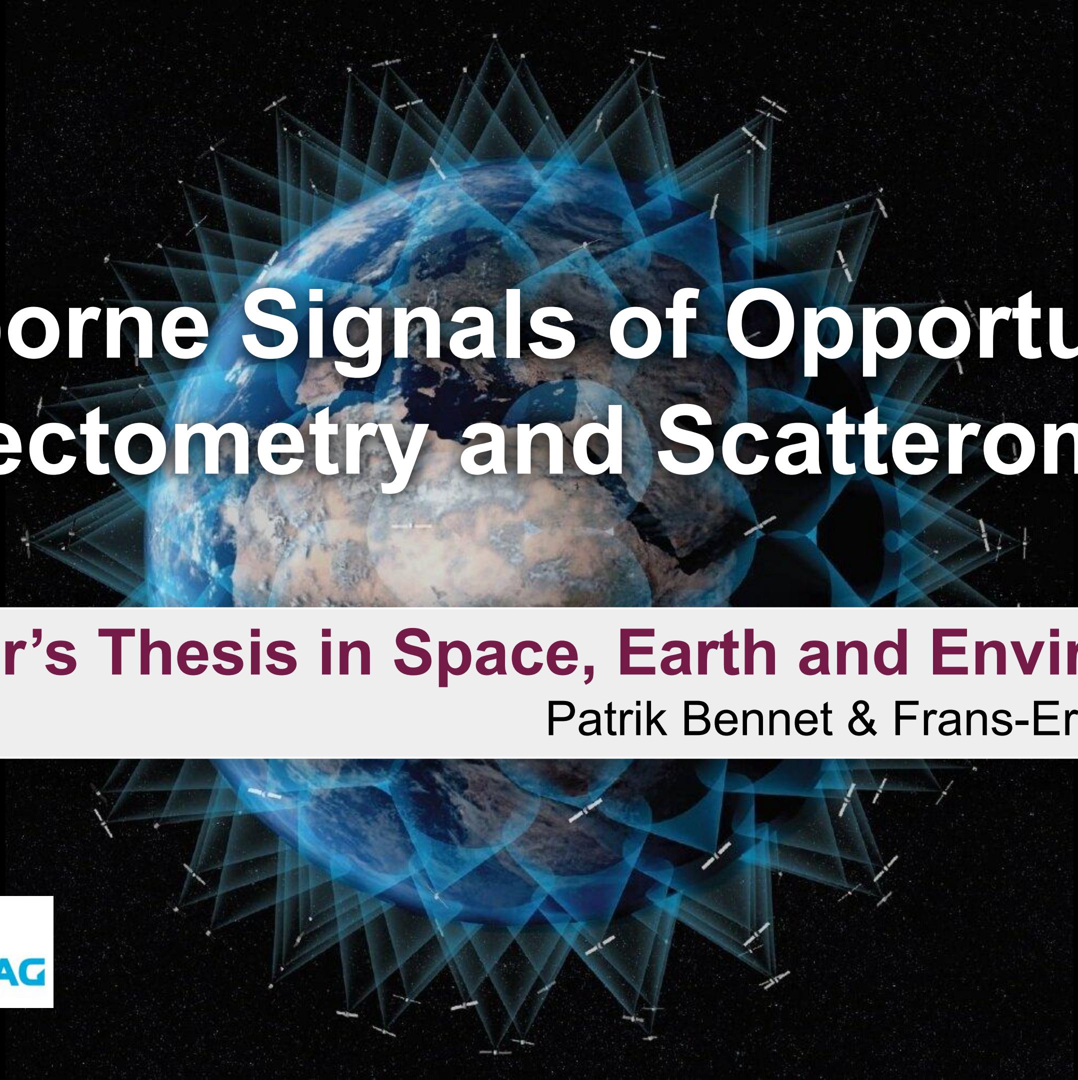

Spaceborne Signals of Opportunity for Reflectometry and Scatterometry

A Master’s Thesis in Space, Earth and Environment

Patrik Bennet & Frans-Erik Isaksson

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The thesis

- The team
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  - Chalmers examiner: Rüdiger Haas, Department of Space, Earth and Environment
  - Frans-Erik Isaksson, Communication Engineering
  - Patrik Bennet, Communication Engineering
- Report URL: https://hdl.handle.net/20.500.12380/302039


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Spaceborne Signals of Opportunity for Reflectometry and Scatterometry

An overview study with experimental results of an implemented passive reflectometry system using Ku-band TV-DBS opportunity signals indicating soil moisture measurement prospects

Master's thesis in Communication Engineering

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Gothenburg, Sweden 2020

Passive reflect- & scatterometry (1/3)

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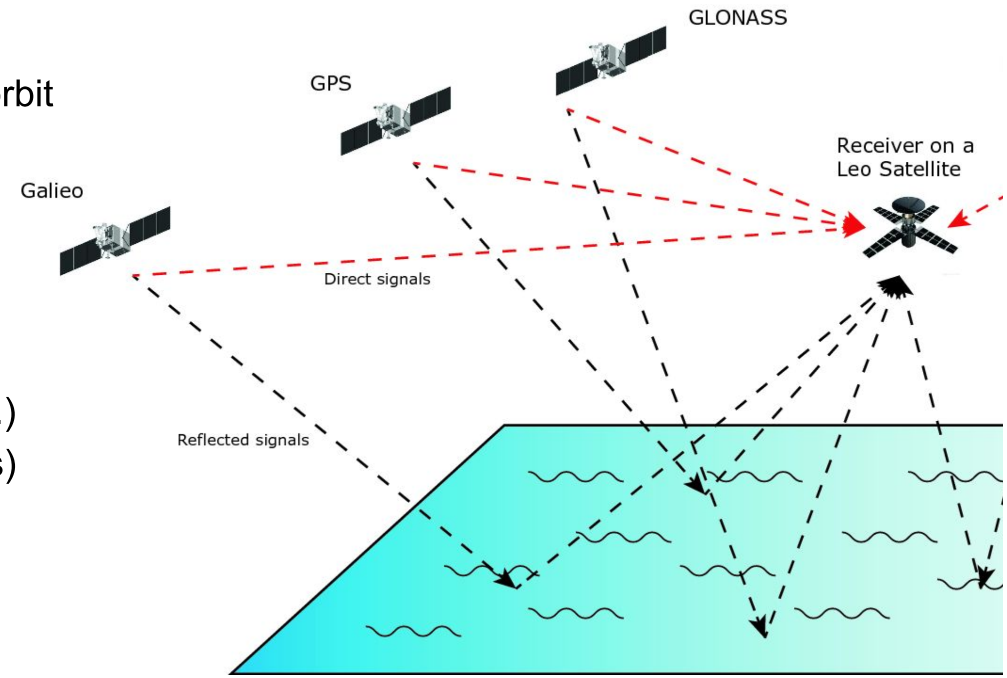
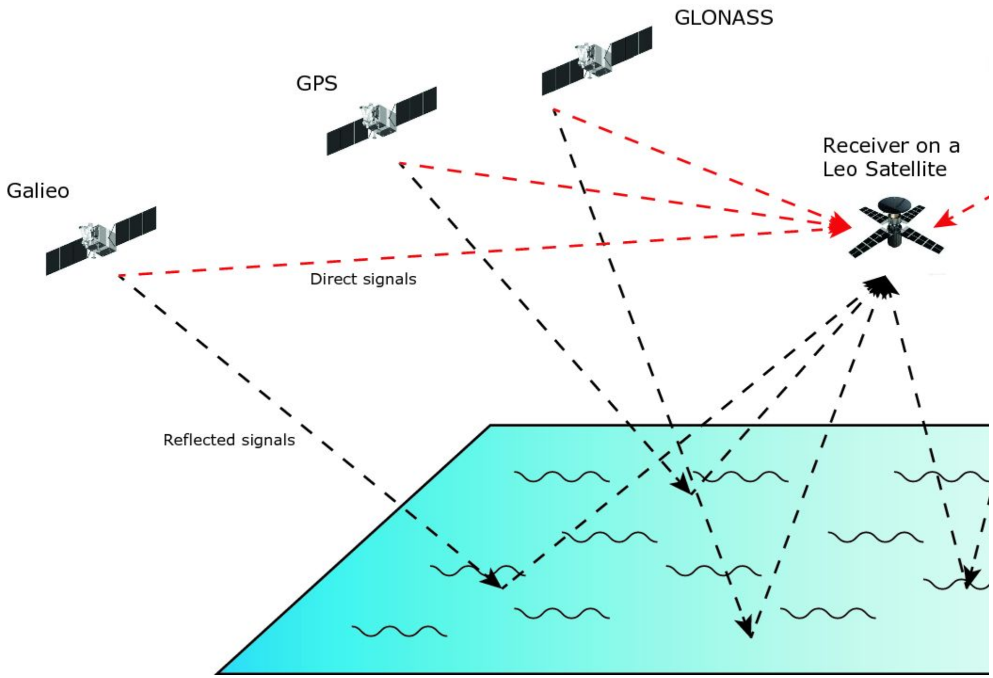
- Principle
  - Observe reflected and/or scattered signals from existing transmitters in orbit to infer surface and/or atmospheric properties
- Some applications
  - Altimetry (phase, delay)
  - Soil moisture (SNR, interference, pol.)
  - Ocean winds (sea surface roughness)
  - Vegetation (SNR, polarisation)
  - Precipitation (volume scattering)
  - Cryosphere snow & ice structure



Passive reflect- & scatterometry (2/3)

