Project ID: **Fly-Radar**

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Call: **H2020-MSCA-RISE-2020**

WP6 –Validation and test field campaign:

D6.4: Final Scientific Assessment Report

Lead contributor	**IRSPS**
Other contributors	**UCBL** **Hyperion Seven** **CO.RI.S.T.A.**

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under MSCA-RISE2020 grant agreement No 101007973.

List of Abbreviations (if necessary)

DEM	Digital Elevation Model
ETUS	Embedded Transmitting Unit System
GPR	Ground Penetrating Radar
GPS	Global Positioning System
HH	Horizontal-Horizontal polasization
H2020	Horizon 2020
IMU	Inertial Measurement Unit
PLA	Polylactic Acid
PRF	Pulse Repetition Frequency
SAR	Synthetic Aperture Radar
UAV	Unmanned Aerial Vehicle
VLOS	Visual Line of Sight
VV	Vertical-Vertical polarisation

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1. Introduction and summary of the activities

This deliverable presents a comprehensive overview of all the ground and flight tests carried out on the FlyRadar system between June 2024 and July 2025, as well as the analyses performed on the data acquired during these campaigns. These activities were led by partner UCBL, with the active collaboration of IRSPS, Hyperion Seven, CO.RI.S.T.A and other key project partners. Since the end of August 2024, Prof. Gian Gabriele Ori (IRSPS PI and Project Coordinator) has been in secondment at UCBL to support the resolution of technical and scientific issues and to coordinate the collocations and field campaigns.

The **II Joint Collocation** of the project (Milestone 4 – April and May 2025) was relocated to Lyon due to technical and organizational difficulties encountered during the integration of the drone and radar systems. Challenges related to flight stability required that these tests be carried out in a more controlled environment. The work successfully validated the modified drone's ability to operate under high outdoor temperatures and confirmed that the operation of the radar does not interfere with the drone's electronic systems. During some tests in March 2025 the drone suffered a significant crash, which caused damage and caused some factory fixing. It led to delays in the overall project timeline. The system was fully repaired by the end of May 2025.

On June 17, during a test flight with the sounder antenna, another crash occurred, causing major damage to the infrastructure. Fortunately, the team at Université Claude Bernard Lyon 1 was able to carry out in-house repairs. This in-house recovery allowed to carry on the III Collocation in Lyon at the end of June.

The **III Joint Collocation** took place in late June 2025 at the Université Claude Bernard Lyon 1 and in Vernay. As part of this activity, a comprehensive series of indoor and field tests was conducted on June 26–27. The first day was dedicated to indoor experiments, while the second day focused on field tests at Vernay. All tests were carried out with the radar and antennas mounted on the drone in its final flight configuration.

The **IV Joint Collocation**, the last one, was then carried out from 21 to 23 July 2025 on the Bouichet plateau in southern France. This campaign aimed to evaluate the radar system under more realistic field conditions in SAR mode. The flights on 22 and 23 July were successfully completed using both vertical and horizontal polarisations, resulting in approximately 40 GB of high-quality data.

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The results and analyses presented in this deliverable, covering all test campaigns from June 2024 to July 2025, have been crucial to solving key issues regarding the stability and integration of the FlyRadar system and lay the groundwork for future improvements and scientific applications.

The results of these Collocation data are still under analysis and are partially submitted in this document, but the final version will be provided with the Final report. A careful analysis of the two crashes and also some critical behaviour of the drone has been produced by anomalous (high speed or changing direction, behaviour of the wind).

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2. Drone modification

The drone used for the project is a Tundra tetracopter built by Hexadrone society. The drone has been modified to fulfil the requirements of the projects.

- Custom white paint + varnish (body): to protect the drone from high temperatures and to limit the abrasion by sand
- Cooling module with dual 12V fans: to prevent high temperature inside the drone
- Remote controller: H16 PRO with antenna mounts - to assure the communications between drone and ground station
- Landing gear leg – Extended (unit): to assure the take-off and landing with the antennas

An aluminium bar (fig. 1) has been fixed to support antennas. The GPS module (provided by Corista) is fixed above and in the centre of mass of the UAV. A GoPro camera is installed to record a video of the areas overflown by the drone (https://www.flyradarproject.eu/videos/).

Figure 1: View of the FlyRadar instrument with the sounder antenna. The attaching mechanism (in red) between the antennas and the horizontal bar have been modified to strengthen the system.

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3. Descriptions and results of the tests of the FlyRadar

To facilitate a comprehensive understanding of the validation efforts, the following test log outlines all major activities performed using the GPR and SAR antennas, including test conditions, goals, and configurations used during both ground and flight operations.

Date	Antenna Type	Test Type	Description / Test Area	Objectives
06/06/2024	GPR	Ground Test	Radar powered on, UAV on the ground	Verify interference between UAV and radar; test “NoMachine” software and data acquisition
06/06/2024	GPR	Low-altitude Flight (8 m)	1. Over a rainwater tank (4 m deep) with pipes at 10–30 cm and 3 m depth 2. Over an asphalt road 3. Over a swimming pool	System integration test; verify UAV behaviour with radar on
06/06/2024	GPR	Medium-altitude Flight (16 m)	Same areas as low-altitude flight	Data acquisition at higher elevation
10/2024	SAR	Ground Assembly Test	SAR antenna mounting with 3D printed parts, SolidWorks simulation	Mechanical integration: robustness test of supports and assembly process
10/2024	SAR	Flight Test	General area; tested with a 3 kg case under the drone	Flight stability test with SAR antennas; compare with GPR performance

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26/06/2025 (III Collocation)	SAR	Indoor Test (HH and VV)	Laboratory tests at Laboratoire de Géologie de Lyon. Antennas mounted on drone. Tests in HH and VV configurations; signal analysis in time and frequency domains.	Verify correct functioning of radar system; assess antenna coupling and transmitted bandwidth.
26/06/2025 (III Collocation)	SAR	Roof Test (HH and VV)	Radar positioned on roof of 6th floor of University building. Antennas pointed toward the ground. HH and VV configurations tested.	Analyze received signals in real environment from elevated position; assess target detection capability.
27/06/2025 (III Collocation)	SAR	Field Test (HH and VV)	Field tests conducted in Vernay near an archaeological site. Tests in HH and VV configurations with flight tracks recorded.	Verify radar functioning and antenna coupling during real-environment flights; evaluate imaging capabilities (unfocused images).
22/07/2025 (IV Collocation)	SAR	Flight Test (take-off incident)	Bouichet Plateau (Southern France). During take-off, the FlyRadar-equipped drone overturned. After the incident, a Mavic 2 was used to acquire	Acquire topographic data for context mapping and prepare for subsequent radar flights.

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			aerial images to create a DEM and orthophoto.	
23/07/2025 (IV Collocation)	SAR	Flight Test (Vertical polarisation)	Bouichet Plateau. Four parallel flight lines: two at 20 m and two at 50 m altitude, approx. 150 m length each. Radar in SAR mode, vertical polarisation.	Data acquisition to validate SAR performance over rocky outcrop terrain.
23/07/2025 (IV Collocation)	SAR	Flight Test (Horizontal polarisation)	Bouichet Plateau. Same flight lines as previous test. Radar in SAR mode, horizontal polarisation.	Compare horizontal vs vertical polarisation; test system stability and data quality.

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GPR Flight Test Details:

- Automated Flights:
  - Number of flights: 3
  - Mode: Pre-programmed (automated)
  - Duration per flight: 10–12 minutes
  - Average speed: 8 m/s
  - Distance per flight: 4.5 km
  - Equipment: GPR antennas
  - Radar status: Active throughout each flight
- Short Flights:
  - Number of flights: 10
  - Duration per flight: 1–2 minutes
  - Equipment: GPR antennas
  - Radar status: Active throughout each flight
  - Purpose: Conducted short-range scans over specific targets of interest

SAR Flight Test Details:

- Short-Duration Flights:
  - Number of flights: 5
  - Duration per flight: ~ 5 minutes
  - Average speed: 5 m/s
  - Distance per flight: ~ 1.5 km
  - Equipment: SAR antennas
  - Radar status: Active during flights
  - Purpose: Evaluation of data acquisition performance in short operational missions simulating localized area exploration

The details of the flights conducted during the III and IV Collocation phases will be presented in the following chapters

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4 II Joint Collocation (Lyon)

A first series of tests of the whole system with GPR antennas was conducted on 06 June 2024. The objectives of these tests were:

- ✓ To check how electronics of UAV and Radar behave when both active
- ✓ To check how the drone reacts with the radar in operation
- ✓ To record data in flight for the first time for further processing

4.1 Ground tests

After installing the ETUS on the UAV, it was necessary to recalibrate the UAV's Inertial Measurement Unit (IMU). This requires rotating the UAV along all three axes—a procedure that is challenging and typically requires the assistance of two or three people. This mandatory calibration must be performed before each mission.

The FlyRadar computer can be operated remotely via a Wi-Fi connection that is independent of the UAV's control system. The "NoMachine" software allows the FlyRadar desktop to be viewed from a Windows tablet. This setup enables remote initiation of data acquisition (Figure 2).

The acquisition program, provided by Corista, manages the data collection. The parameters used correspond to the settings configured by Corista prior to shipping the ETUS to Lyon, and they were not modified.

