



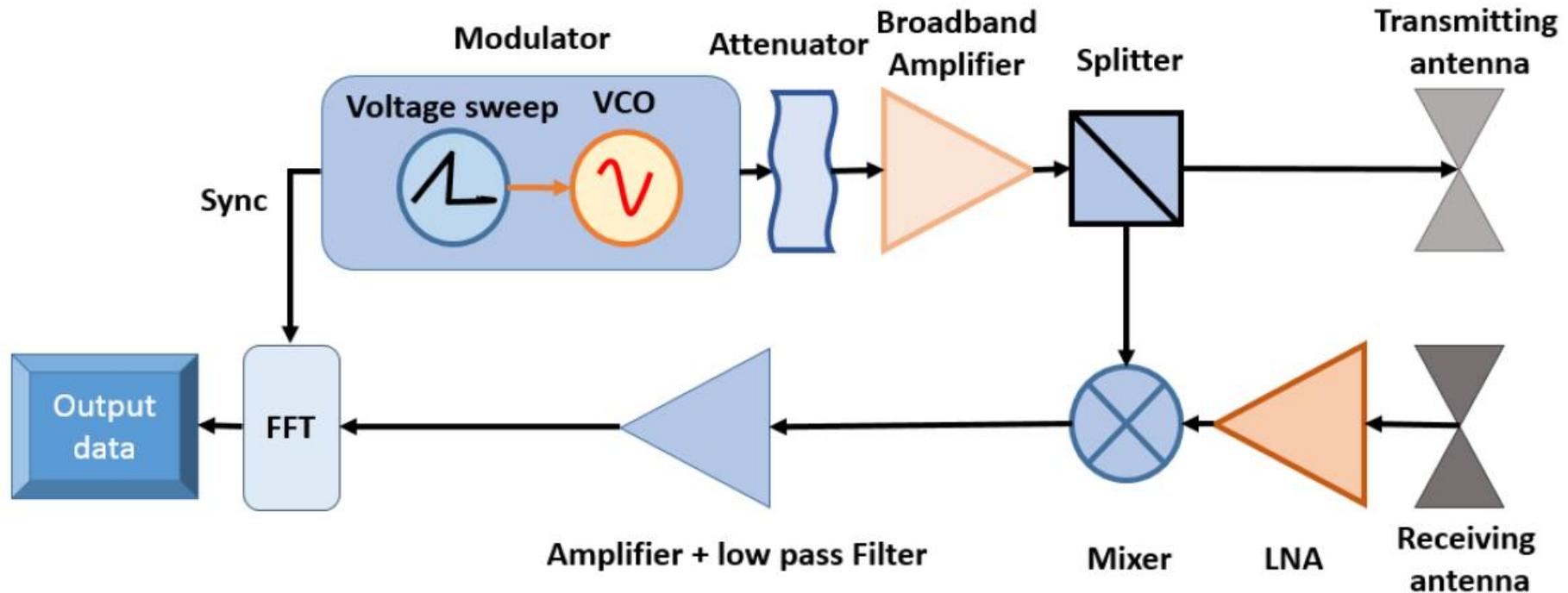
University of Maribor, Slovenia

Laboratory for Signal Processing and Remote Control

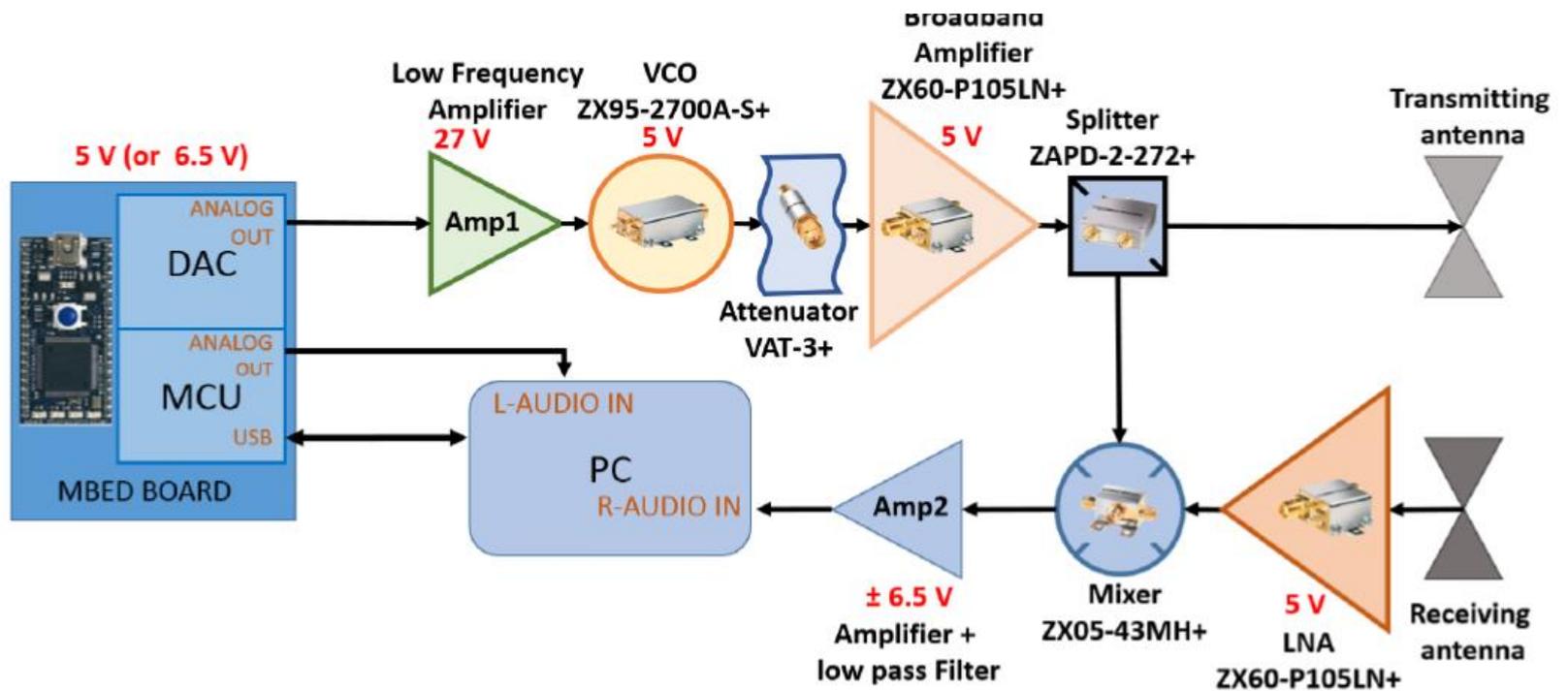
Dušan Gleich, Klemen Kropec, Primož Smogavec, Gloria Gjuran

- **FMCW educational design**
- **FMCW compact design**
- **Drone navigation**
- **Steeped frequency radar design**
- **Echo cancelation**
- **Synthetic Aperture Radar – under construction**

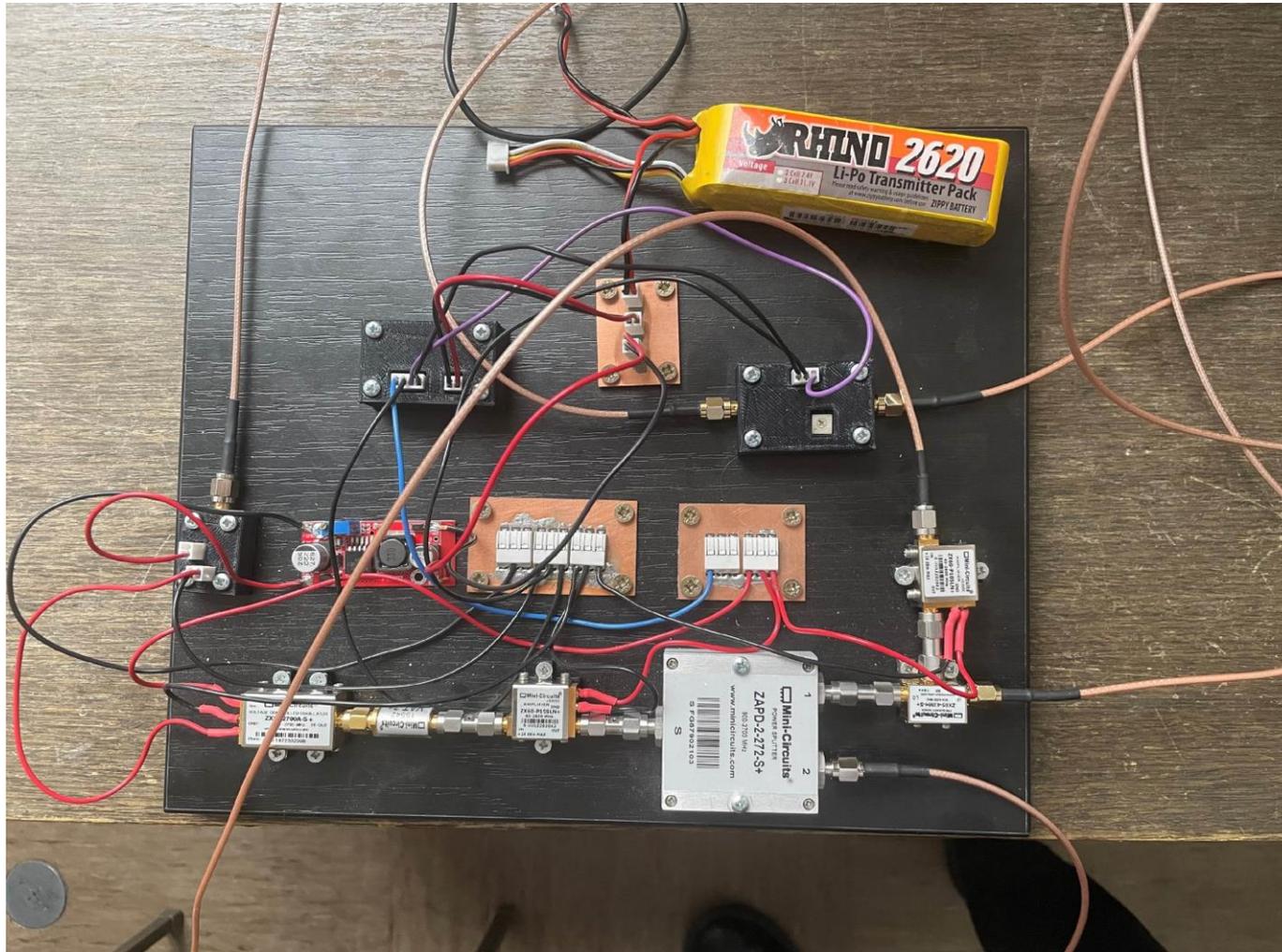
Frequency modulated Continuous wave (FMCW) radar design



