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ONERA SAR-Light UAV Platform

Latest Developments and SAR Results

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Abstract — ONERA is one of the leading organizations in experimental research on aeronautic topics. Works on Airborne Radar began forty years ago with the first airborne demonstrator named RAMSES. At the end of the aircraft's life (Transall C160), ONERA invested in the miniaturization and transfer of sensors to the SETHI and BUSARD platforms and conduct many and various experiments in remote sensing. New microwave and platform technologies allow ONERA team to continue miniaturization task, and to obtain very low SWaP sensors embedded on-board compact UAV. This paper presents these sensors, the platform and latest results in remote sensing domain.

Keywords — SAR, UAV, remote sensing, high resolution.

I. INTRODUCTION

In 2020 ONERA, the French Aerospace Lab, took advantage of more than 40 years of experience in the expertise, development, implementation and data processing of airborne remote sensing systems to develop very low SWaP (Size, Weight and Power consumption) active sensors that can be embedded on-board small UAV platforms.

This self-financed project aims to provide the scientific community with an efficient and low cost measurement system.

The ONERA SETHI and Busard platforms are still active and updated with latest technologies and concepts, and are used for high performance and long range measurement campaign all over the world.

This third experimental research platform will address short range high precision calibrated data acquisition.

II. PLATFORM

The SAR-Light platform is based on DJI M600 UAV (Fig. 1). Compared to avionics platform, this UAV is low cost to purchase, deploy and use. It is a compact hexa-copter with 1.6



Fig. 1. SAR-Light platform based on DJI M600 UAV

m width and 0.76 m height. It weighs 9.1 kg (with battery) and can board 6 kg of payload. Maximum ground speed is 18 m/s (without payload and wind) and maximum altitude is 2500 m but airworthiness French regulations limit usually to 120 m. Its autonomy is 35 minutes without payload and 15 minutes with heaviest one.

These performances allow ONERA to develop compatible payloads and conduct experiments with many acquisition geometry and configuration possibilities.

III. SENSORS

A. Common Central Elements

SAR-Light, in the vein of SETHI and BUSARD, is a flexible, configurable and plug and play research platform. Standardisation of input and output of RF front-end allow common central elements as control and command, signal generation, signal sampling and recording systems.

Payloads have their own electric power from dedicated batteries.

1) Digital Core

Digital core that supports generation, sampling, recording and control/command is based on a small flexible PXIe standard chassis. This concept is a compromise between low SWaP, flexibility and performance. PXIe standard delivers stable and filtered electric power, and high precision triggers and clock distribution. COTS PXIe boards are delivered with firmware and software examples that can be used or customised, and very powerful performances with FPGA and processor chips.

The digital core is composed by central processing unit and RF vector signal transceiver in PXIe standard that are linked by backplane buses mechanically installed in a light weight 3D printed custom chassis (Fig. 2).



Fig. 2. PXIe generation and sampling board (left) and digital-core in 3D printed chassis (right)

Table 1. RF vector signal transceiver performances.

Sampling Rx channels	1
Sampling freq.	Up to 1.25 GS/s
Analog bandwidth	9 kHz – 6 GHz
Instantaneous bandwidth	1 GHz
Storage data rate	200 MB/s
Storage capacity	2 TB

Digital core performances are summarized in Tab. 1.

2) Inertial Navigation System

Antenna trajectory and attitude knowledge is a big challenge with light platform that are sensitive to aerologic conditions. However this knowledge, with high precision, is crucial in SAR domain to be able to synthesize a high quality trajectory (and thus synthetic antenna) and obtain good focalisation and image quality.



Fig. 3. SAR-Light compact INS

This high precision trajectory restitution is obtained with a compact SBG Inertial Navigation System (Fig. 3) coupled with GNSS receiver.

Depending on GNSS configuration or expected resolution and precision, this navigation system is sometimes not enough performing and autofocus algorithm may be used to achieve better focalisation [3].

B. Quad polarisation X-Band SAR

First RF imaging system that has been developed and tested on-board the SAR-Light platform is a X-band FMCW radar with quad linear polarisation capacity (Fig. 6).