- Main needs
  - Market study (for drones) show that soil moisture mapping is the most attractive remote sensing application (agriculture industry, insurance firms, governments)
  - This and other applications also of interest for e.g. scientific, weather prediction and catastrophe warning purposes



Passive reflect- & scatterometry (3/3)

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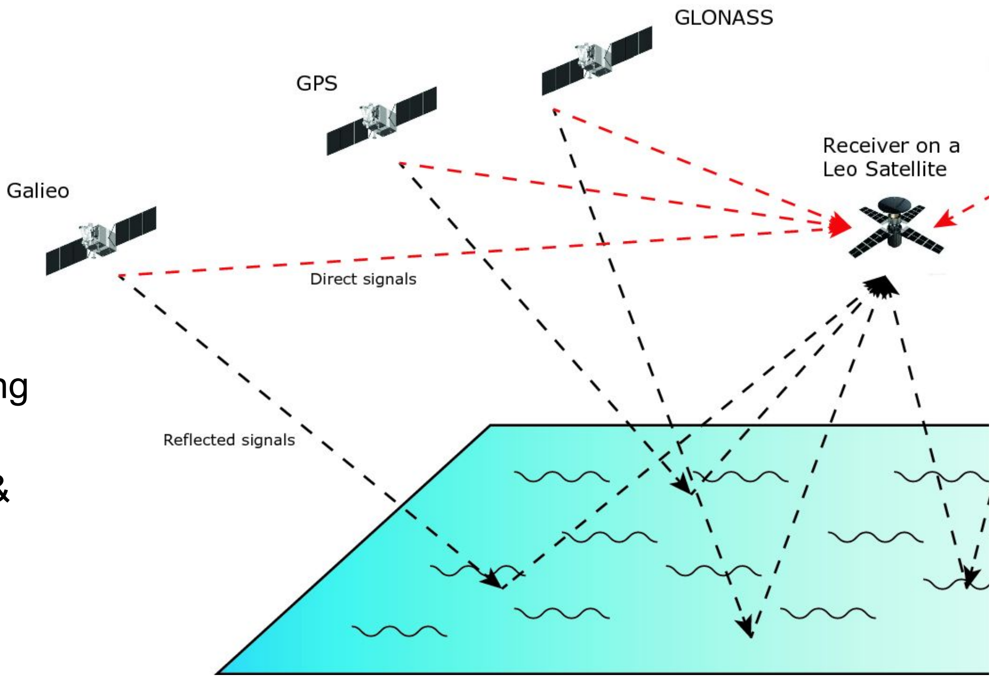
- Active systems
  - **Pros**: *Signal design, simple geometry*
  - **Cons**: *Frequency allocation, power consuming, large satellites, coverage limited to own Tx beam*
- Passive systems
  - **Pros***:* No on-board transmitter, small satellites, constellations, re-use existing signals, simultaneous tracking of multiple transmitters, large coverage & fast revisit times
  - **Cons**: Complex geometry, signals not intended for remote sensing



Spaceborne signals of opportunity

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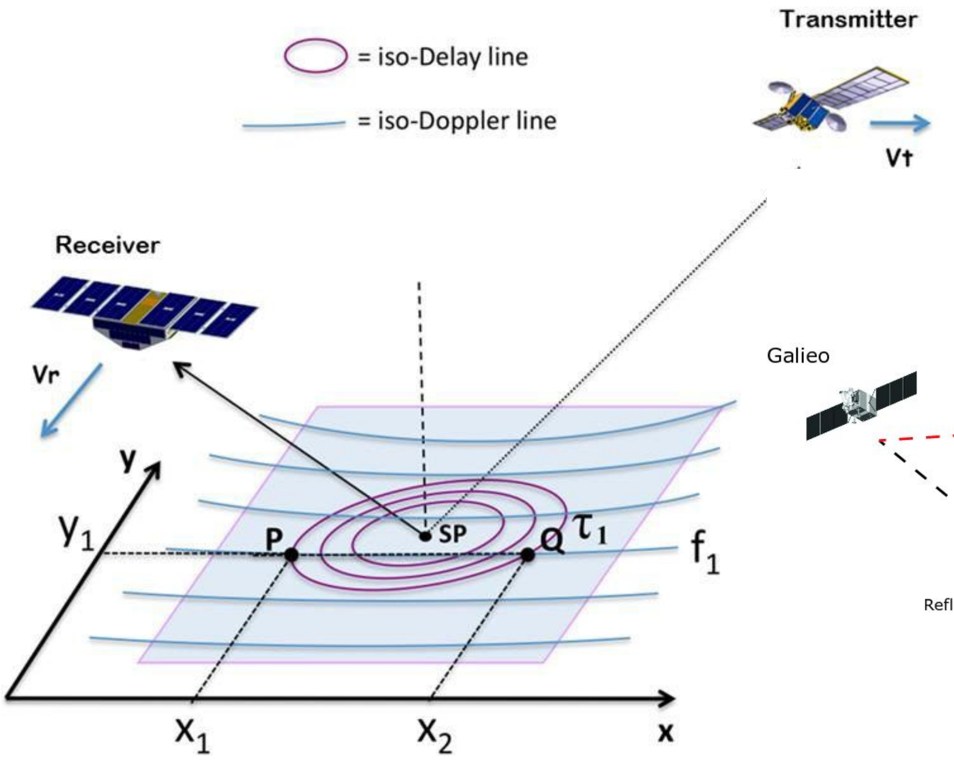
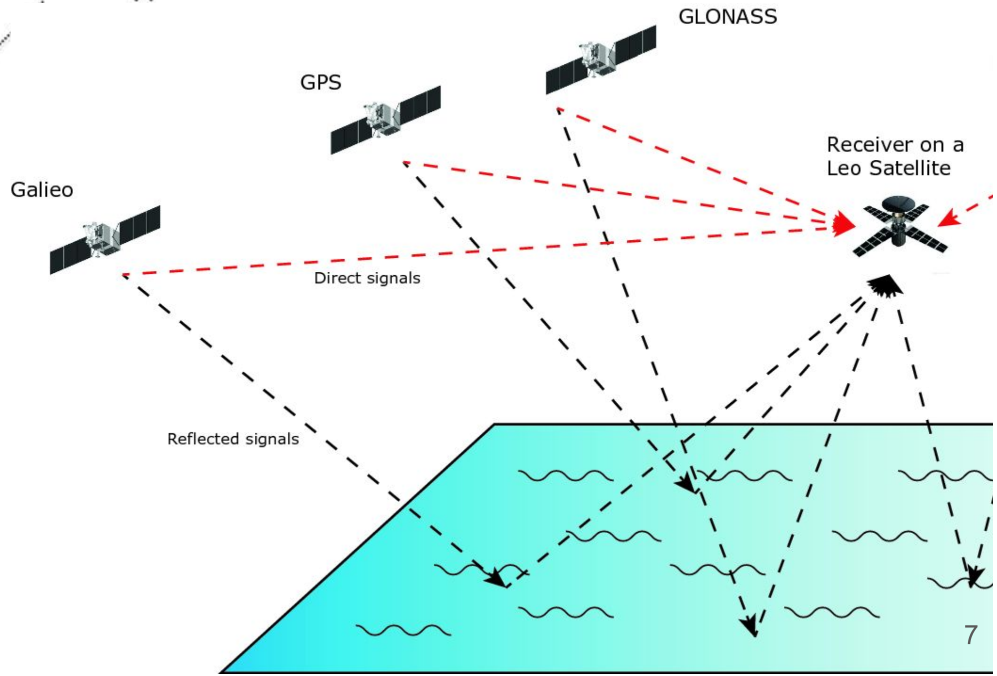
- GNSS
  - Signal properties well known, almost global coverage.
  - Low power, small bandwidth, only L-band.
- Direct broadcast satellites (DBS)
  - Large bandwidth & power, L to Ku bands, almost global coverage.
  - Unknown signal content.
- Mobile communication satellites
  - Future >10000 satellites (e.g. Kuiper, Starlink), very large bandwidth, up to V-band.
  - Unknown signal, bursty transmission.
- (Active remote sensing instruments)
  - Signals well known, expanding on current systems.