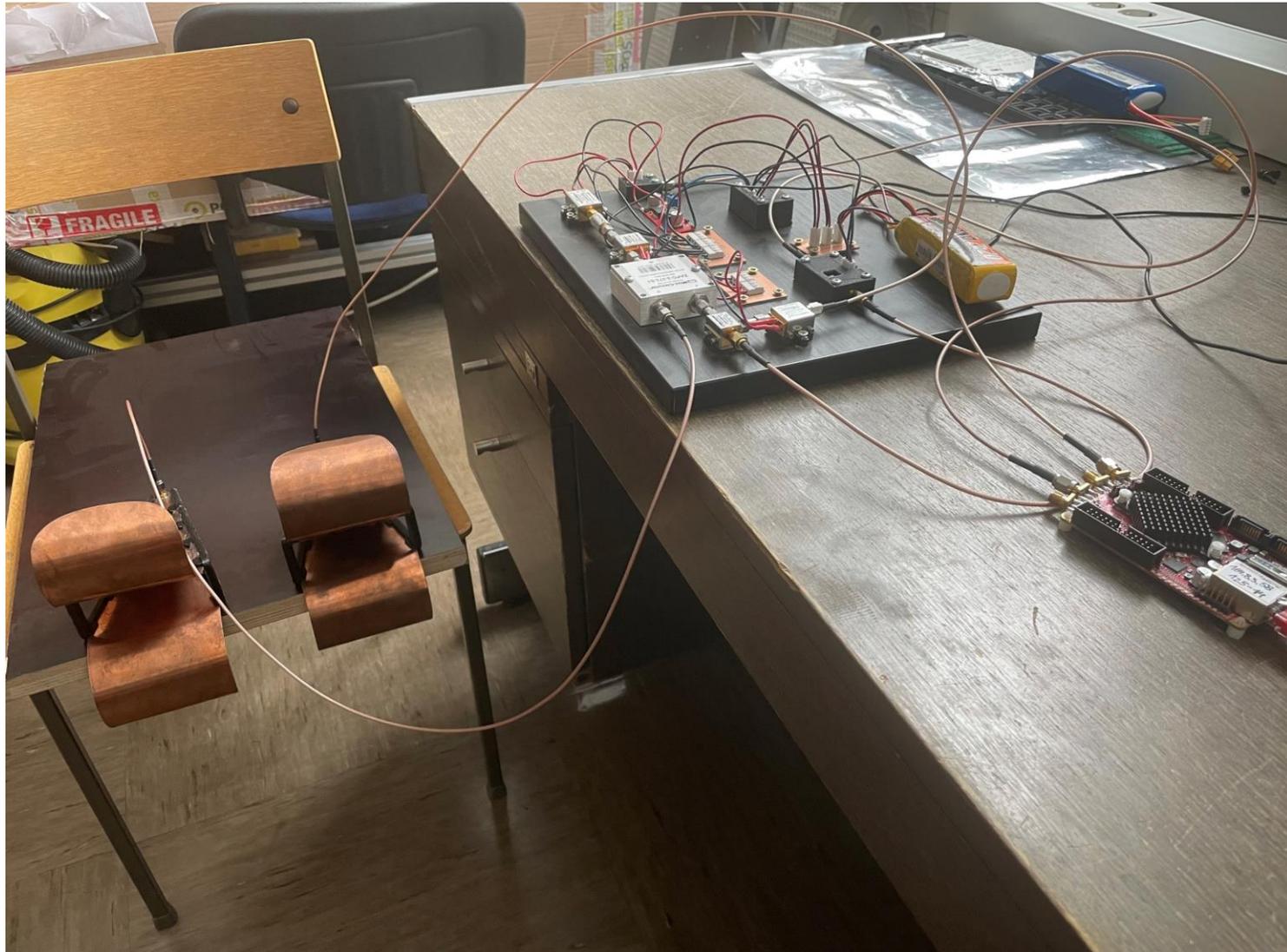
FMCW design



FMCW design



FMCW design



Time based signals

$$f_s = 15,258 \cdot 10^3 \text{ Hz}$$

$$B = 1.3 \text{ GHz}$$

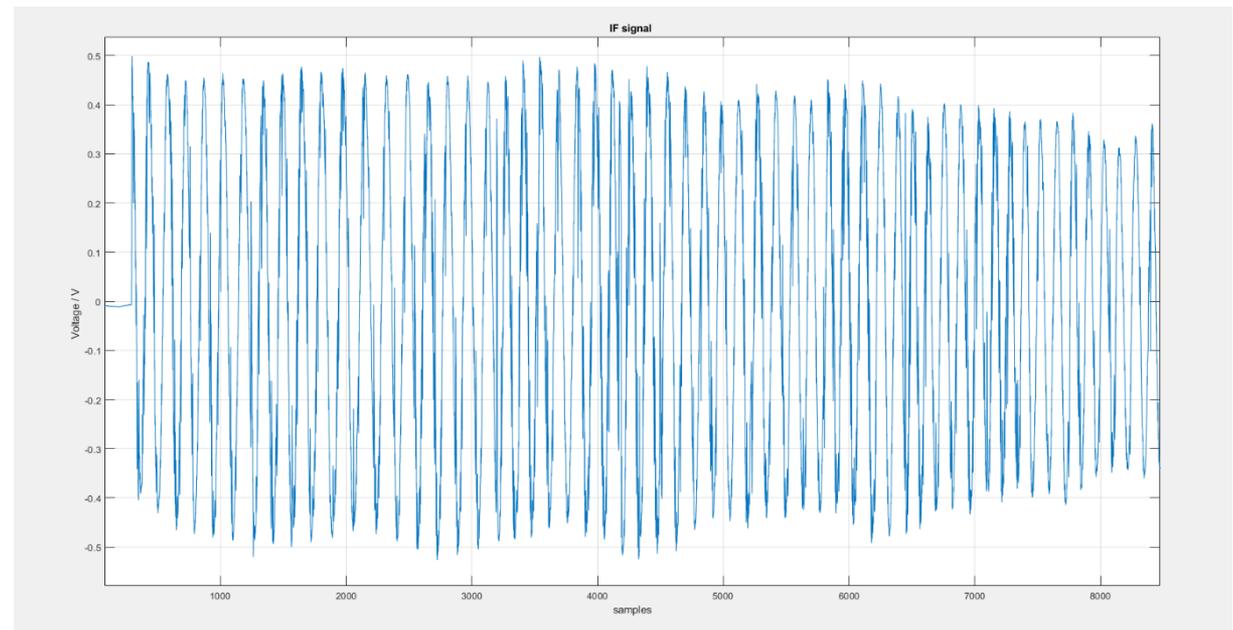
$$S = B/\tau = 1.3 \cdot 10^9 \text{ Hz}^2$$

$$D = 16\text{m}$$

$$d_K = \frac{0,666 \cdot c \cdot f_z}{S}$$

$$f_z = 104,3027 \text{ Hz}$$

$$dk = 16\text{m}$$



Compact implementation of FMCW



FMCW Radar

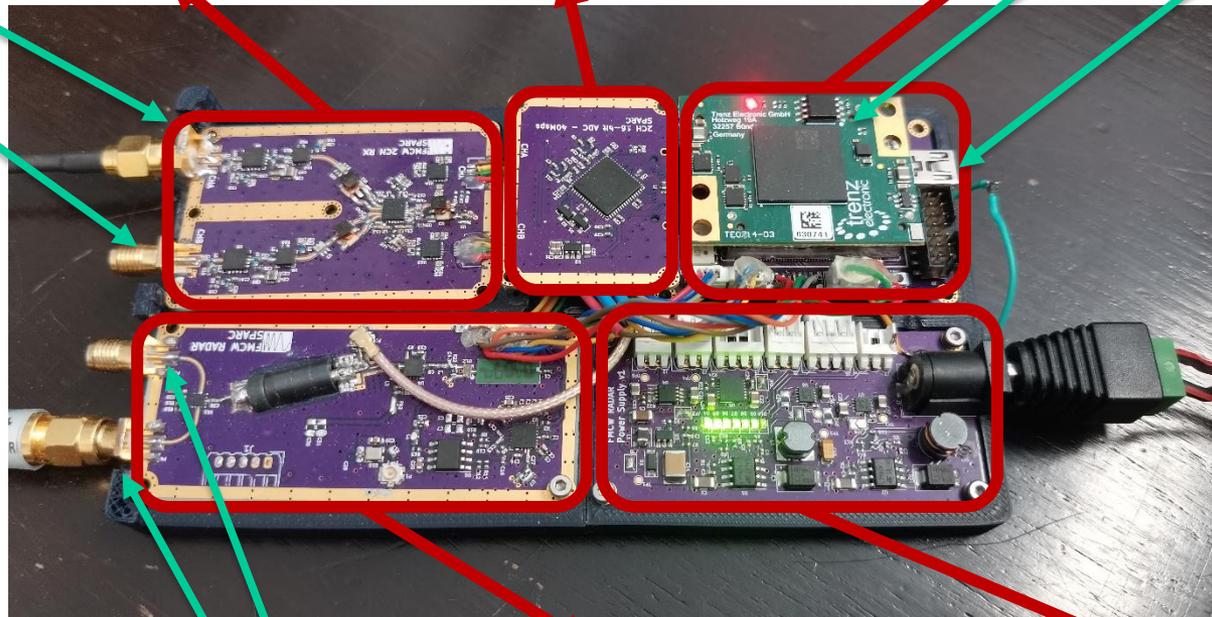
Receiver Module:

- Heterodyne Receiver
- Channel A
- Channel B

ADC Module

FPGA/Controller Module

- FPGA
- USB Connection



Transmitter Module:

- Integrated PLL and VCO
- Channel A
- Channel B

Power Supply Module

Control Software

- 3rd revision of FMCW L Band RADAR software was created as a stand-alone and self-contained Windows application.

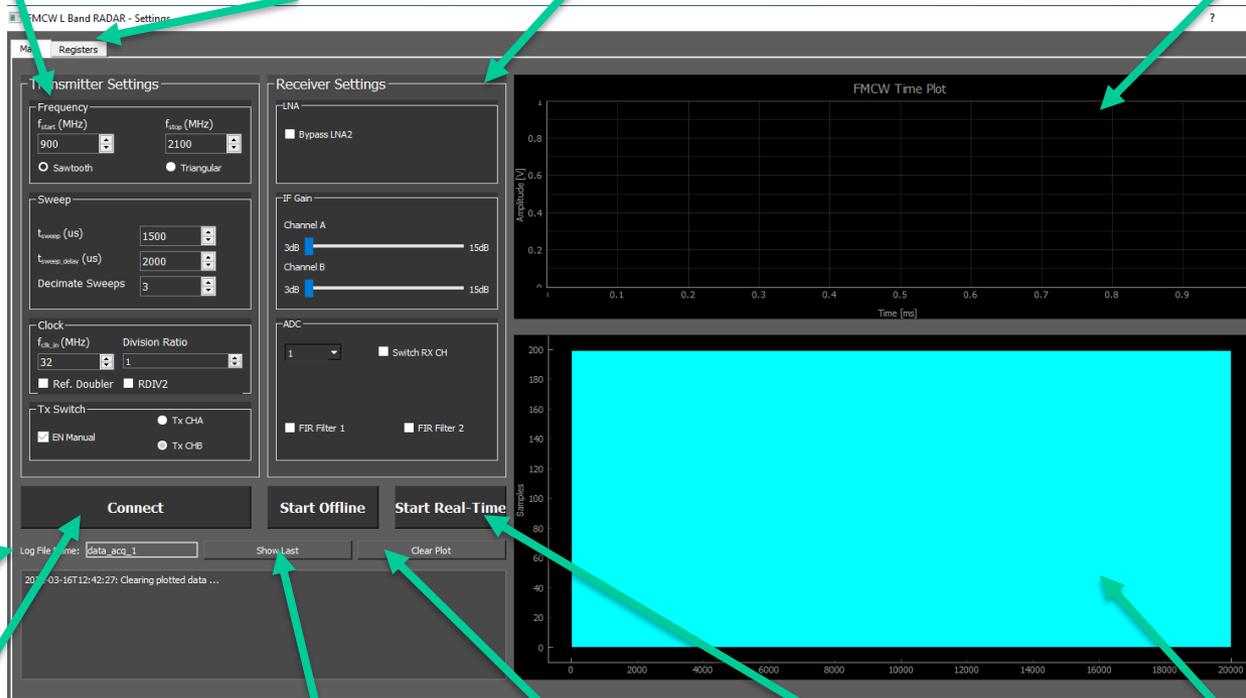
Control Software

Transmitter Settings

Receiver Settings

Time Signal, Individual Sweep

PLL Registers



Log File Name

Connect to the Device

Start/Stop Buttons

Spectrogram

Clear Plot Button

Show Data from the last Acquisition

Control Software

Transmitter Settings

Start Frequency

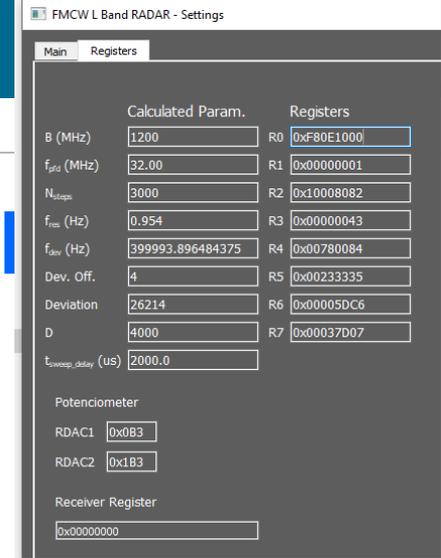
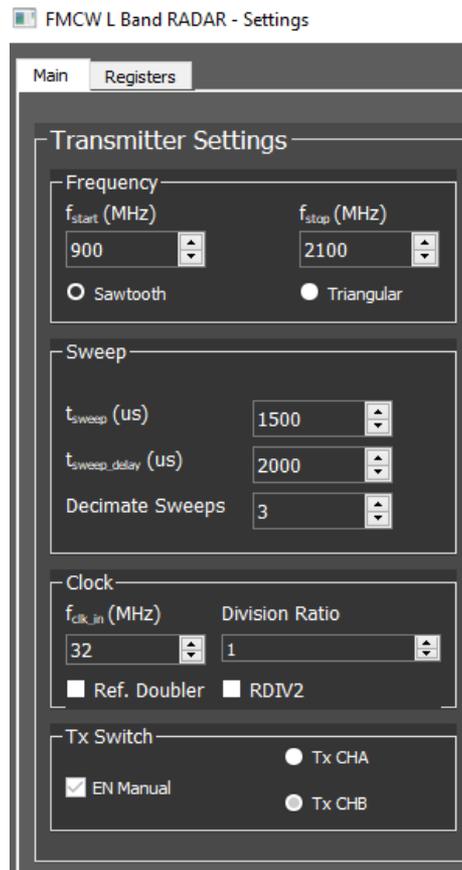
Stop Frequency