The Tx and Rx antennas developed are based on eight dipoles triangular lattice array arrangement (Fig. 4). The radiating element is defined by a printed cross-dipole which allows for achieving a large bandwidth and a dual linear polarization. Antennas allow a [8.3 – 11.1 GHz] bandwidth considering a VSWR less than 2. The radiation pattern half-power beamwidth is included between [20° - 30°] over the entire bandwidth for both polarization. The antenna gain and isolation between polarization are, respectively, better than 13.5

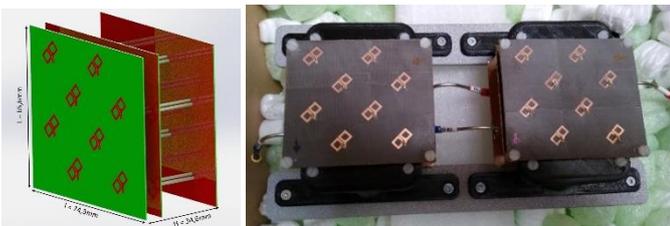


Fig. 4. X-Band antenna design and realisation

dB and 20 dB. The isolation between Tx and Rx antennas is better than 50 dB over the entire bandwidth for all polarisation combinations.

The microwave front-end is designed with X-Microwave components that are a good compromise for compactness, performance and modularity. COTS components (and some custom) are available in block form and radar is obtained by building block assemblies on specific plate that allow high precision alignment of component outputs/input. They are linked without cable, reducing losses and impedance mismatch issues. This architecture is modular and flexible, but high quality integration conducts to high performances (Fig. 5).

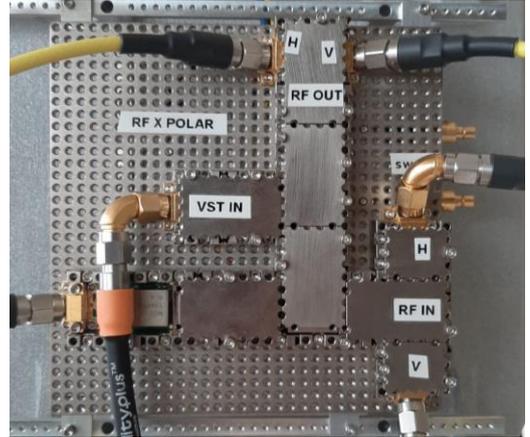


Fig. 5. X-Band compact and modular microwave front-end



Fig. 6. X-Band SAR System on-board the DJI M600 platform

Table 2. SAR-Light X-Band SAR performances.

Radar autonomy	25 min
Total weight	5.2 kg
Size	280 x 250 x 310 mm ³
Central frequency	10 GHz
Bandwidth	Up to 1.8 GHz
Incidence angles	15°, 30°, 45°, 60° and 75°
Transmit power	0.08 W

C. Quad polarisation C-Band SAR

Promising results obtained with platform and first X-Band SAR sensor motivated ONERA to develop a second component, at C-Band, more dedicated to scientific and civilian applications (Fig. 8). As for X-Band one, the C-Band SAR sensor has quad-pol capacities.

Antenna parts are made with the same philosophy as X-band ones. Regarding the weight and mechanical dimensions

available, the C-band antennas are designed with a four dipoles circular array arrangement (Fig. 7). C-band antennas allow a [4.5 – 7.6 GHz] bandwidth considering a VSWR less than 2 for both polarization. Both polarization radiation pattern half-power beamwidth are included between [20° - 30°] over the entire bandwidth. The antenna gain and isolation between polarization are, respectively, included between [8 – 13 dBi] and better than 20 dB. The isolation between Tx and Rx antennas is better than 40 dB over the entire bandwidth for all polarisation combinations.

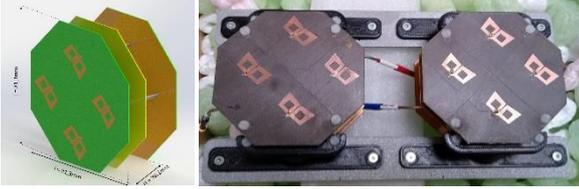


Fig. 7. C-Band antenna design and realisation

With same logic than X-Band sensor (Fig. 5), microwave front-end is based on X-Microwave components.



Fig. 8. C-Band SAR System on-board the DJI M600 platform

Table 3. SAR-Light C-Band SAR performances.

Radar autonomy	25 min
Total weight	5,6 kg
Size	280 x 250 x 310 mm ³
Central frequency	5.2 GHz
Bandwidth	800 MHz
Incidence angles	15°, 30°, 45°, 60° and 75°
Transmit power	0.25 W

D. Quad polarisation UHF (including L)-Band SAR

To address low-frequency ultra-wide-band target signature measurement and study, and foliage and ground penetration topic analysis, the third payload that has been studied is an UHF Band quad-polarization SAR sensor (Fig. 9). Main challenge is about long wavelength and ultra wide bandwidth (71 %) antenna implementation on small platform. Studies have been

Table 4. SAR-Light UHF -Band SAR performances.

Radar autonomy	20 min
Total weight	6.5 kg
Size	280 x 250 x 1000 mm ³
Central frequency	900 MHz
Bandwidth	600 MHz
Incidence angles	45°
Transmit power	0.07 W

conducted on antenna design and platform/antenna interaction on antenna pattern.

