

Sentinel-2 NG SWIR Detector

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ABSTRACT

Several Copernicus missions are currently based on LYNRED SWIR detectors and are delivering state-of-the-art data on a daily basis, such as Sentinel-2 and Sentinel-5. Copernicus Expansion missions being developed will also benefit from LYNRED SWIR technology for the LSTM VNIR-SWIR and CO2M SWIR detectors. LYNRED benefits from the largest heritage (space proven) in infrared detection in the SWIR domain in Europe.

ESA is now preparing the Copernicus NG missions. The challenge of the Sentinel-2 NG mission is to ensure continuity with the current Sentinel-2 mission while enhancing observing capabilities. Improvement of the spatial sampling distance as well as addition of new spectral bands is requested, which is directly linked to the detector design. LYNRED has been selected by ESA in 2023 for the pre-development of the Sentinel-2 NG SWIR detector. The objective of the detector pre-development phase is to demonstrate a TRL5, by the end of 2026, for a detector specifically designed for the mission. In that purpose, ESA, LYNRED, ADS and OHB (the two selected S2 NG AB1 instrument primes) have been working together to propose the best detector design, adapted to both instruments, and fully fitting the mission goals. This paper presents the Sentinel-2 NG SWIR detector design and verified performances.

Keywords: LYNRED, SWIR, Detector, Sentinel-2 NG

1. INTRODUCTION

For more than 20 years, LYNRED has been involved in the development and the production of high quality and high reliability SWIR detectors for earth observation applications [1] [2]. SWIR staring arrays and SWIR linear arrays have been successfully developed. The next figure presents the timeline of LYNRED SWIR detectors development, mission notification and launch date. To date, more than 100 SWIR flight models have been successfully delivered by LYNRED.

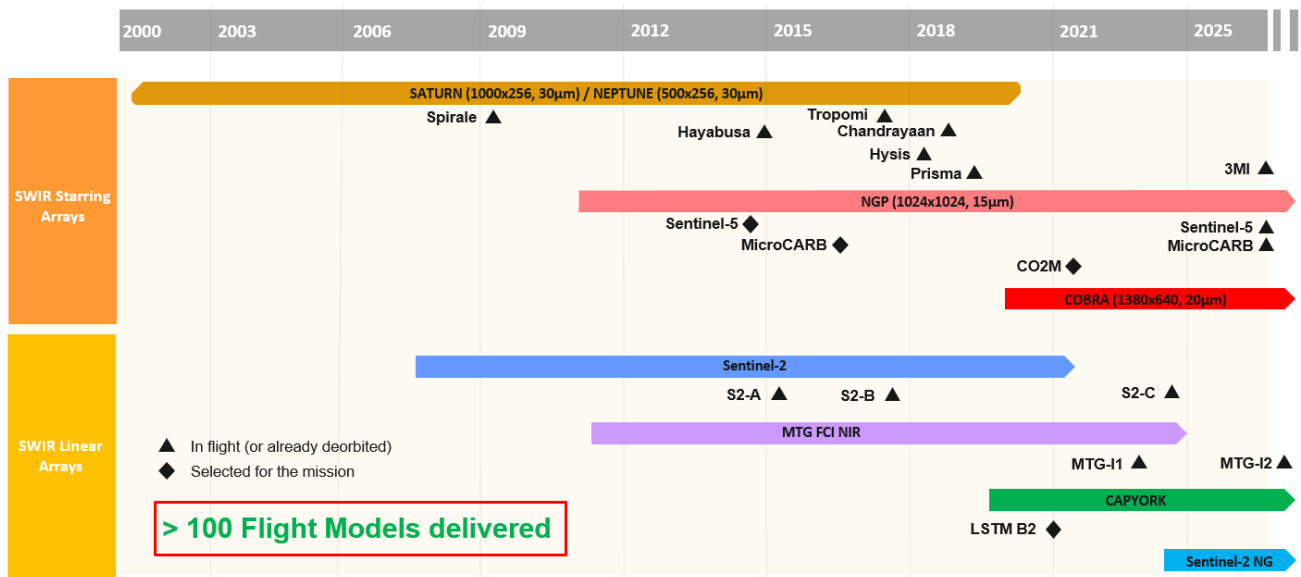


Figure 1. LYNRED SWIR detectors heritage.

