SAR-Light - First SAR Images from the New Onera SAR Sensor on UAV Platform

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ABSTRACT

Remote sensing data are usually collected by SAR instruments on-board airplanes or satellites and many applications have been developed in a wide range of scientific subjects. 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.

Index Terms— SAR, UAV, imagery

1. INTRODUCTION

SAR sensors are in constant evolution following technologies innovations. 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. Since few years, miniaturization of remote sensing sensor has opened a new era with the use 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 (1), operating in X-band and in mono-polarization (VV). UAVs flexibility offers new perspectives for remote sensing applications with a wide variety of geometric configurations. The interest of collecting SAR data with such platforms have already been reported in the literature [4][5].

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.

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

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.

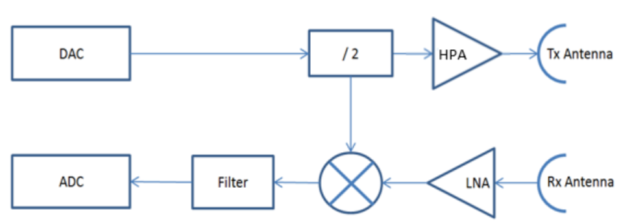


Fig. 2. FMCW Radar block diagram.

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 com-

Table 1. SAR-Light X-Band.

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

ponents like multipliers, filters and amplifiers permit one to adapt the radar chain to the required frequency band and geometry (Fig. 3) while respecting the strong constraints of weight and size.

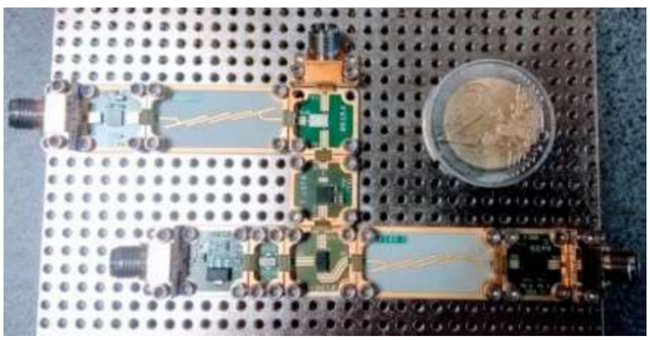


Fig. 3. Custom RF design with X-Microwave modules.

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 (inertial measurement unit) 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 monopolarization (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. The imaged area is mainly a field of bare soil, plowed shortly before the acquisitions. To evaluate the SAR image quality, five trihedrals were deployed and geolocated with an accuracy of few centimeters. An EM absorber area (2.4m x 2.4m) was also installed to estimate the instrument noise level. Over 60 SAR-Light images in 2.5 days were acquired during this flight test campaign.

Table 2. Waveform used for the SAR-Light Campaign

Parameter	Values
Central Frequency	9.8 GHz
Bandwith	600 MHz
Pulse duration (μs)	$125\mu s$
Pulse Repetition Interval	$130\mu s$
Sampling Frequency	10 MHz
Beamwidth (Rge x Azi)	$22°$ x $22°$

4. EXPERIMENTAL RESULTS

This section is dedicated to the presentation of experimental results over two areas and for two different incidence angles. SAR images are generated without requiring autofocus technique. Only adapted post-processing of the trajectography data during acquisition has been necessary.

4.1. Calibration area

An illustration of a SAR image collected the 08 of April 2021 with an incidence angle of $45°$ is displayed in Figure 6. Five trihedrals are clearly visible and the EM absorber can be spotted between the up-left trihedrals. Figure 5 shows impulse responses measured over five trihedrals. Range resolution of 0.25m and azimuth resolution of 0.5m are achieved with a PSLR (Peak Side Lobe Ratio) of 13.3 dB in range and of 11.9 dB in azimuth and with ISLR (Integrated Side Lobe Ratio) of 10.4 dB in range and 10.7 dB in azimuth. These performances can be reached for an azimuth resolution of 0.25m by using autofocus techniques and by having better trajectory accuracy. Geolocation accuracy in range and in azimuth and radiometric measurements averaged over 12 runs of acquisition are presented in table 3. Range geolocation accuracy is stable over the runs and depends on the knowing of electronic delays. Azimuth geolocation accuracy is larger compared to range one and depends on the inertial measurement unit and post-processing qualities. Radiometric accury is measured from the trihedrals RCS (theoretical value of $26.4dBm^2/m^2$). The instrument noise (NESZ) measured in a tree shadow is always lower than $-32.2dBm^2/m^2$. At last,

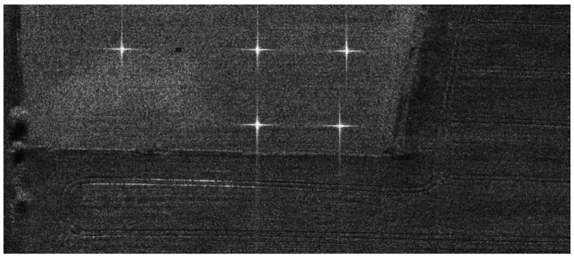


Fig. 4. SAR-Light SAR images at X-band VV polarization – incidence $45°$ – Calibration area – Range is the vertical axis (with the near range at the top) and azimuth is the horizontal axis.