Measurement techniques





Current systems & research

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- CYGNSS mission (2016)
    - NASA
    - Application: ocean wind speed mapping (hurricane forecasting)
    - Constellation of 8 small satellites in LEO, tropics coverage
- PRETTY mission (2020/21)
    - ESA, TU Graz, RUAG Space
    - Application: Altimetry
    - iGNSS-R
    - LEO 3U CubeSat
- Current research
    - CYGNSS data map flood inundation during the 2017 Atlantic hurricane season (2018)
    - TechDemoSat-1 (2015)
    - Chalmers sea-level GNSS-R (2018)
    - X-band TV signal PARIS sea surface scattering (2014)
    - & more…

Experiment definition

Technique

- *Interferometric (PARIS)*

Application

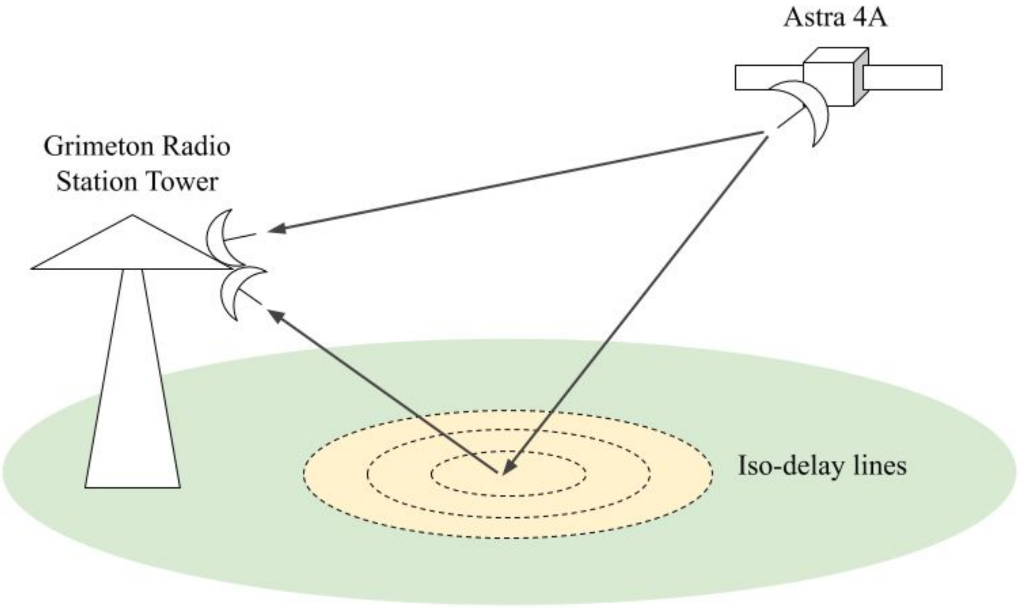
- *Soil moisture mapping (SNR)*

Signal source

- *Ku-band GEO TV-DBS Astra 4A*
- *33 MHz bandwidth, 50 dBW EIRP*
- *52 transponders, 40 MHz/channel*

Measurement setup

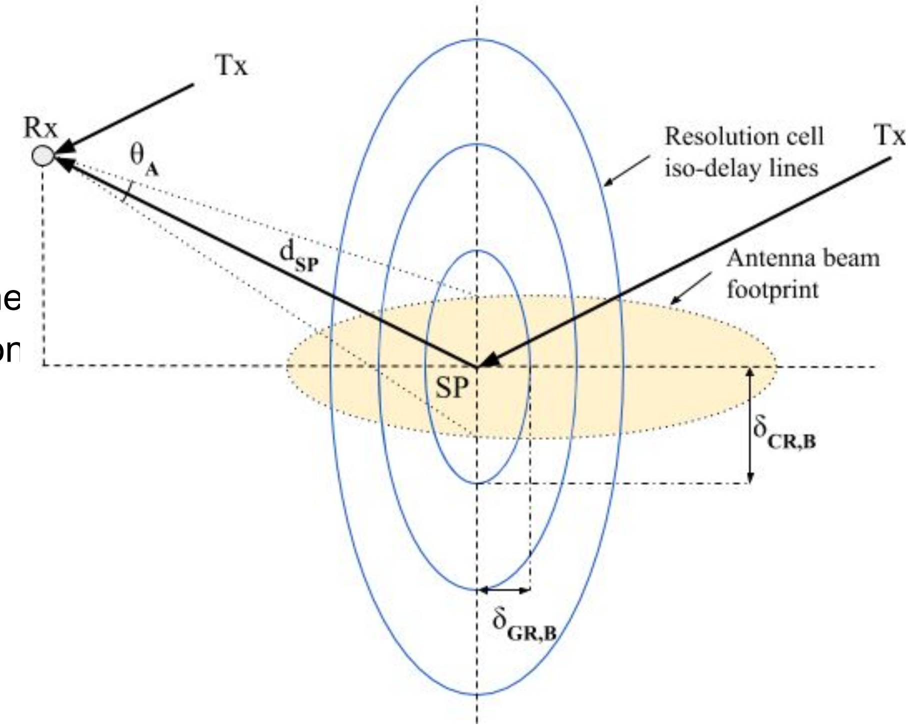
- *The World Heritage Grimeton Radio Station antenna tower*
- *Installation at 120 meters height*
- *Flat area surrounded by agriculture*



Pilot study conclusions

Expected system performance

- Geometry, resolution, soil moisture, reflection and scattering effects, DSP and Monte Carlo simulations of measurement accuracy.
- Coherent integration result
  - "Mean SNR" (per uncorrelated measureme of 18.5 dB using 50 ms coherent integratior time.
  - Exponentially distributed SNR.
- Overall
  - Direct path SNR: 7 dB
  - Reflected path mean SNR: -44 dB
  - 2 delay lines expected.



Experiment Hardware Block

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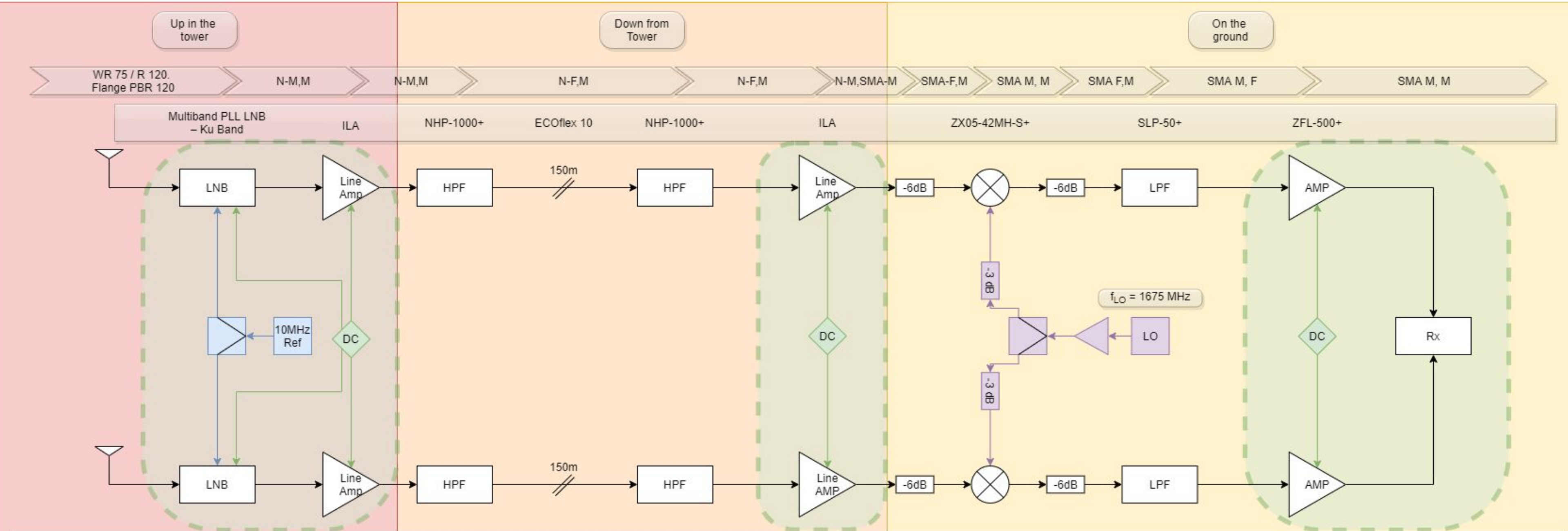
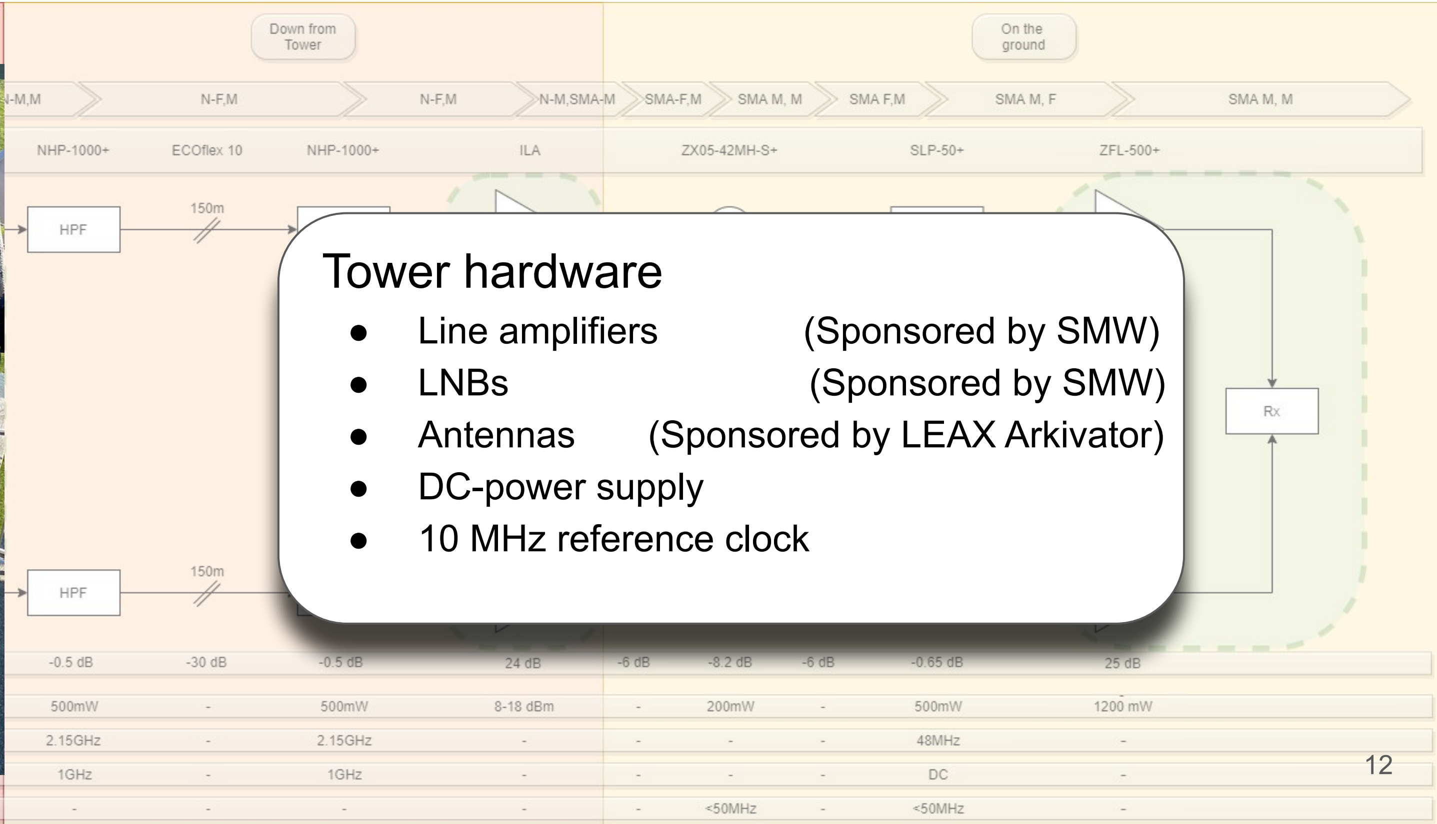