SWIR detectors have been produced since the early 2000's with the famous SATURN / NEPTUNE family, 1000x256 or 500x256 30μm pitch detectors. Several missions based on these detectors are currently in flight. The 15μm pitch was then introduced with the Sentinel 2 SWIR detector development in the mid 2000's (see next figure). S2 A/B/C are currently in-flight and at the heart of the Copernicus Sentinel 2 mission, delivering state of the art images on a daily basis (see next figure).

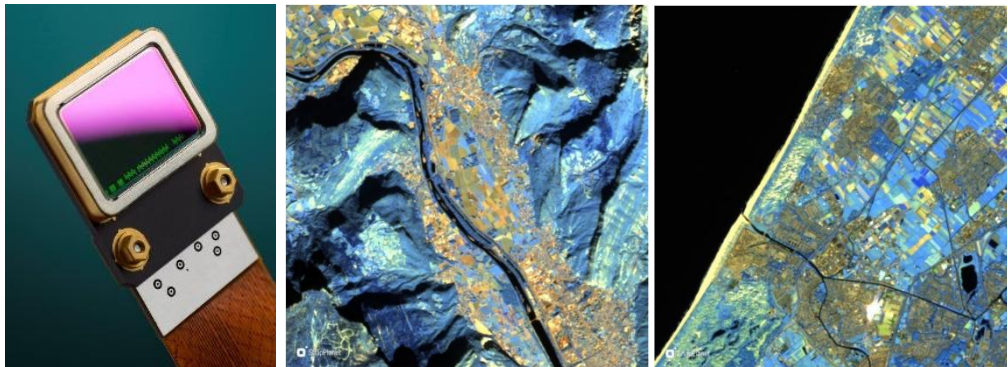


Figure 2. Sentinel 2 SWIR Detector (left). S2B SWIR image of LYNRED facilities at Veurey-Voroize (France) (middle). S2B SWIR image of ESA-ESTEC facilities at Noordwijk (the Netherlands). Courtesy of SnapPlanet.

LYNRED was selected by ESA in 2024 to develop the Sentinel-2 NG (S2NG) SWIR detector through the mission A-B1 phase. The objective of this phase is to demonstrate a TRL5 maturity by the end of 2026. Both A-B1 primes OHB and ADS were extensively involved in the detector architecture choices, under ESA supervision, to make sure that the detector is fully adapted to both possible instruments.

This paper intends to present the Sentinel-2 NG SWIR Detector. A brief description of the Sentinel-2 NG mission novelties compared to the current Sentinel-2 mission is provided to clarify the proposed detector architecture. The detector itself is then described, together with its verified performance. Finally, the industrial challenges of the Sentinel-2 NG mission and LYNRED's industrial capabilities are discussed.

2. SENTINEL-2 NG MISSION IMPROVEMENTS AND RELATED SWIR DETECTOR DESIGN

The current Sentinel-2 mission provides high-resolution, multi-spectral imaging through the optical Multi-Spectral Instrument (MSI). It offers 13 spectral bands from visible (443nm) to short wave infrared (2.2 μ m), divided in two focal planes: CMOS detectors for VIS-VNIR, MCT hybridized detectors for SWIR. Each focal plane is composed of 12 staggered detectors. LYNRED was responsible for the delivery of the SWIR detectors, covering the B10 (1.37 μ m), B11 (1.61 μ m) and B12 (2.2 μ m) SWIR bands.

The main objective of the Sentinel-2 NG mission is to guarantee continuity of high-quality multi-spectral imaging, and to enhance observing capabilities. While heritage spectral bands are maintained, a set of new spectral bands are requested in order to propose new applications. Additionally the requested spatial sampling distance is divided by a factor of two.