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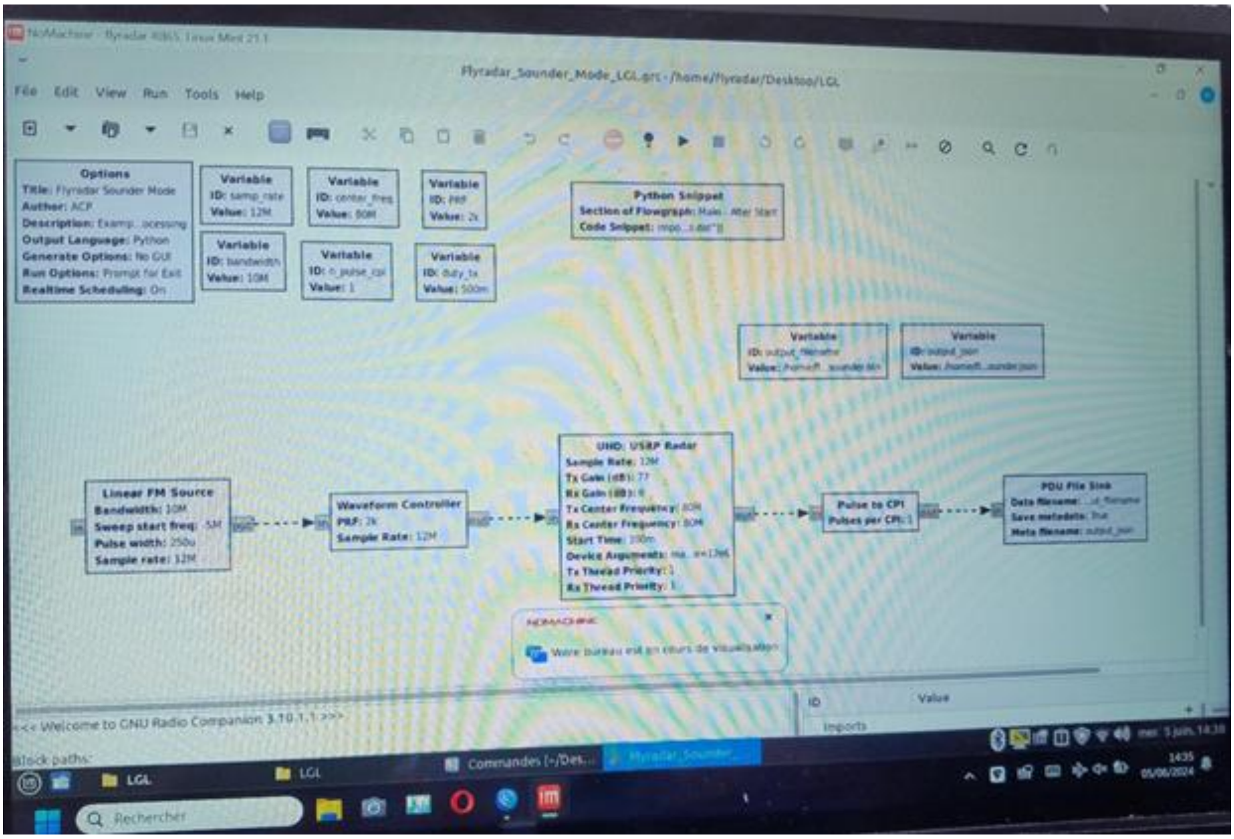

Figure 2: The control view with "No machine" software.

For the first test, the drone was powered on, but the propellers were not activated.

No interference between the drone and the radar was observed.

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4.2 Flight tests Description

1. The radar is powered on first, and data recording begins.
2. The UAV is then powered on.
3. The flight starts in manual mode.

Before take-off, wind conditions must be calm. Wind can cause instability or even lead to a crash, especially since the antennas unbalance the UAV.

Flight Sequence

- Initial Phase:
  The UAV performs a low-altitude flight very close to the ground.
- Flight at 8 meters elevation:
  - Over a rainwater tank (4 meters deep).
    The tank is connected to pipes buried at depths ranging from 10 to 30 cm, and others buried at 3 meters.
  - Over an asphalt road.
    A pipe is buried between 10 and 30 cm below the surface.
  - Over a swimming pool.
- Flight at 16 meters elevation:
  - Over the same swimming pool.
  - Over an asphalt road with a buried pipe at 10 to 30 cm depth.
- Return Flight:
  The UAV retraces its route and performs a landing procedure.

During hovering or in windy conditions, the drone and its antennas may resonate, causing vibrations or instability.

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Shutdown Procedure

- Stop the drone's engines.
- Then stop the radar to end the data recording.

No interference between the radar and the drone was observed. Once again, we confirmed that wind is a critical factor. Flying appears to be impossible when wind speeds exceed 10 km/h. The pilot must avoid sudden movements, and the UAV should remain in dynamic flight mode—hovering should be avoided whenever possible.

4.3 Tests with SAR Antennas

The drone was tested in flight conditions with the SAR antennas (figure 3). Before the test, the integration of the antennas was realized.

To minimize on-site logistics, it was decided to reuse the existing GPR antenna mounts as much as possible. The solution initially proposed by the antenna manufacturer (IØJXX di Donzello Rosanna), which involved mounting the antennas perpendicular to the aluminium beam, was ultimately rejected for several reasons:

- The antennas did not point downward (NADIR orientation).
- The tilt angle could not be adjusted, which was a requirement from the scientific team.
- The antennas could potentially interfere with the UAV's propellers.

As a result, the antennas were mounted at the ends of the aluminium beam.

Several configurations were tested. The final setup uses 3D-printed parts that guide the assembly. These components were designed in SolidWorks and printed in PLA using an Ender 3D printer.

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Figure 3: View of the drone with SAR antennas and a case with 3kg under the drone. Drone ready for take-off.

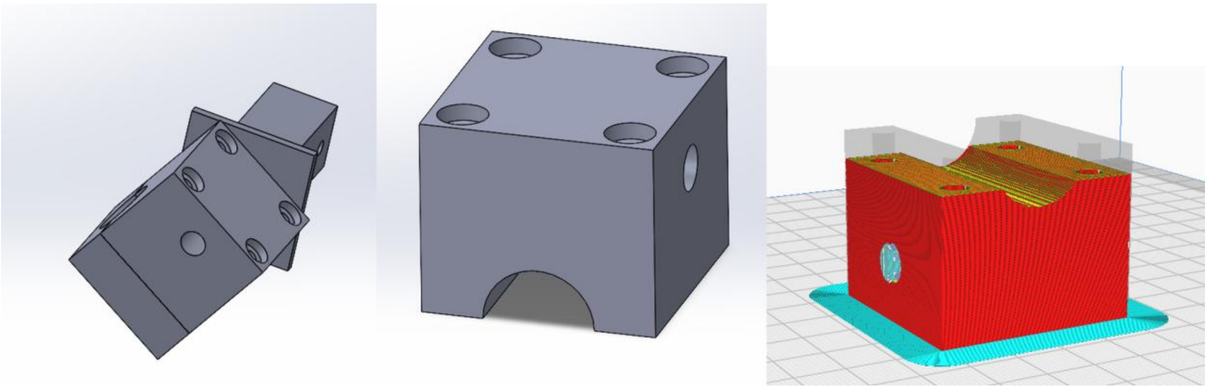

Figure 4: Final assembly and detail with SolidWorks. Print simulation with Ender Software.

Before each flight, all Yagi elements—about ten per antenna—must be assembled, along with the antennas themselves, onto the aluminium bar. This process takes at least an hour. The antennas cannot be transported with the Yagi elements attached, as they are extremely fragile and easily bent.

It would be wise to carry spare Yagi elements and their mounting screws to perform field repairs if necessary. During pre-flight assembly, part of a mounting component was damaged. We managed to repair it on-site, but this incident highlights the need to further improve the robustness of the system.

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The drone performs well in flight. Although the antennas affect the drone's balance, this effect is less pronounced with the SAR antennas than with the GPR ones. The SAR antennas are lighter and offer less wind resistance, making the drone noticeably more manoeuvrable and responsive compared to when equipped with GPR antennas. In any case, both types of antennas alter the drone's flight behaviour compared to flying without a payload. Therefore, test flights must be conducted in open areas free of obstacles such as cliffs or trees, especially at operational flight altitudes. To maintain proper flight control and trajectory, the pilot must be able to intervene in real time. For this reason, the drone must always remain within visual line of sight. It is crucial that the drone stays in motion during flight. When stationary, there is a risk of antenna resonance. Excessive resonance can lead to loss of control. Finally, wind must be strictly avoided. Even moderate wind can destabilize the system and lead to a crash.

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5. Descriptions and results of the tests of the radar in GPR mode

The radar has been tested in GPR mode to evaluate the recording of data and the quality of the data. The first tests were conducted in Lyon. The radar with GPR antennas was installed on board of the drone which was attached to a table (fig. 5). The first tests were realized with the drone in an "off" position. A second series of tests were done with the propeller installed and the drone in an "on" position.

Figure 5: Test of the radar in the laboratory with the drone in "off" position. The radar is installed on board the drone. The GPR antennas are visible on both sides of the drone. The computer is connected to the radar to activate the emission and reception of the signal. In this configuration, a plate in aluminium is set under the emission antenna to test the possible interferences with the environment.

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The radar is first programmed with the GNU Radio Software (fig. 6). The duration of emission and recording are set as the characteristics of the pulse (central bandwidth, pulse width, sampling rate).

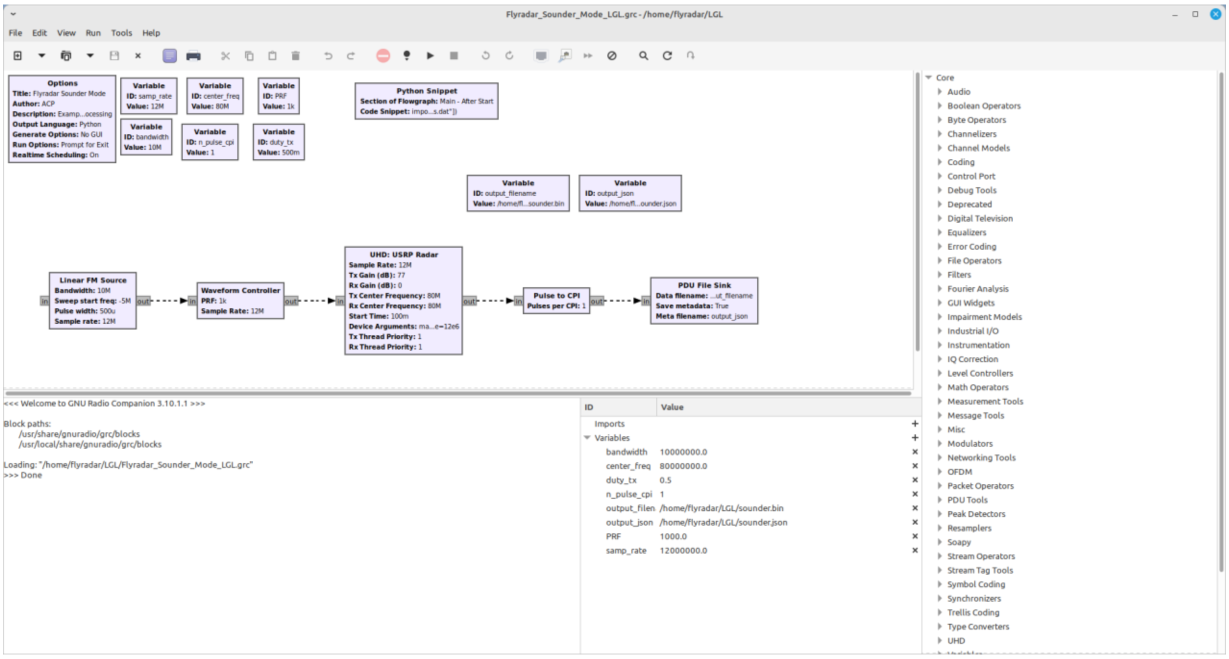

Figure 6: windows view of the GNU Radio software with which the parameters of the radar are set for both emission and recording.

