Ref. Ares(2024)739608 - 31/01/2024

FlyRADAR

Project Title: "Low-frequency multi-mode (SAR and penetrating) radar onboard light-weight UAV for Earth and Planetary exploration"

Call: H2020-MSCA-RISE-2020

WP5 – Model Qualification Campaign

D5.2: Qualification Report, Final

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Other contributors	Consorzio di ricerca su sistemi di telesensori avanzati (6 – CO.RI.S.T.A)
	Hyperion Seven (5 – Hyperion Seven)
	International Research School of Planetary Sciences (1 – IRSPS)

Due date	
Delivery date	15 January 2024
Deliverable type	Report
Dissemination level	PU

Document History

Version	Date	Description
V1.0	31 May 2022	Pre-Flight campaign version
V1.1	15 Jan 2024	Qualification Report, final

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Table of Contents

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1. Introduction

This report presents a series of tests conducted on the FlyRadar project. The objective of these tests was to evaluate the performance and reliability of the radar system under various configurations and modes as well as the flight performances of the drone with a dummy payload matching the weight and span of the radar unit with its antennas.

2. Indoor test of the radar unit

2.1. *Conditions of the test and material*

The indoor tests on the radar unit were carried on at the *Consorzio di ricerca su sistemi di telesensori avanzati* (CO.RI.S.T.A) facilities in Naples in December 2023. The radar apparatus consists of the *Ettus* E320 (ref) Software-defined Radio (SDR) connected to an ODSS R86S mini-computer (ref). The tests were performed on sounding and SAR modes at nominal frequencies and 10 dBm with Yagi and Logperiodic antenna types respectively.

Three different configurations were used to test different aspects of the radar unit:

- Configuration 1: the radar is connected directly through the TX port to a spectrum analyser.
- Configuration 2: the radar TX port is connected to a 6-dB divider which splits the signal to a spectrum analyser and a 40-dB attenuator. The latter is connected back to the RX port of the radar (Fig. X)
- Configuration 3: TX and RX antennas are connected directly to the radar. The antennas are pointed towards a target located 60 m away.

2.2. *Sounding mode*

2.2.1. Transmitted signal: Frequency and bandwidth

The first test was performed in Config. 1 and consisted of checking the transmitted signal by the radar with a spectrum analyser. Using the inboard software, the signal was set to a maximum value of 10 dBm and successfully transmitted at 80 MHz with a 10 MHz bandwidth. These values are consistent with the requirements presented in the qualification plan (deliverable 5.1).

2.2.2. Theoretical penetration depth

Theoretical penetration depths were estimated for such frequency assuming diverse geological settings to range from 2 to 50 m. As the transmitted signal frequency is consistent with the frequency used to model the penetration depth, it should match the initial requirements.

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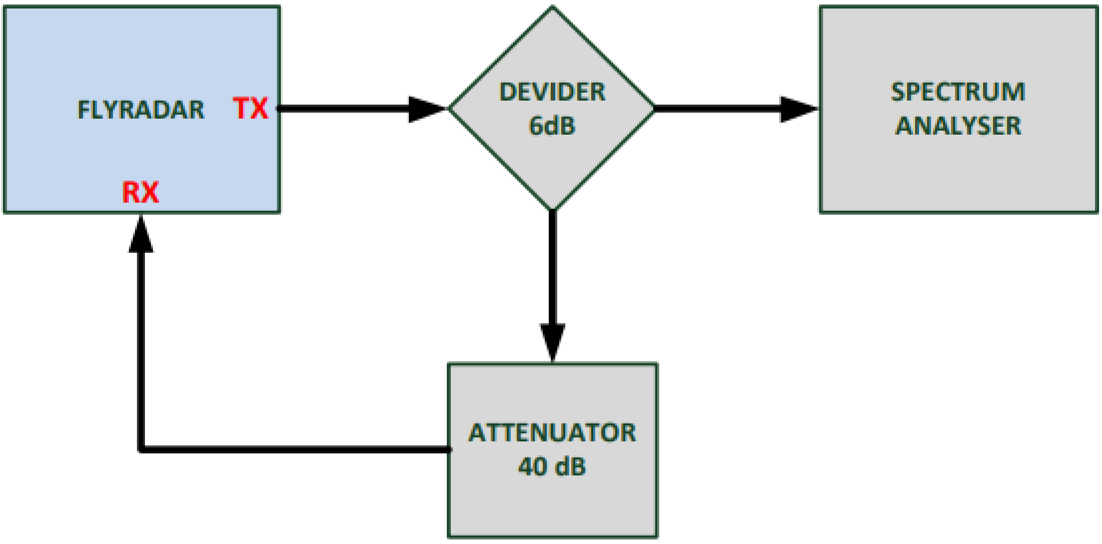

Figure 1: Test Configuration 2 (extracted from Co.Ri.S.T.A test report).

