



HAL
open science

SAR-Light: the new ONERA SAR sensor onboard UAV

Sebastien Angelliaume, Nicolas Castet, Xavier Dupuis

► **To cite this version:**

Sebastien Angelliaume, Nicolas Castet, Xavier Dupuis. SAR-Light: the new ONERA SAR sensor onboard UAV. EUSAR 2022 -14th European Conference on Synthetic Aperture Radar, Jul 2022, Leipzig, Germany. hal-04134546

HAL Id: hal-04134546

<https://hal.science/hal-04134546v1>

Submitted on 20 Jun 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

SAR-Light: the new ONERA SAR sensor onboard UAV

Sebastien Angelliaume^a, Nicolas Castet^a, Xavier Dupuis^a

^aDEMR, ONERA F-13661 Salon cedex Air - France

Abstract

Radar remote sensing data are used in a wide range of applications such as the detection and tracking of targets, the characterization of the environment or the estimation of geophysical parameters. These data are usually collected by SAR instruments on-board airplanes or satellites. However, developments in technologies permit radar sensors to be miniaturized, which now allow them to be embedded on-board smaller platforms such as UAVs. ONERA is currently developing a new line of SAR instruments on-board UAV, called SAR-Light. In its first version, it is a mono-polarized (VV) SAR operating in X-band at high spatial resolution (0.25 m). This paper presents the SAR-Light instrument and describes the performance obtained during a flight tests campaign carried out in April 2021 in the South of France.

1 Introduction

The evolution of technologies, especially digital ones, allows a miniaturization of remote sensing sensor. This permanent revolution has enabled the passage of ONERA's radar sensors from a Transall C-160 (RAMSES – [1]) and a STEMME (BUSARD – [2]) to a Falcon 20 (SETHI – [3]) in the period 2005-2010. The progress made since that time has been considerable and a new era has since opened, that of UAV platforms.

SAR-Light is the new sensor developed by ONERA, the French Aerospace Lab. This is a high resolution SAR system embedded onboard a DJI M600 UAV (Fig. 1). It operates in X-band and in mono-polarization (VV). UAVs platforms allow the acquisition of experimental radar data in a wide variety of geometric configurations, at controlled costs. Its flexibility of use and implementation makes it a privileged tool for the generation of EM reference databases and the development of remote sensing applications. Due to their flexibility, they offer new perspectives in remote sensing, some of which are not directly accessible from an airborne or spaceborne instrument (trajectory constraints, temporal flexibility, instrument noise level, etc.). The interest of collecting SAR data with such platforms have already been reported in the literature [4][5].



Fig. 1: SAR-Light – The new ONERA SAR sensor onboard a DJI M600 UAV.

This paper is organized as follows: Section 2 presents the SAR-Light instrument, Section 3 describes a campaign of acquisition dedicated to the evaluation of the radar instrument and results are reported in Section 4.

2 The SAR-Light instrument

SAR-Light is a lightweight low consumption FMCW radar designed for UAV platform. The main characteristics of the system are given table I.

TABLE I
SAR-LIGHT X-BAND

Features	Values
Radar autonomy	25min
Battery	4000mA/h – 22.2V
Total weight	5,6kg
Size	280x250x310mm
X Band – Center frequency	9.8GHz
Bandwith	Up to 1200MHz
Incidence angles	45 °, 60 ° and 75 °
Power output	0.03W

System development is based on a modular strategy using PXIe digital cards, X-Microwave modules, custom patch antenna and compact inertial unit. An on-board CPU controls the whole system.

2.1 The Radar Sensor

The sensor operates in FMCW mode by transmitting frequency modulated continuous waves (Fig. 2) with transmit and receive antenna.