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The results of this first test are shown on figure 7. The signal received by the reception antenna has the expected characteristics in terms of duration and amplitude.

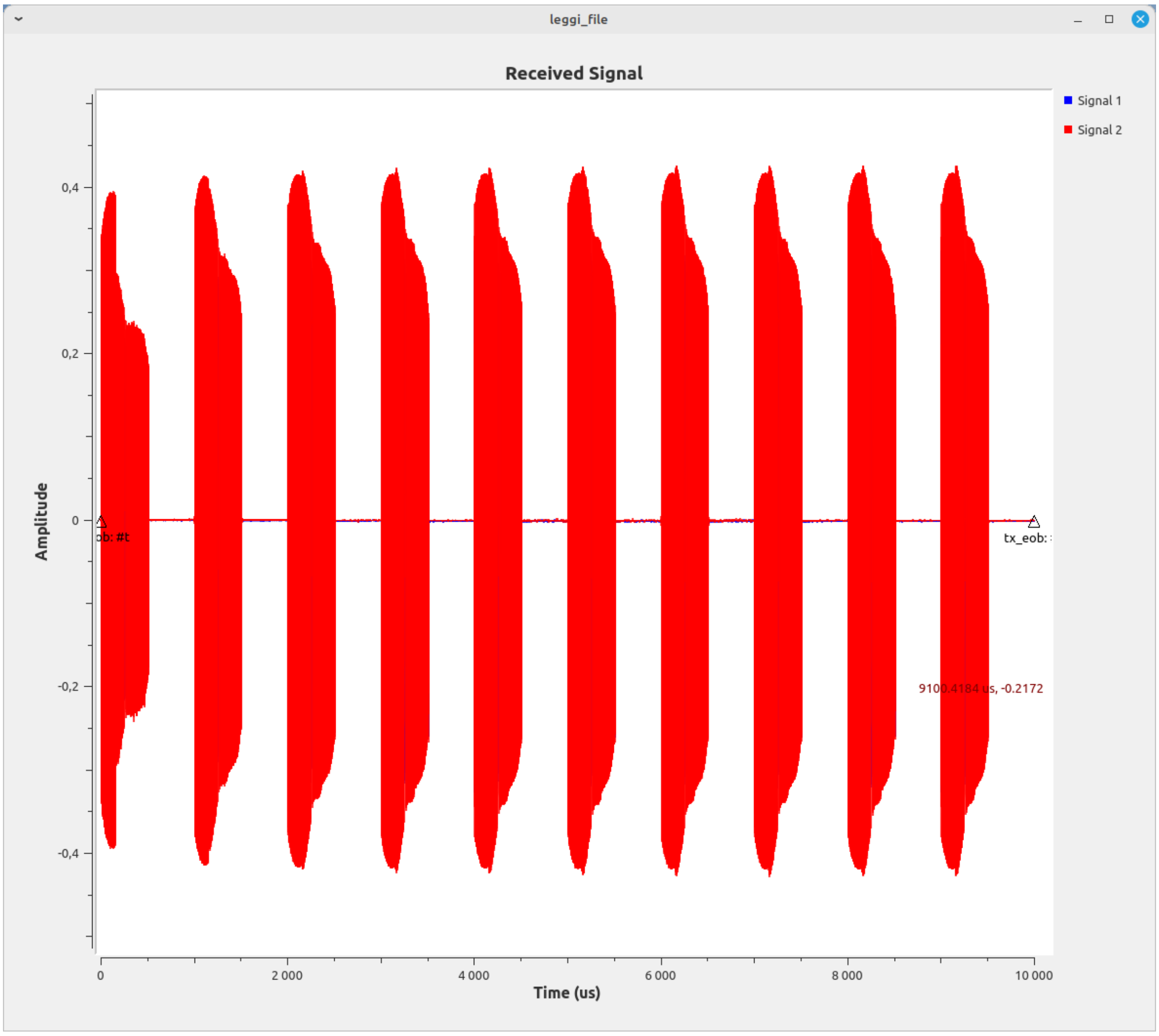

Figure 7: Signal received by the reception antenna and displayed on MATLAB. The horizontal axis is time. Ther vertical one is the amplitude of the signal. One can see that the received signal displays a regular pattern like the emission pattern. The system behaves as expected.

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In a second series of the test the drone was set in “on” position with engines running. As in the previous case the signal received by the antenna is registered (fig. 8). The signal is modified when the drone is running. This pattern will be further investigated to evaluate if this signal remains invertible to study the underground.

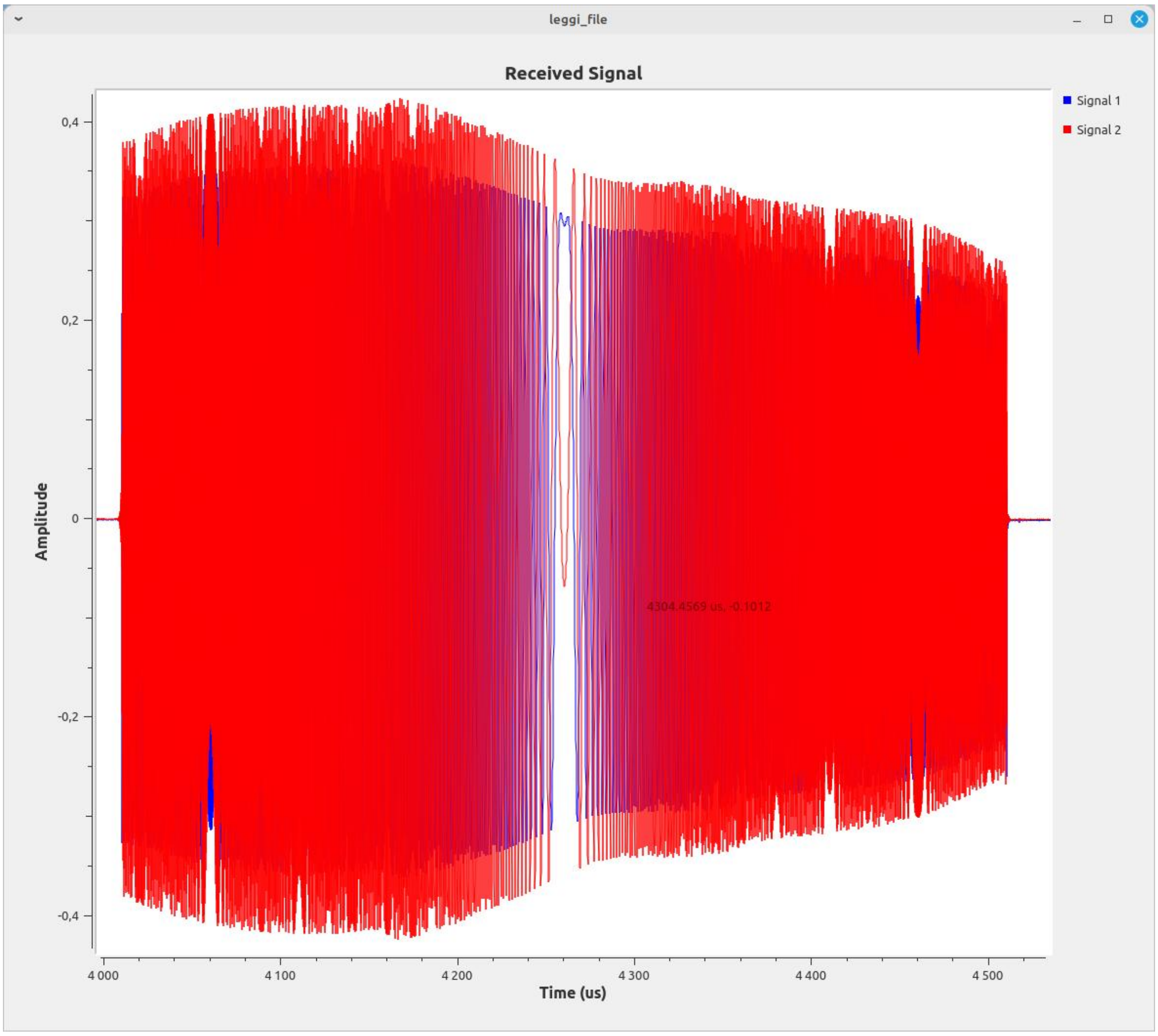

Figure 8: The received signal with engines on seems modified relative to the previous static case. The horizontal axis is time. Ther vertical one is the amplitude of the signal. Notice that the duration of the registration is shorter than those of figure 7.

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The third lab tests were conducted with an aluminium plate emplaced under the reception antenna. This simulates the presence of a strong conductive body in the underground. The results of these tests are shown in figure 9. The presence of such a conductive body does not affect the received signal.

