The ONERA Airborne Multi-Frequency SAR Imaging Systems

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Abstract — RAMSES-NG and SETHI, the airborne SAR systems developed by ONERA, integrate new generation of radar and optronics payloads. They can operate over a wide range of frequency bands from UHF-VHF, to X-band including L band with long range, very high resolution, polarimetric and interferometric capabilities. Collected and processed Data are exploited for various studies in the field of Defence, Security and Remote sensing applications. In this paper, we describe these two SAR Systems and associated digital remote control. In conclusion some typical results are presented.

Keywords— SAR, ONERA, SETHI, BUSARD, Optronics, Ultra High Resolution, long range

I. INTRODUCTION

With the objective of maintaining and updating its Airborne Remote Sensing acquisition capabilities, ONERA has been developing a new system family compatible with medium size/ small aircrafts. The first of these new systems, called SETHI is dedicated to civilian applications and is operated since 2007 [1]. RAMSES-NG is the follower of SETHI and is dedicated to defense and security applications. Like SETHI, RAMSES NG is a plug and play pod-based system and can carry the same payloads as SETHI, ranging from VHF-UHF to X band and/or optical sensors with a wide range of acquisition geometries. While SETHI propose full polarimetric UHF, L and X-bands sensors recently improved with single-pass Interferometric and ATI options for X-band component, RAMSES NG is able to operate new generation payloads at long range and an ultra high resolution instrumented X band system. This system is equipped with 2-axes motorized antennas, high speed sampling acquisition system with adjustable dynamic range, multi sampling windows capability, associated to high resolution visible and hyperspectral cameras.

SETHI system on the one hand, with the low frequency component enriched with images provided by cameras, can cover many SAR applications mainly dedicated to environment surveillance domain e.g. tropical forest density estimation, tree height measurements or deforestation damages. VHF-UHF band demonstrate foliage and ground penetration capability. Ocean observation is also considered with focus on pollution detection, currents velocity measurement with the new X-band ATI capability and sea clutter backscattering measurement. Tomography and POLINSAR have been also investigated with SETHI.

RAMSES NG, on the other hand, can operate Coherent Change Detection (CCD) at long range and decimetric resolution at X-band. Furthermore, sub-decimetric resolution is compatible with the new sensor hardware and is currently investigated.

II. SETHI AND RAMSES NG DESCRIPTION

A. The Aircraft

SETHI and RAMSES NG are operating on the same type of platform, namely a Falcon 20 Dassault aircraft. For SETHI experiments, the aircraft belongs to AVDEF company (Fig. 1, a) based in Nimes (south of France), while the RAMSES NG platform (Fig. 1, b) is operated by DGA-EV, the Flight Test Center of the French Ministry of Defense based in Istres.

Figure 1. : SETHI (a) and RAMSES NG (b)

B. The cabin description

The specific cabin installation includes 6 bays for RAMSES NG and 5 bays for SETHI and two operators’ seats (Fig. 2) for both systems. Most of control and operation parts are automated and centralized.

Figure 2. SETHI cabin installation
Photos on figure 3 present the RAMSES NG (a) and SETHI (b) on-board installation. Each 19” wide bay has a maximum weight of 120kg, and a 21U useful capacity. Overall, the cabin has a total payload capacity of 126U and 720 Kg.

Two pods (Fig. 1) are installed under the wings to carry antennas and cameras. The links between the pods and operators in the cabin comprise a fiber optics Gigabit Ethernet network for the control and command, and very low losses cables for the RF signals. All these cables have been integrated inside the wings (Fig. 4).

Figure 3. Bays and operators installation RAMSES NG (a) and SETHI (b)

C. Sensors development

Figures 5 and 6 show the radars implementation for SETHI, which can also be integrated into the RAMSES-NG platform. A new generation of sensors, shown in Figures 7 and 8, have been specifically developed with the support of the French Ministry of Defense onboard the RAMSES-NG aircraft.