Regarding the SWIR detectors, the main impacts of the NG mission requirements concern the number of spectral bands, the number of pixels in a row, and the total number of SWIR detectors to be delivered to populate one FM focal plane. A comparison of these parameters between Sentinel-2 and Sentinel-2 NG is given in the next table.

	Sentinel-2	Sentinel-2 NG
SWIR spectral bands (central wavelength)	B10 (1.37 μ m), B11 (1.61 μ m), B12 (2.2 μ m)	B10 (1.37 μ m), B11 (1.61 μ m), B12a (2.13 μ m), B12b (2.21 μ m), B12c (2.26 μ m)
Number of pixels in a row	1298	1978
Number of detectors per focal plane	12	15

Table 1. Comparison between Sentinel-2 and Sentinel-2 NG missions on some detector related parameters.

The addition of new spectral bands and more pixels in a row, while enhancing the proposed SNR, is a technical challenge. Moreover, all the detectors necessary to populate the two Sentinel-2 NG satellites (30 FM detectors and some FM spares) are to be delivered in a time frame of 18 months. An industrial challenge is then added to the technical challenge for the Sentinel-2 NG mission. LYNRED strong heritage in space detectors associated to performant industrial capabilities intend to propose the best answer to the Sentinel-2 NG mission challenges.

3. SENTINEL-2 NG SWIR DETECTOR DESCRIPTION

The S2NG SWIR Detector have been specifically designed for the S2NG mission. It is a packaged Infrared Focal Plane Array (IRFPA) based on a Mercury Cadmium Telluride (MCT) detection circuit with well-mastered intrinsic doping, hybridized onto a CMOS readout circuit (ROIC). It operates in the SWIR domain ([0.9 μ m, 2.5 μ m]) for focal plane temperatures ranging from 150K to 200K. S2NG operational temperature is 190K. The package is an open cooler-less design based on a molybdenum baseplate, a flexi cable and a connector. This package design previously showed its robustness through qualification for several space missions (MTG IRS, METIMAGE, TRISHNA, LSTM). The S2NG SWIR detector is presented in the next figure.

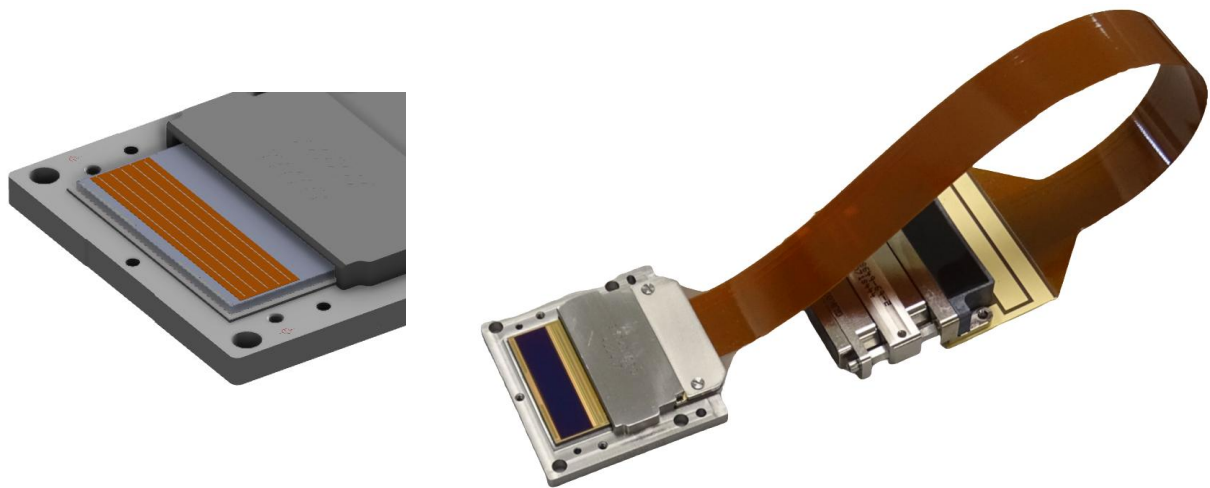


Figure 3. IRFPA integrated onto the molybdenum baseplate (3D view, left), full S2NG SWIR detector (photo, right).