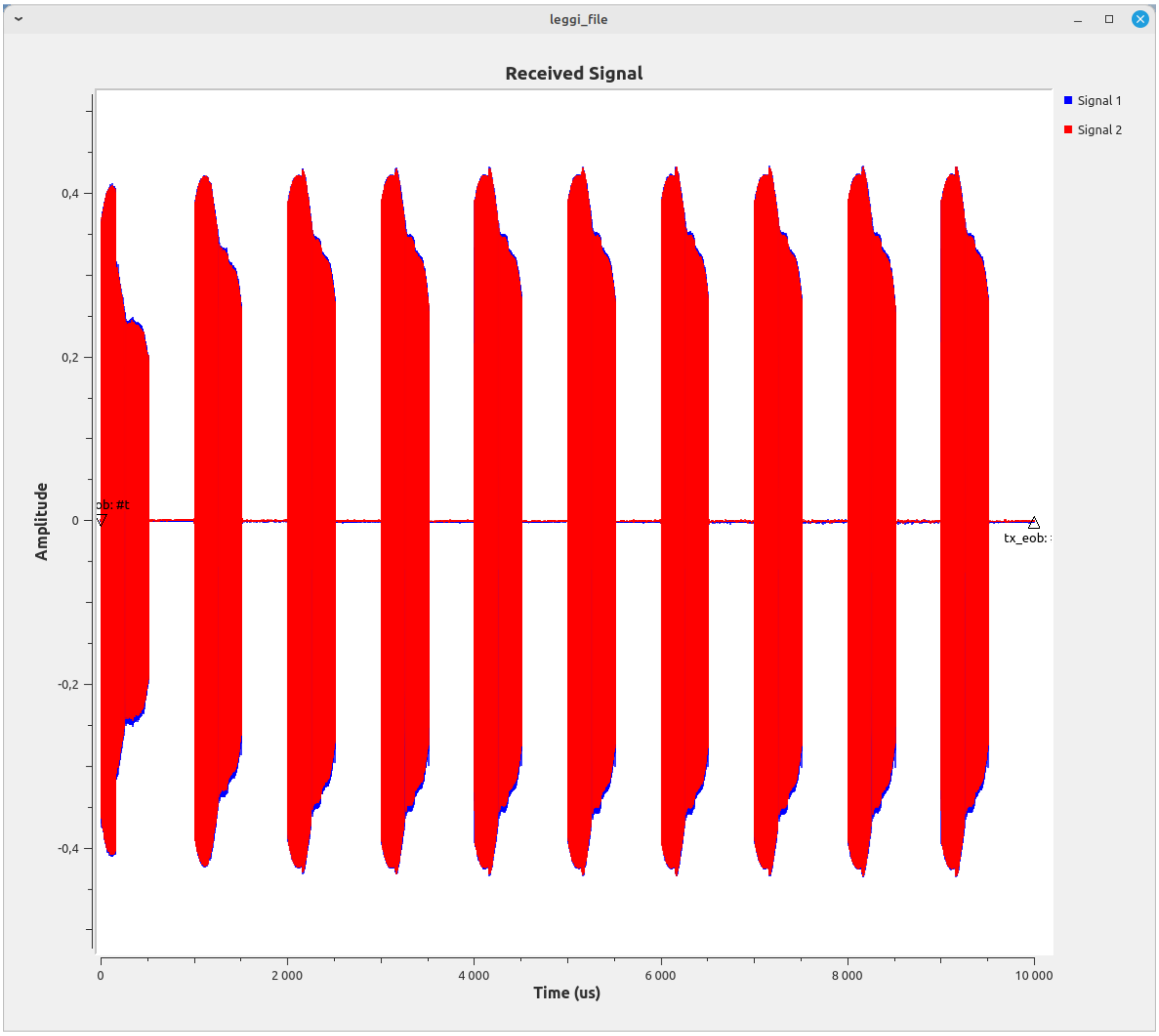

Figure 9: Received signal in case of a strong conductive body under the reception antenna. The signal is not affected.

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A series of tests were carried out with the drone flying a few meters above the ground and the radar in operation (figure 10). This test, carried out over longer periods than the laboratory tests, revealed a communication fault between the radar and the control computer. It appears that the computer cannot accept the data stream emitted by the radar over a period exceeding one minute.

Figure 10: The complete system before the flight. The receiving rate of the control computer was found to be too low.

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6. III Joint Collocation tests (Lyon)

As part of the activities planned for the III Collocation, tests on the FlyRadar prototype were conducted at the University of Lyon ("Laboratoire de Géologie de Lyon") on June 26–27, 2025. The first day was dedicated to indoor experiments, while the second day focused on field tests at Vernay. All tests were carried out with the radar and antennas mounted on the drone in its final flight configuration.

The radar parameters applied during these tests are summarized in the following Table. The following sections describe the tests performed and present the main results.

Parameter	Value
Pulse duration	682.67 μs
Transmitted bandwidth	40 MHz
Sampling frequency	48 MHz
Centre frequency	435 MHz
Pulse Repetition Frequency (PRF)	200 Hz

6.1 Indoor tests

Main goal of these tests is to verify the correct functioning of radar system to transmit and receive signal and to characterise antenna coupling.

First tests have been performed in laboratory room, both in HH and VV configurations.

Figure 11 shows received and averaged signal in time (left) and frequency (right) domains, for HH configuration. From leftward plot it is evident a limited amount of saturation, while rightward plot confirms transmitted bandwidth value.

Figure 12 shows some results of compressed and averaged signa. In particular, leftward plot shows peak value of coupling and rightward plot the received signal amplitude.

Same test have been performed in VV polarisation and results are shown in Figure 13 and Figure 14. No significant differences can be highlighted, but a small decrease of peak value on compressed signal.

Some other tests have been performed by positioning radar system on the roof (6th floor) of University building and pointing antennas toward ground. Figure 15 shows received signal amplitude for HH (left) and VV (right) configuration for the compressed and averaged signal. From rightward plot (VV) it is evident a target at about 0.6 μs of delay, corresponding to about 90 m.

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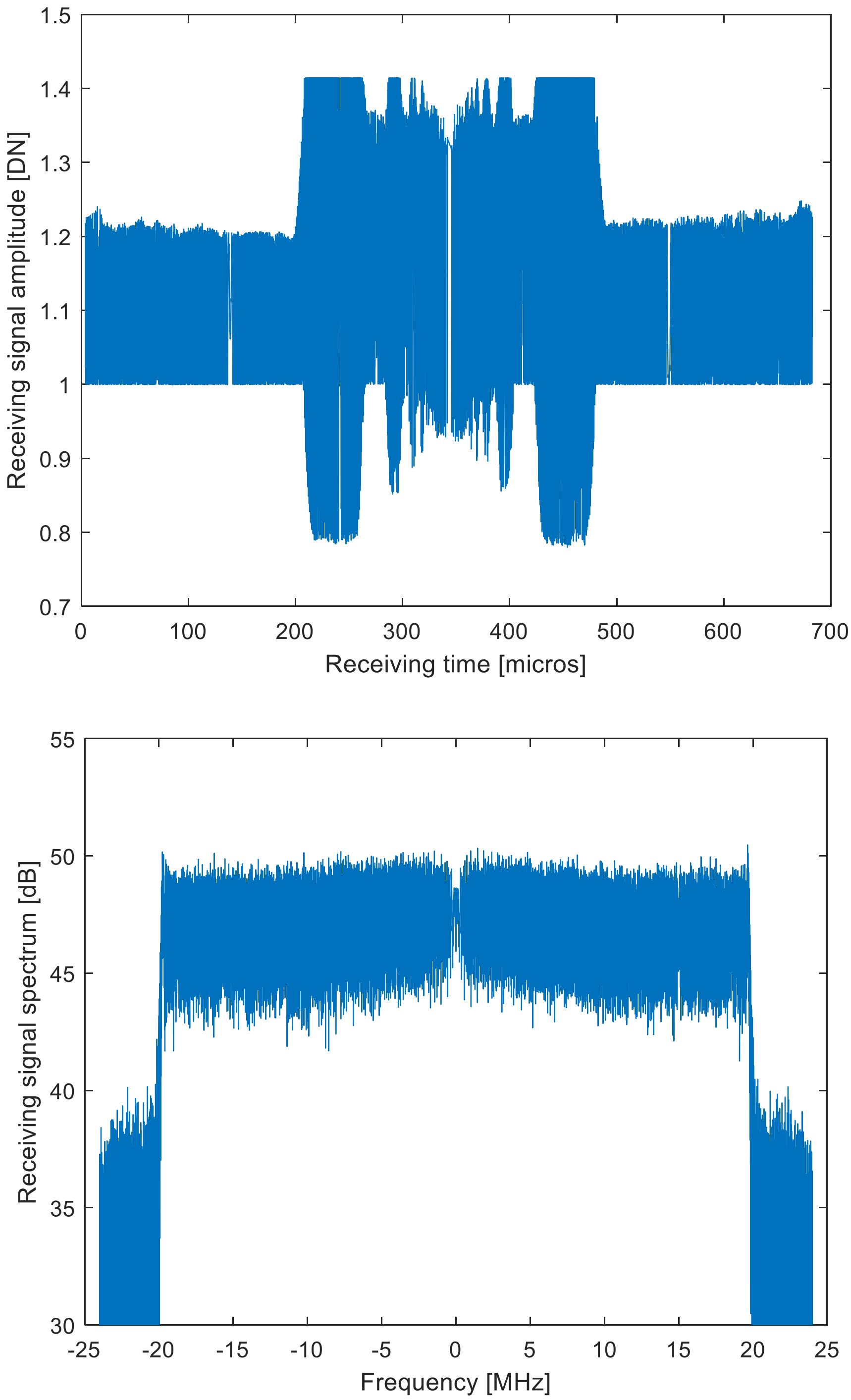

Figure 11: Laboratory test, HH configuration: received and averaged signal in time (left) and frequency (right) domains.

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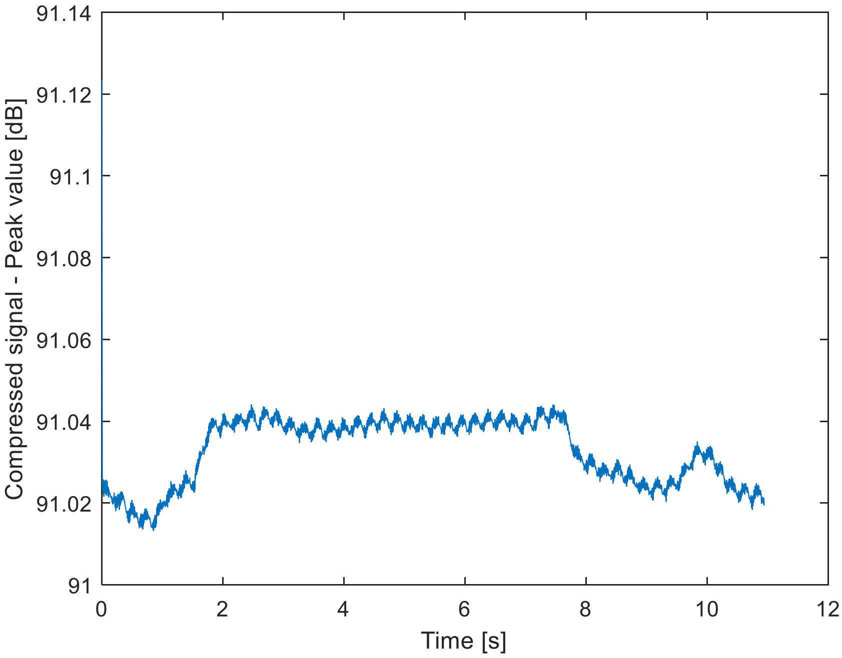

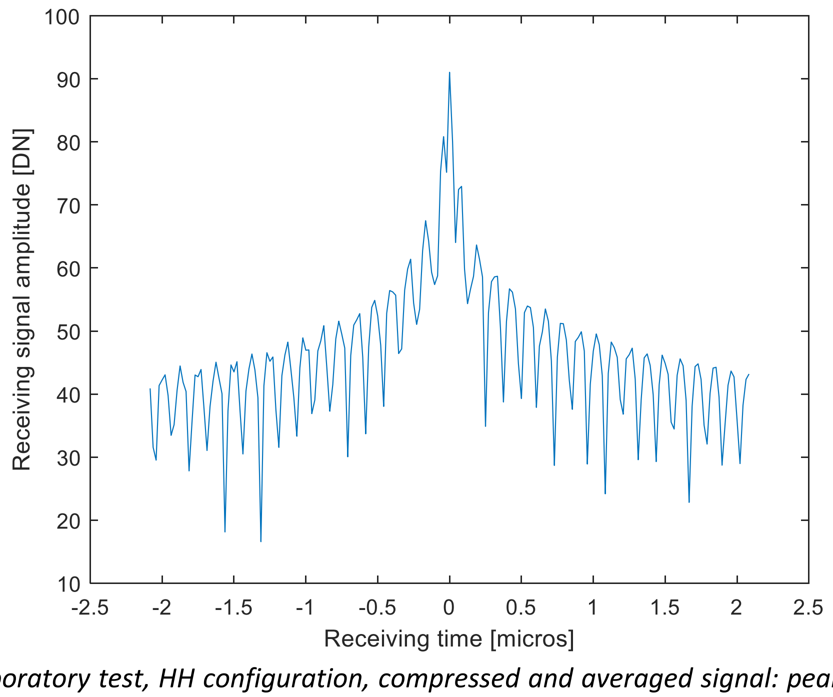

Figure 12: Laboratory test, HH configuration, compressed and averaged signal: peak value (left) and received signal amplitude (right).