Shape (Sawtooth, Triangular)

PLL Clock Source

Division Ratio for the PLL Clock

Ref. Doubler and RDIV2 are PLL register for doubling the PLL Clock and the PLL Reference Frequency – better frequency resolution

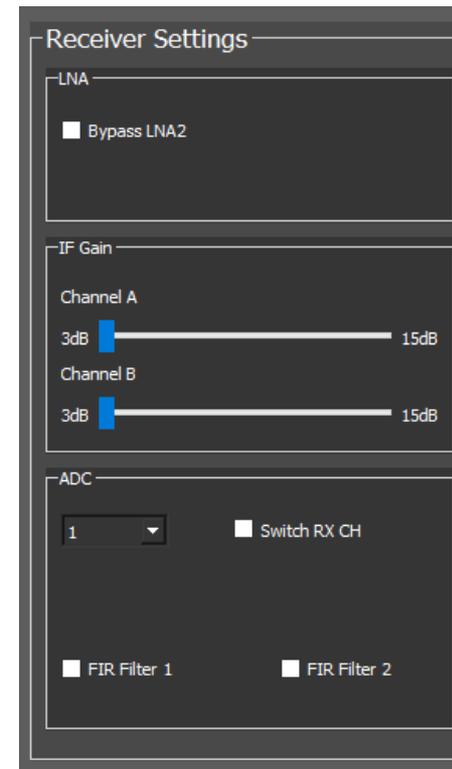


- PLL Register Map – calculated every time when the acquisition starts
- Sweep Duration
- Delay between two sweeps
- Sweep Decimation on the FPGA
- Tx Switch Currently not implemented

Control Software

Receiver Settings

- **Onboard Receiver LNA can be bypassed**
- **Receiver Gain Settings for Cha and CHB**
- **Decimation on the FPGA**
- **Switching between CHA and CHB**
- **Enabling FIR filters on the FPGA**

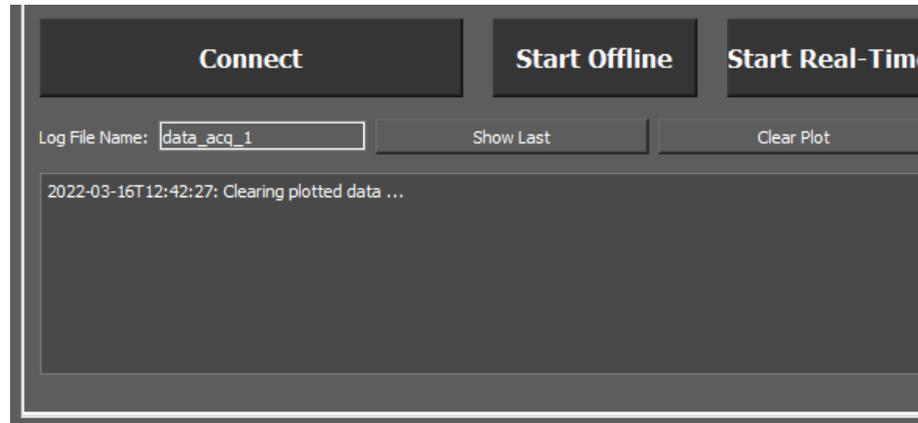


Control Software

Other

Connect Button:
Connect or Disconnect
to/from the device
over USB

Log File Name: Name
of the file for the
current acquisition



- **Start Offline:** start acquisition without real-time data plot (faster acquisition)
- **Start Real-Time:** start acquisition with real-time data plot (slower acquisition, real-time data plot)

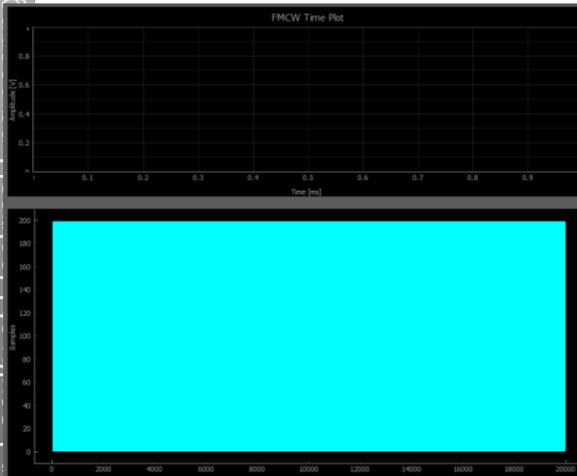
- **Message Box:** Shows event and additional data
- **Clear Plots:** clears up the Individual signal graph and Spectrogram fields
- **Show Last:** plots data in separate windows (time domain and frequency domain plot) of the Log File Name



Control Software

Plot Area

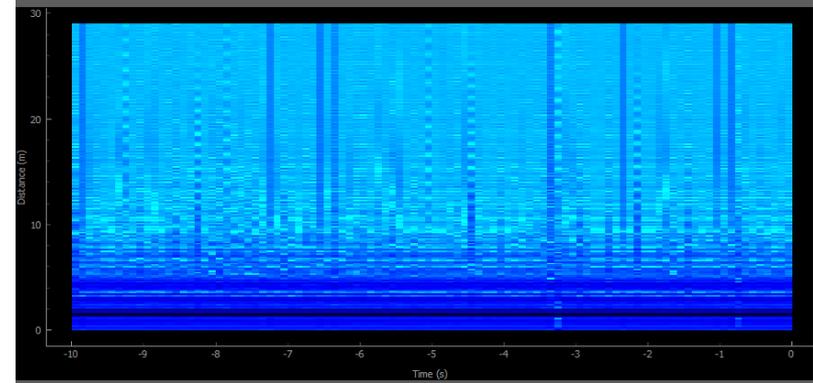
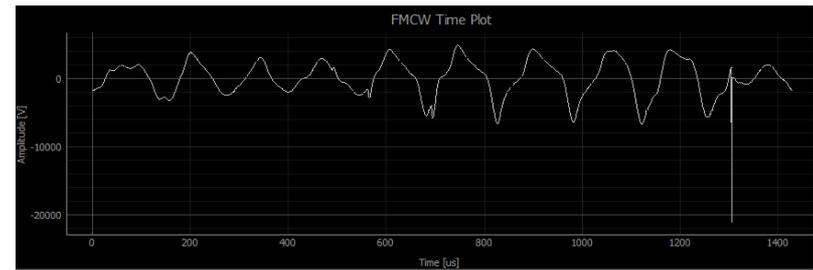
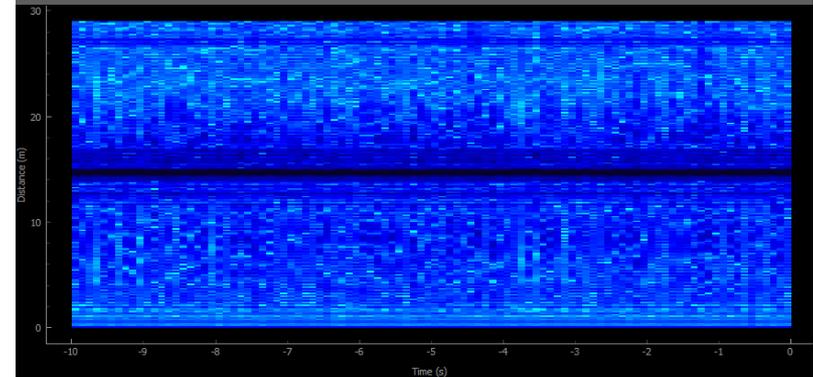
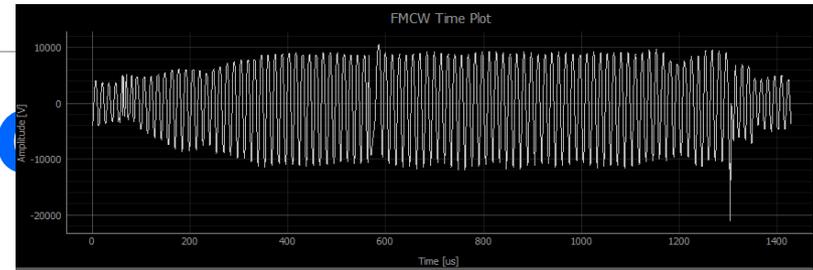
Plots individual sweep in real-time



Plots Spectrogram in real-time

Sample plot:

- 15 m cable between Transmitter and Receiver (above)
- 1.5 m cable between Transmitter and Receiver (below)

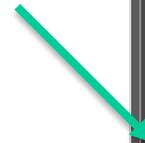


Control Software

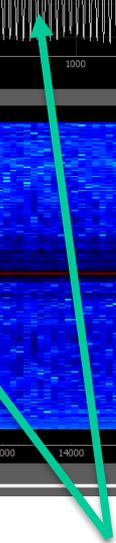
Real-time operation

University in Maribor, Faculty of Electrical Engineering and Computer Science

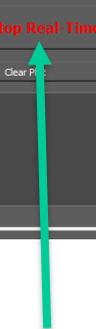
Sweep Decimation is set automatically



Real-Time data plot

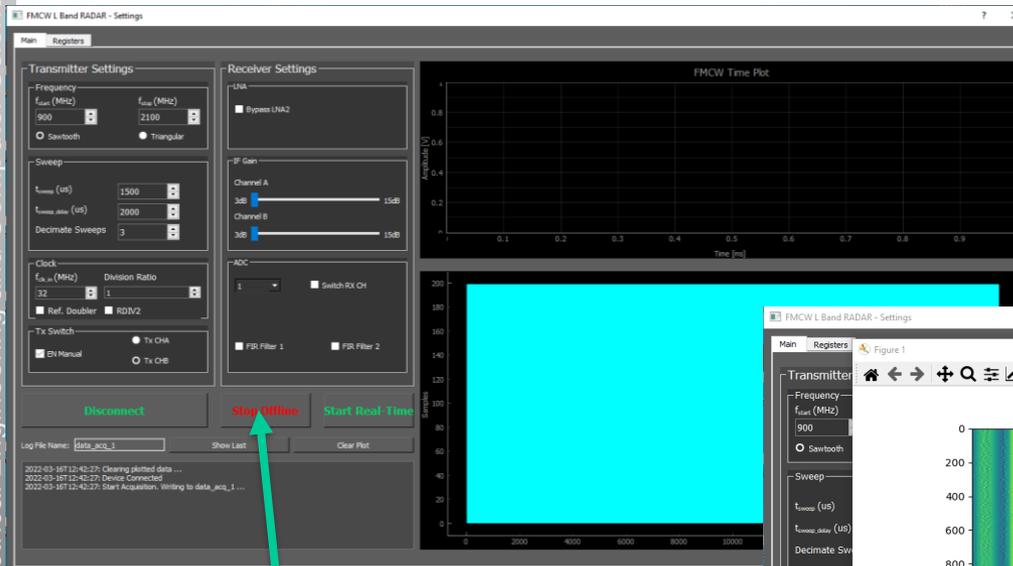


Stop Real-Time Button for terminating the acquisition



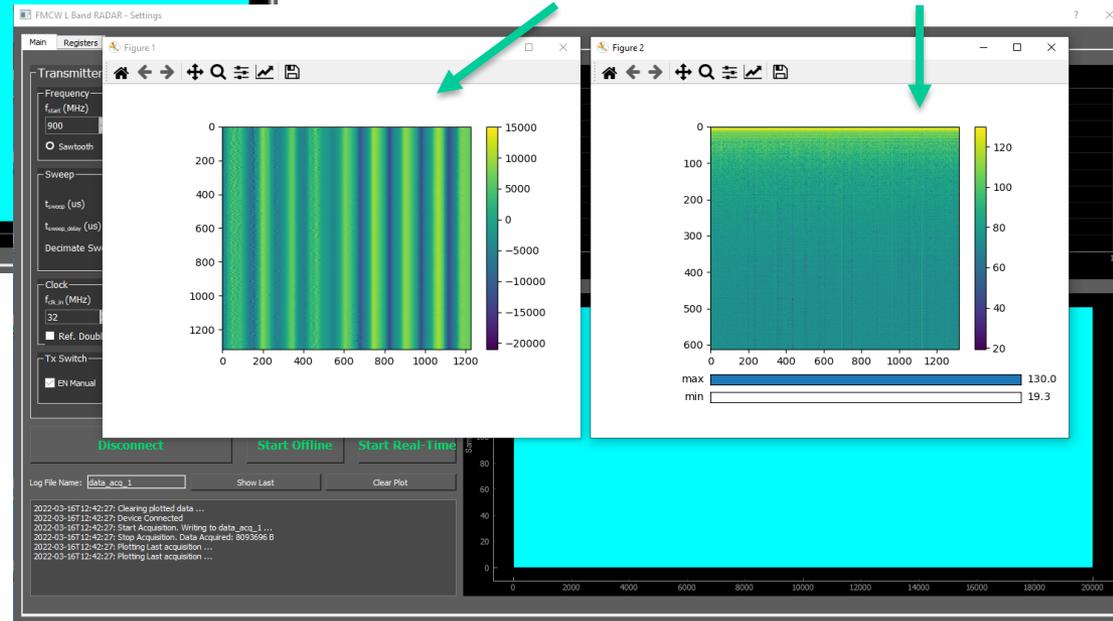
Control Software

Offline operation



Sweeps arranged into image
(time domain)