Studies on the whole system are still ongoing.



Fig. 9. UHF-Band SAR System on-board the DJI M600 platform

IV. EXPERIMENTAL RESULTS

After many laboratory tests conducted to validate sub-functions and then full system on ground level, some airborne experimental campaign have been conducted over calibration (corner reflectors) and opportunity targets with X- and C-Band configurations in the south of France (Fig. 10).



Fig. 10. GoogleEarth® (left), SAR-Light X-Band (middle), C-Band (right) imagery. Radar images are colour composition of quad pol (RGB = Hh, Hv, Vv) and high resolution (25 cm).

Image quality has been measured on five corner reflectors and results are coherent with expectation (Fig. 11):

- Slant range resolution (-3 dB) = 0.25 m
- Azimuth resolution (-3 dB) = 0.5 m
- Mean PSLR = 13.3 dB (range) / 11.9 dB (azimuth)
- ISLR = 10.4 dB (range) / 10.7 dB (azimuth)

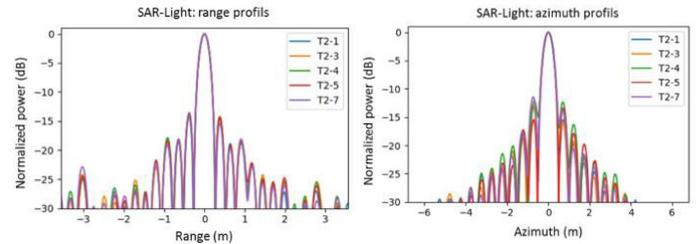


Fig. 11. Impulse responses measured over 5 trihedrals with X-Band

Another experiment has been conducted in X-Band over a complex scene composed by vehicles, devices, boxes, standing, sitting and lying people.

Figure 12 is a high resolution circular imagery (summation of 72 images every 5 degrees) of a truck with a cover hiding a metallic box (bottom right image) or not (bottom left image).

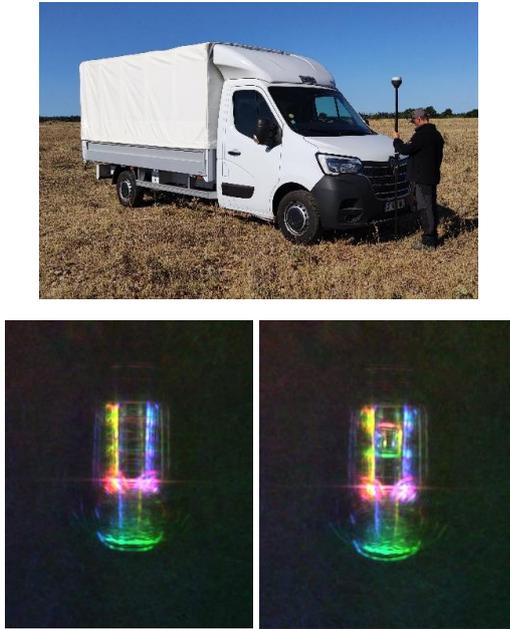


Fig. 12. X-Band circular imagery of truck (up) without (down-left) and with (down-right) metallic box inside

Second results are over standing, sitting and lying people, a car and some boxes in open air and hidden under a tent (Fig. 13).

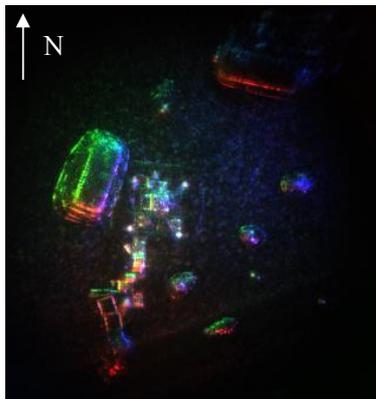


Fig. 13. X-Band circular imagery of complex scene with car, tent, boxes, devices, standing, lying and sitting people.

Last results are on people with different positions and accessories (Fig. 14).



Fig. 14. X-Band circular imagery of standing, lying and sitting people with accessories

V. CONCLUSION AND PERSPECTIVES

We presented in this paper latest results obtained with the ONERA smallest and newest SAR sensor SAR-Light.

Research and development are still ongoing on SAR-Light to improve its capacities and performances as antenna motorization, target pointing and multi-channel for simultaneous multi-wavelength modes.

Following 30+ years of developments and exploitations of SAR sensors, ONERA DEMR is now operating a large range of sensors; from SETHI, to BUSARD and SAR-Light.

Those sensors are now validated and available for SAR data collection for a large panel of purposes, and both defence and civilian applications.

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