ROIC

The ROIC format is adjusted to the specific mission need. The main format drivers are:

- number of bands, **5**: adapted to the 5 SWIR spectral bands of the mission
- number of columns, **1988** (1978 active): maximized to minimize the number of detectors per focal plane
- number of rows per band, **8**: to increase the SNR by external TDI
- reference pixels: for real time offset correction
- programmable format: to adjust the number of outputted rows and the distribution of reference pixel rows to the exact mission need

The S2NG SWIR ROIC format is described in the next figure.

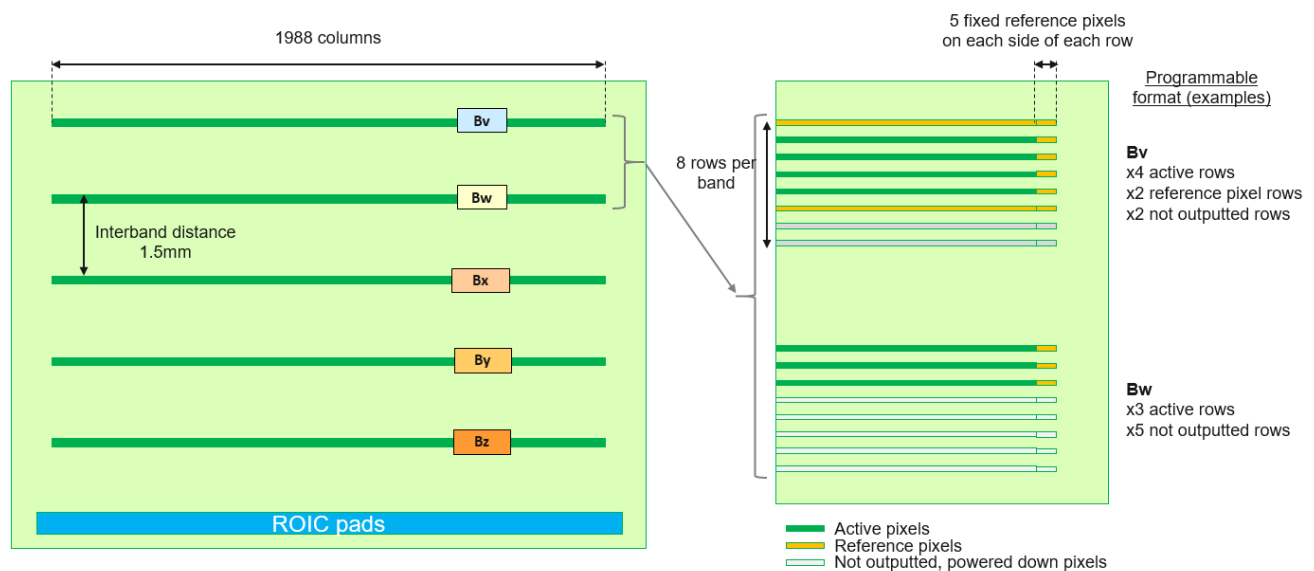


Figure 4. S2NG SWIR ROIC format. 5 bands of 8 rows, programmable format.

The pixel pitch is 15 μ m. The ROIC input stage type is capacitive transimpedance amplifier (CTIA) and offers three operational gains: 80ke-, 285ke- and 325ke-. On-chip correlated double sampling (CDS) is available for each gain in order to reduce the readout noise and optimize the signal to noise ratio (SNR) performance. Snapshot integration and different

reading modes are proposed: Integration While Read (IWR), Integration Then Read (ITR), multiple non-destructive reading.