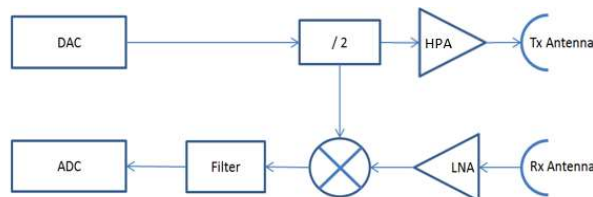


Fig. 2: FMCW Radar block diagram

The hardware architecture of the microwave part is the key element of the radar. A microwave board has been prototype with RF module and X-Mblocks. Addition of components like multipliers, filters and amplifiers permits to adapt the radar chain to the required frequency band and geometry (Fig. 3) while respecting the strong constraints of weight and size.

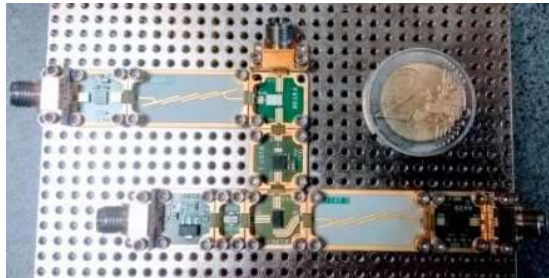


Fig. 3: Custom RF design with X-Microwave modules.

The digital part is mainly composed of a vector signal transceiver that generates the chirp and digitizes the baseband response with a central processing unit that record the raw radar and IMU data.

2.2 IMU and Trajectory

Precise knowledge of the trajectory during data acquisition is one of the key points to achieve an efficient focalization of SAR data, especially when using an UAV platform. Yet, the development of a compact lightweight system implies strong constraints on the on-board elements and a compromise is often required between performances and size. The chosen solution for SAR-Light is based on specific category of MEMS technology developed by SBG System.

The IMU uses the differential spatial augmentation system during the acquisitions. The raw data is then recorded and a differential method is applied to refine the actual position (longitude, latitude, height) of the UAV. Post processed kinematic (PPK) would be the best solution to correct GNSS errors but it requires several GNSS stations distributed on the ground. This is not problematic for sensor that travel over a large area of the Earth (such as airplanes or satellites) but that could be a strong issue for radar on-board UAVs.

SAR-Light operates in X-band (9.8GHz) i.e. at 0.03m wavelength, which requires very precise knowledge of the trajectography data. That is only achieved with ground stations sufficiently close to the measurement area.

3 Experimental campaign

The first experimental campaign of acquisition with the SAR-Light instrument was carried out in April 2021, in South of France (coordinates in WGS 84: lat. = 43.82145° – long. = 4.11363°).

SAR data were collected at X-band with the main objective to evaluate the performances of the SAR-Light instrument. The spatial resolution is 0.25 m (600 MHz bandwidth) and images are processed with an azimuth (along-track) resolution equal to the range resolution

(across-track). The radar was operated in mono-polarization (VV) mode for this campaign.

During the flight tests, three geometric configurations were explored corresponding to incidence angles in the middle of the swath of 45 °, 60 ° and 75 °. The range between the radar and the illuminated area was kept constant (~ 170m) for these three configurations, which implies the flight altitudes of 120m, 85m and 44m respectively. Imaged area is 80m in slant range and around 250m in azimuth. The waveform used for this airborne campaign of measurements is reported Table 2 below.

TABLE II
WAVEFORM USED FOR THE SAR-LIGHT CAMPAIGN.

PARAMETER	VALUE
Central Frequency (GHz)	9.8
Bandwith (MHz)	600
Pulse duration (μs)	125
Pulse Repetition Interval (μs)	130
Sampling Frequency (MHz)	10
Beamwidth (Rge x Azi - deg)	22 x 22

The imaged area is mainly a field of bare soil, plowed shortly before the acquisitions. Trihedrals were installed on the field as well as an EM absorber area (2.4m x 2.4m) to estimate the instrument noise level, see. Fig. 4.



Fig. 4: Illustrations of the measurement area, trihedral and EM absorber area.