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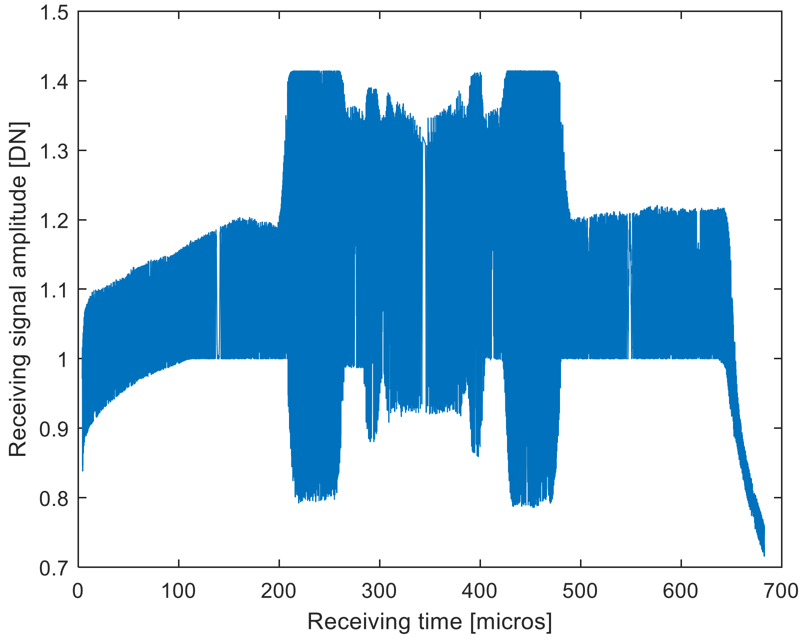

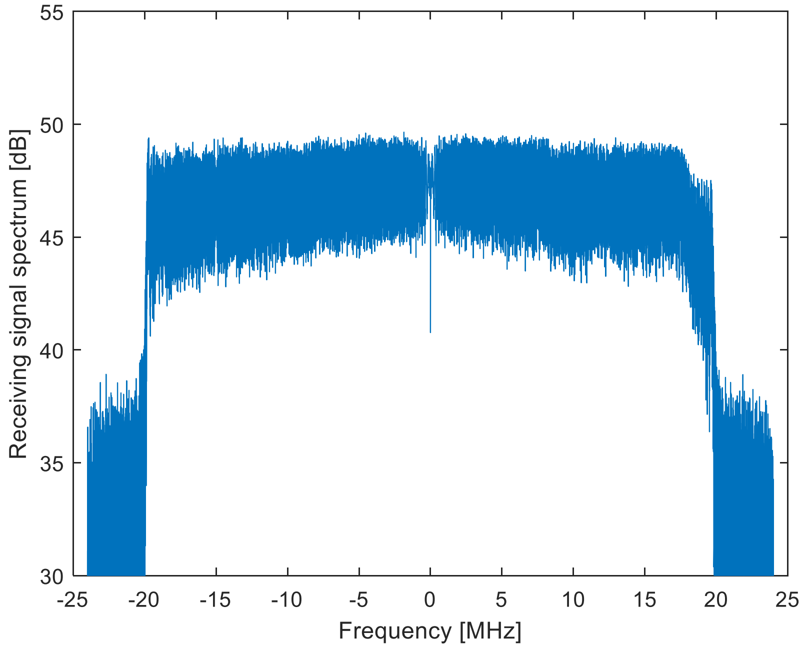

Figure 13: Laboratory test, VV configuration: received and averaged signal in time (left) and frequency (right) domains.

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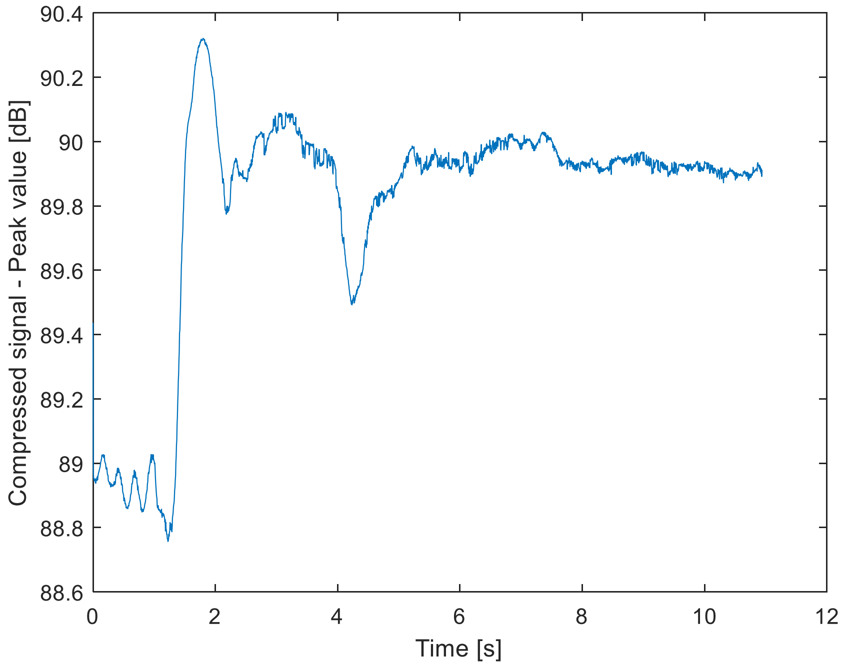

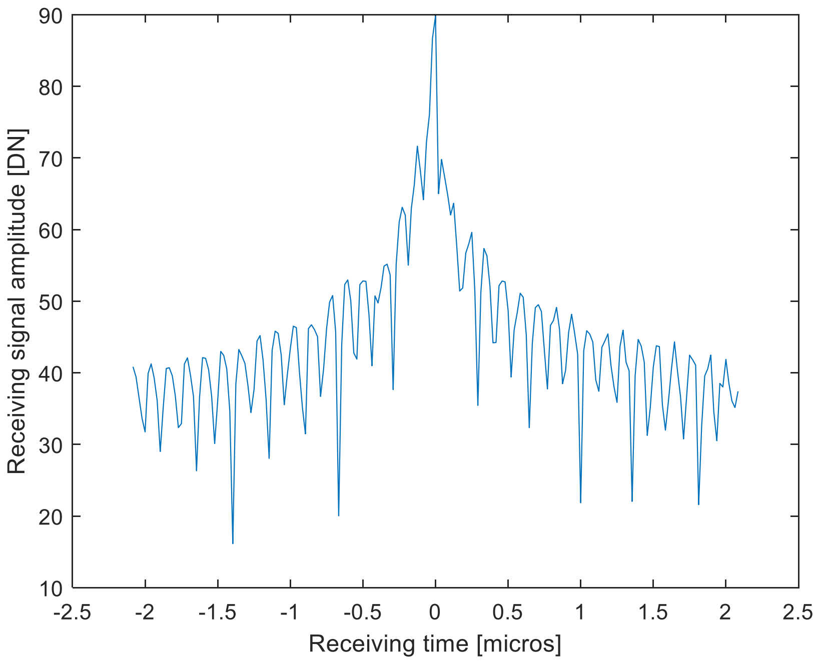

Figure 14: Laboratory test, VV configuration, compressed and averaged signal: peak value (left) and received signal amplitude (right).

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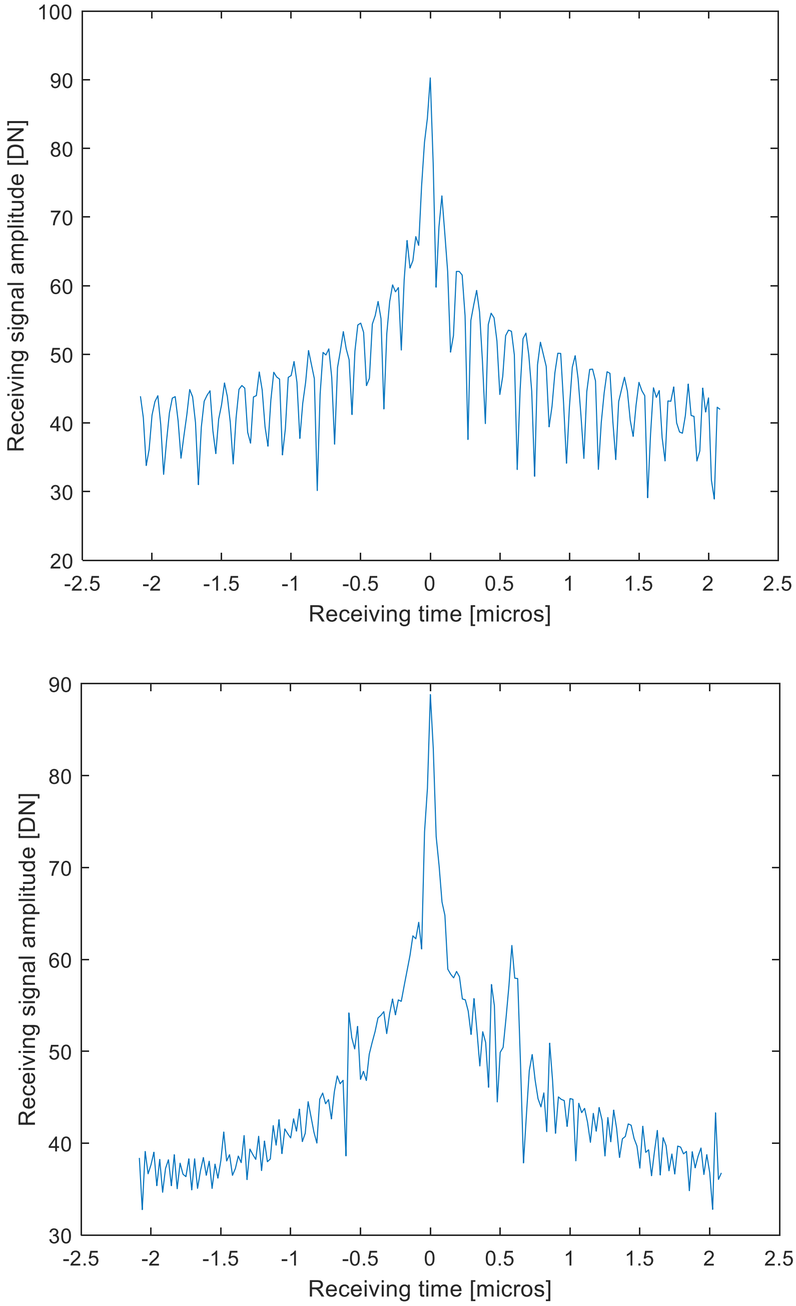