The ROIC operates with seven analog outputs, and proposes a maximum full frame rate of 710Hz. Frame rate can be increased if less rows are outputted. For example a frame rate of 1400Hz is possible if only four rows per band are outputted.

Finally, the design is optimized to offer the possibility of staggering the detectors at focal plane level. ROIC pads are gathered on one side of the ROIC, interband distance is optimized to group the bands as close as possible to the ROIC edge.

Detection circuit

The detection circuit is made of MCT. The cut-off wavelength is adjusted to the required $2.5\mu\text{m}$ by adjusting the alloy composition. LYNRED uses its standard SWIR $15\mu\text{m}$ pitch with intrinsically doped active layer by mercury vacancies [3] space proven technology (Sentinel-2, Sentinel-5, CO2M, LSTM B2, ...), adapted to the S2NG ROIC format. It is hybridized onto the ROIC using LYNRED standard flip chip space proven technology, and benefits from an anti-reflective coating to optimize performances and reduce light reflection into the instrument. No major evolutions of the detection circuit or the hybridized circuit are proposed, apart from the format, in order to maximize the benefit of LYNRED's large heritage and secure flight models delivery and robustness to the mission.

4. MAIN DETECTOR PERFORMANCES

The performance evaluation is performed at detector level (and not IRFPA only), which is representative of the mission configuration. Especially the impact of the interconnection on the electrical performances (capacitive load of the flexi cable) is part of the measured performances. Most of the following performances are measured with all 40 rows selected and outputted, which is probably a worst case compared to the future mission need. Indeed the number of outputted rows will be adjusted, per band, as a tradeoff between SNR, reference pixel row need, and pixel frequency (a lower pixel frequency offers more margin to the front-end electronics to sample the pixel signal). The temperature of the detector is set at 190K. The ROIC setpoint (in terms of settling time, power management, chronograms adjustments, ...) is determined by early ROIC testing before going to full performances characterization.

All the results presented in the following are preliminary, as the detector characterization campaign is on-going.

ROIC performances

Power dissipation

Current of each power supply is measured. Power dissipation is the sum of each power supply product voltage*current.

Temporal ReadOut Noise (TRON)

TRON is the standard deviation of the output level with low integration time in dark conditions, over 1000 frames. It is the ROIC contribution to the total noise included in the SNR.

Charge Handling Capacitance (CHC)

CHC is the linear part of the well fill.

Non-linearity

Flux (respectively integration time) linearity is the response of the detector to a linear ramp of input irradiances (respectively integration times). Non-linearity is the gap to the perfect ramp.

The total power dissipation is measured at 190mW, which is compliant to ESA requirement (200mW) and will facilitate the instrument thermal design and stability.

The below table presents the measured values, for each gain, of the charge handling capacity (CHC) and the readout noise (TRON) expressed in both microvolts and electrons. While CHC values are at the expected level, the readout noises are lower than the design values. Final SNR will benefit from these low readout noises. All these values are compliant to ESA requirements.

	Gain 1	Gain 2	Gain 3
CHC (ke-)	90	280	325
TRON (μV)	355	250	245
TRON (e-)	16	37	42

Table 2. Measured CHC and TRON for each gain. CDS ON.

The detector is characterized in terms of linearity as a function of both integration time and flux, as presented in the next figure. The integration time linearity ensures that the detector will behave linearly in case a change of integration time is needed (between bands, for a specific measurement, ...). The flux linearity is necessary to properly assess the input flux when measuring the detector signal, which is the objective of the detector during the mission. Both integration time and flux non-linearity show very low level, well below ESA requirement of 1%. The flux linearity presented here is preliminary, a full measurement on the specified irradiance range is being performed at LYNRED. Nevertheless, these two characterization steps show that the detector is behaving as expected.