Both projects have been running for several years with the development of mechanics, electronics, radar racks and control and command systems. Main developments have focused on:

- The new Ultra High Resolution long range X band component (Fig. 7). This system is based on a stepped chirp frequency digitally generated waveform with more than 3GHz bandwidth, two-axes motorized parabolic antennas with target designation capacity and a 8kW peak high power TWT amplifier.
- An Interferometric pod to pod X-band configuration coupled with an ATI capacity. This development is based on two additional receiving antennas localized in one pod (Fig. 8) while the transmit and one receive antennas are implemented in the other pod, thus providing simultaneous cross-track and along-track baselines.
- Two optronics sensors (Fig. 9). The first one is a nadir-looking hyperspectral camera with 1600 spatial pixels and 160 spectral bands. The other one is a 39Mpixels side-looking camera producing high resolution images in visible band.
- A high speed sampling system (Fig. 10). The high bandwidth waveforms are associated to a high speed digital sampling system specially developed for this project and based on a 9U VXS rack. This system can simultaneously acquire up to 16 channels with a 1.4GB/s data rate and a 3.2GHz analog input bandwidth, the
The aircraft has been modified to accommodate a high speed link between the cabin and the pods (Fig. 3). For that purpose different cables, as generic as possible, associated to different functions (RF, Control and Synchronization), were inserted through the wings. Losses in the cables are less than 0.2dB/m at 14GHz and they support up to 500W power at 18GHz. The fiber optics Gigabit Ethernet network will allow real time visualization of the optical sensors in the cabin on the one hand, and on the other hand, real time communication with the two-axes antennas for target designation. Moreover, an auxiliary power unit has been installed to provide the electric power necessary to the payload.

The table below presents the main SETHI radar parameters:

<table>
<thead>
<tr>
<th>Radar</th>
<th>X</th>
<th>L</th>
<th>VHF_UHF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center frequency</td>
<td>9.5 GHz</td>
<td>1.3 GHz</td>
<td>340 MHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>1.5 GHz</td>
<td>200 MHz</td>
<td>240 MHz</td>
</tr>
<tr>
<td>Transmit peak power</td>
<td>200 W</td>
<td>200 W</td>
<td>500 W</td>
</tr>
<tr>
<td>Best achievable resolution</td>
<td>12 cm</td>
<td>75 cm</td>
<td>65 cm</td>
</tr>
<tr>
<td>Antenna</td>
<td>Horn</td>
<td>Patch array</td>
<td>Dipoles</td>
</tr>
<tr>
<td>Elevation aperture</td>
<td>16°</td>
<td>30°</td>
<td>80°</td>
</tr>
<tr>
<td>Azimuth aperture</td>
<td>16°</td>
<td>10°</td>
<td>50°</td>
</tr>
<tr>
<td>Nb of channel</td>
<td>Polar: 2 Interfer: 2 ATI: 3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Table II presents RAMSES NG radar parameters:

<table>
<thead>
<tr>
<th>Radar</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center frequency</td>
<td>9.5 GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>4 GHz</td>
</tr>
<tr>
<td>Transmit peak power</td>
<td>8 kW</td>
</tr>
<tr>
<td>Best range achievable resolution</td>
<td>3.8 cm</td>
</tr>
<tr>
<td>Antenna</td>
<td>parabol</td>
</tr>
<tr>
<td>Elevation aperture</td>
<td>5°</td>
</tr>
<tr>
<td>Azimuth aperture</td>
<td>7°</td>
</tr>
<tr>
<td>Nb of channel</td>
<td>1</td>
</tr>
</tbody>
</table>

### III. CONTROL AND COMMAND SYSTEM

RAMSES NG and SETHI are flexible systems that have the ability to integrate different payloads dispatched between the cabin and the two pods. Figure 11 present a general synoptic of the system in his X-band/2 axes motorized system configuration. The distribution between cabin and pod of different analogic and digital elements is described including the command and control system.