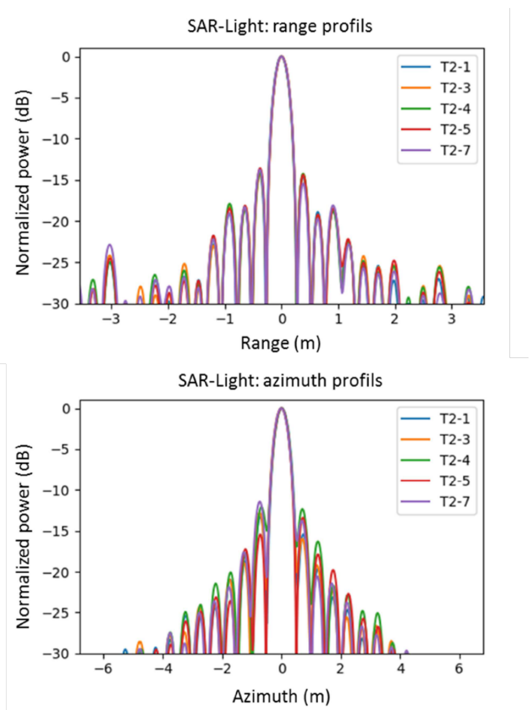


Fig. 5. Impulse responses measured over 5 trihedrals.

Table 3. Geolocation and radiometric accuracy performances of corner reflectors.

	Values
Slant range	between $1cm$ and $8cm$
Azimuth	between $29cm$ and $42cm$
Radiometric calibration	+/- $1dB$
NESZ	$< -32.2dBm^2/m^2$

Figure 6 shows an image of the same area for $75°$ incidence.

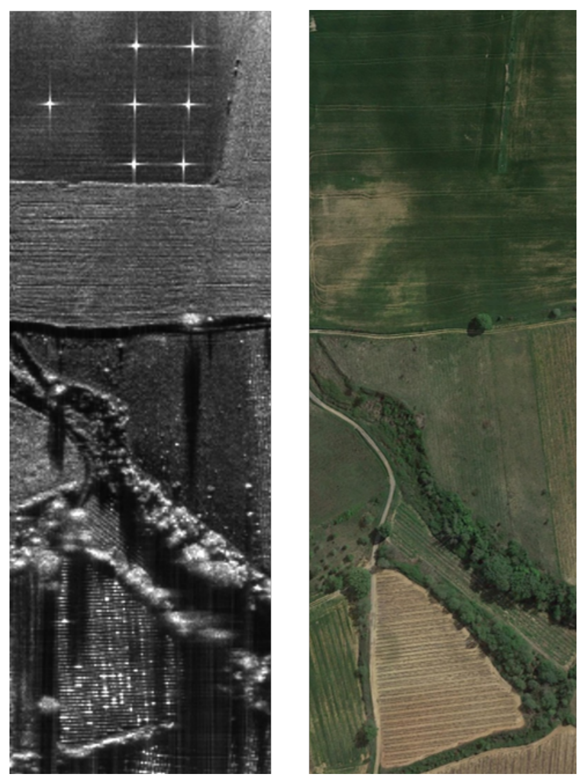


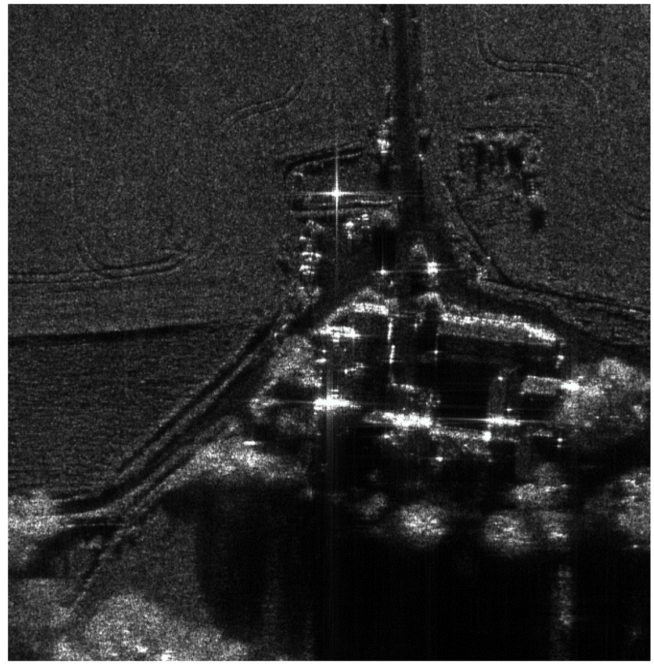
Fig. 6. SAR-Light SAR image at X-band VV polarization – incidence $75°$ - Calibration area - Left: SAR image. Right: GoogleEarth view.

4.2. Mas Guyot area

To further illustrate results of SAR-Light, SAR image from MAS Guyot are is presented in Figure 7. Resolutions of 0.25m are also achieved in this image and NESZ is equal to $-35 dBm^2/m^2$.

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.



SAR Image

GoogleEarth view

Fig. 7. SAR-Light SAR image at X-band VV polarization – incidence 75° - Mas Guyot area.

6. REFERENCES

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