4 Evaluation of Performances

SAR-Light collected a large number of images during the flight test campaign (61 in 2.5 days) so as to study the temporal stability of the instrument. An illustration of a SAR image collected the 08 of April 2021 with an incidence angle of 45° is displayed Fig. 5. The Range

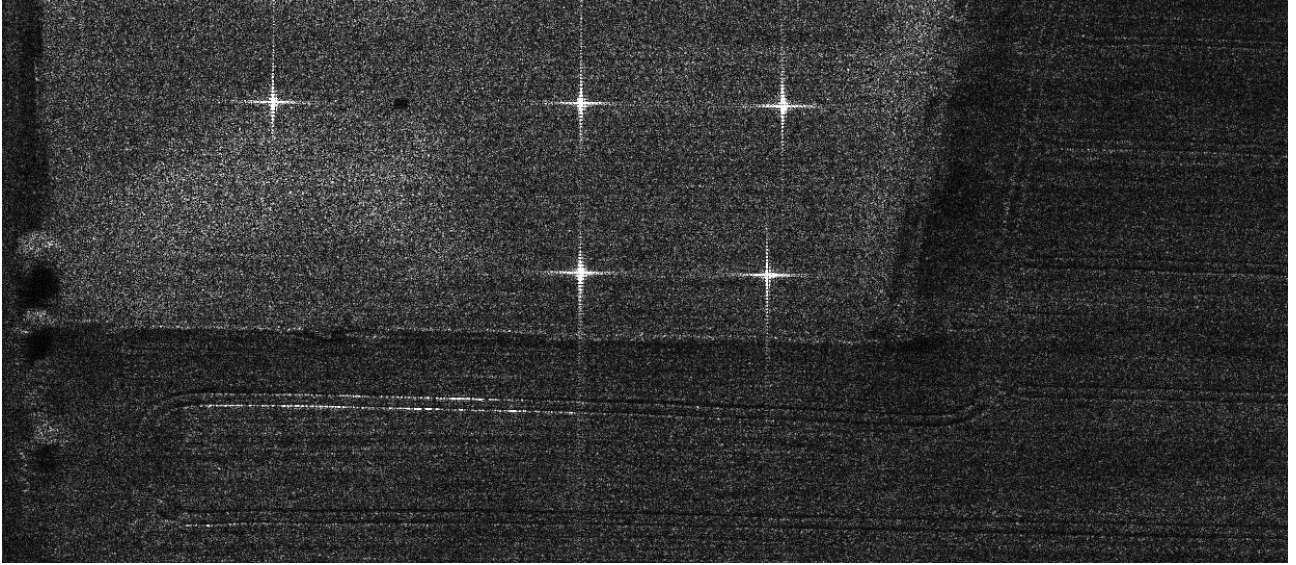


Fig. 5: SAR-Light SAR images at X-band VV polarization – incidence 45° – Range is the vertical axis (with the near range at the top) and azimuth is the horizontal axis.

4.1 Focalisation

An adapted post-processing of the trajectography data during acquisition and a control of the SAR processing allow focusing the radar data collected by SAR-Light with overall good performances without requiring autofocus technique. The obtained resolution is equal to 0.25m in both range and azimuth directions, the PSLR (Peak Side Lobe Ratio) is on average equal to 13.3 dB in range and 11.9 dB in azimuth, the ISLR (Integrated Side Lobe Ratio) is on average equal to 10.4 dB in range and 10.7 dB in azimuth (see Figs. 6 and 7). These values illustrate the performances obtained with the SAR-Light sensor, but they can be greatly degraded when the trajectography data are not sufficiently controlled.

