Ref. Ares(2025)4471230 - 04/06/2025

Project ID:	**Fly-Radar**
Project Title:	***"Low-frequency multi-mode (SAR and penetrating) radar onboard light-weight UAV for Earth and Planetary exploration"***
Call:	**H2020-MSCA-RISE-2020**

WP6 –Validation and test field campaign

D6.3: Validation Test Report – Final

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Due date	31/05/2025
Delivery date	04/06/2025
Deliverable type	Report
Dissemination level	PU

1 Document History

Version	**Date**	**Description**
V1	31st May 2025	Final Draft
V2	3rd June	Revision 1
V3	4th June 2025	Revision 2 and Final Version

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)

ETUS	**Embedded Transmitting Unit System**
GPR	**Ground Penetrating Radar**
GPS	**Global Positioning System**
H2020	**Horizon 2020**
IMU	**Inertial Measurement Unit**
PLA	**Polylactic Acid**
SAR	**Synthetic Aperture Radar**
UAV	**Unmanned Aerial Vehicle**
VLOS	**Visual Line of Sight**

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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.

1. Introduction - Objectives of the documents

This deliverable describes the results of ground and flight tests of the FlyRadar system conducted in Lyon between June 2024 and February 2025 by partner UCBL as lead partner, with the collaboration of the main partners involved in the tests, including IRSPS. Prof. Gian Gabriele Ori (IRSPS PI and project Coordinator) is in fact in secondment at UCBL since the end of August 2024 to help resolve all technical and scientific issues encountered and coordinate the collocations/field campaigns.

These tests constitute the second joint collocation of the project (milestone 4); which has been moved to France due to technical and organizational problems encountered in the drone-radar integration, in particular on the flight stability of the prototype; which required that the preliminary tests be carried out in a more controlled environment.

The work has been substantial and allowed to validate the modified drone's ability to operate under high outdoor temperature conditions. The tests also demonstrated that the drone's electronics are not affected by the operation of the radar.

It should be noted that during flight tests conducted in late March 2025, the drone sustained significant damage due to a crash. This incident has had a severe impact on the overall project time-line and the scheduling of subsequent tests. Nevertheless, the fly-radar has been successfully repaired before the end of May 2025.

The results obtained in the second joint collocation have been crucial to solve all the main issues faced regarding the stability of the fly-radar, allowing the planning and setting up of the upcoming field tests: the III Collocation is now scheduled for late June 2025 (up to early July 2025) near Lyon to allow quick adjustments, if needed; while the IV Collocation is planned to take place in Tabernas Desert in Spain, a site already identified as a suitable terrestrial analogue in Deliverable D1.2, due to logistical constraints in Morocco. See Below in the Conclusions and recommendations (§ 5) for more details.

This document describes first the modifications realized on the drone and then describes the tests.

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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. 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 drone

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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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

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3.1 First tests of the whole system with GPR antennas

A first series of tests was conducted on 06 June 2024. The objectives of these tests were:

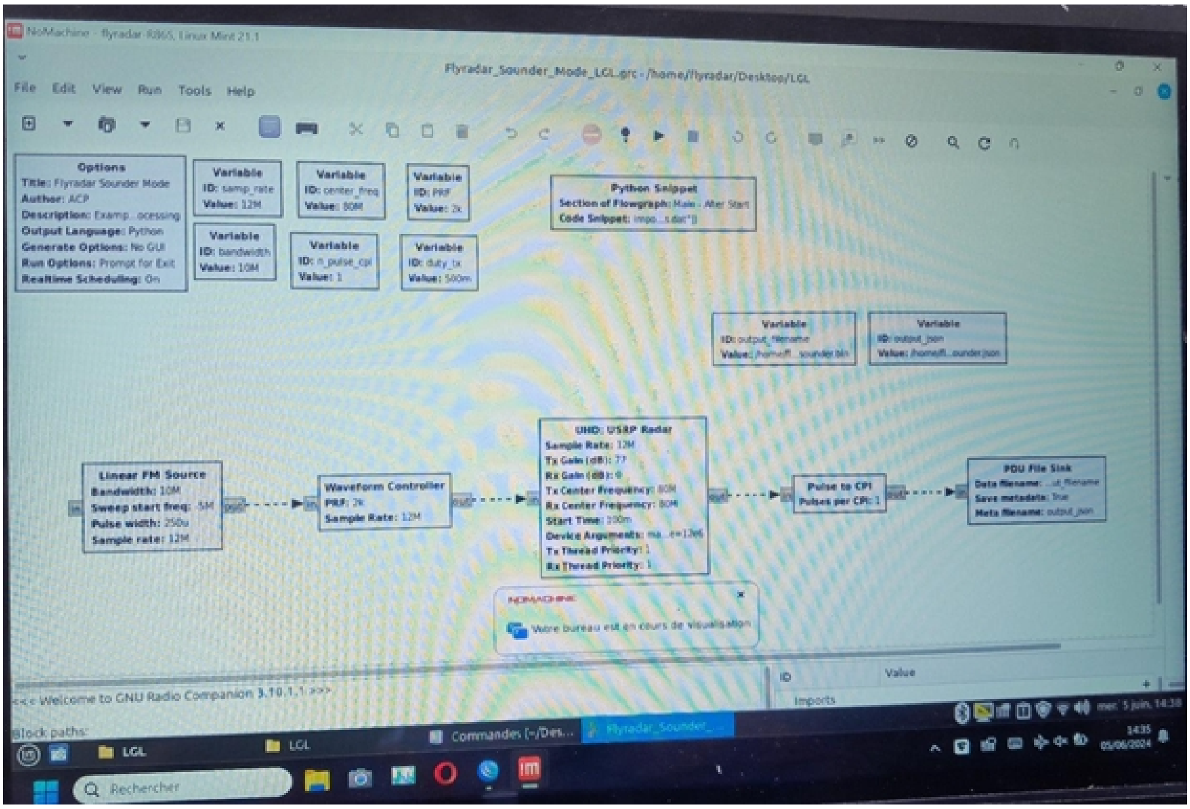
- ✓ To check how electronics of UAV and Radar behave when both active
- ✓ To check how the drone reacts with the radar in operation
- ✓ To record data in flight for the first time for further processing

3.1.1 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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Author: ACP
Description: Examp...ocessing
Output Language: Python
Generate Options: No GUI
Run Options: Prompt for Exit
Realtime Scheduling: On

Variable
ID: samp_rate
Value: 12M

Variable
ID: center_freq
Value: 80M

Variable
ID: PRF
Value: 2k

Variable
ID: bandwidth
Value: 10M

Variable
ID: n_pulse_cpi
Value: 1

Variable
ID: duty_tx
Value: 500m

Python Snippet
Section of Flowgraph: Main - After Start
Code Snippet: impo...s.dat")

Variable
ID: output_filename
Value: /home/fl...sounder.bin

Variable
ID: output_json
Value: /home/fl...ounder.json

Linear FM Source
Bandwidth: 10M
Sweep start freq: -5M
Pulse width: 250u
Sample rate: 12M

Waveform Controller
PRF: 2k
Sample Rate: 12M

UHD: USRP Radar
Sample Rate: 12M
Tx Gain (dB): 77
Rx Gain (dB): 0
Tx Center Frequency: 80M
Rx Center Frequency: 80M
Start Time: 100m
Device Arguments: ma...e=12e6
Tx Thread Priority: 1
Rx Thread Priority: 1

Pulse to CPI
Pulses per CPI: 1

PDU File Sink
Data filename: ...ut_filename
Save metadata: True
Meta filename: output_json

Votre bureau est en cours de visualisation

<<< Welcome to GNU Radio Companion 3.10.1.1 >>>

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.

3.1.2 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.

Shut-down 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.

3.2 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.