2.2.3. Signal reception

A second and third tests were performed in Config. 2 and 3 to check the received signal on the radar. In the test nr. 2, the transmitted 10 dBm signal is parsed through a resistive 6 dB divider attenuator and checked with a spectrum analyser on one channel (Fig. 1). The signal was measured at 80 MHz with 10 MHz bandwidth, at 3.67 dBm. On the other channel, the signal is parsed through a 40 dB attenuator and acquired by the radar software. The signal consisted of 4065, 500 µs-long pulses. Each pulse had a peak amplitude of 32 dB on the main lobe (Fig 2, left). The peak position was measured at t=10.5 µs (Fig. 2), which can be explained by the travel distance between the TX output to the RX input with several metres of cables as well as the delay induced by the internal hardware and the software itself. Figure 2, right, shows a strong coherence between each pulse during the whole duration of the test and a lack of jitter at that level of sampling.

In the third test, the signal is transmitted through a TX antenna, received by the RX antenna, and analysed by the radar software. The received signal was measured to peak around t=10.9 µs with an amplitude of 29 dB (Fig. 3). The strength of the signal is consistent with a signal being reflected by a surface and is less likely to correspond to a product of antenna mutual coupling (i.e. energy absorbed by a receiving antenna from a nearby operating antenna).

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Additionally, the 0.4 μs delay difference between the closed-loop configuration in the second test is consistent with a travel time of a 60 m round-trip between the radar apparatus and the targeted surface.

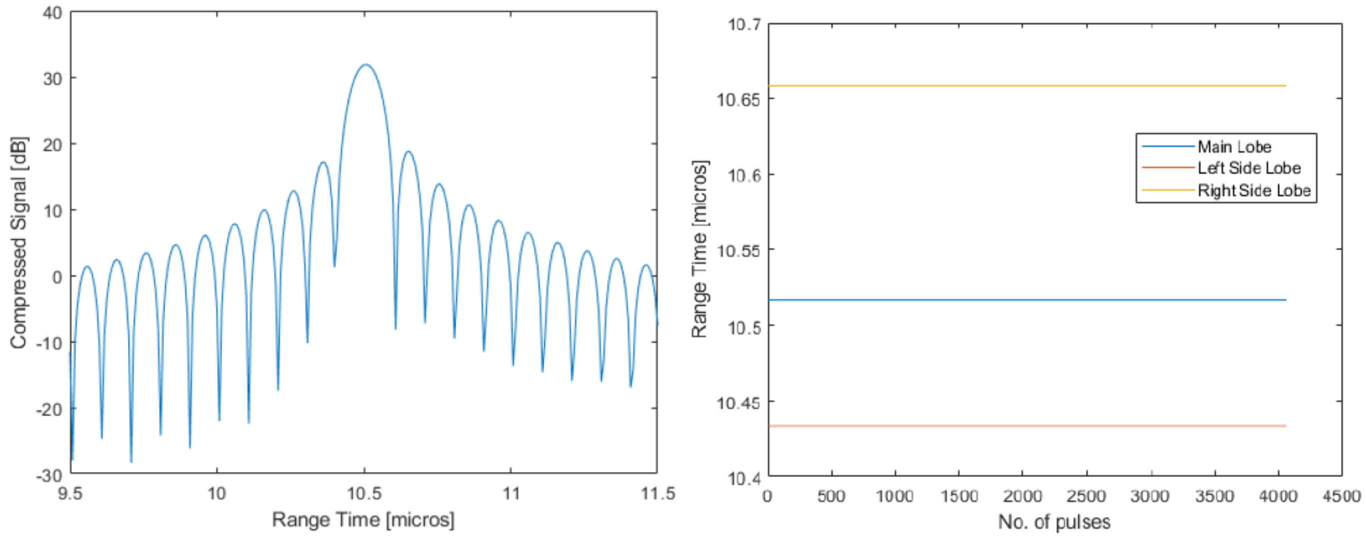

Figure 2: Test nr. 2 results; Left: compressed signal zoomed on the maximum value. Right: Compressed signal peak position throughout the test