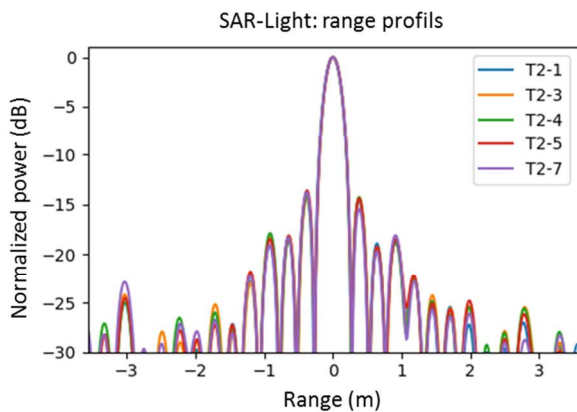


Fig. 6: Impulse responses measured in range over 5 trihedrals.

is the vertical axis (with the near range at the top) and the azimuth is the horizontal axis. Five trihedrals are illuminated as well as the EM absorber area (see the dark area between the 2 trihedrals at the top left). This illustrates the great dynamics of the EM signal recorded by the SAR-Light instrument.

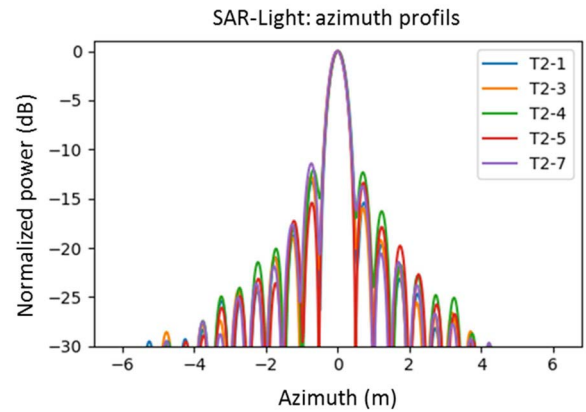


Fig. 7: Impulse responses measured in azimuth over 5 trihedrals.

4.2 Geolocation

We now report on the geolocation accuracy obtained with the SAR-Light instrument. The position of the corner reflector deployed on the ground were measured in WGS84 (latitude, longitude and altitude) with an accuracy of few centimeters. The geolocation accuracy is estimated along both range and azimuth axis from different SAR acquisitions collected during the flight tests campaign. Results are given Figs. 8 and 9 with the geolocation accuracy in meter plotted for 3 corner reflectors and for 12 runs of acquisition. The first 7 runs have been acquired April 8 in the early morning, runs 8 to 10 the same day in the afternoon and the last 2 (runs 11 and 12) the following day.

The mean geolocation accuracy in range is very stable (see Fig. 8), ranging between 1 and 8cm, with a min/max error between -14 to 24cm. Note that we had to re-estimate the electronic delays between the flights to maintain sufficient geolocation accuracy along the range axis. Otherwise, a geolocation error up to 1.7m is obtained. The mean geolocation accuracy in azimuth depends on the inertial measurement unit and post-processing qualities. It varies between 29 and 42cm, with a min/max error ranging between 5 to 62cm (see Fig. 9).

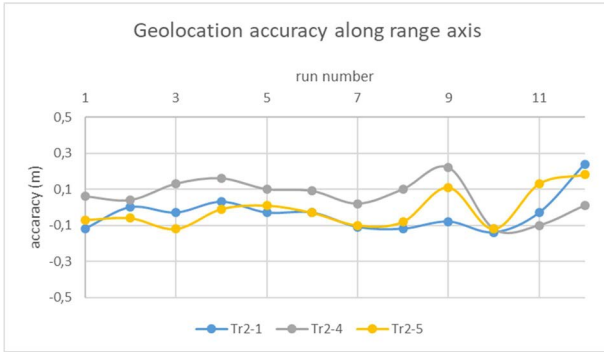


Fig. 8. Corner reflectors geolocation accuracy along slant range axis for 12 runs.

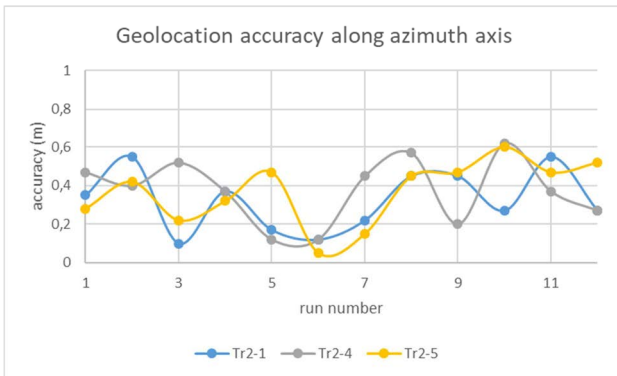


Fig. 9. Corner reflectors geolocation accuracy along azimuth axis for 12 runs.