Gain and Loss:	+30/36 dB	60 dB	24 dB	-0.5 dB	-30 dB	-0.5 dB	24 dB	-6 dB	-8.2 dB	-6 dB	-0.65 dB	25 dB
$P_{max\ in}$:	-	-	8-18 dBm	500mW	-	500mW	8-18 dBm	-	200mW	-	500mW	1200 mW
$f_{max\ out}$:	10.7GHz	12.75GHz	2.15GHz	2.15GHz	-	2.15GHz	-	-	-	-	48MHz	-
$f_{min\ out}$:	12.8GHz	10.95GHz	0.95GHz	1GHz	-	1GHz	-	-	-	-	DC	-
f_{wanted}:	-	11.881GHz	1.881	-	-	-	-	-	<50MHz	-	<50MHz	-

Experiment Hardware Block



Tower hardware

- Line amplifiers (Sponsored by SMW)
- LNBs (Sponsored by SMW)
- Antennas (Sponsored by LEAX Arkivator)
- DC-power supply
- 10 MHz reference clock

Experiment Hardware Block

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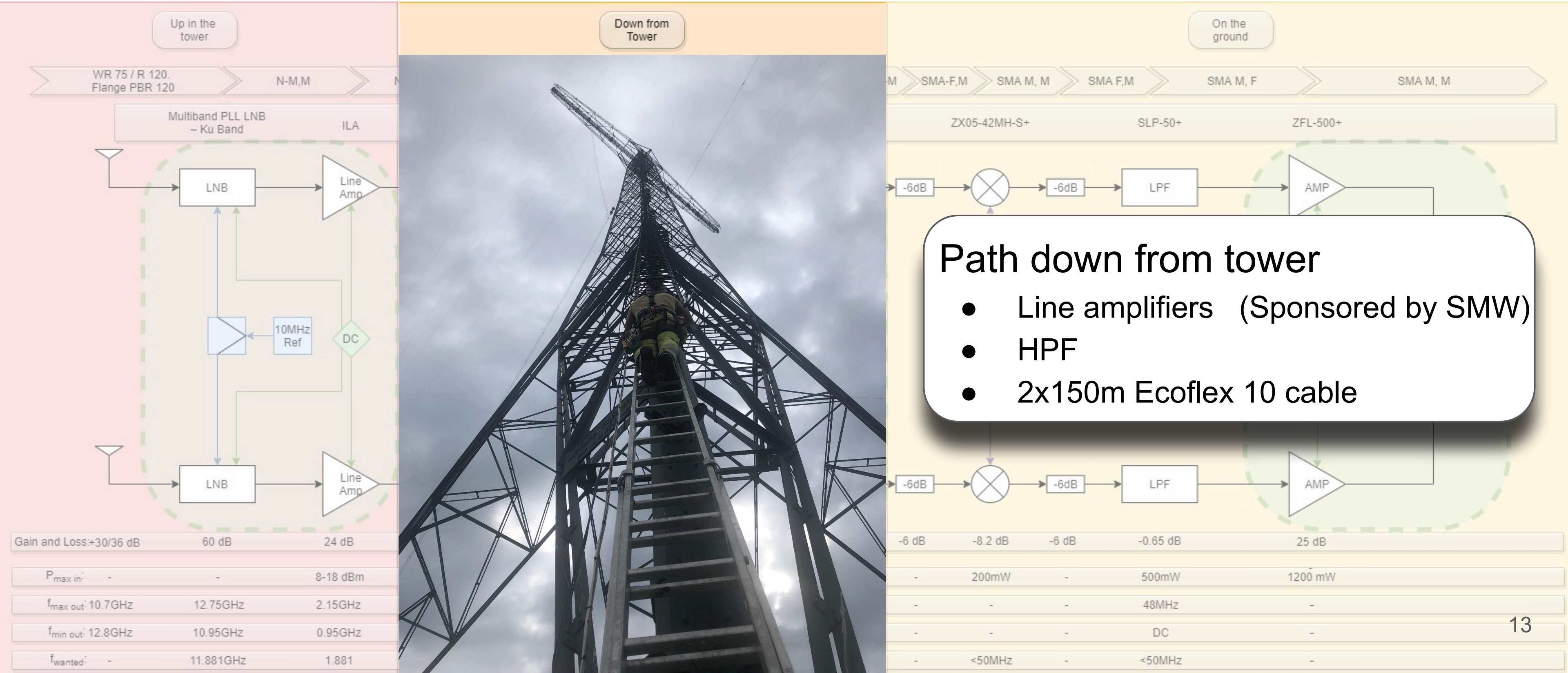

Path down from tower

- Line amplifiers (Sponsored by SMW)
- HPF
- 2x150m Ecoflex 10 cable

Experiment Hardware Block

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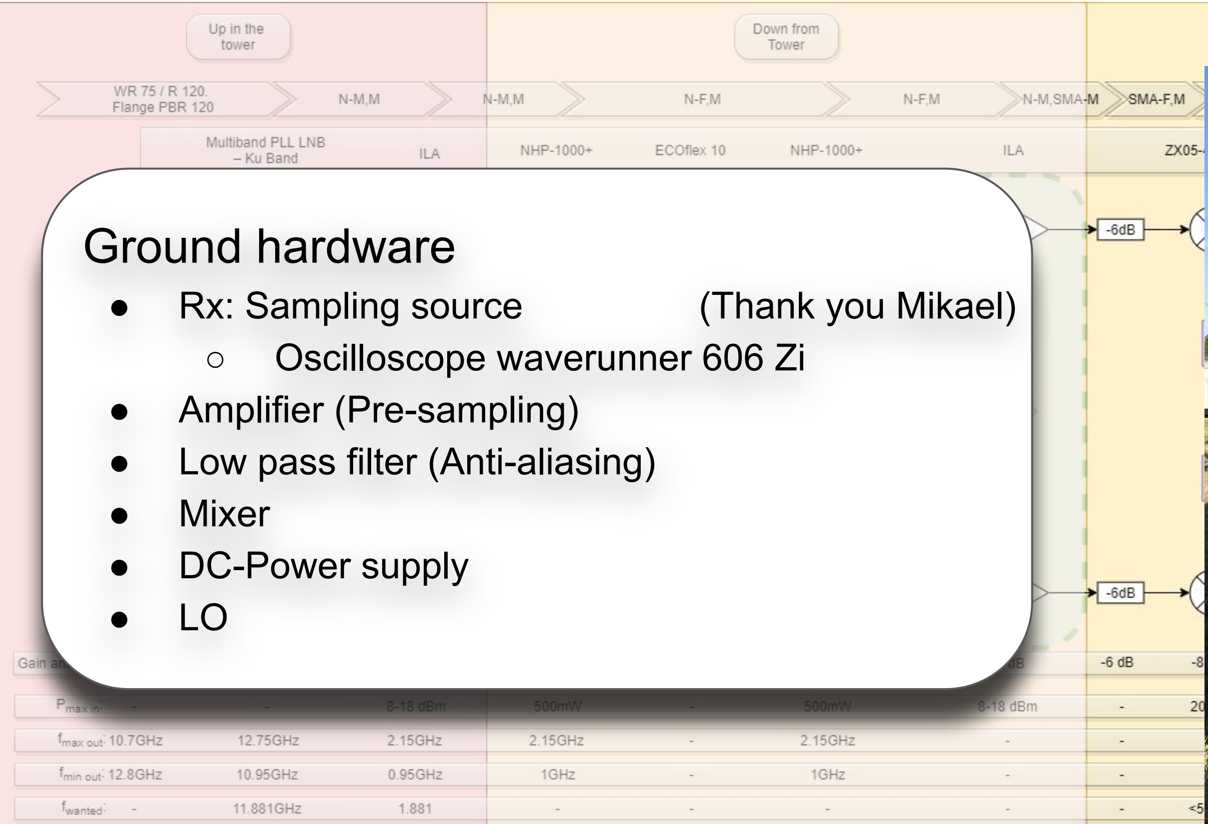