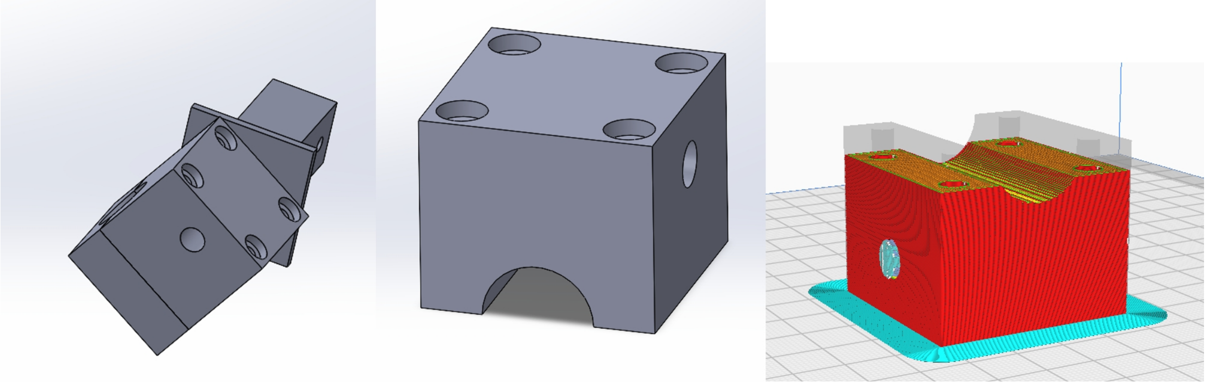

Figure 4: Final assembly and detail with SolidWorks. Print simulation with Ender Software.

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.

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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4. 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.

2

3 *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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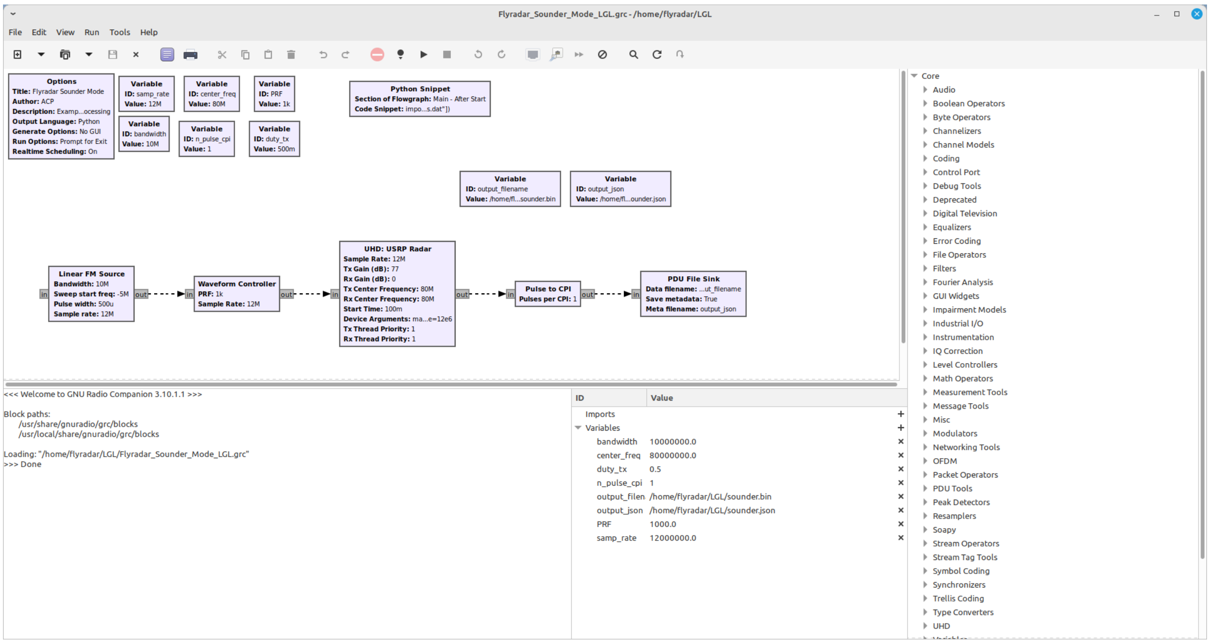
The radar is first programmed with the GNU Radio Software (fig. 6). The duration of emission and recording are set as the characteristics of the pulse (central bandwidth, pulse width, sampling rate).

