rho_x[f_m]$

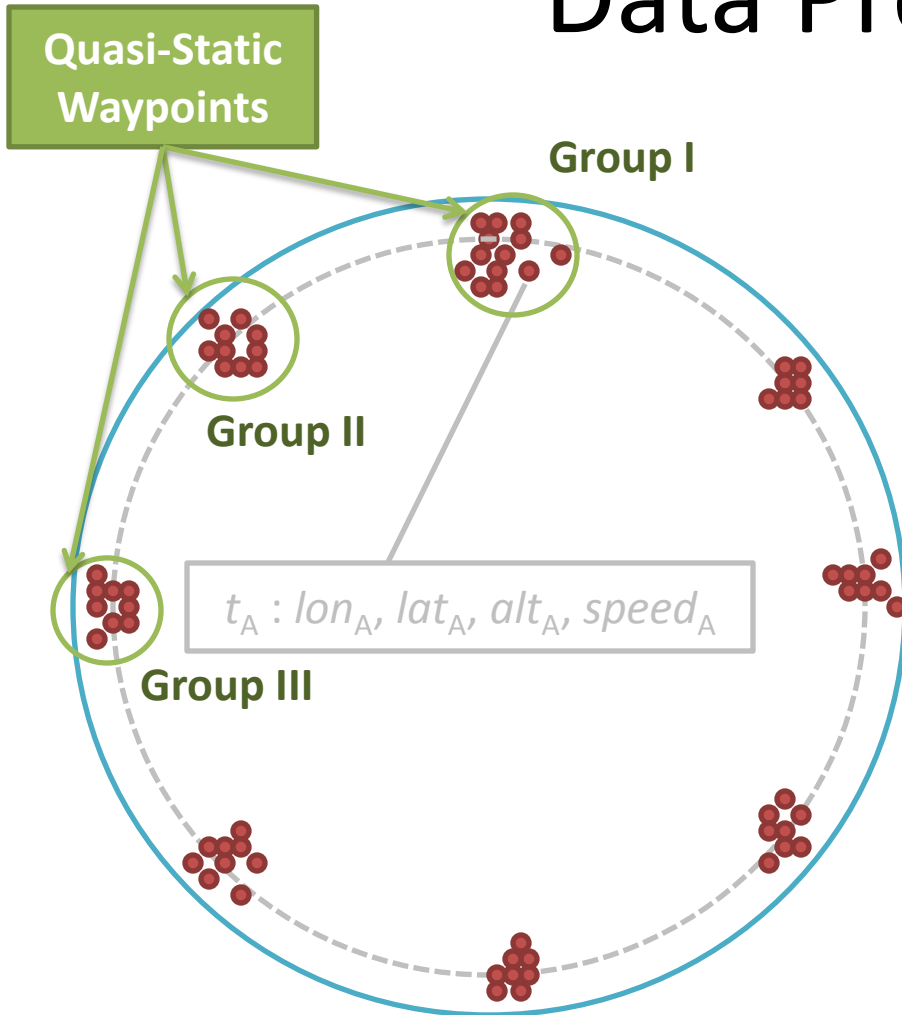
$f_3], \dots, \rho_y[f_m]$

$], \dots, \rho_{n-1}[f_m]$

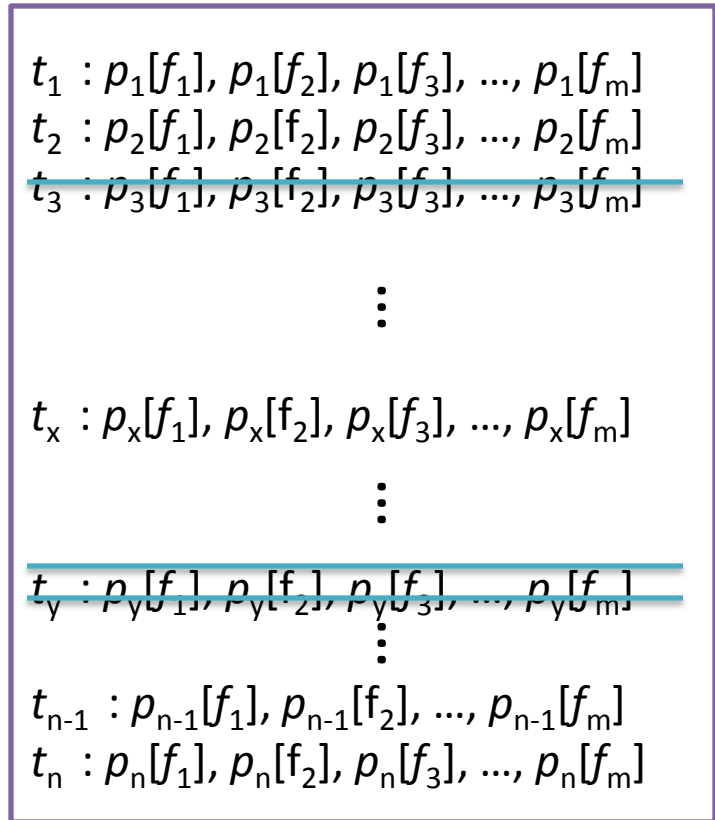
$[f_3], \dots, \rho_n[f_m]$

ower Log