#### A. Cabin control and command description

Electronic boards were developed to control and command all the new racks integrated in the bays. Each board uses a PIC18 microcontroller and communicates with the operators through CAN network. The 112bits of Microchip digital I/O programmable components placed on “External Communication Board” are used to control the radar components of the rack (amplifiers, attenuators, switches). The SD card memory, on “Monitoring Board” (Fig. 12 (a)) is used to record in a log file the environment parameters of the rack acquired by various sensors (temperature and humidity). Radar power supplies and currents are monitored by “Power Management Board” (Fig. 12 (b)). All the boards communicate through internal CAN bus. All the information provided by the microcontrollers system is available in real time on the radar operator’s screen.
B. Pods

The SAR dedicated payloads in the pods can be oriented and moved about the elevation axis during operation. This flexibility is provided by four “motorized columns” for each pod on which different sizes and types of antennas, typically horn or patch arrays, can be attached. The incidence angle of each antenna can be modified during the flight with a high accuracy (0.1 degree) in order to vary the acquisition geometry.

The new long range high resolution X band payload is mainly dedicated to Spot Light mode. This is achieved by a two axes motorized system with high accuracy (0.1°) and high speed (50°/s in azimuth and 10°/s in elevation).

IV. CALIBRATION AND EXAMPLES OF RESULTS

For each flight campaign, calibration devices are deployed on ground for images quality assessment. Radar noise floor (NESigma0), resolution, ISLR, PSLR can thus be calculated as presented in figure 13.

Figure 14 presents several images simultaneously obtained with SETHI in X, L and UHF bands in VV polarization coupled with visible camera. The same area has been also imaged with the Hyperspectral camera in a nadir configuration from a separate overflight.
Figure 16 is an example of result obtained during this campaign. The 30 cm resolution X-band image presented was processed from data acquired at 45 km range.

![Figure 16. X-band image acquired with RAMSES NG at 45 km range (30 cm resolution)](image)

Figure 17 is a first result of ultra high resolution image. Measured resolution is around 5 cm, the body shape of the person lying on the ground is recognizable.

Such resolution obtained from a waveform which provides a total bandwidth of 3.4 GHz generated by 5 chirps of 720 MHz each. In order to illuminate the scene with a sufficient duration in accordance to Doppler resolution condition, a specific sliding spotlight mode has been operated with the two-axes motorized parabolic antennas described in paragraph C.

![Figure 17. Ultra high resolution image](image)

The target designation mode operated with this system has been also used for measurements along a circular trajectory. Aircraft motion, generally important in such configuration, can thus be compensated and area of interest on ground is always illuminated by the radar beamwidth. A specific algorithm has also been developed in order to obtain a complete 360° image of the target from non-coherent combination of elementary very high resolution images. Figure 18 presents examples of such results obtained on small aircraft; colors are coding angular sectors corresponding to successive images.

![Figure 18. Small aircraft images provided from circular configuration.](image)

Figure 19 is an illustration of coherent change detection application in X-band. In the coherent image, wheels traces are clearly visible on the ground and reflect the passage of a vehicle between the two measurements. The amplitude image does not allow to identify this activity.

![Figure 19. Coherent change detection](image)

V. PERSPECTIVE AND CONCLUSION

ONERA developed highly modular and flexible airborne experimental SAR system complemented by optical sensors. The system design based on two pods is compatible with any types of aircraft of the Falcon 20 classes. RAMSES NG is now upgraded with two axes motorized which allows spotlight mode, it is also included significant maximum range improvement at X-band, up to 60 km and very high resolution (over 3 GHz bandwith).

Next step will consist of adding a new multichannel antenna which will add a GMTI and STAP capacity to RAMSES NG, such system will be operated in 2014.

ACKNOWLEDGMENT

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Figure 19. Coherence detection illustration

REFERENCES