2



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Python Snippet
Section of Flowgraph: Main - After Start
Code Snippet: impo...s.dat"])

Variable
ID: output_filename
Value: /home/fl...sounder.bin

Variable
ID: output_json
Value: /home/fl...ounder.json

Linear FM Source
Bandwidth: 10M
Sweep start freq: -5M
Pulse width: 500u
Sample rate: 12M

Waveform Controller
PRF: 1k
Sample Rate: 12M

UHD: USRP Radar
Sample Rate: 12M
Tx Gain (dB): 77
Rx Gain (dB): 0
Tx Center Frequency: 80M
Rx Center Frequency: 80M
Start Time: 100m
Device Arguments: ma...e=12e6
Tx Thread Priority: 1
Rx Thread Priority: 1

Pulse to CPI
Pulses per CPI: 1

PDU File Sink
Data filename: ...ut_filename
Save metadata: True
Meta filename: output_json

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<<< Welcome to GNU Radio Companion 3.10.1.1 >>>

Block paths:
    /usr/share/gnuradio/grc/blocks
    /usr/local/share/gnuradio/grc/blocks

Loading: "/home/flyradar/LGL/Flyradar_Sounder_Mode_LGL.grc"
>>> Done
```

ID	Value
Imports	
Variables	
bandwidth	10000000.0
center_freq	80000000.0
duty_tx	0.5
n_pulse_cpi	1
output_filen	/home/flyradar/LGL/sounder.bin
output_json	/home/flyradar/LGL/sounder.json
PRF	1000.0
samp_rate	12000000.0

3 *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.

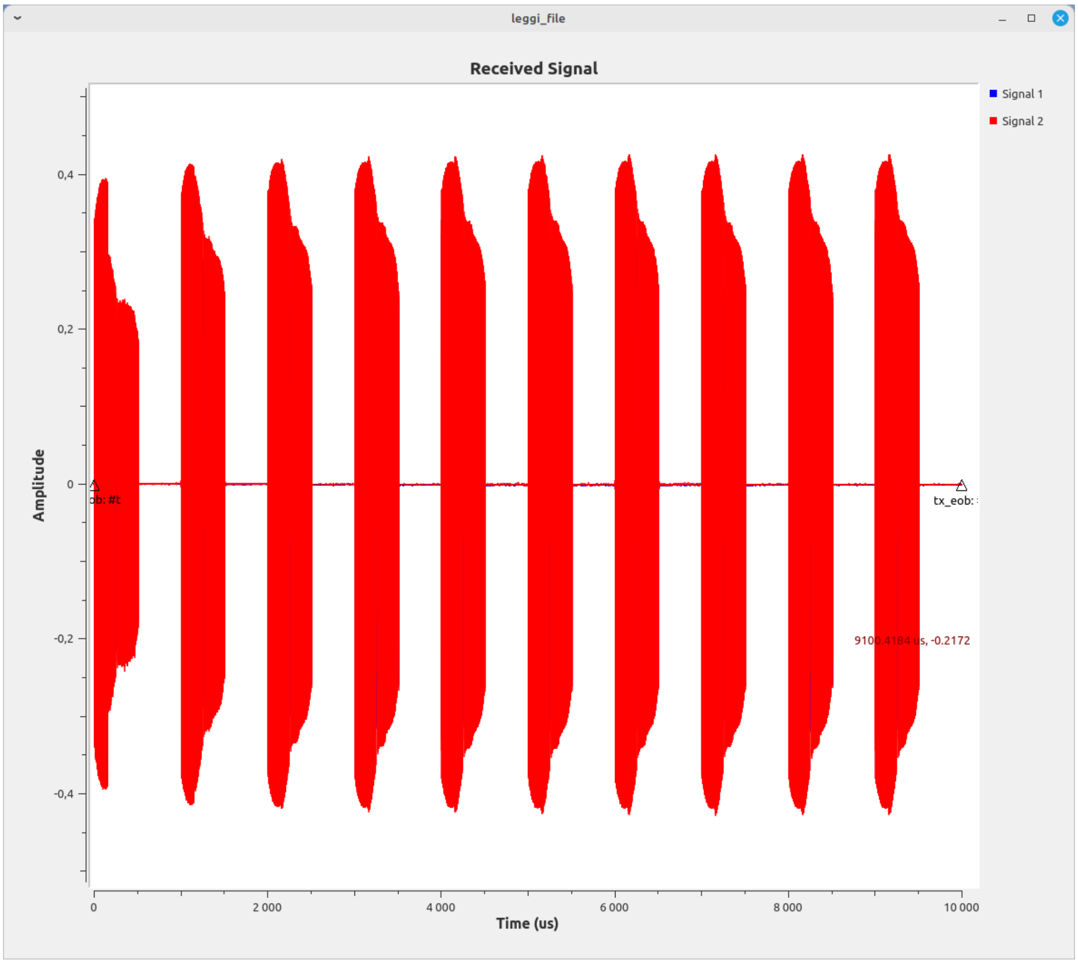

Figure 7: Signal received by the reception antenna and displayed on MATLAB. The horizontal axis is time. Ther vertical one is the amplitude of the signal. One can see that the received signal displays a regular pattern like the emission pattern. The system behaves as expected.

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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.