# Data Processing

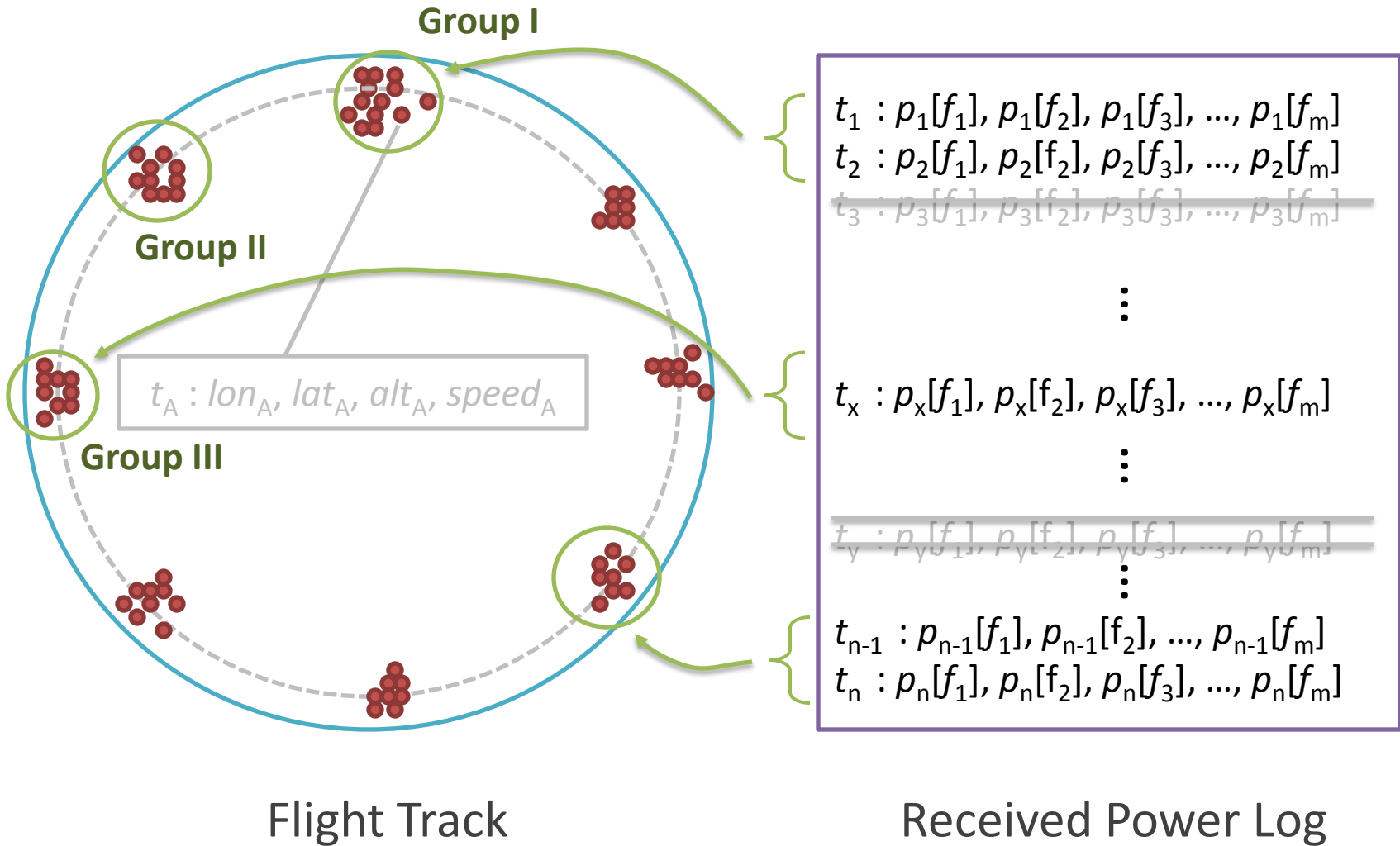


Flight Track



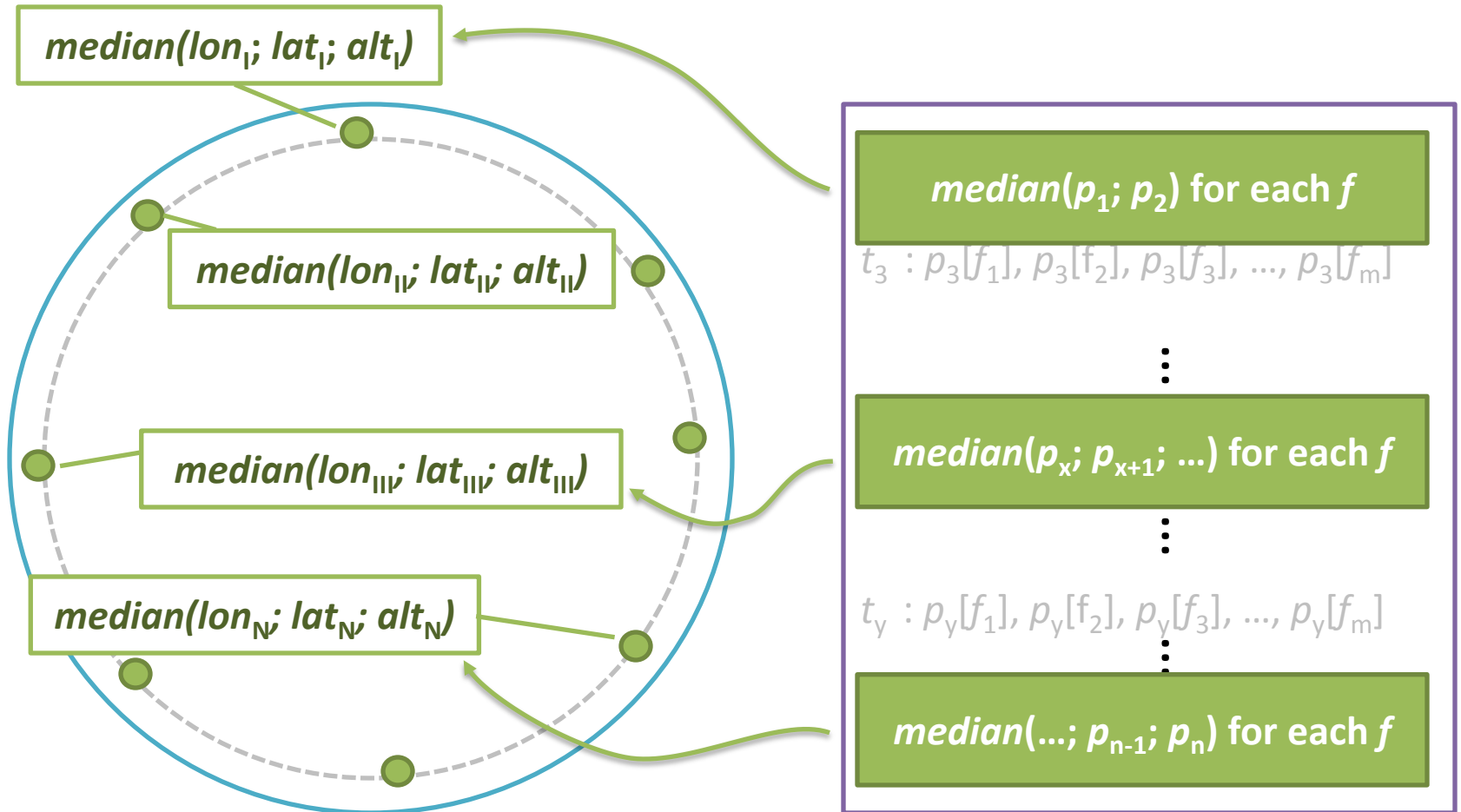
Received Power Log

# Data Processing





# Data Processing



Flight Track

Received Power Log

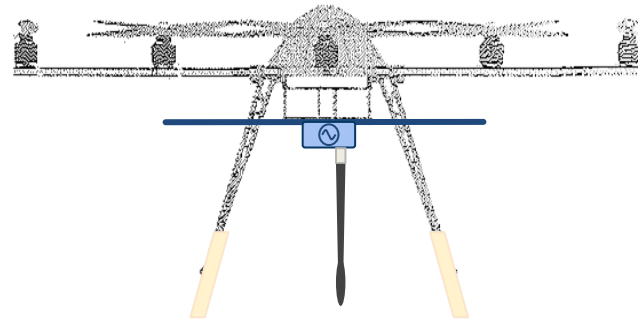
# First Task

## Pattern of the Test Signal Source

- The UAV will be always oriented towards the AUT
- Measured with a calibrated antenna