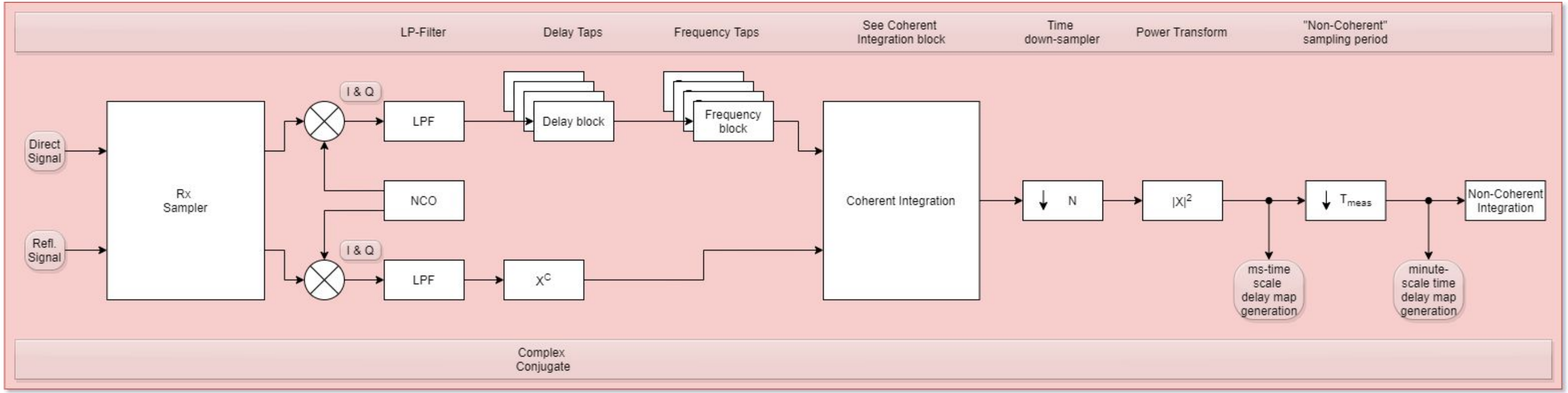
Ground hardware

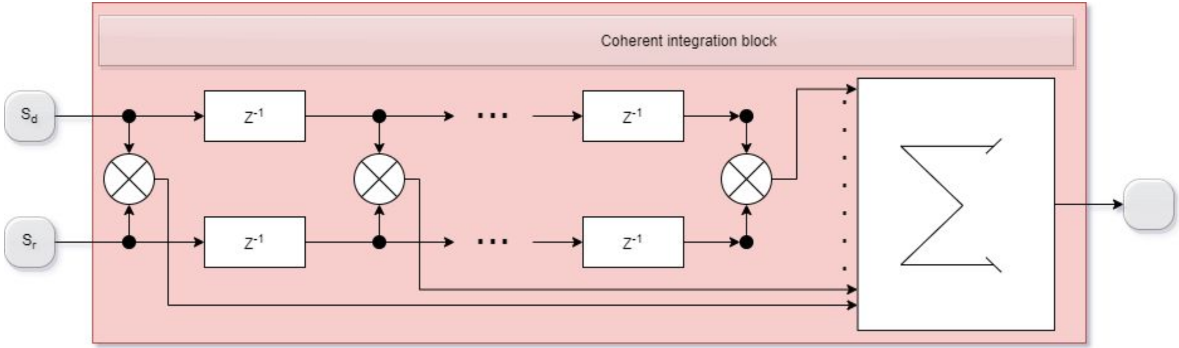
- Rx: Sampling source (Thank you Mikael)
  - Oscilloscope waverunner 606 Zi
- Amplifier (Pre-sampling)
- Low pass filter (Anti-aliasing)
- Mixer
- DC-Power supply
- LO

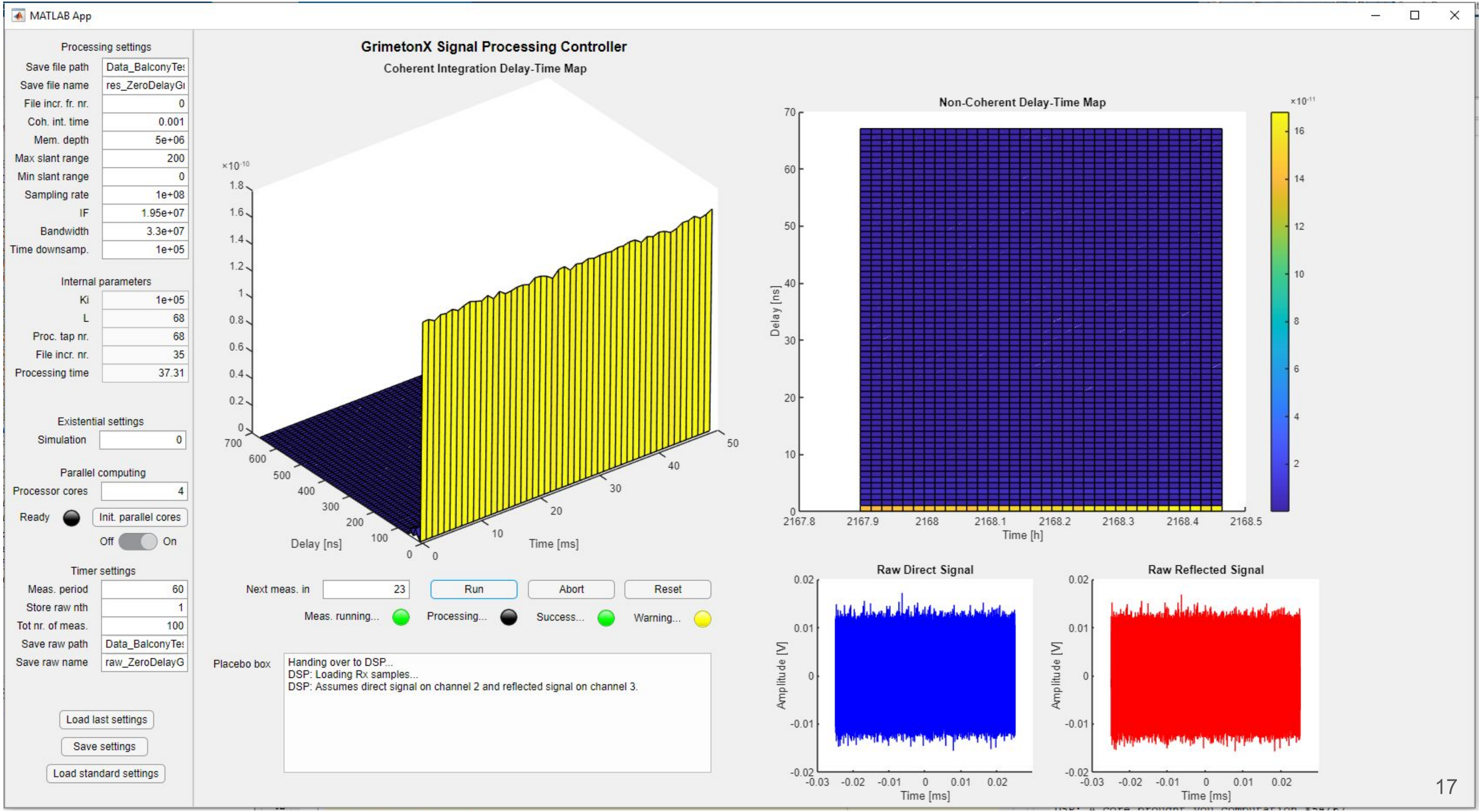
Sponsorship shoutout

Couldn't do this without you!

Experiment Software Design

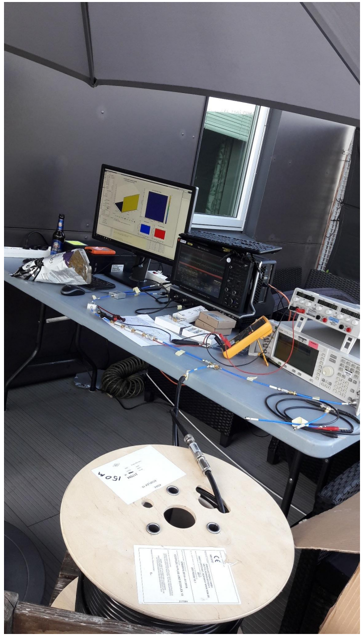





MATLAB App
Processing settings
Save file path
Data_BalconyTe:
Save file name
res_ZeroDelayGi
File incr. fr. nr.
0
Coh. int. time
0.001
Mem. depth
5e+06
Max slant range
200
Min slant range
0
Sampling rate
1e+08
IF
1.95e+07
Bandwidth
3.3e+07
Time downsamp.
1e+05
Internal parameters
Ki
1e+05
L
68
Proc. tap nr.
68
File incr. nr.
35
Processing time
37.31
Existential settings
Simulation
0
Parallel computing
Processor cores
4
Ready
Init. parallel cores
Off
On
Timer settings
Meas. period
60
Store raw nth
1
Tot nr. of meas.
100
Save raw path
Data_BalconyTe:
Save raw name
raw_ZeroDelayG
Load last settings
Save settings
Load standard settings
GrimetonX Signal Processing Controller
Coherent Integration Delay-Time Map
Delay [ns]
Time [ms]
Non-Coherent Delay-Time Map
Delay [ns]
Time [h]
Next meas. in
23
Run
Abort
Reset
Meas. running...
Processing...
Success...
Warning...
Placebo box
Handing over to DSP...
DSP: Loading Rx samples...
DSP: Assumes direct signal on channel 2 and reflected signal on channel 3.
Raw Direct Signal
Amplitude [V]
Time [ms]
Raw Reflected Signal
Amplitude [V]
Time [ms]

Expedition collage: Balcony

- Special thanks to Vanessa and Per that allowed us to use their balcony on the day of their wedding!