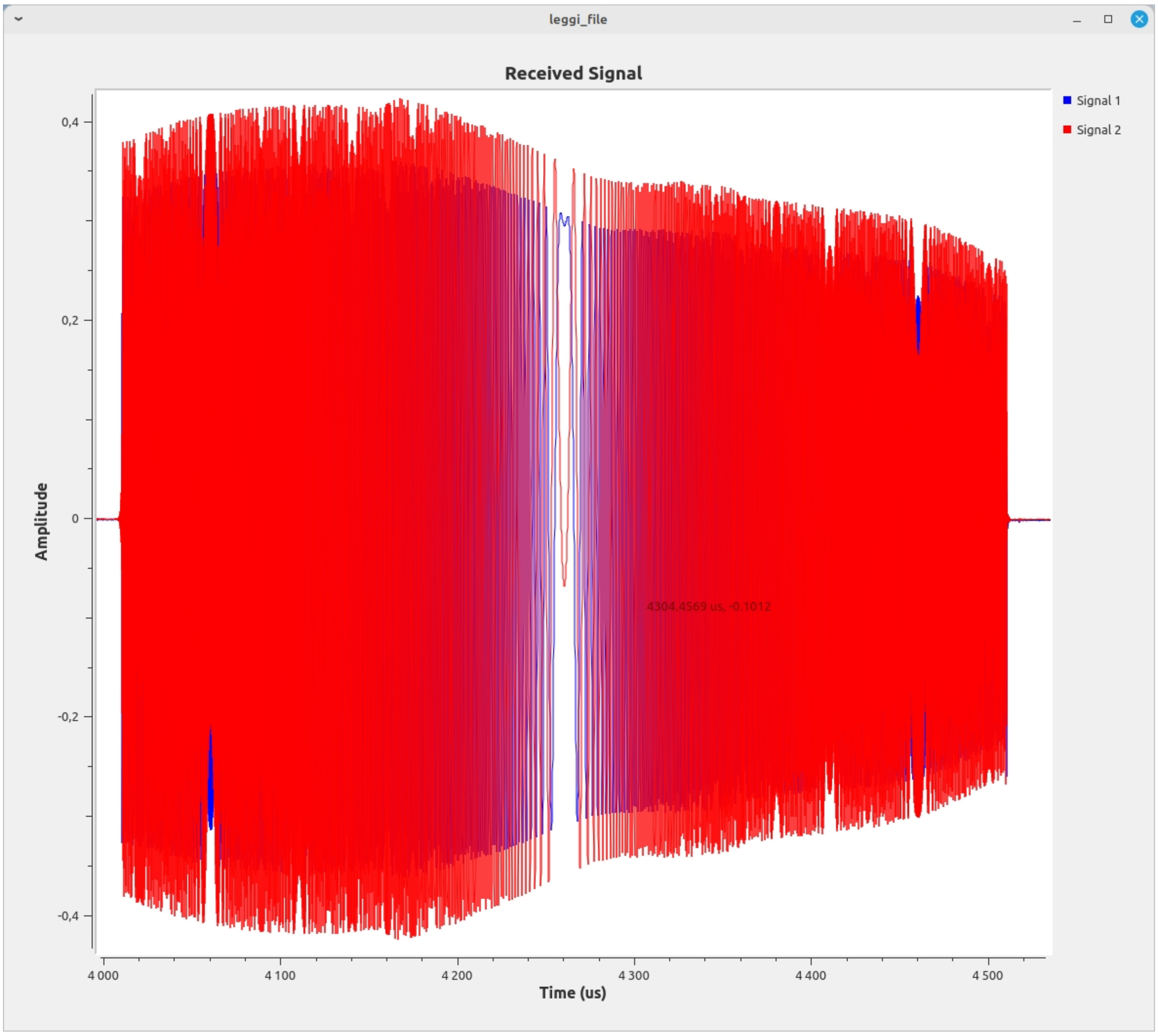

Figure 8: The received signal with engines on seems modified relative to the previous static case. The horizontal axis is time. The vertical one is the amplitude of the signal. Notice that the duration of the registration is shorter than those of figure 7.

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.

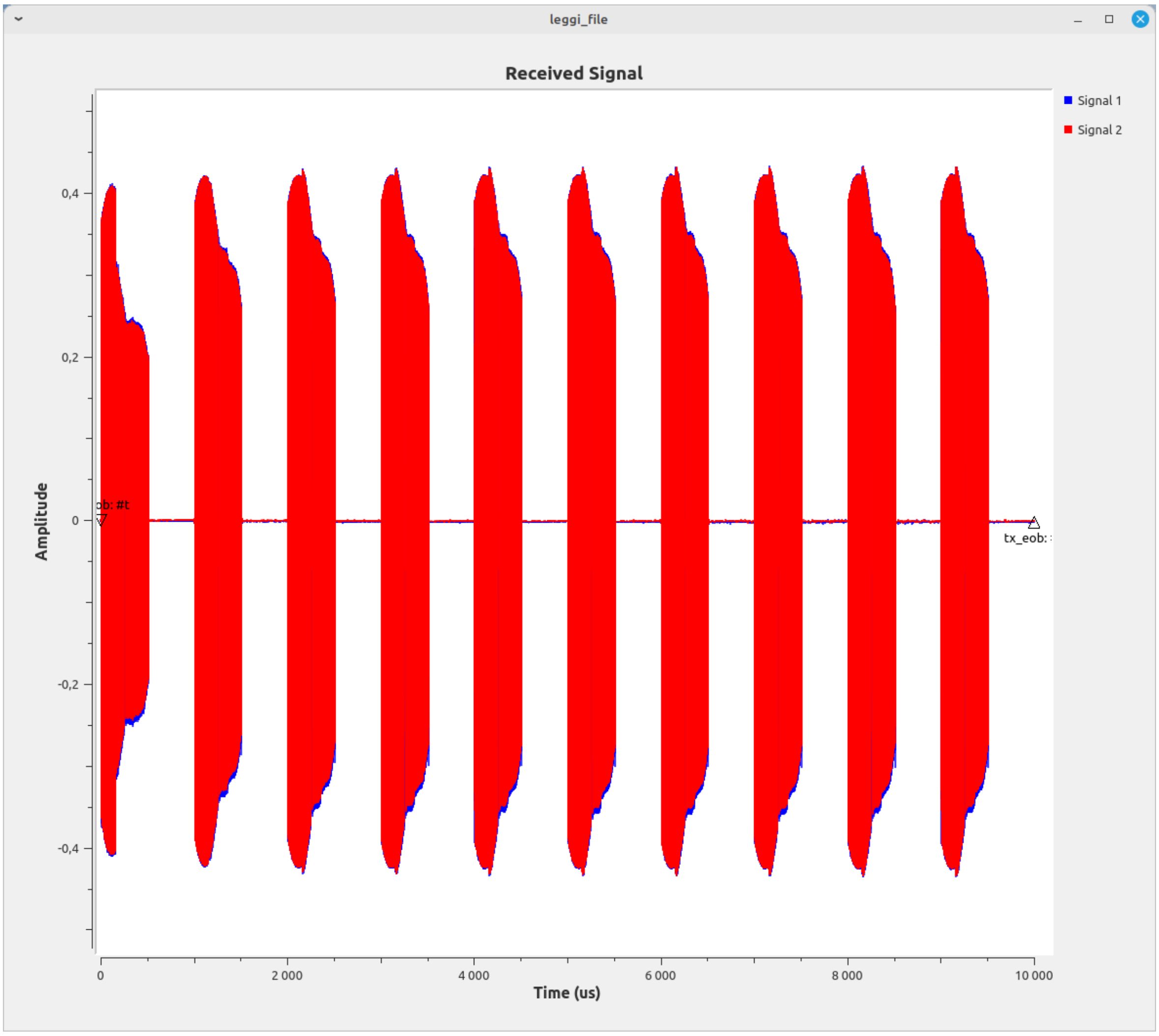

Figure 9: Received signal in case of a strong conductive body under the reception antenna. The signal is not affected.

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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. Another computer supporting a higher data rate will be tested soon.

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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5. Conclusions and Overlook

The tests validated the radar's signal integrity and coherence across all modes and confirmed the drone's ability to carry the radar payload while maintaining stable and efficient flight. Although weather conditions during testing were moderate, the drone performed close to or above expectations.

The radar behaves as expected if it operates for durations less than a few seconds. For experiments lasting longer than a minute, the control computer is not able to record the data stream arriving from the radar. Tests are planned soon with another on-board computer.