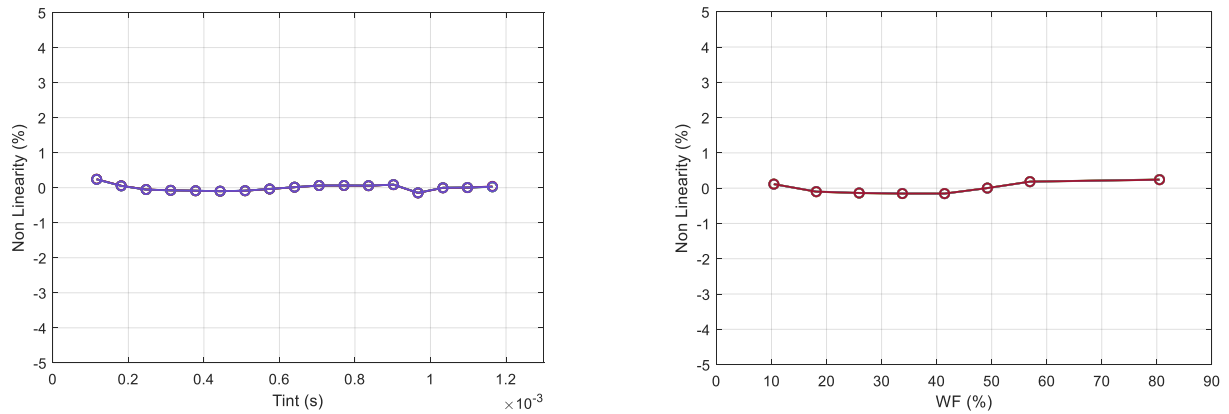


Figure 5. Measured non-linearity as a function of the integration time (left). Measured non-linearity as a function of the flux (preliminary), expressed in detector well filling (right).

Detection circuit performances

Dark current density

Variation of the output voltage for different integration times in dark conditions. Dark current contributes negatively to the SNR through its shot noise. Dark current sensitivity to temperature is calculated by measuring the dark current density for several temperatures.

Spectral Detection Efficiency (SDE)

SDE is the relative response of the detector to different wavelengths. It is measured using a spectrometer. The absolute SDE (also called quantum efficiency) is the absolute response of the detector to an input irradiance at a given wavelength, measured with band-pass filters on a radiometric test bench. Standard deviation (in %) is the Photo-Response Non Uniformity (PRNU).

The dark current density and related performances are measured in a closed cryostat, to ensure no parasitic flux impacts the measurement. The next figure presents the dark current density histogram measured on one band at 190K, and the fluctuation of the dark current density as a function of the temperature. The measured histogram shows a median value of $0.2 \text{ fA}/\mu\text{m}^2$ which is close to the typical expected value for this technology and below ESA requirement ($0.5 \text{ fA}/\mu\text{m}^2$). The pixel to pixel dispersion is contained well below $1 \text{ fA}/\mu\text{m}^2$. The dark current fluctuation with temperature traduces the dark current regime. These tests confirm that the dark current is fully mastered: at a very low level and in the expected regime. All the bands were successfully tested with similar results.

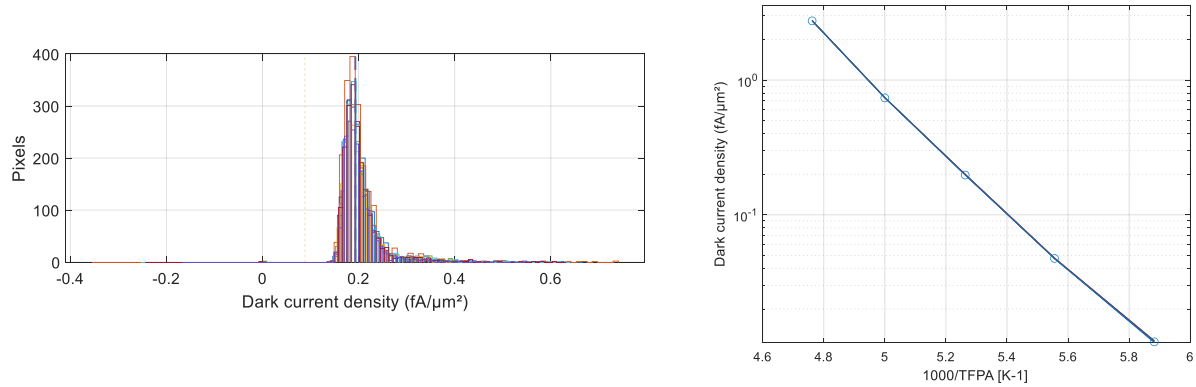


Figure 6. Measured dark current density (@190K) histogram for one band (left). Measured dark current sensitivity to temperature (right).