4.3 Radiometric calibration

In this last sub-section we report on the stability on the radiometric calibration accuracy using the same runs of acquisition as in 4.2. The measured RCS are always between +/- 1 dB of the theoretical value (26.4 dBm²/m²).

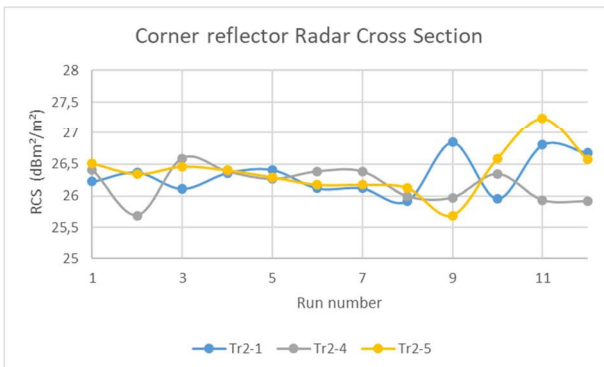


Fig. 10. Radiometric calibration accuracy in dBm²/m² for 3 corner reflectors over 12 runs.

Finally, we estimate the instrument noise (NESZ) in a tree shadow. The shadow area was not very large but gives a superior limit of the NESZ, that is: NESZ < -32.2 dB m²/m². Another way to estimate this key parameter is to measure the reflectivity over the EM absorber (see Fig. 2) but the covered area was too small and we obtained a level 3 dB higher than the previous value.

5 Conclusion

SAR-Light is the new line of UAV-borne SAR instruments currently under development at ONERA. The first version of SAR-Light is an X-band mono-polarized (VV) SAR sensor collecting data with a spatial resolution of 0.25m and covering a swath of around 80m (in slant range geometry).

As reported in this paper, a first flight tests campaign carried out in April 2021 has enable the acquisition of experimental SAR data and the validation of the instrument's performances. After this first successful step, the developments and evolutions of SAR-Light will continue with the addition of a full-polarimetric capacity and the integration of sensors operating at different frequency bands, namely C and UHF-bands, while improving the robustness and stability of the system.

6 Acknowledgment

Research presented in this paper is part of the CARACAS and IMA³ projects, funded by ONERA. Authors are very thankful for colleagues from ONERA involved in the development of the SAR-Light instrument as well as those who participated in flight tests and ground activities in April 2021.

7 Literature

- [1] P. Dreuillet *et al.*, "The ONERA RAMSES SAR: latest significant results and future developments," *2006 IEEE Conference on Radar*, 2006.
- [2] O. Ruault du Plessis *et al.*, "ONERA SAR facilities," in *IEEE Aerospace and Electronic Systems Magazine*, vol. 26, no. 11, pp. 24-30, Nov. 2011.
- [3] G. Bonin *et al.*, "The new ONERA multispectral airborne SAR system in 2009," *2009 IEEE Radar Conference*, 2009.
- [4] E. Schreiber, A. Heinzl, M. Peichl, M. Engel and W. Wiesbeck, "Advanced Buried Object Detection by Multichannel, UAV/Drone Carried Synthetic Aperture Radar," *2019 13th European Conference on Antennas and Propagation (EuCAP)*, 2019, pp. 1-5.
- [5] M. Lort, A. Agasca, C. López-Martínez and T. M. Marín, "Initial Evaluation of SAR Capabilities in UAV Multicopter Platforms," in *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 11, no. 1, pp. 127-140, Jan. 2018, doi: 10.1109/JSTARS.2017.2752418.