Spectrogram



Stop Offline Button for terminating the acquisition

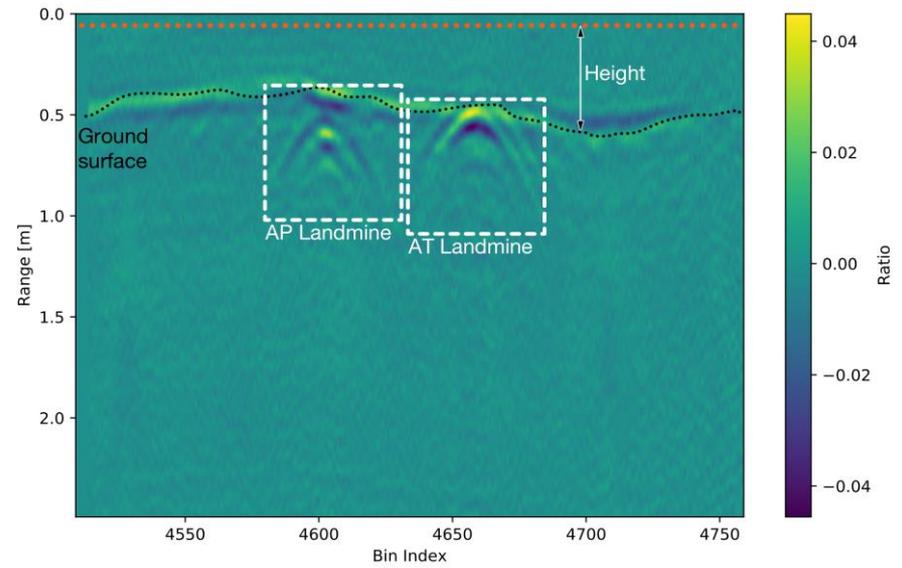
Show Last – last acquisition was plotted in separate windows

Miniature Ground Synthetic Aperture Radar v1

- **FMCW SAR radar attached to a hexacopter**

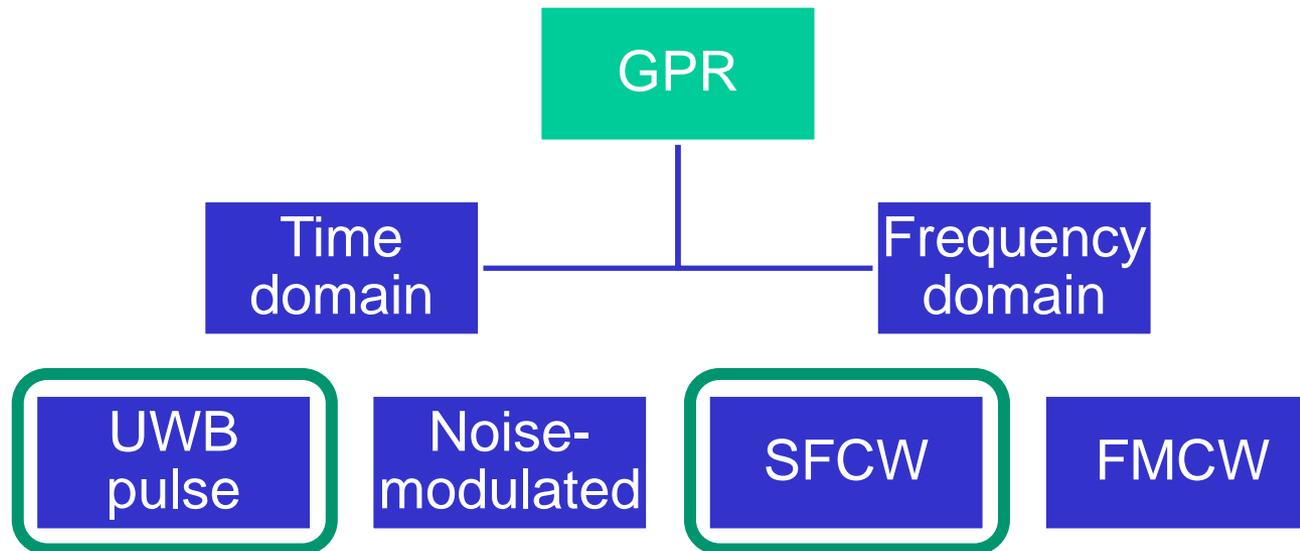


GPR attached to a hexacopter v2



Ground penetrating radar (GPR)

- The technical design of ground penetrating radars can be classified into two groups.



UWB pulse GPR: Main parts and working principle

Use of UWB pulse technique

Main parts:

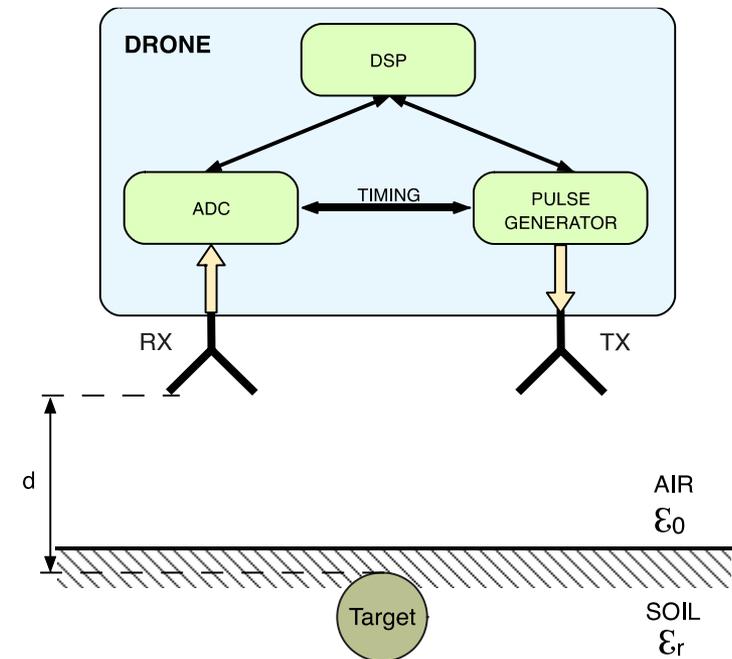
- Pulse generator
- UWB antennas
- High speed ADC
- Digital signal processor (DSP)

$$v = \frac{c}{\sqrt{\epsilon_r}}$$

Velocity of EM wave

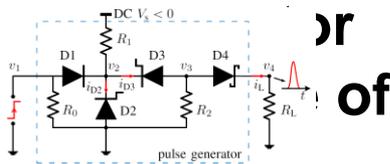
$$d = \frac{v \cdot t}{2}$$

Target distance

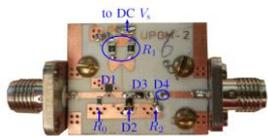


UWB pulse GPR: Design

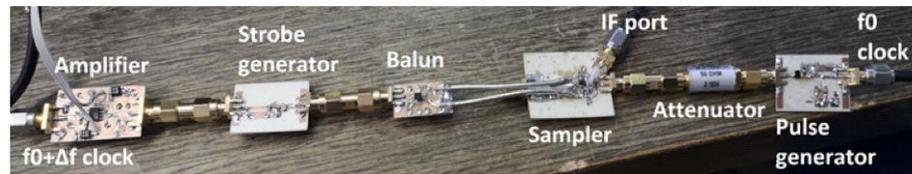
- Pulse



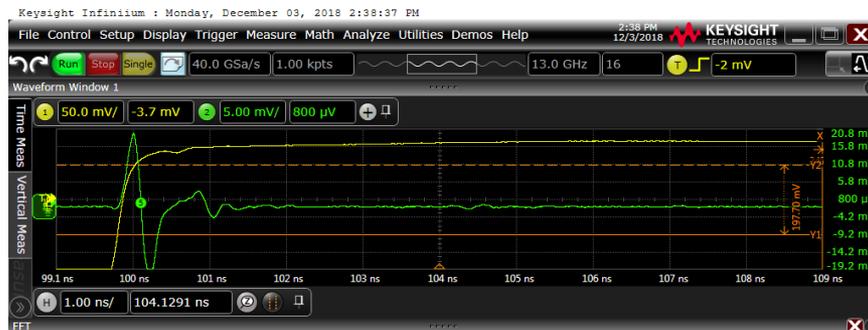
SRD
diode



- Designed PCB board



Developed UWB pulse radar system



- D1 = Blocking negative input voltage
- R1 = Current limiter
- R0,L = impedance matching
- D2,3 = SRD
- D4 = pulse formation switch

UWB pulse GPR: signal detection

Sampling mixer

To detect pulses with bandwidth of 5 GHz, at least 10 GHz sampling rate is required

Input RF signal f_0 ,

Strobe signal $(f_0 \pm \Delta f)$,

Reconstruction time $1/\Delta f$

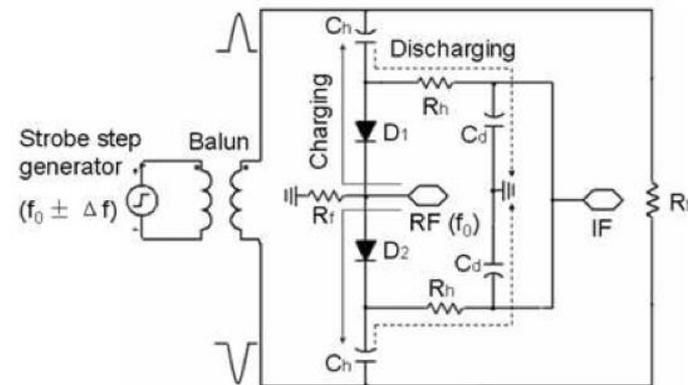
Example:

$$f_0 = 10MHz$$

$$\Delta f = 1kHz$$

$$f_0/\Delta f = 10,000$$

$$300ps = 3\mu s$$



Pulses from balun opens the bridge and RF signal charge C_h . When bridge is closed, signal discharging trough R_h and C_d . On IF port appears the stretched RF signal.