Grimeton expedition results

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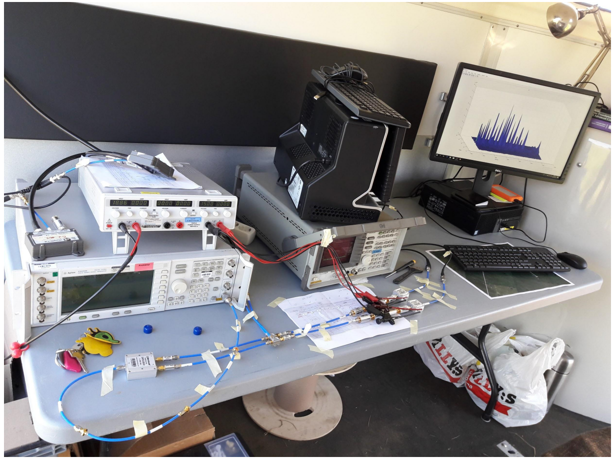
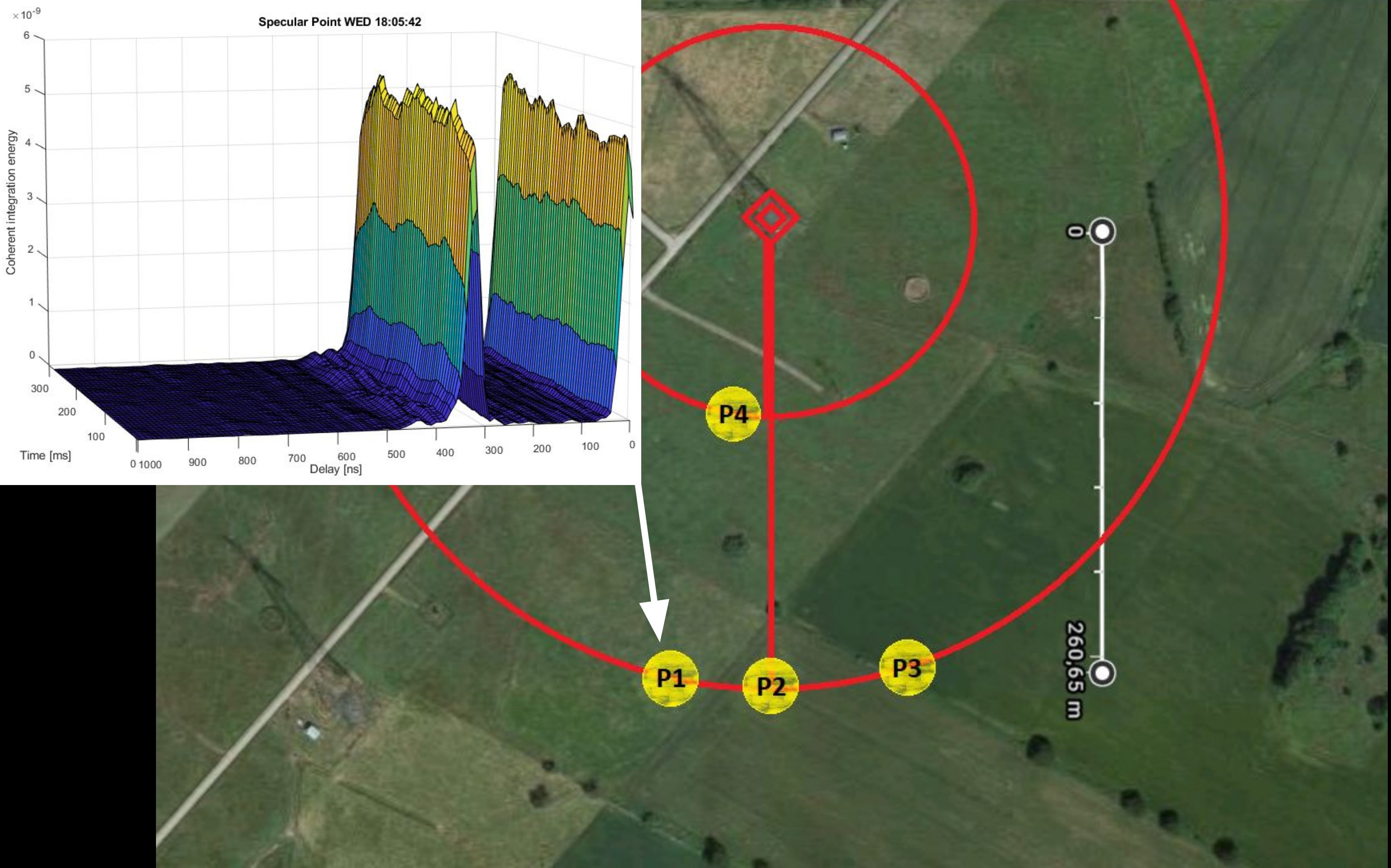
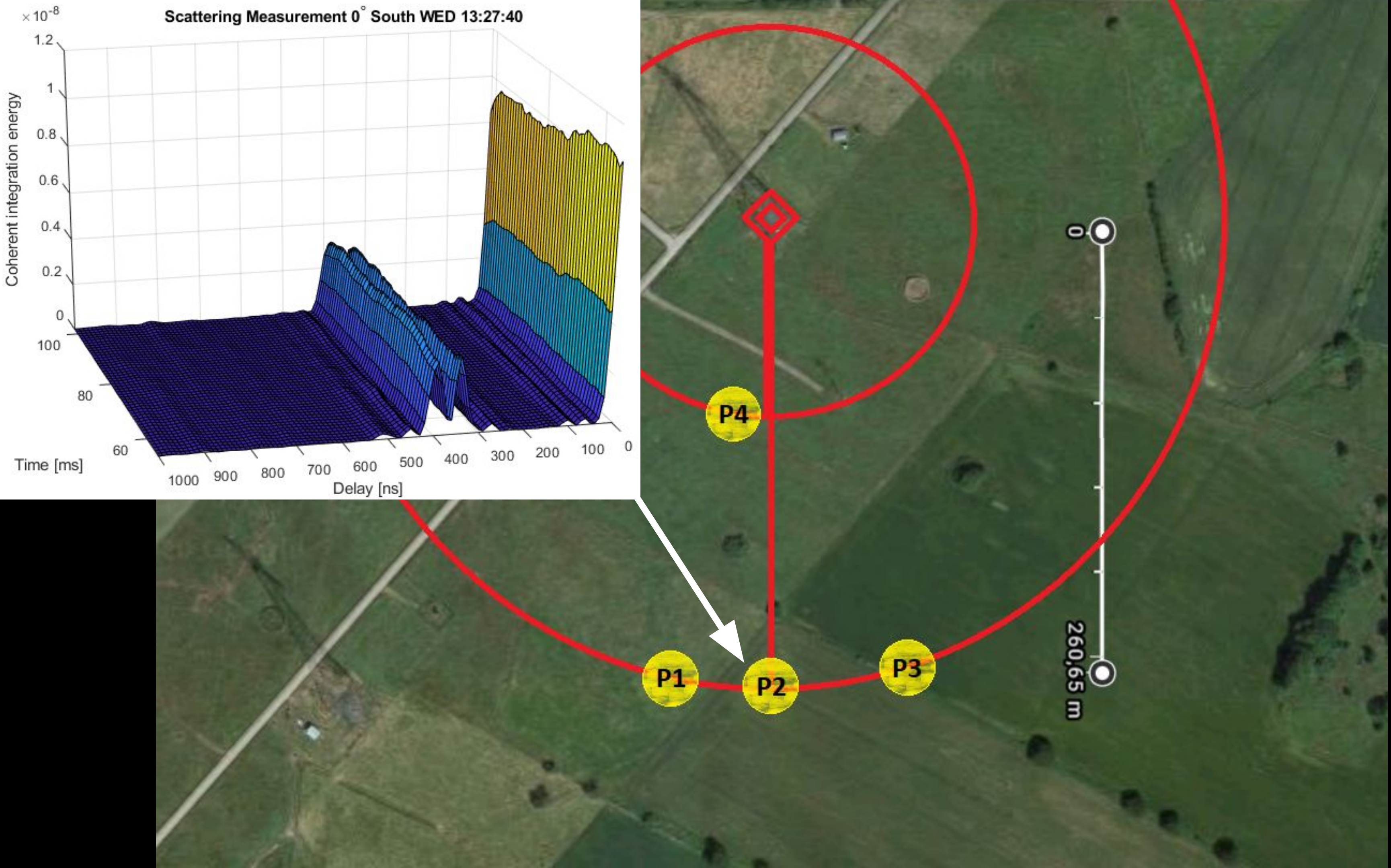
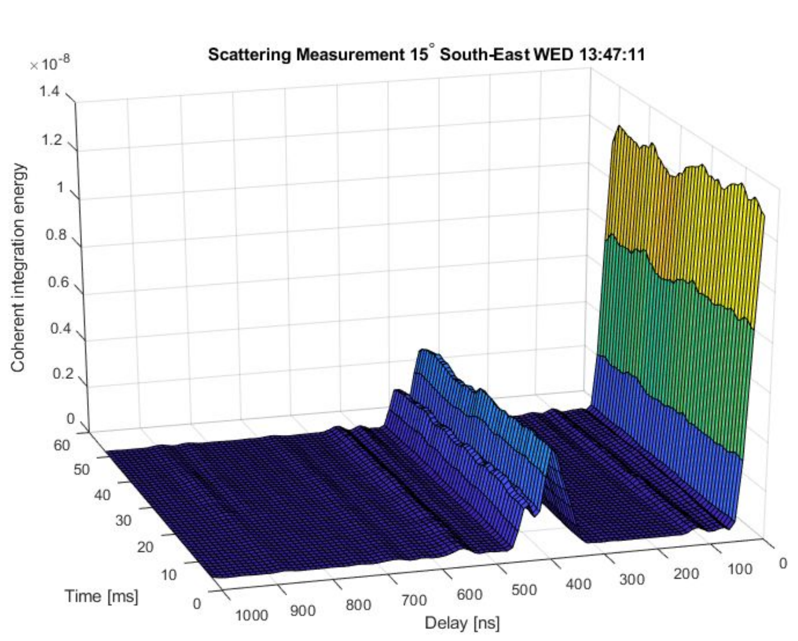