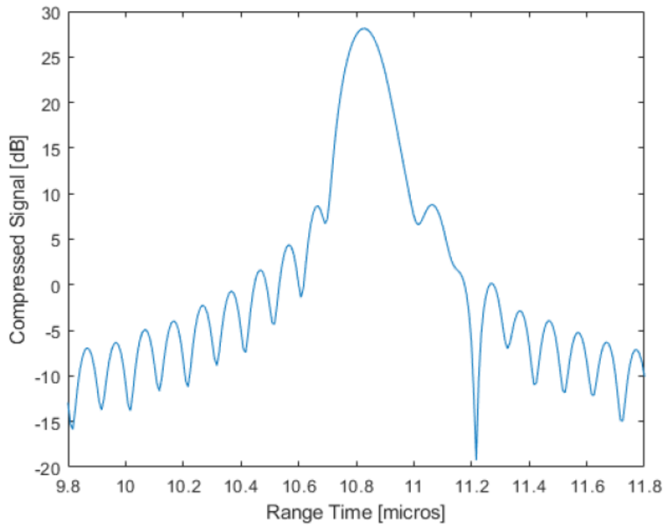

Figure 3 Compressed signal zoomed on the maximum value (Test nr. 3)

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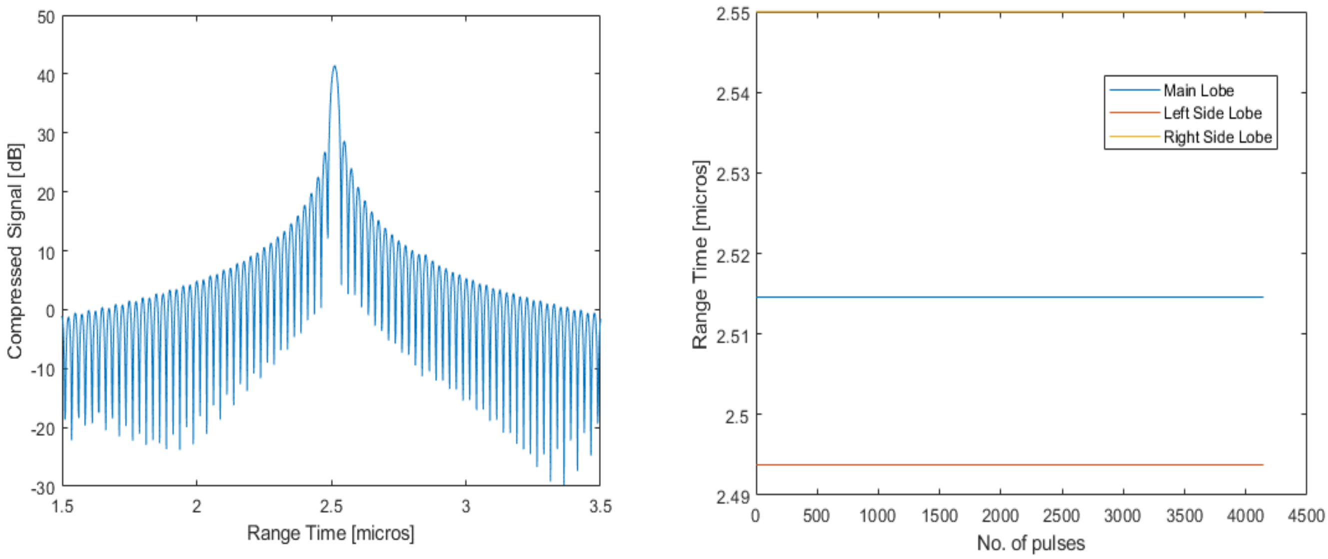

Figure 4: Test nr. 5 results; Left: compressed signal zoomed on the maximum value. Right: Compressed signal peak position throughout the test

2.3. *SAR mode*

2.3.1. Frequency and bandwidth

The fourth test was performed in SAR mode under Config. 1 and consisted of checking the frequency and bandwidth transmitted by the radar unit. The signal was successfully transmitted at 435 MHz with a 40.25 MHz bandwidth, within the range of the requirements.