SFCW GPR: Working principle

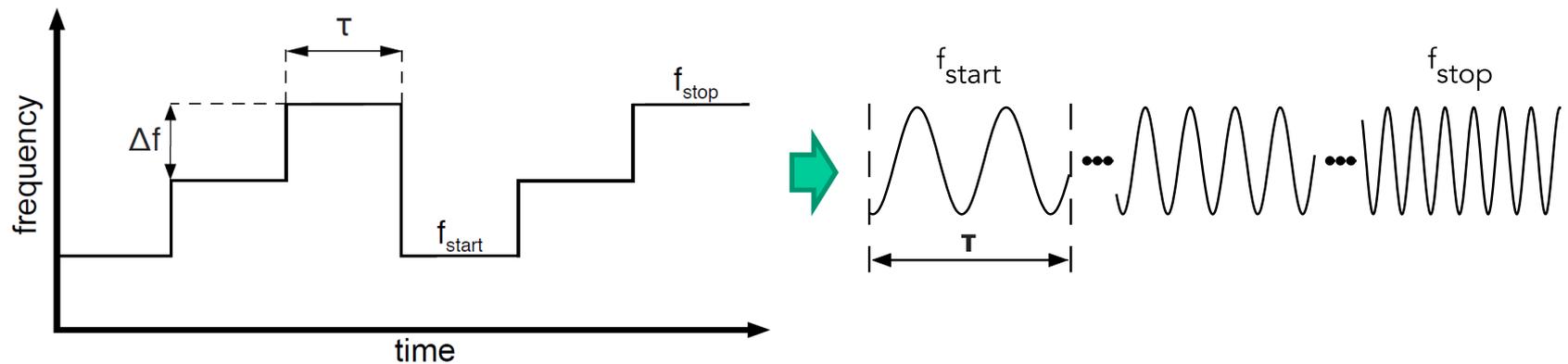
Transmitter output

Maximal measuring d $f_n = f_0 + n\Delta f \quad n = 0, 1, 2, \dots, N$

$$R_{max} = N\Delta R$$

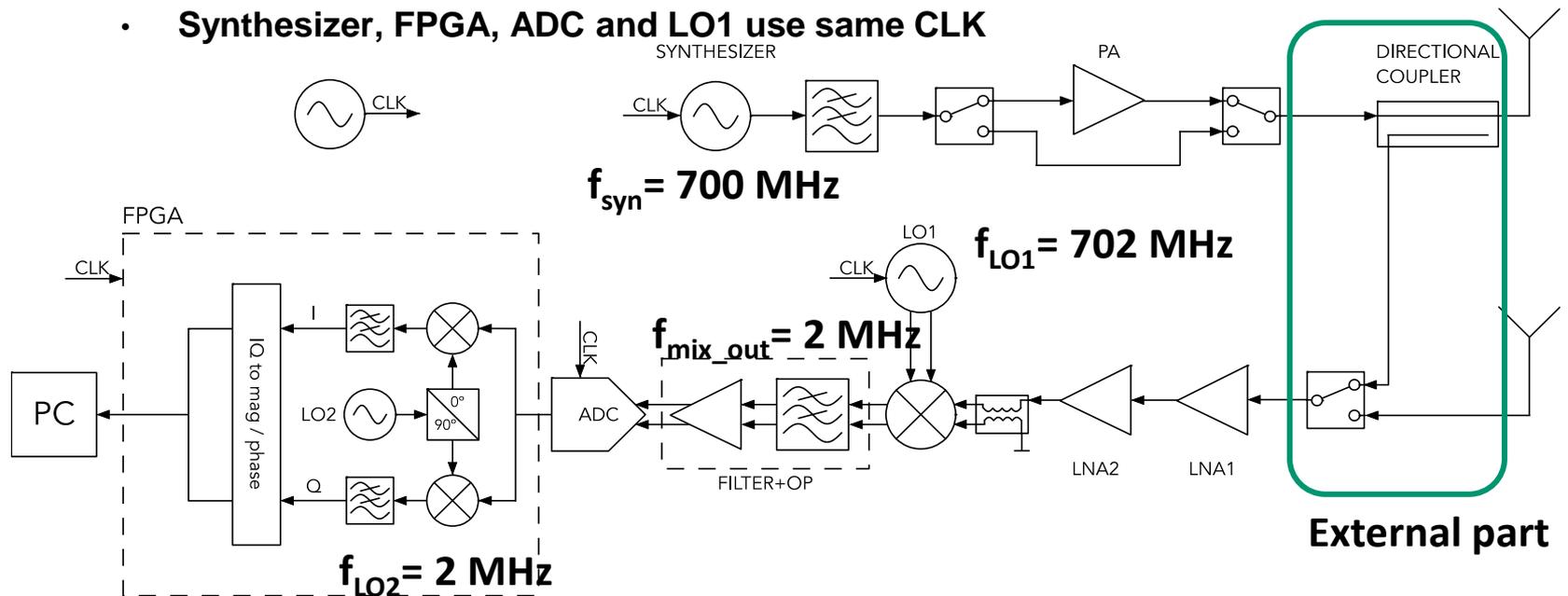
Resolution

$$\Delta R = \frac{c}{2B}$$



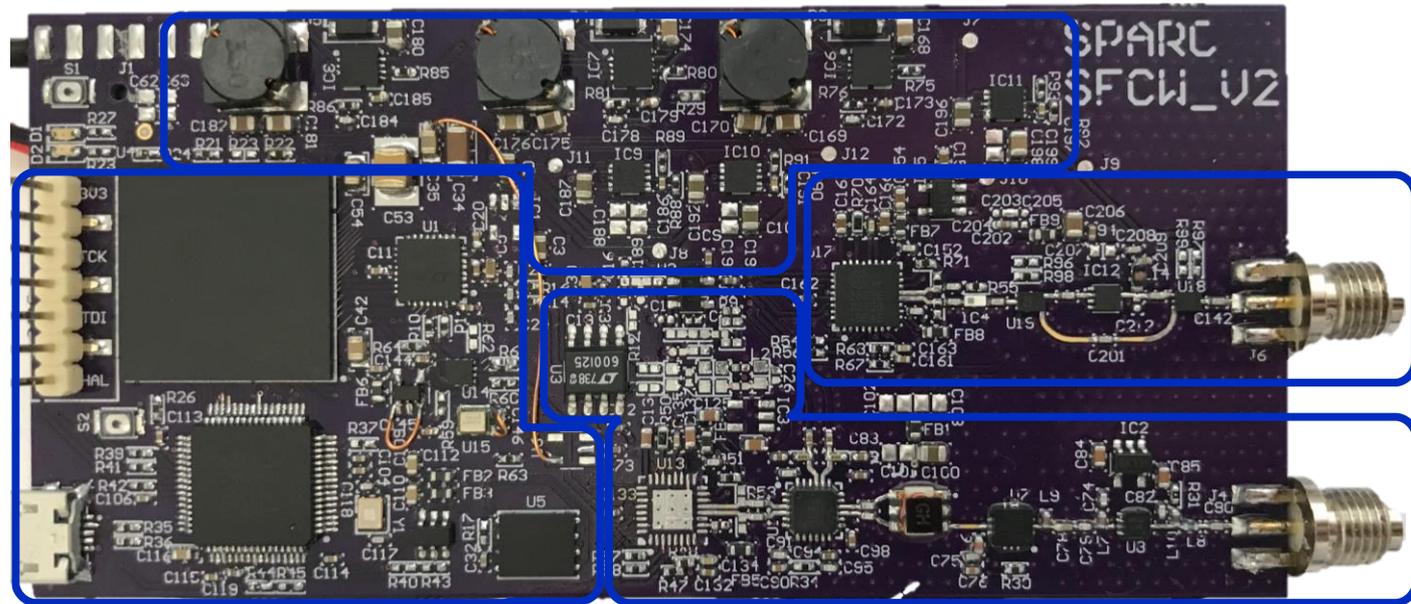
SFCW GPR: Design

- Super-Heterodyne structure (SFCW RADAR V2)
 - Synthesizer, FPGA, ADC and LO1 use same CLK



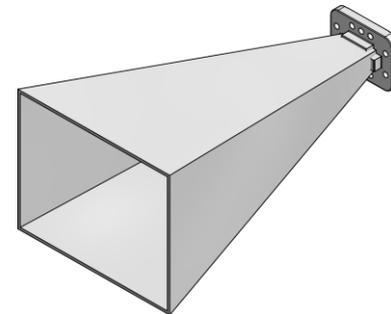
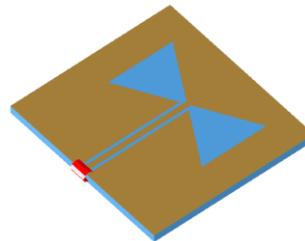
SFCW GPR: Design

- Hardware parts
 - Power
 - Processing
 - Transmitter
 - Receiver



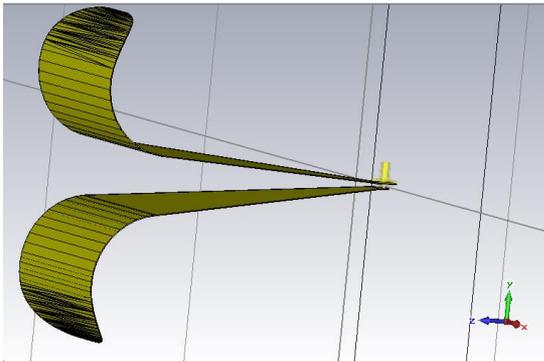
GPR UWB antenna

- **There are many know types of UWB antennas**
 - **Resistively loaded dipole antenna**
 - **Bow-tie antenna**
 - **Spiral antenna**
 - **Horn antenna**
 - **Log-periodic antenna**



GPR UWB antenna

- **Design of combined Horn and Vivaldi antenna**



Antenna 3D model

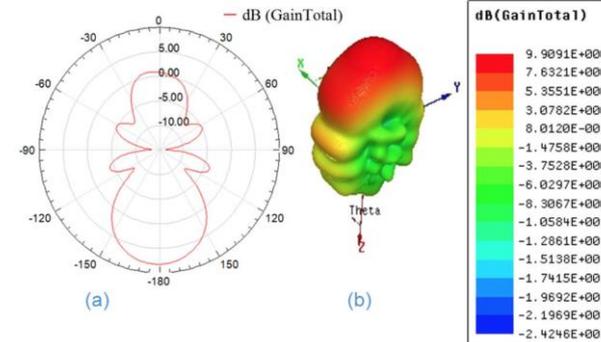
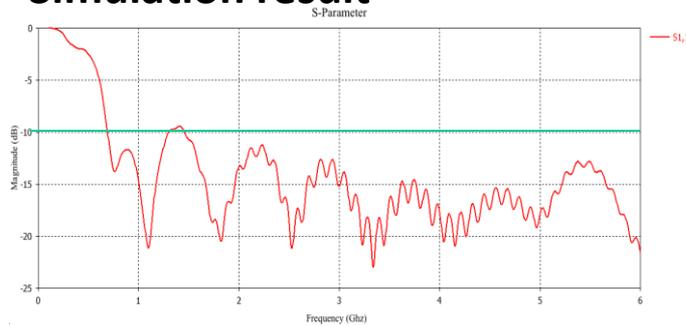
Simulation were
microwave



A. Ahmed, Y. Zhang, D. Burns, D. Huston, and T. Xia, "Design of uwb antenna for air-coupled impulse ground-penetrating radar," IEEE Geoscience and Remote Sensing Letters, vol. 13, no. 1, pp. 92–96, Jan 2016.

GPR UWB antenna

Simulation result



VNA measurement result (700 MHz – 3.9 GHz)



**Antenna gain at 2.7 GHz
(Max. approximately 9.9 dBi)**

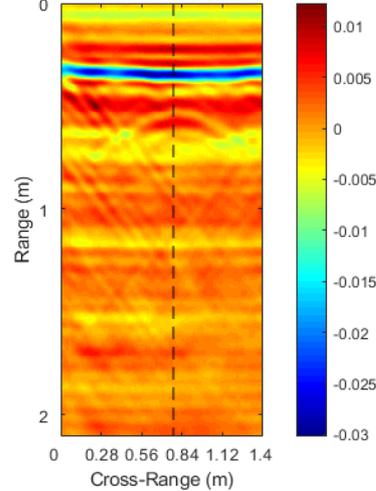
SFCW & UWB pulse GPR: Experimental results

• B-Scan of metal AP landmine 12 cm below ground surface

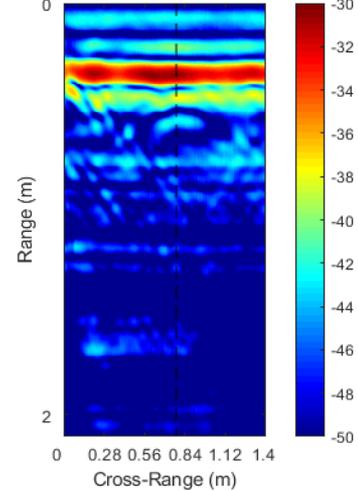
- Landmine perimeter: 7 cm
- Landmine height: 17 cm
- Antenna distance to surface: 10 cm



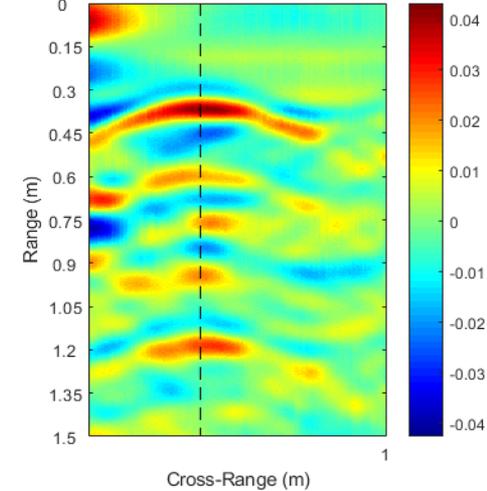
SFCW B-Scan (Real part)



SFCW B-Scan (Magnitude)