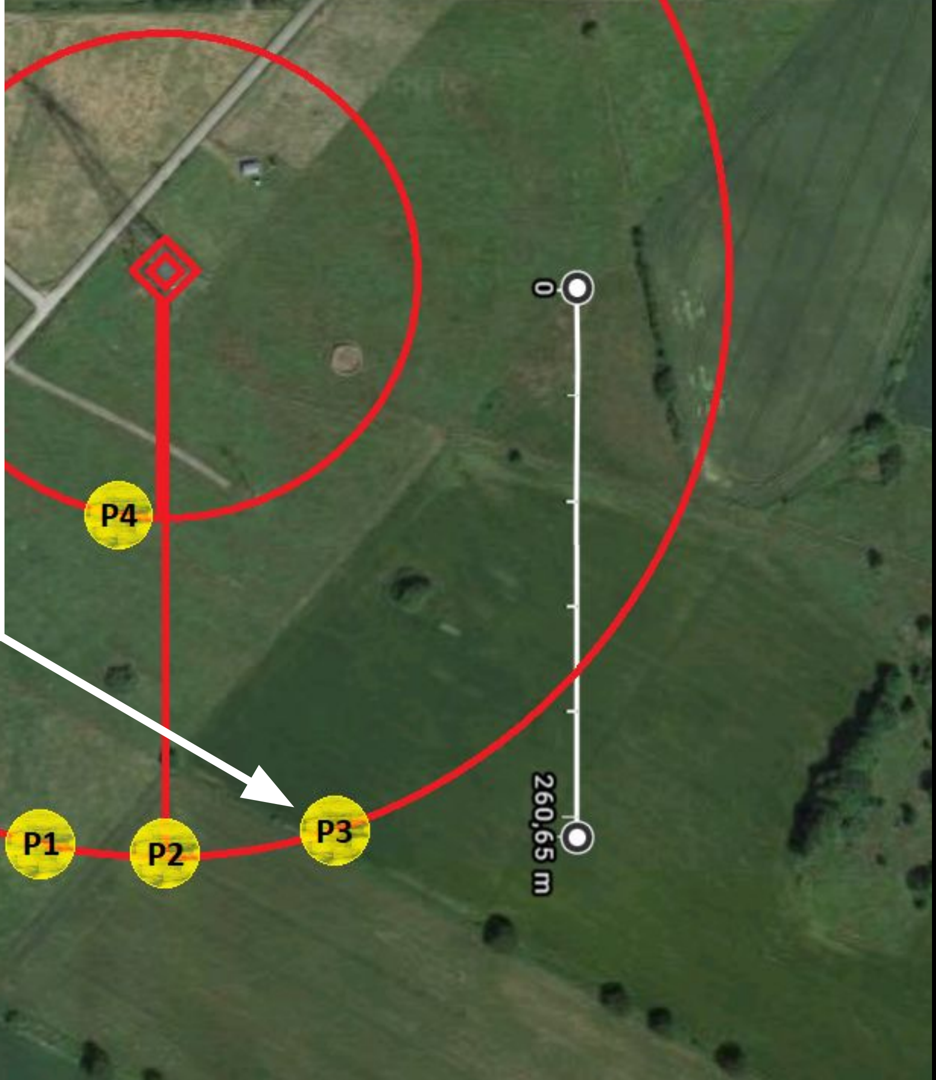

P4
P1
P2
P3
0
260,65 m
Astra 4A

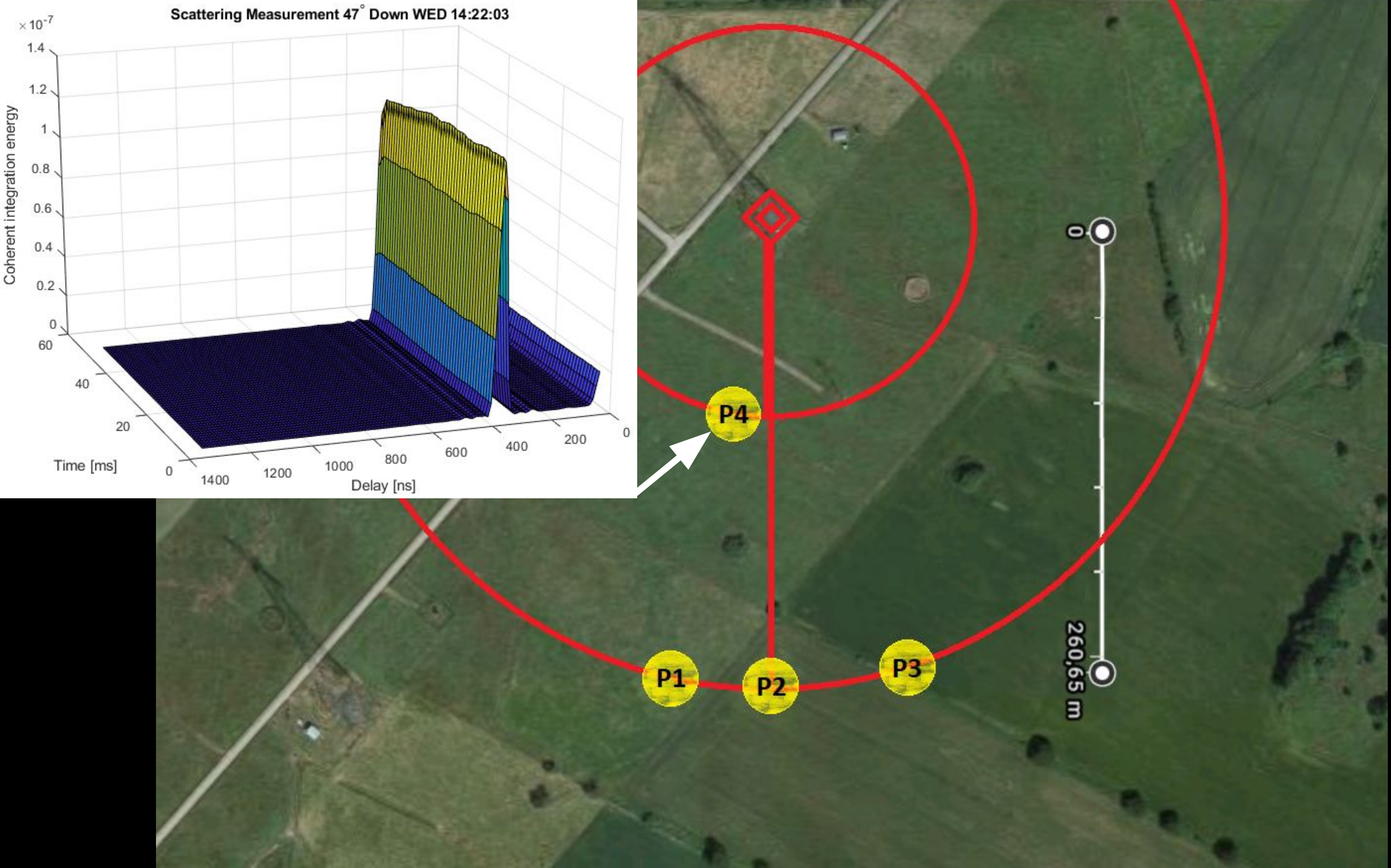

Specular Point WED 18:05:42
×10^-9
Coherent integration energy
Time [ms]
Delay [ns]
0
260,65 m
P1
P2
P3
P4



Scattering Measurement 0° South WED 13:27:40
×10^-8
Coherent integration energy
Time [ms]
Delay [ns]
P1
P2
P3
P4
0
260,65 m


Scattering Measurement 15° South-East WED 13:47:11
×10⁻⁸
Coherent integration energy
Time [ms]
Delay [ns]
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
10
20
30
40
50
60
1000
900
800
700
600
500
400
300
200
100
0