$$P_R = P_T - L + G_T + G_R$$



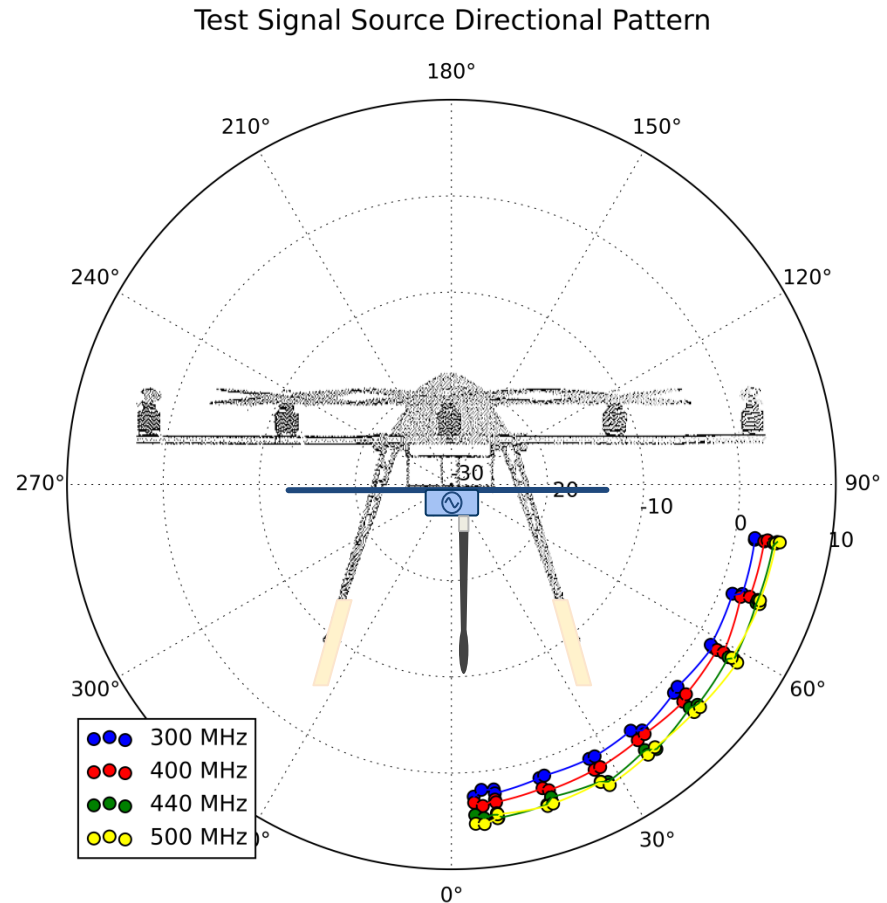
# First Task

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# Proof of Concept

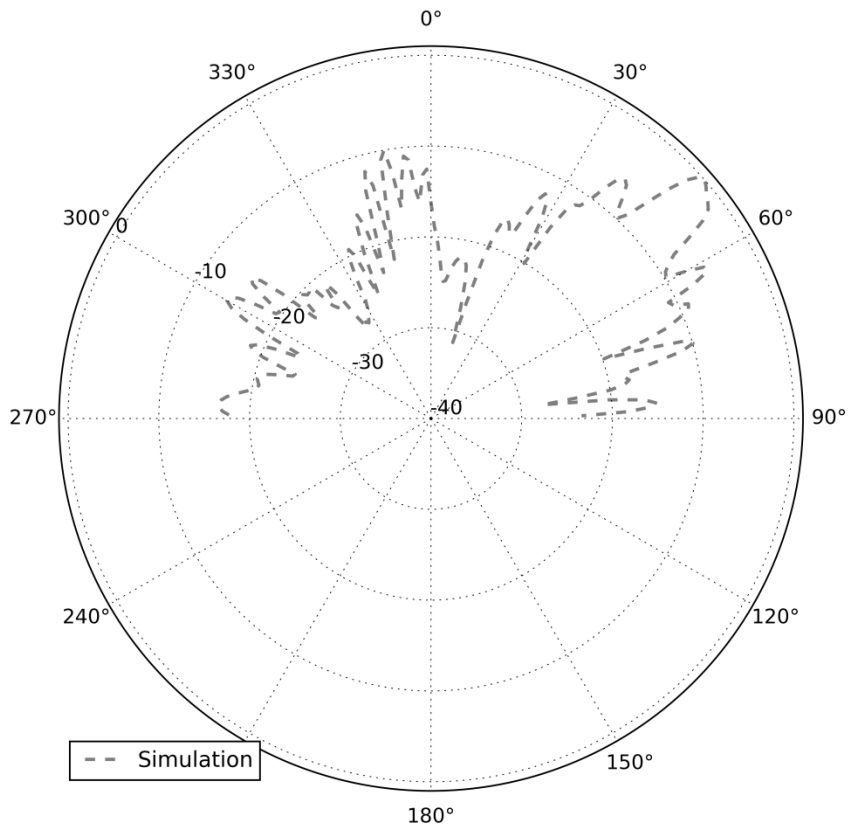


- AUT: 6m-dish antenna
- $f = 328.5$  MHz
- Flights @ different distances
- 1 day mission