Figure 15: Laboratory test, compressed and averaged signal: received signal amplitude for HH (left) and VV (right) configuration.

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6.2 Field Tests

Main goal of these tests is to verify the correct functioning of radar system to transmit and receive signal, to characterise antenna coupling and, mainly, to verify flight capability in real environment.

Field tests have been conducted in Vernay, near to an archaeological site.

Tests have been performed in both HH and VV configurations, and corresponding tracks are shown in Figure 16.

Figure 19 show received and averaged signal in time (left) and frequency (right) domains, for HH configuration. In this case, no signal saturation is present.

Figure 20 shows the obtained unfocused image, where bright targets can be identified.

Same plots for VV polarisation are reported in Figure 21 and Figure 22.

In this case, received and averaged signal in time (left) and frequency (right) domains of Figure 21 is very different to that obtained by indoor tests.

Moreover, in case of VV polarisation, unfocused image (Figure 22) shows bright targets and features.

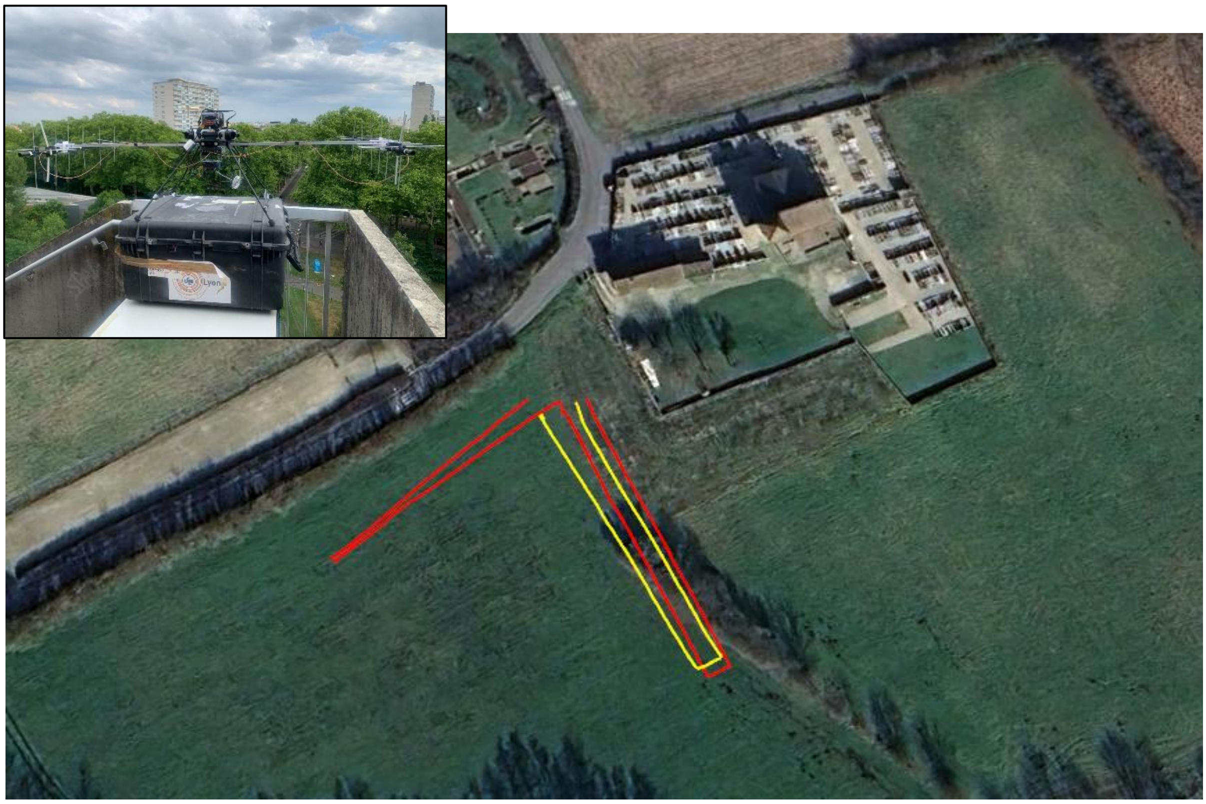

Figure 16: Field test tracks: HH in red and VV in azimuth. At the top left, a photo of FlyRadar from the sixth floor of the University building.

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Figure 17: SAR antenna assembly and integration phase.


Figure 18: Landing phase during a test of the III Collocation.

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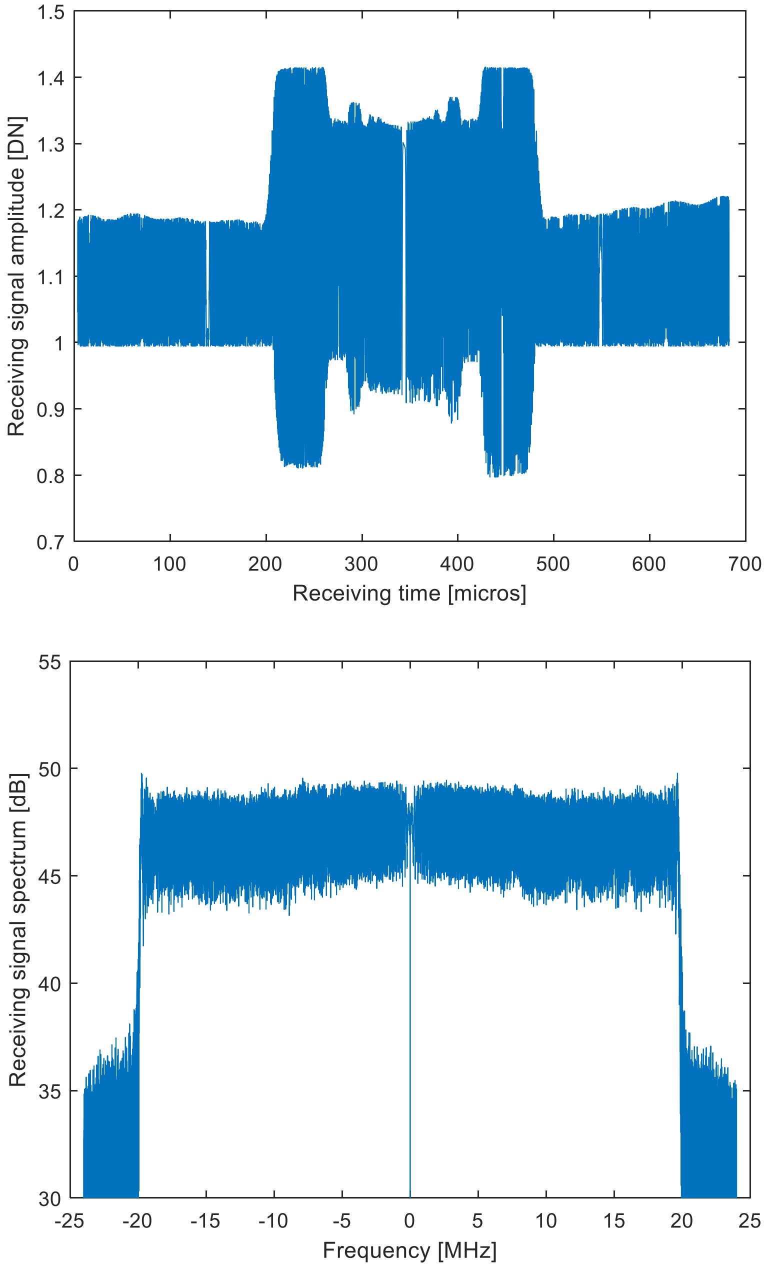

Figure 19: Field test, HH configuration: received and averaged signal in time (left) and frequency (right) domains.