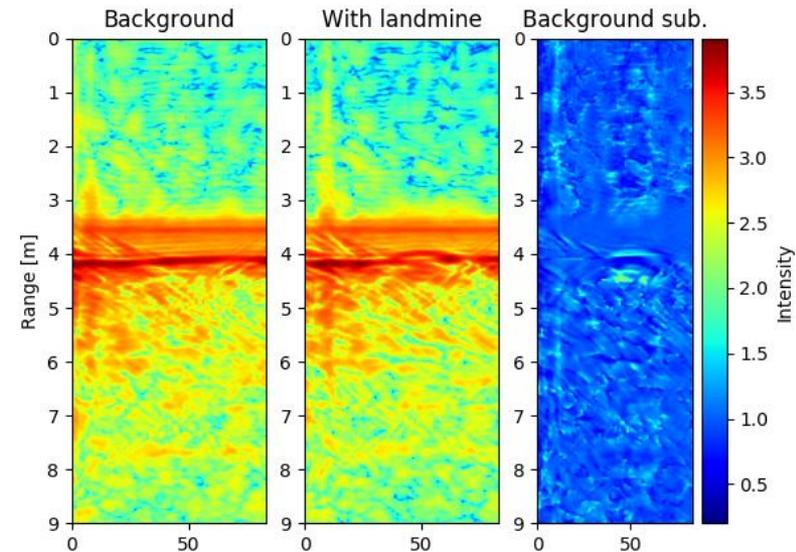
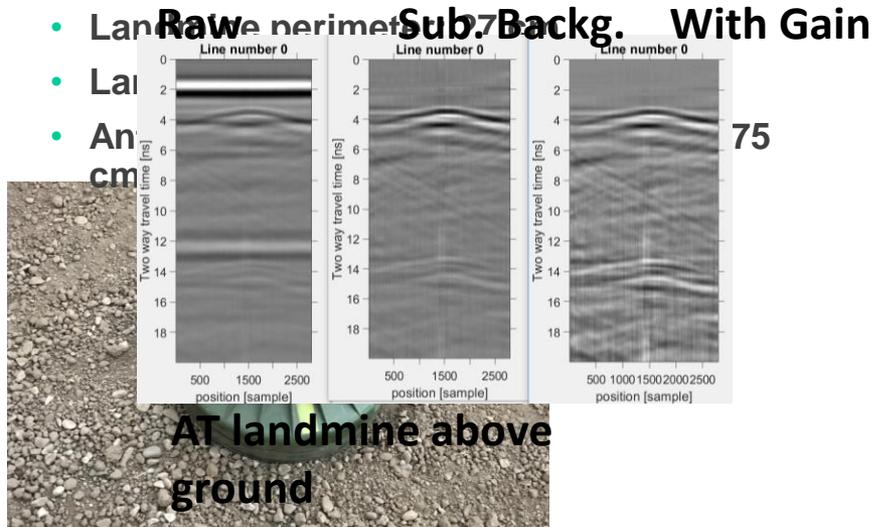
Baseband-Pulse B-Scan (Magnitude)



SFCW & UWB pulse GPR: Experimental results

- **B-Scan of AT landmine above ground surface**

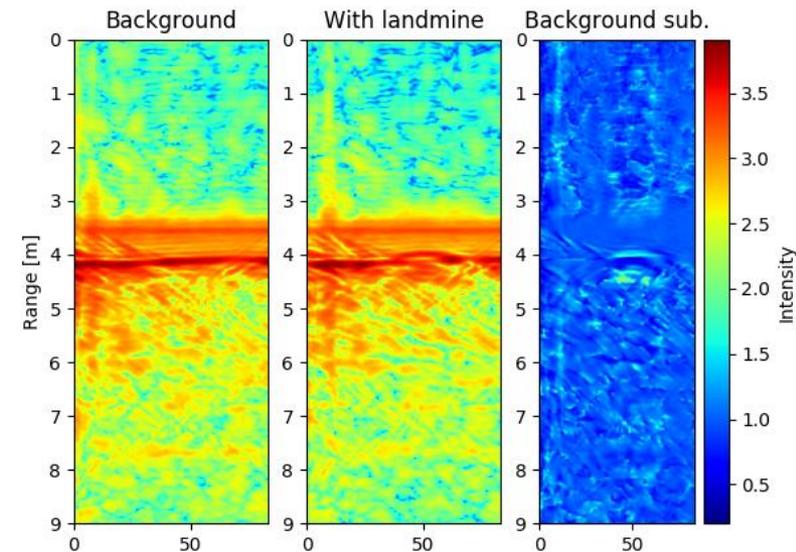
- Landmine perimeter
- Latency
- Antenna



SFCW & UWB pulse GPR: Experimental results

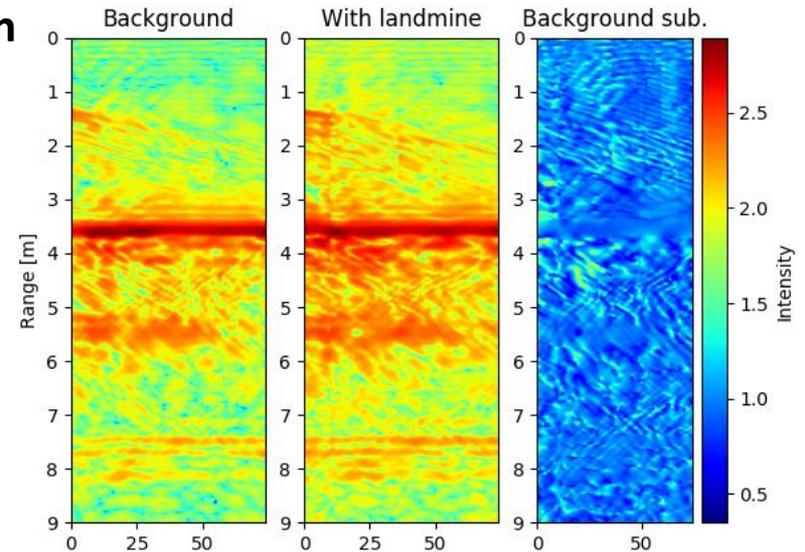
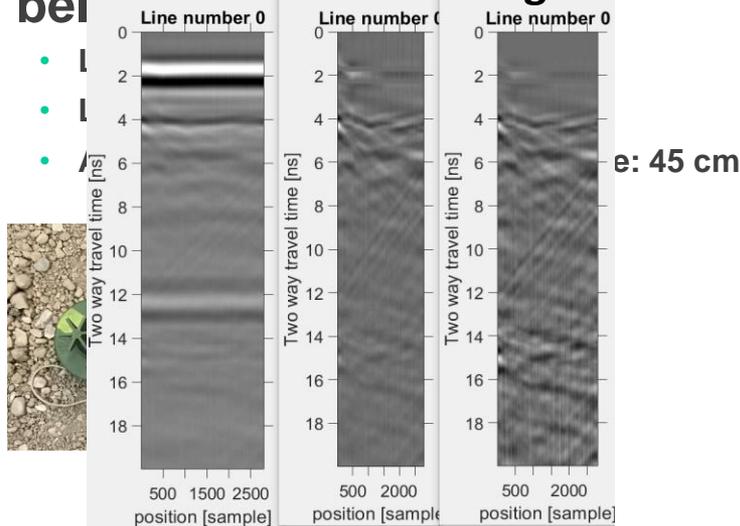
- **B-Scan of metal AP landmine above ground surface**

- Landmine perimeter: 7 cm
- Landmine height: 17 cm
- Antenna distance to ground surface: 75 cm



SFCW & UWB pulse GPR : Experimental results

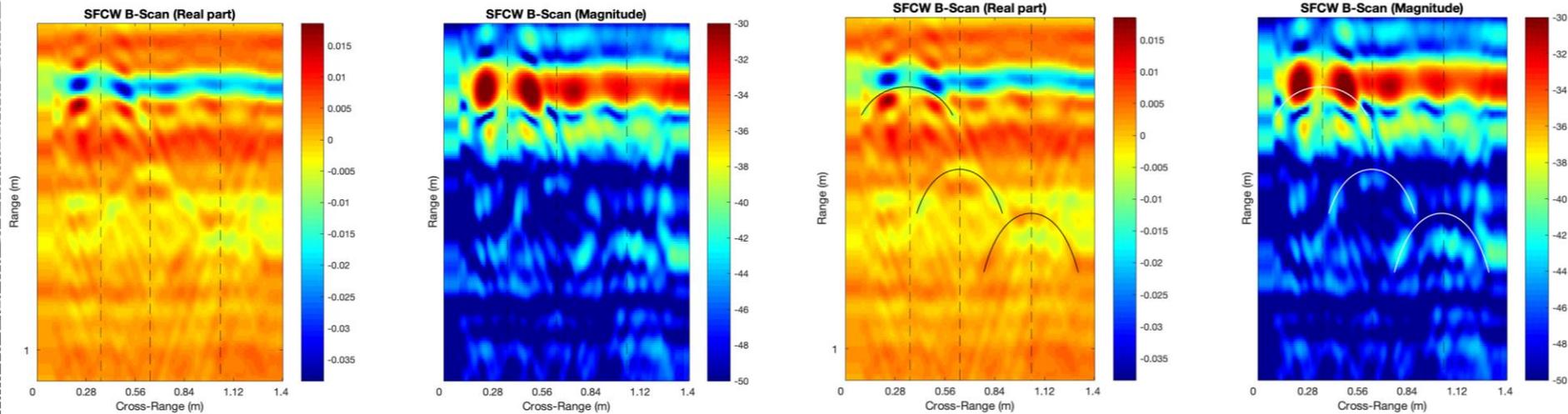
- **B-scan of plastic AP landmine below**



AP landmine below ground

Air-coupled GPR: Challenges

- B-Scan of three buried landmines (5 cm, 15 cm, 25 cm)