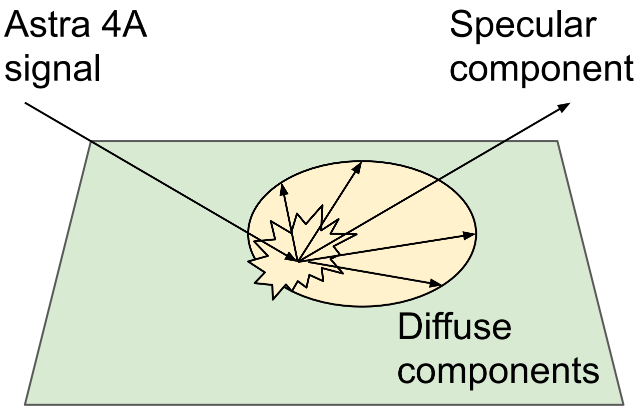

P1
P2
P3
P4
0
260,65 m



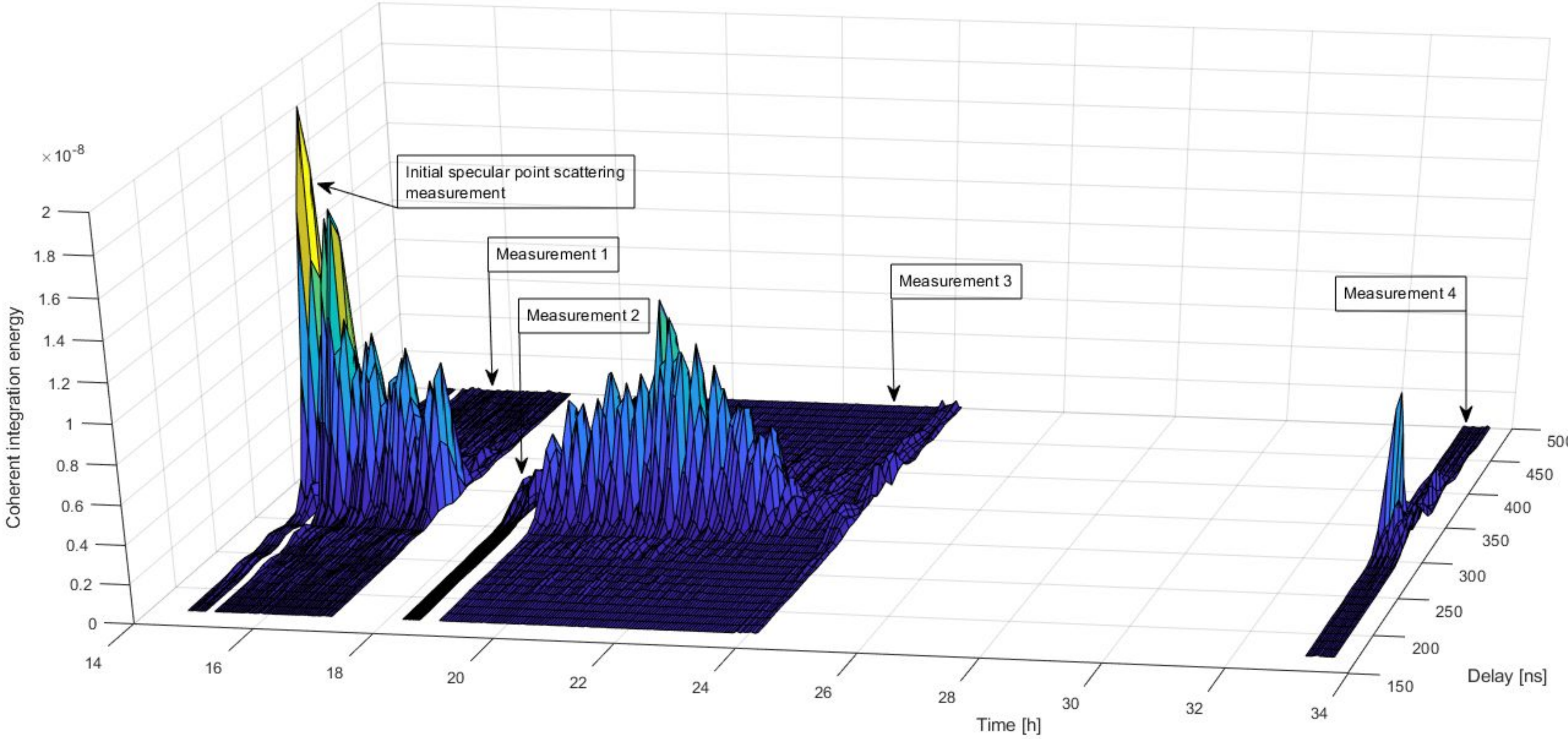
Scattering Measurement 47° Down WED 14:22:03
Coherent integration energy
×10^-7
Time [ms]
Delay [ns]
P1
P2
P3
P4
0
260,65 m

Signal scattering measurements

- Experiment results
  - Strong correlation peak at delay corresponding well to calculated delay.
  - Observed signal at both specular and diffuse points.
  - SNR at about 10-24 dB (theoretically 18.5 dB).
  - SNR changes over time.
  - More measurements would be required to with certainty characterise the scattering. Especially in the backward direction.



Measurement time series



Conclusion of results

- A model of the system performance (the pilot study)
  - Including geometry, resolution, soil moisture, reflection and scattering effects, DSP and Monte Carlo simulations of measurement accuracy.
  - Corresponds well to experimental results of what is seen so far.
- A Ku-band TV-DBS opportunity signal PARIS design
  - Including complete hardware setup, DSP implementation and a system control and measurement automation app.
  - Experimental observations of promising measurement SNR, but slow oscillations present.
- Ku-band DBS opportunity signal agriculture experimental observations
  - Indications on a rough scattering environment being present, while having promising SNR.
  - Extraction of soil moisture observables seem possible, but further measurements and analysis is required to clarify this.

Speculation on future prospects (1/3)

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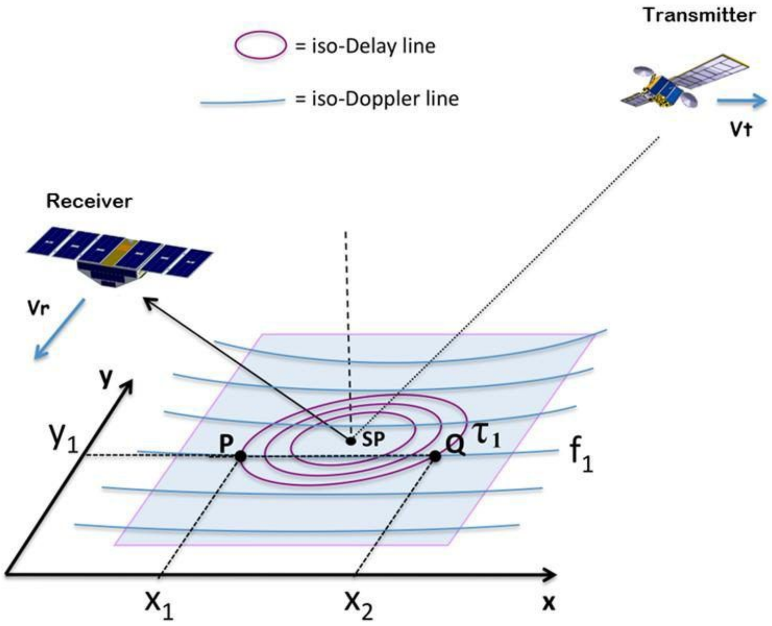
- Proposed further work
  - Develop a dedicated uC/FPGA measurement system with agile antenna platform.
  - Perform more point measurements.
  - Obtain and analyse longer measurement time series covering events of interest (rain, drought).
  - Expand to product cases and other applications.

- Product case 1: ground-based system
  - Easy installation on e.g. radio/TV masts, low maintenance, cheap start up.
  - Few antenna, technology and power limitations.
  - Long integration time, no iso-Doppler lines.
  - Continuous but limited (~1-10 km) coverage.

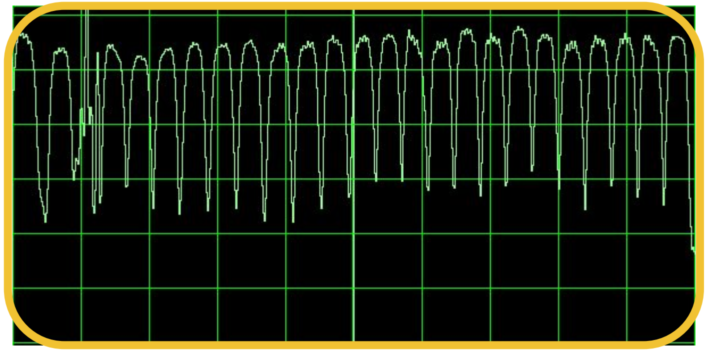
Speculation on future prospects (2/3)

- Product case 2: drone-based system
  - More maintenance, larger start-up cost.
  - Small antennas, lightweight, agile & compact tech., must be power efficient.
  - Large coverage, Doppler lines, ~min-h revisit
  - Models indicate ~6 dB SNR reasonable.
- Product case 3: LEO constellation
  - Very expensive start-up (but less than active EO).
  - Lightweight, compact, very power efficient & robust.
  - Very large coverage, revisit time dependent on constellation.
  - Performance heavily dependent on antenna directivity, beamwidth / sweep and required resolution - might be doable, but trade-offs.



Speculation on future prospects (3/3)

- Space for signal processing tricks?
  - Many channels from same signal source.
  - Coherence bandwidth ~ c/resolution $\lesssim$ 50 MHz
    $\Rightarrow$ Possibly combine parallel TV-channels as simultaneous non-coherent observations!
  - Otherwise, combine coherently $\Rightarrow$ instant SNR improvement, but no speckle reduction.
  - Heavy on processing, but may exploit aliasing effects to put ease on this (noise-type trade-off?).



- Possible stakeholders
  - Agriculture industry, flooding/drought disaster warning departments, insurances, environmental research (just for soil moisture application).


Thank you for listening!
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CHEVAUX

Any Questions?

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RUAG Space in the distance