2.3.2. Signal reception

Similar to the tests performed in sounding mode, the signal reception in SAR mode was tested in Config. 2 and 3. The test nr. 5, in a closed loop configuration, the signal transmitted of 4144, 500 µs-long pulses. The main lobe peak position occurred at t=2.5 µs (Fig. 4) and was stable during the whole duration of the test (Fig. 4, right). The signal obtained in Config. 3 in the sixth and last test could however indicate some coupling (Fig. 5), although, real life test conditions following the full system integration would be required to assess that. This could be mitigated by using a window to reduce the side-lobe level. Overall, the lack of jitter observed in the test nr. 5 shows that the signal is strongly coherent pulse by pulse, which should allow for synthetic aperture processing.

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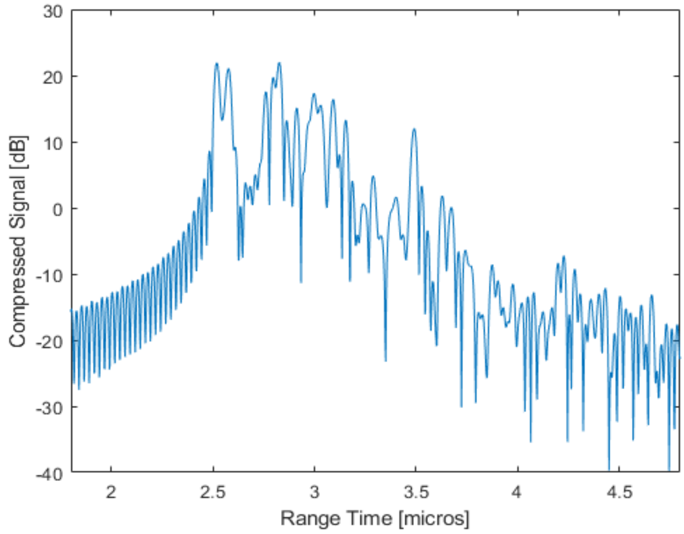

Figure 5: Compressed signal with a zoom around maximum value (test nr. 6)

Figure 6: mounting configuration of the antennas and the dummy radar.

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Figure 7: In-flight UAV with attached antennas and dummy payload.

3. Dummy-payload flight tests

The purpose of the tests carried out and described down below is validate the antenna and radar mounting system on the UAV (Fig. 6) and check the in-flight performances of the fully integrated system against the requirements described in the qualification plan (deliverable 5.1).

3.1. *Flight plan and conditions*

3.1.1. First flight

The first flight was performed in February 2023 in the vicinity of Hyperion Seven facilities (Fig. 7). The two antennas (0.8 kg) as well as a 2.2 kg box matching the radar mass were mounted to the UAV. The flight plan consisted of a set of straight lines, cumulating 5.3 km of distance, and for a duration of 12 min. The aircraft reached a maximum speed of 17.8 $m.s^{-1}$ and an average of 8.4 $m.s^{-1}$. The weather was clear with little to no wind.

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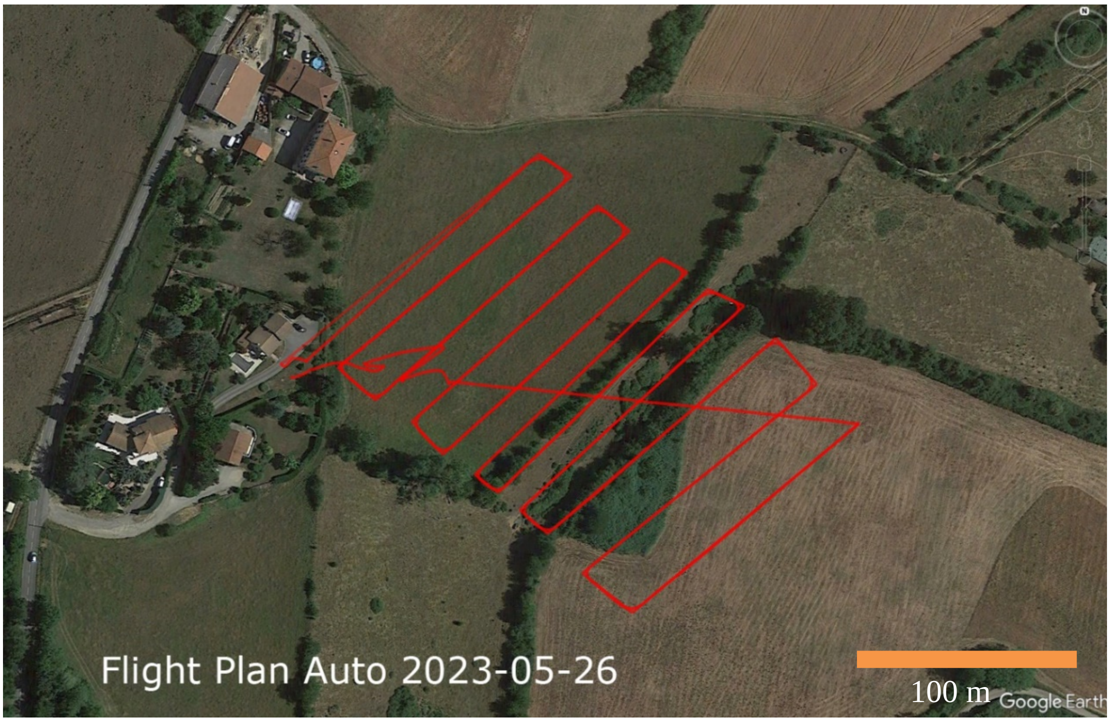