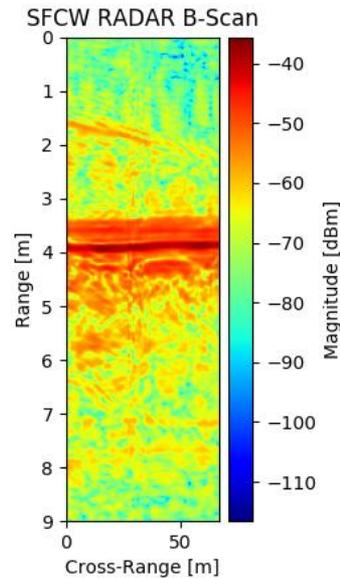


Marked Landmines

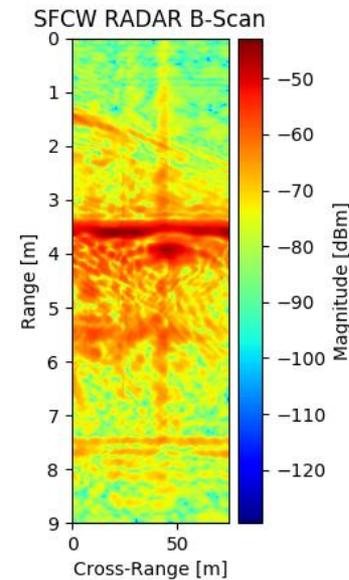
Air-Coupled GPR: Challenges

- **B-Scan test of buried metal stick at different antenna height**

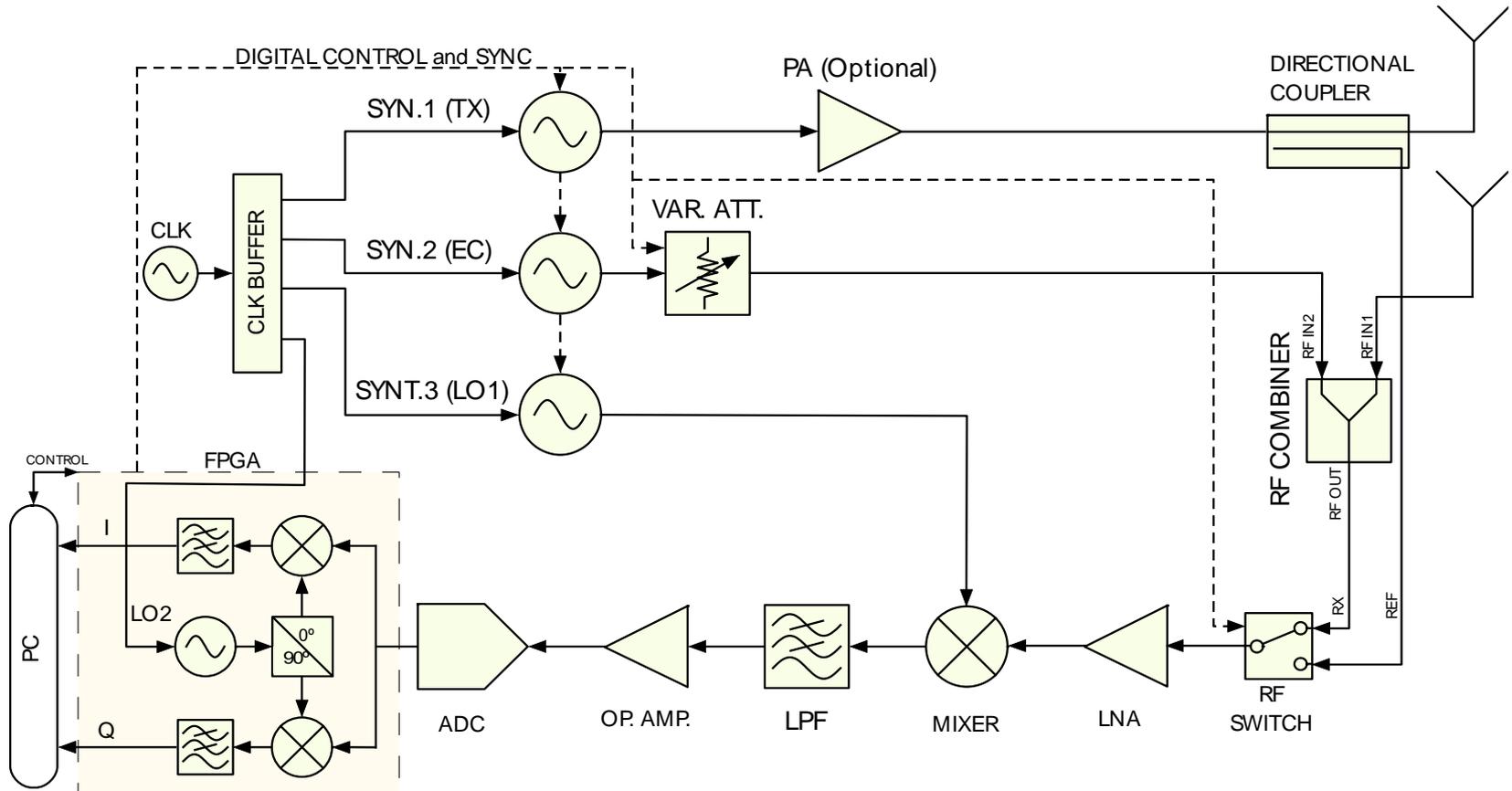
- **Antenna distance to ground surface: 75 cm**



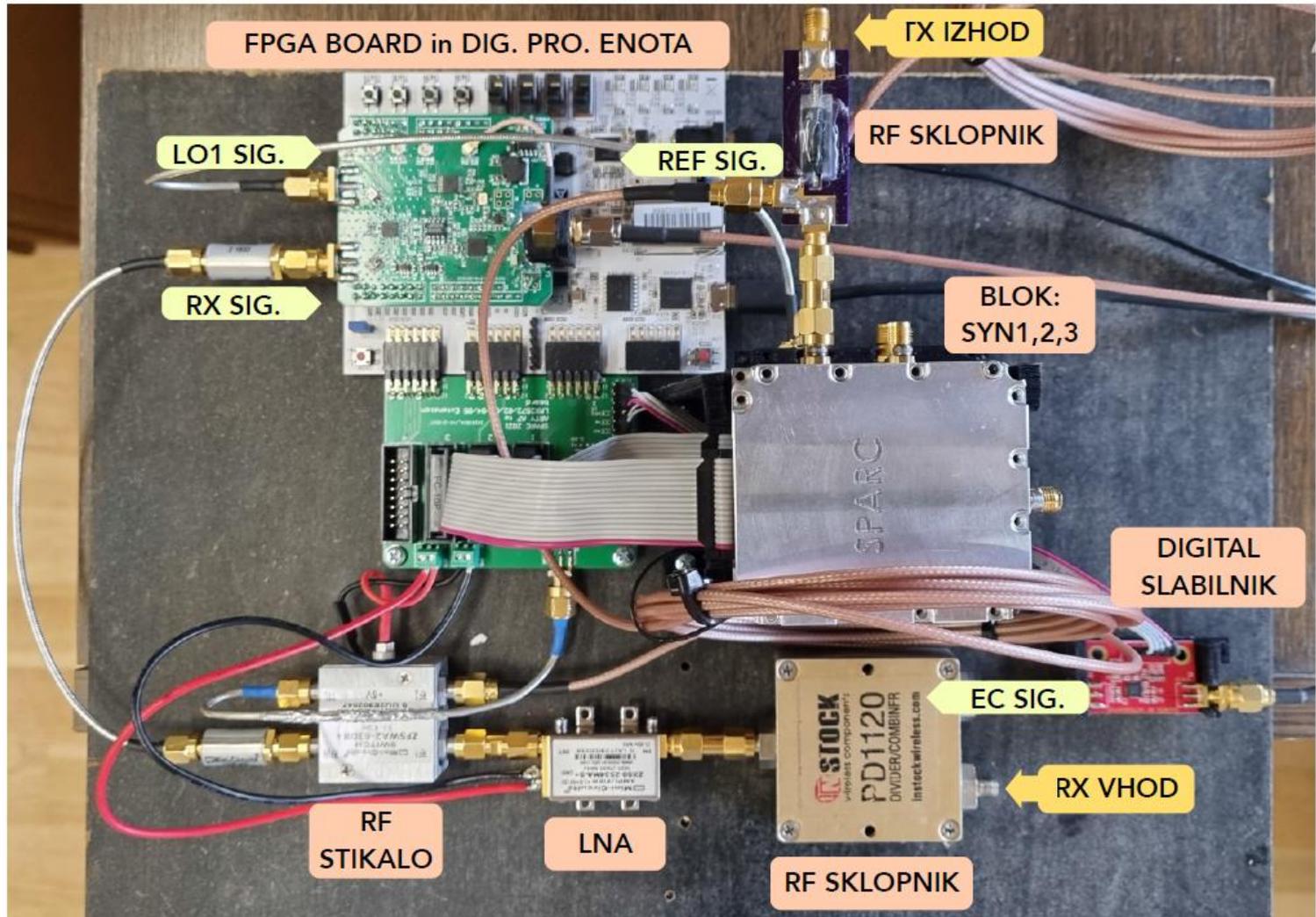
- **Antenna distance to ground surface: 45 cm**

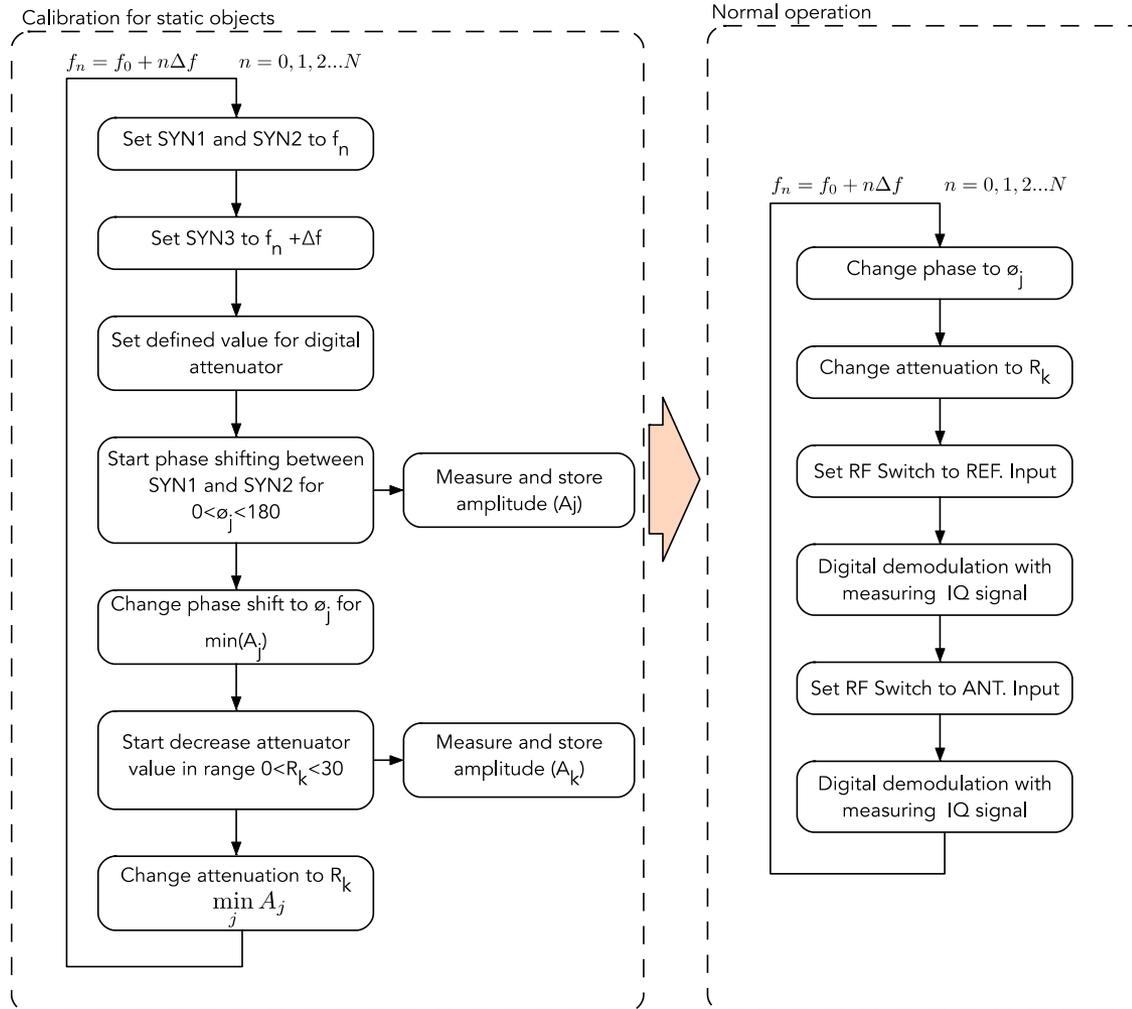


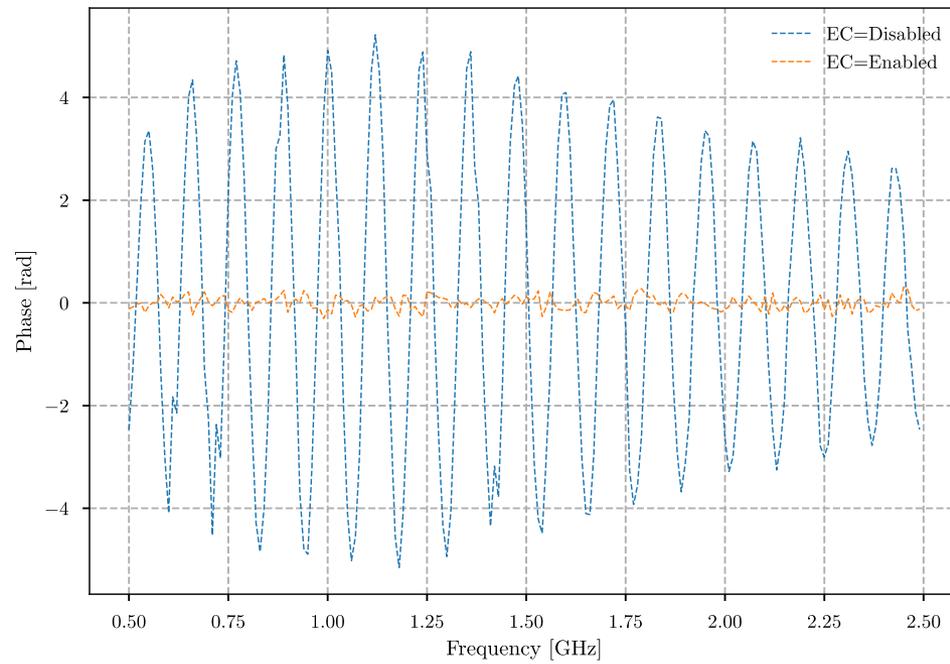
Air cupled SFCW radar – echo cancelation