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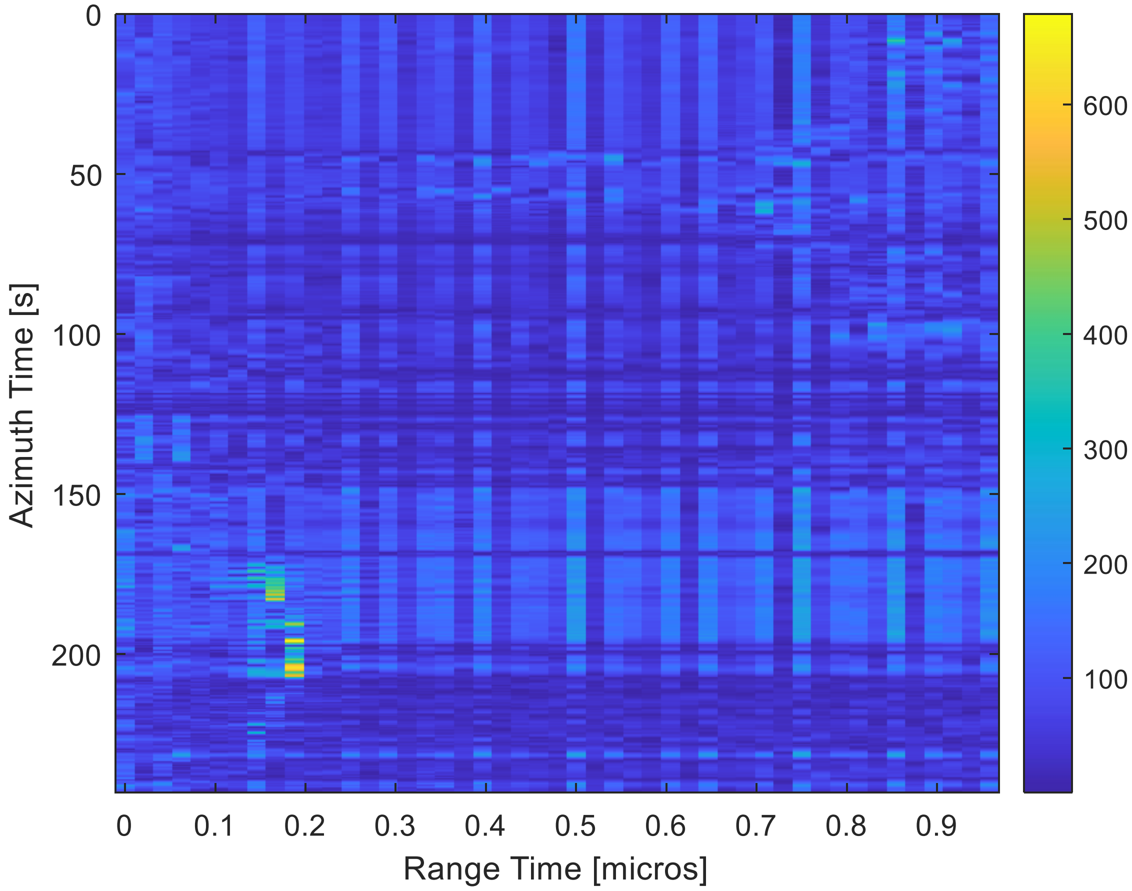

Figure 20: Field test, HH configuration: unfocused image.

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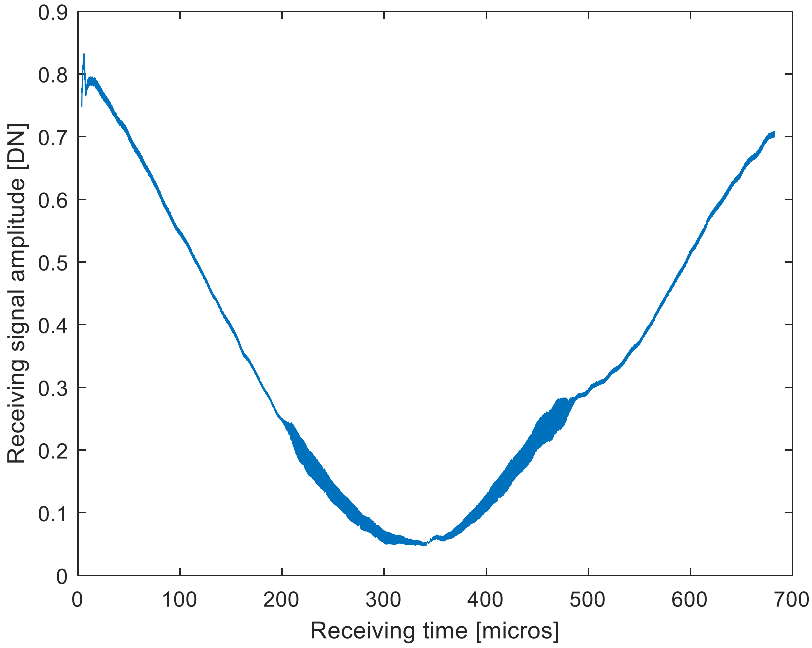

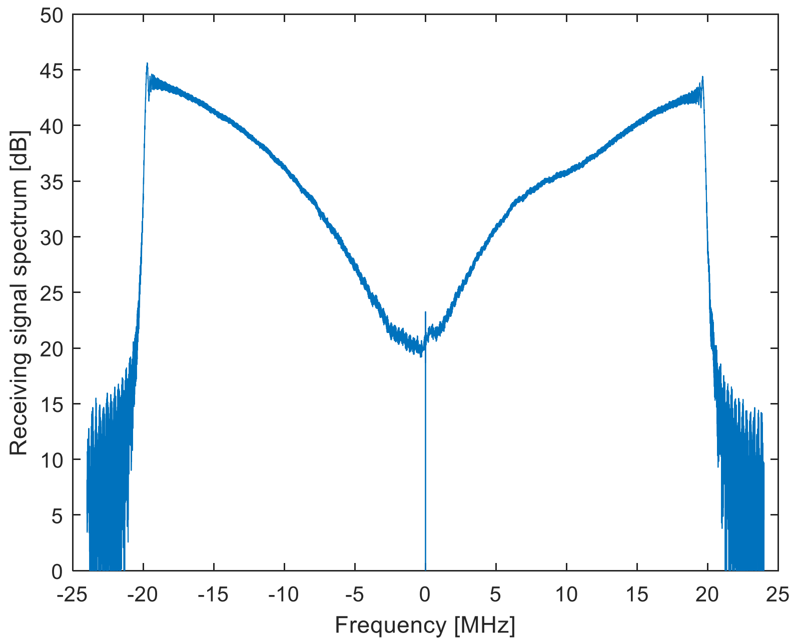

Figure 21: Field test, VV configuration: received and averaged signal in time (left) and frequency (right) domains.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under MSCA-RISE2020 grant agreement No 101007973.

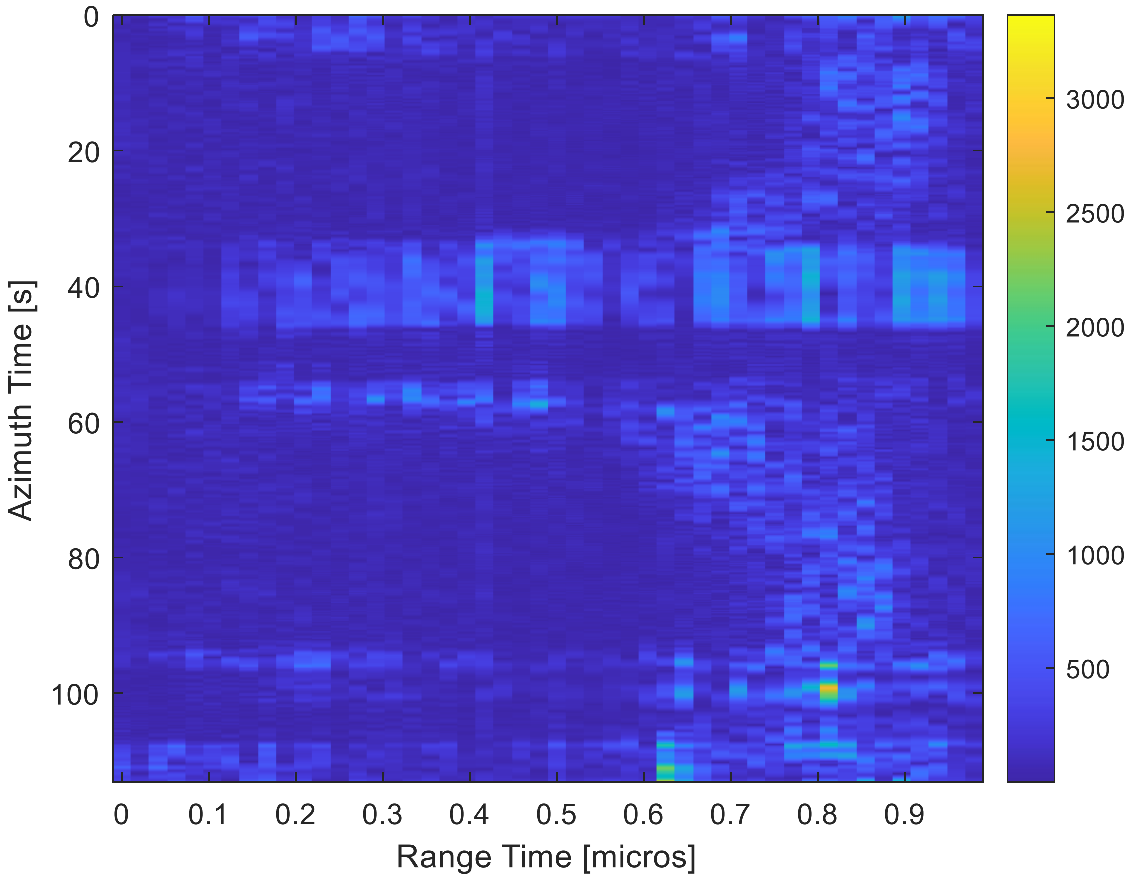

Figure 22: Field test, VV configuration: unfocused image.

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6. IV Joint Collocation tests (Bouichet Plateau)

The third series of test flights for the FlyRadar instrument was conducted from 21 to 23 July 2025 on the Bouichet plateau (coordinates: X: 432300, Y: 4752400, Z: ~500 m above sea level – UTM 31N), located between the towns of Quillan and Carcassonne in the Aude department, southern France (Figure 23). The Bouichet plateau consists of exposed lacustrine limestone formations dating from the Late Maastrichtian to the Danian–Montian stages. Vegetation is sparse and discontinuous, interspersed with limestone outcrops either in situ or in the form of angular decimetric blocks (Figure 24).

Figure 23: Quillan is located in the Aude Department, just North of the Pyrénées

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Test flights were scheduled in the early morning to minimize the impact of local wind conditions, which typically intensify from 8:00 a.m. onwards.

Figure 24: Southward view of the Bouichet plateau.

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The first test flight was conducted on Tuesday, 22 July at 08:00 (Figure 25). During take-off, the FlyRadar-equipped drone overturned. Although the damage was minor (three broken propellers), it was sufficient to suspend testing for the remainder of the day. A Mavic 2 drone (Figure 26) was subsequently deployed to acquire aerial images of the test area for the generation of a Digital Elevation Model (DEM) and an orthophoto (Figure 27 and Figure 28). Both products were processed on the afternoon of 22 July.

Figure 25: The FlyRadar instrument on the Bouichet plateau during radar configuration. Note the control screen beneath the drone.

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Figure 26: The FlyRadar instrument and the Mavic 2 drone on the Bouichet plateau.