Figure 8: Flight plan of the second flight (May 2023)

3.1.2. Second flight

The second flight was performed in May 2023 in similar conditions as the first one, although the dummy radar mass was increased from 2.2 to 3.2 kg. In addition, a spacer was added to the antennas bringing the total payload mass to 4.5 kg. A more specific flight plan was defined beforehand and consisted of 11 successive straight and parallel lines of 140 m each, simulating a radar survey (Fig. 8). The cumulative distance covered was 1.5 km. The altitude of operation was set to 50 m and the speed to 10 $m.s^{-1}$ with decreased speed during turns to keep the aircraft stable. The weather was slightly windy with average wind speed of 6 $km.h^{-1}$ and gusts up to 20 $km.h^{-1}$ (or 5.5 $m.s^{-1}$).

3.2. *Autonomy and range*

Assuming a 20 percent safety of margin, the extrapolated autonomy is estimated to be 19 and 30 min for the heavy and light payload configurations respectively. With an average speed of 8.4 $m.s^{-1}$, the minimum range is estimated to be 9.56 km with a 4.5 kg payload. The range can be improved to 15 km assuming a 3 kg total payload. The range required by the qualification plan was set to 15 km, meaning that this could be reached only by

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keeping the payload light or increase the average speed (i.e. longer straight lines and less turns).

3.3. *Mounting and stability*

The integrated configuration is stable under slightly windy conditions (5.5 $m.s^{-1}$). However, the qualification required nominal flight attitude up to 11 $m.s^{-1}$, but these weather conditions were not met during the tests reported here. Experience from these flights show nonetheless that even small gusts could lead to unstable conditions for the UAV, and rolling movements should be avoided. Generally, dynamic flight mode showed better stability than hovering mode, and therefore should be preferred during real operations.

4. Post-integration flight

4.1. Integration

4.2. Flight plan and conditions

4.3. Radar performance

4.3.1. Sounding mode

4.3.2. SAR mode

4.4. Weather conditions

5. Conclusion

The qualification campaign of FlyRadar demonstrated that, concerning the radar, signal generation and acquisition is nominal, and that no antenna coupling could be identified during the indoor tests. With a high degree of oversampling, no jitter could be measured which should therefore allow for synthetic aperture processing. Future outdoor tests, post-integration should test the actual radar system performance.

Test flights demonstrated that the mounting of the antennas as well as a dummy payload matching the radar mass allowed for nominal flight conditions. The system should allow for a minimum range of 9.5 km but up to 18 km, close to the required value (15 km). Stability was ensured despite slightly windy conditions, at 50 m of elevation, although dynamic flight mode should be preferred. Future tests should demonstrate the ability to operate under hot temperatures (45°C) and the ability to perform a real survey.

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6. References

- Radar testing report – PBN-COR/NTE/005/23 – Giovanni Alberti, Luca Ciofaniell; 6th January 2024. Co.Ri.S.T.A.

- Antennas flight test report #1 – Philippe Grandjean; 15th February 2023, Hyperion Seven

- Antennas flight test report #2 – Philippe Grandjean; 1st June 2023, Hyperion Seven

- FlyRadar D5.1: Qualification Plan

7. Annex: Table of qualification results

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