During additional flight tests in March 2025, the drone crashed and sustained structural damages. As a result, it underwent repairs and maintenance, which required approximately two months (March–May 2025) of work in the factory premises. This caused a delay in the schedule and affected the planning of upcoming field campaigns. However, it also revealed hidden problems that are now resolved and allowed to further improve the prototype.

By the end of May 2025, new flight tests were in fact successfully conducted, confirming that the current configuration is fully functional and the system operates as intended. On 22 May, a flight test was conducted with the GPR antennas mounted, and no issues were encountered. The III Collocation, previously planned in Morocco with the objective to start the scientific analysis, is now scheduled in Lyon and adjacent areas around the second half of June 2025. Carrying out the III Joint Collocation in Lyon and adjacent areas (instead of Morocco) would allow to speed up the field tests and apply quicker adjustments, whether needed.

The IV Collocation, initially planned to take place in Morocco by 31st May 2025, had to be moved to early July 2025 for the reasons/delays previously described. The set of tests included in the IV Collocation will be carried out for both technical and scientific purposes. According to the Fly-Radar Grant Agreement, this will be the only Collocation that will also deal with science and scientific data, providing the needed datasets for the scientific analysis and evaluation. Results of the IV Collocation will be fully included in deliverable D6.4 Final Scientific Assessment Report; which will be submitted by 31st July 2025.

Since the IV Collocation will fall at the very end of the project, we decided, as a mitigation measure, to move the Collocation in Spain for the sake of prudence and efficiency. For

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instance, should replacements- be necessary, it would be much easier to gather them in Spain and/or bring them from UCBL/Hyperion rather than to import them in Morocco (previous location of the Collocation). Importing replacements in Morocco would in fact involve the gathering of special import permissions that implies a few days of work; which are not a problem during nominal operations, but they can become critical in this situation. Besides logistical constraints, another reason for this change of location is the complexity and time necessary to modify/re-obtain the flight authorizations we already obtained in Morocco; which would have involved a full re-submission of all the documents and, most likely, the start of new authorizations' procedures. As a consequence of the delays caused by the fly-radar crash and of the time constraint dictated by the end of the project, it would have been impossible to carry out the IV Collocation in Morocco.

In conclusion, the final Campaign will take place in Spain, in particular in the Desierto de Tabernas (Andalusia); which is an alternative location already identified as suitable terrestrial analogue in Deliverable *D1.2 Preliminary Terrestrial Analogue Description (§. 2.1)*. The Tabernas area offers both scientific and operational advantages: it is an arid region with sparse vegetation and well-preserved sedimentary and alluvial structures shaped by episodic heavy rains. From a logistical perspective, the site is easily accessible via road and from Almería Airport.

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