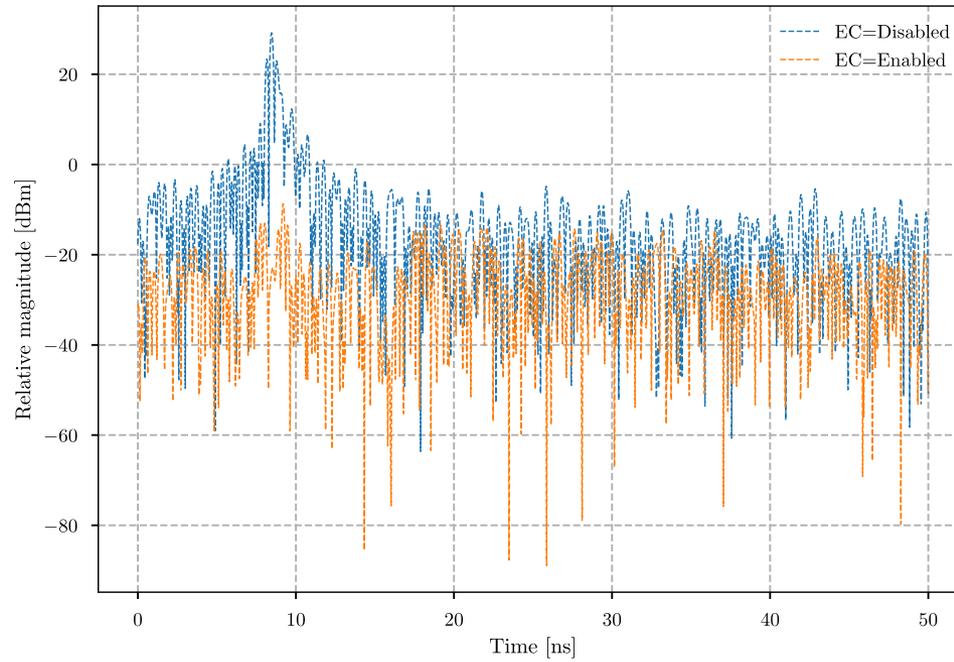


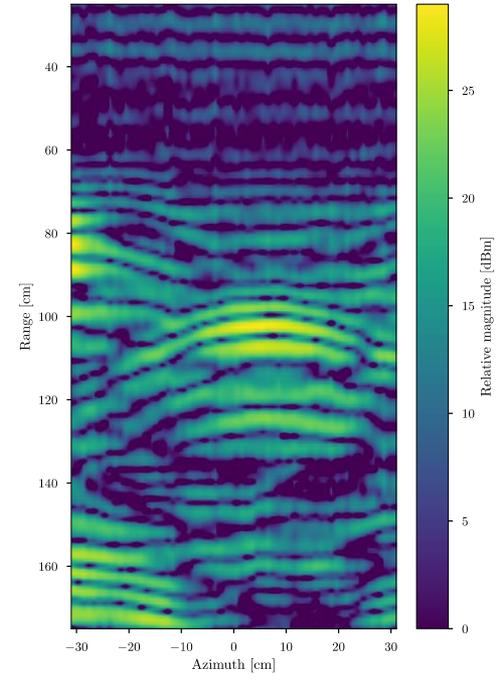
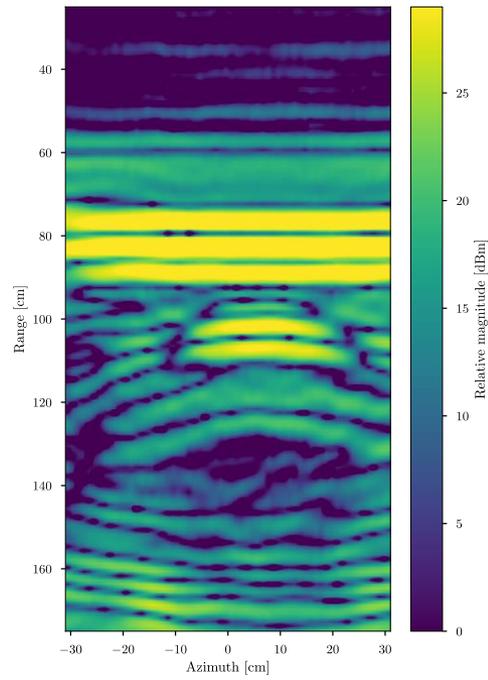
Echo cancelation system











Drone control

Introduction

- **RTK (real time kinematics) system:**
 - Rover
 - Base/Rover
 - Rover position in Base
- **User interface development for flight planning.**

Hardware

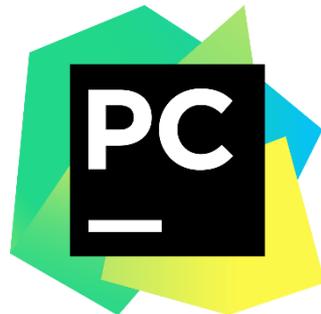
2 simpleRTK2B (ZED-F9P)

2 Xbee radio moduls

2 GNSS in 2 Radio antennas

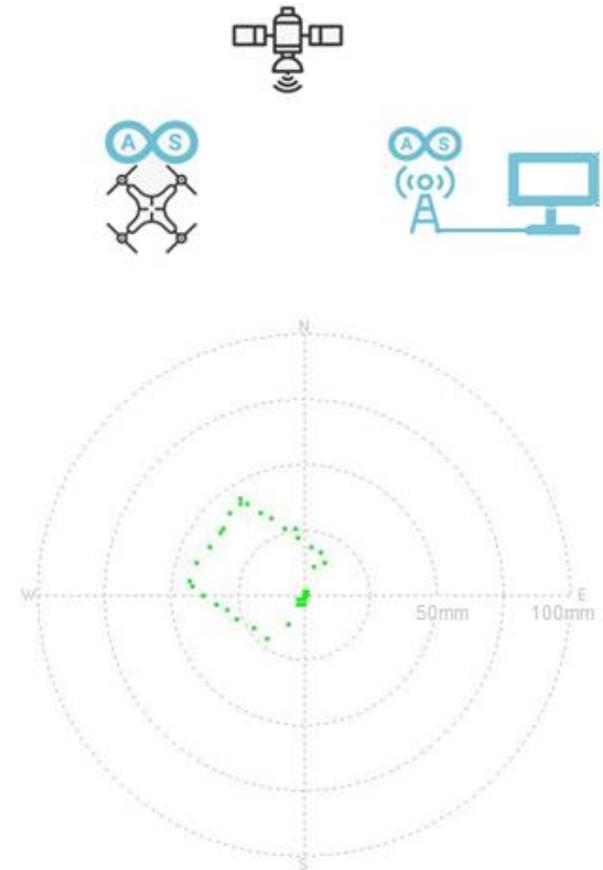
Programski jezik: Python, Tkinter,

PyCharm



RTK system

- **NTRIP correction**
- **Position Correction of base station**
- **Radio communication**
- **Coordinate acquisition in real time**
- **Centimeter accuracy**

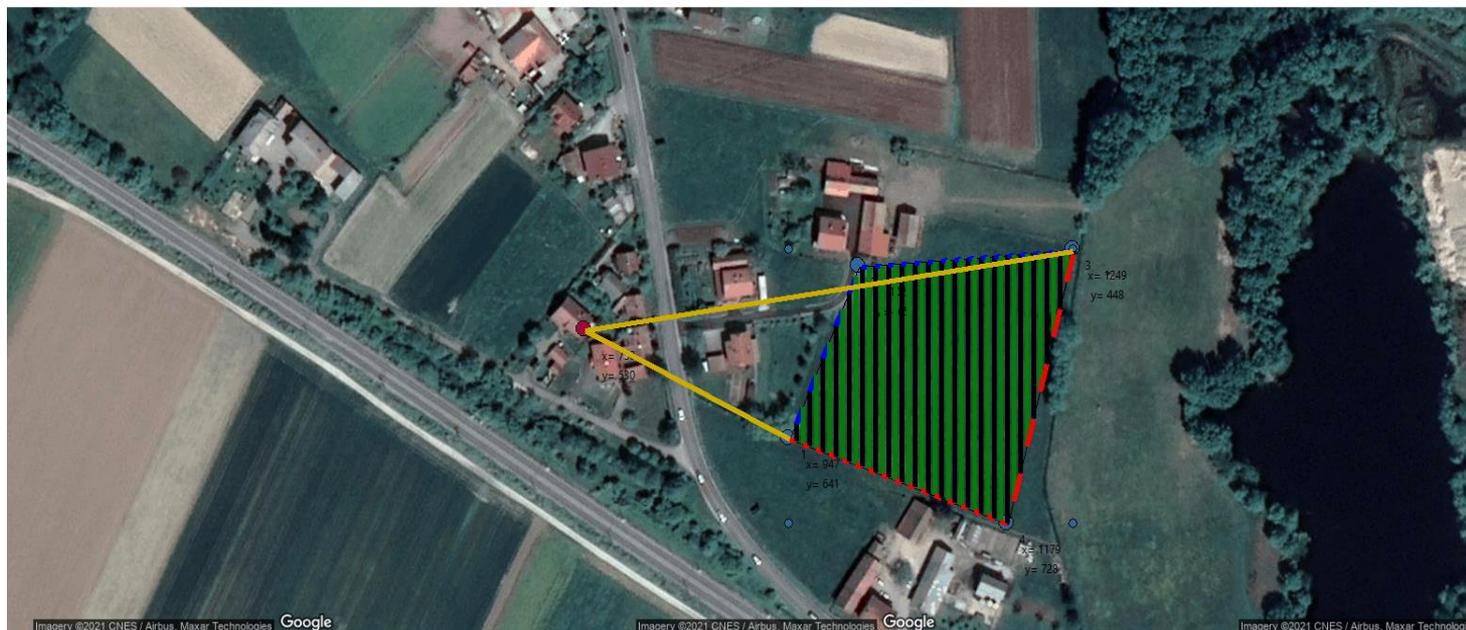


Namenska aplikacija



Path planning

SMARTpath



Ustvari pot preleta

Poveži

Briši

Prekini povezavo

X(mm)	Y(pix)	ZOOM
3000	1	18

Start

Parametri

4_1_2020_Size640_ZOOM18.png
 4_1_2020_Size640_ZOOM19.png
 4_1_2020_Size640_ZOOM20.png
 C_B_C_Size640_ZOOM18.png
 D

COM18 - USB Serial Device (C) ▾

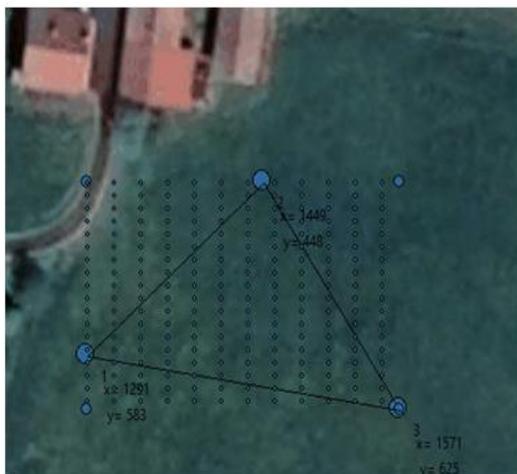
Trenutna lokacija

stop

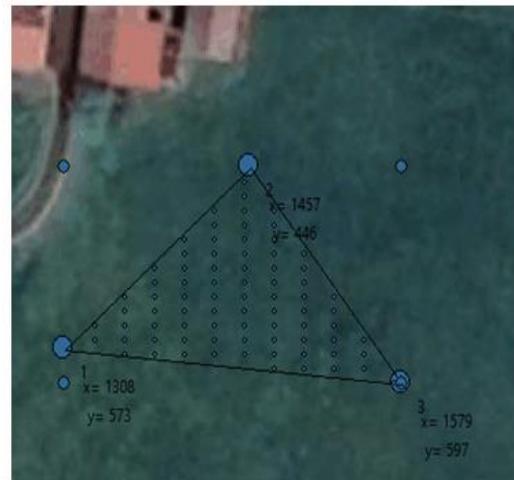
Posodobi

Lat 45.9286326

Lon 15.5804708



X(mm)	Y(pix)	ZOOM
5000	10	19
Koordinate		
Parametri		
4_1_2020_Size640_ZOOM18.png		
4_1_2020_Size640_ZOOM19.png		
4_1_2020_Size640_ZOOM20.png		
C_B_C_Size640_ZOOM18.png		
D		



X(mm)	Y(pix)	ZOOM
5000	10	19
Koordinate		
Parametri		
4_1_2020_Size640_ZOOM18.png		
4_1_2020_Size640_ZOOM19.png		
4_1_2020_Size640_ZOOM20.png		
C_B_C_Size640_ZOOM18.png		
D		



Ustvari pot preleta		
Poveži		
Briši		
Prekini povezavo		
X(mm)	Y(pix)	ZOOM
5000	10	19
Koordinate		
Parametri		
4_1_2020_Size640_ZOOM18.png		
4_1_2020_Size640_ZOOM19.png		
4_1_2020_Size640_ZOOM20.png		
C_B_C_Size640_ZOOM18.png		
D		





Synthetic Aperture Radar using drone, under construction



Conclusion

- **The goal is to develop bistatic radar**
- **2 radar platform attached to separate drones**
 - **Micro-controller synchronization**
 - **RTK based control**
- **Chip shortage/high prices**
 - **FPGA design is replaced with STM microcontroller**
- **Radar platforms under development, expected in April first prototype with synchronization module**