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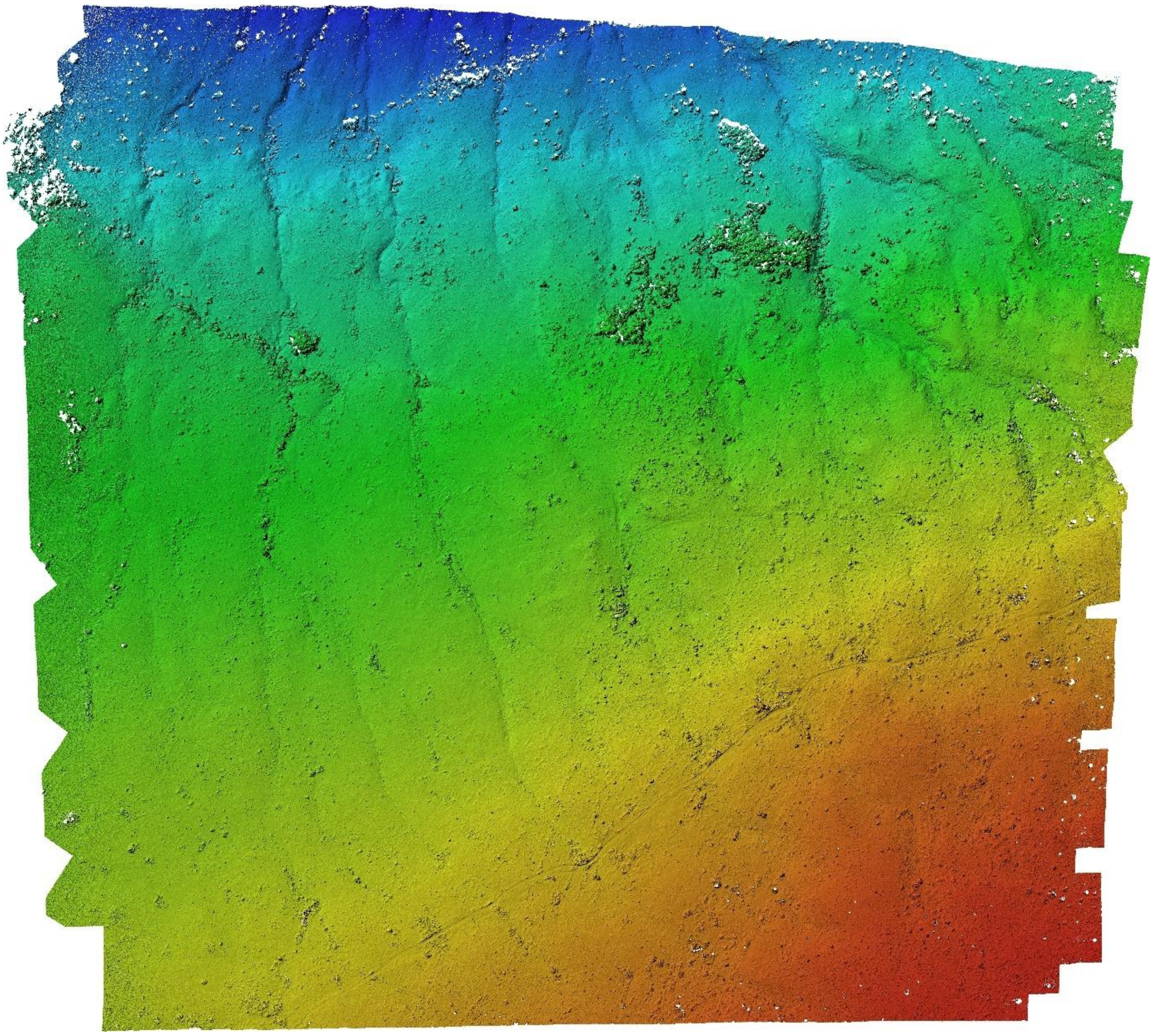

Figure 27: Digital Elevation Model (DEM) of the Bouichet plateau area of interest, derived from imagery acquired with a Mavic 2 drone.

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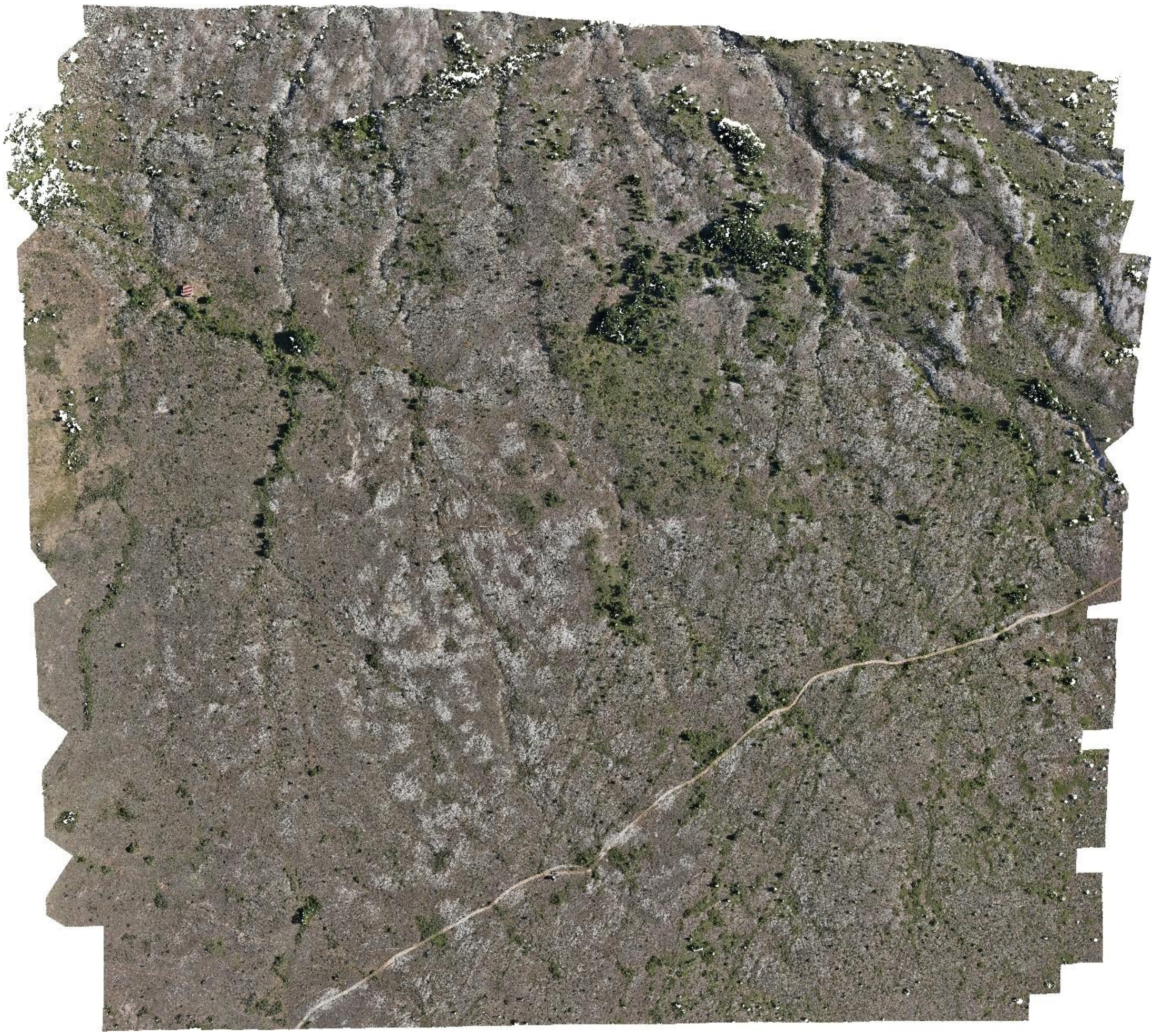

Figure 28: Orthoimage of the Bouichet plateau area of interest, derived from imagery acquired with a Mavic 2 drone.

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A second flight was successfully carried out on Wednesday, 23 July at 07:00. The radar was configured in SAR mode with vertical polarisation (Figure 29). Four parallel flight lines were completed: two at an altitude of 20 metres and two at 50 metres above ground level, each approximately 150 metres in length. A third flight followed at 07:30 with the radar configured in horizontal polarisation, using the same flight plan (Figure 30). Both flights were executed without incident.

The total data volume acquired during these two flights was approximately 40 GB. The radar operated at a central frequency of 435 MHz, with a pulse duration of 682 microseconds and a sampling frequency of 40 MHz.

Figure 29: SAR configuration in vertical polarisation before the second flight on 23 July at 07:00.

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Figure 30: During the third flight followed at 07:30 with the radar configured in horizontal polarisation, using the same flight plan.

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7. Conclusions

The qualification and testing campaigns carried out during the II, III and IV Collocations have been decisive in consolidating the development of the FlyRadar system. These tests successfully validated the integration of the radar unit with the UAV platform and demonstrated the operability of the system in both GPR and SAR modes under different configurations and environmental conditions.

From a radar perspective, the campaigns confirmed that signal generation and acquisition are nominal. Indoor tests (particularly those conducted at CO.RI.S.T.A and during the III Collocation) showed that no significant antenna coupling effects were present and that the transmitted signals consistently met the expected specifications in terms of frequency and bandwidth. Thanks to a high level of oversampling, no jitter was detected in the received signals, ensuring the coherence necessary for synthetic aperture processing.

The UAV proved capable of carrying the radar payload while maintaining stable flight. Test flights confirmed that the antenna mounting system and payload integration allow for nominal flight conditions. Even with a dummy payload matching the radar mass, the platform demonstrated good stability, with a measured operational range of at least 9.5 km and up to 18 km, close to the design requirement of 15 km. During the campaigns, stability was maintained despite slightly windy conditions, especially when operating at 50 m of altitude, although the results confirmed that dynamic flight mode is preferable to avoid resonance effects when hovering.

The key results from the Lyon and Bouichet campaigns are:

- The radar operated reliably in both HH and VV polarisations, meeting all frequency and bandwidth specifications.
- Data acquired during the Lyon (June 2025) and Bouichet Plateau (July 2025) campaigns confirm good signal quality and coherence, demonstrating the ability to detect subsurface and surface features.
- A take-off incident during the IV Collocation resulted in minor damage, which was promptly resolved, with no impact on data quality.

The tests also highlighted some technical aspects requiring further optimization:

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- In specific cases, the data acquisition computer exhibited bottlenecks during long-duration recordings;

- Resonance of the antennas during hovering can induce vibrations, reinforcing the need for dynamic flight whenever possible.

Overall, the FlyRadar system has reached an advanced level of technological maturity. The combined results from the II, III and IV Collocations demonstrate that the platform can acquire high-quality scientific data for both planetary and terrestrial applications. These achievements mark a significant step forward towards future operational surveys using UAV-mounted radar for Earth and planetary exploration.

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