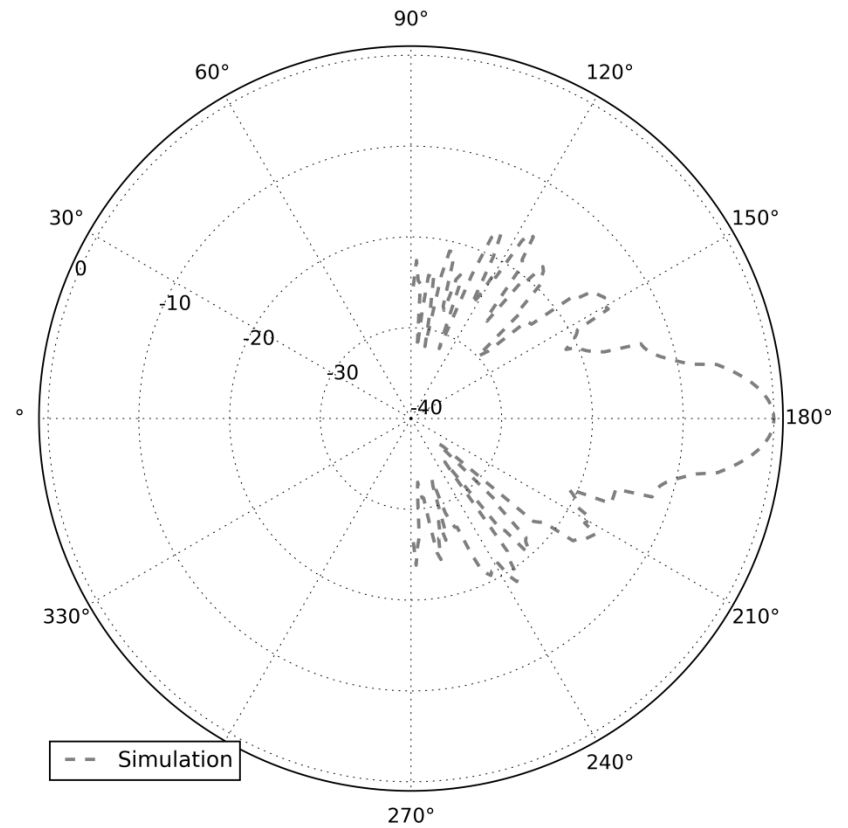
$$P_R = P_T - L + G_T + G_R$$

# Numerical Simulation

6m-dish Declination Directional Pattern

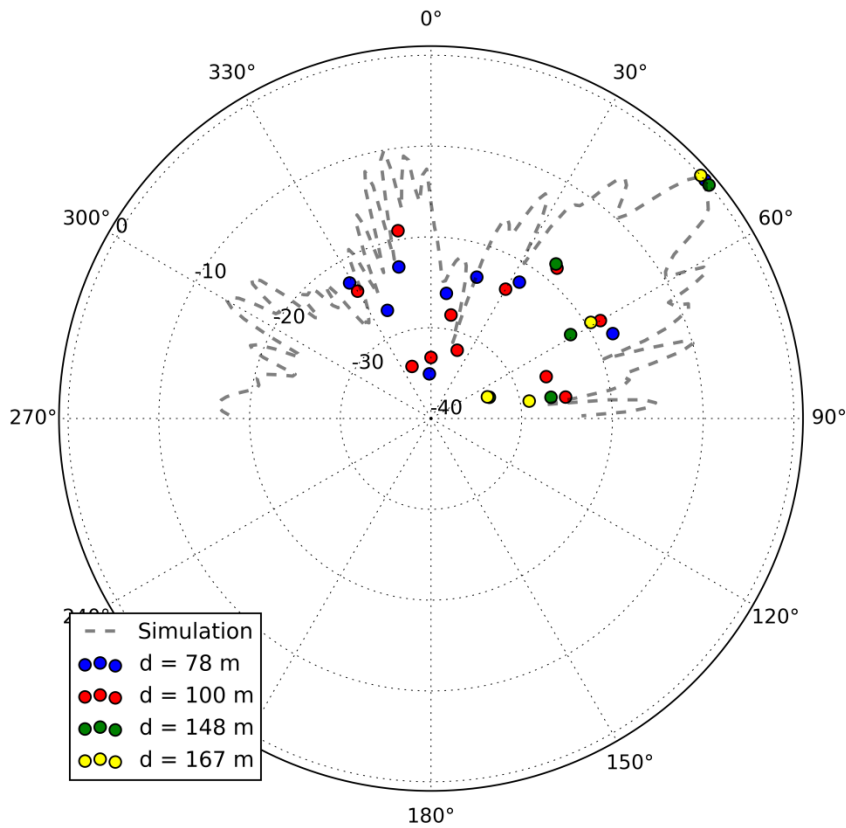


6m-dish Equatorial Directional Pattern

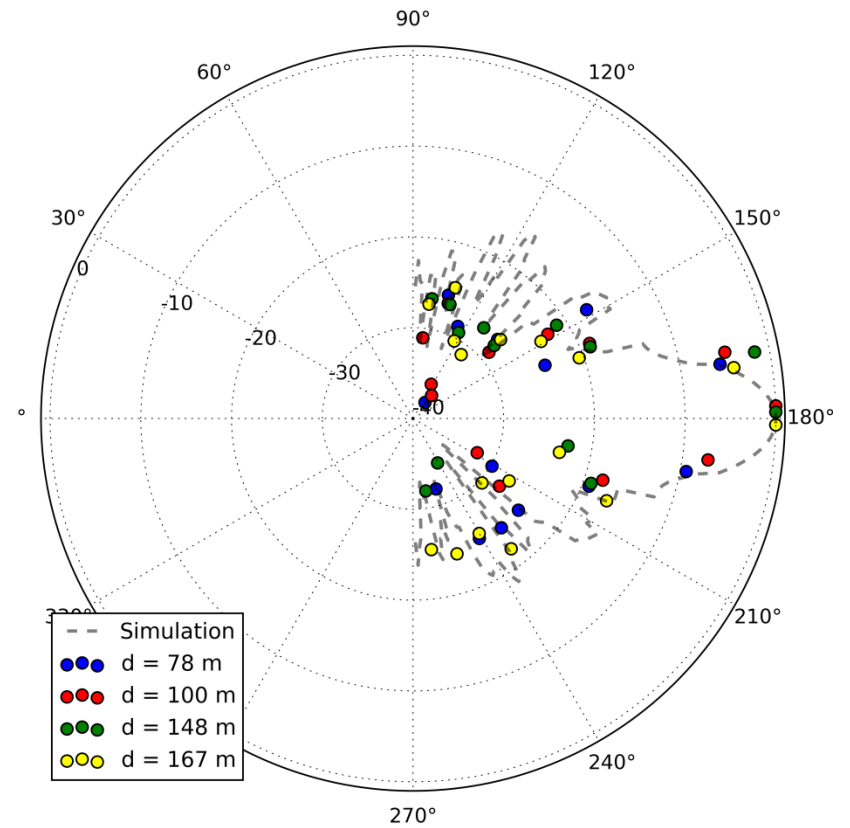


# Measurements

6m-dish Declination Directional Pattern



6m-dish Equatorial Directional Pattern



# Discussion

- Statistical approach (more points are needed)
- Differentiate measurements under dry and humid conditions
- Variability of points location is less sensitive flying far away
- Authorization (BELGOCONTROL) – permission for flying up to 120 m agl

# International Conference on Electromagnetics in Advanced Applications

September 7-11, 2015  
Torino – Italy



# Thank you!

Antonio Martínez Picar  
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