The spectral detection efficiency (SDE) is firstly measured over a large wavelength range in order to characterize the detector cut-on and cut-off wavelengths, and ensure that the spectral behavior is as expected. This result is given in the next figure for the temperature of 190K. The measured cut-off is 2.5 μm, the SDE is flat over the SWIR range [0.9μm, 2.5μm] with some expected low frequency variation due to the anti-reflective coating. Then the absolute value of the SDE, per band, is tested using bandpass filters representative of the specified spectral bands. The test results for the B11 spectral band (central wavelength 1.6μm) is presented in the next figure. The SDE @ 1.6μm is higher than 0.8 which is compliant to ESA requirement. The pixel to pixel dispersion is very low, for a corresponding photo-response non uniformity (PRNU) of 1%, well below ESA requirement (5%).

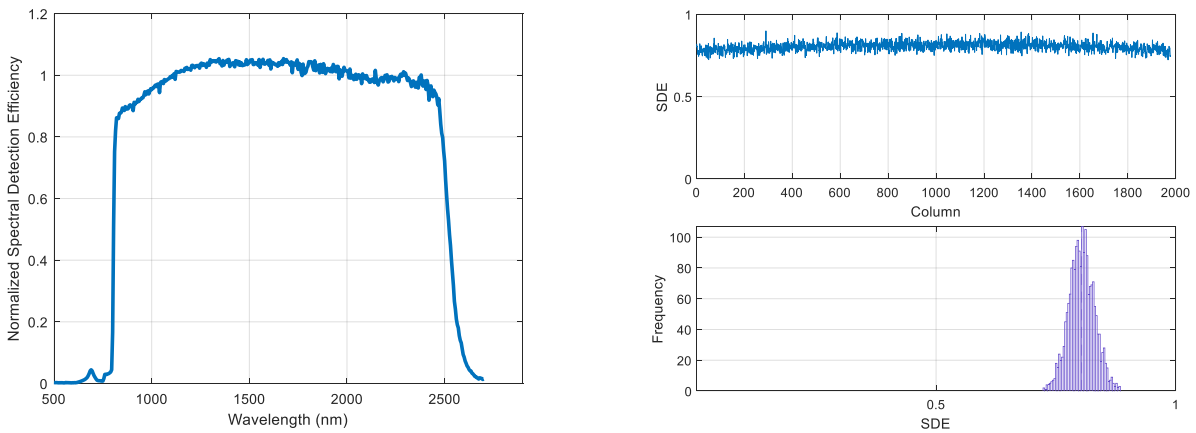


Figure 7. Normalized SDE (@190K) (left). Absolute SDE (@1.6μm, @190K) for all pixels of one row (top right). Corresponding histogram (bottom right).

Full characterization of the detector, including signal to noise ratio and operability is on-going at LYNRED and will be finalized by the end of 2026 to confirm the full adequacy of the detector to the S2NG requirements.

5. LYNRED INDUSTRIAL CAPABILITIES

The S2NG SWIR detector is a hybrid detector based on a detection circuit hybridized on a CMOS readout circuit. The core technologies of this detector (detection circuit, readout circuit and hybridization) are shared with all the hybrid detectors produced by LYNRED for ground applications. LYNRED produced and delivered several thousands of hybrid detectors in 2025, and plan to increase deliveries in 2026 and the following years. Dedicated LYNRED teams constantly monitor the equipments and processes to prevent any drift in the detectors performances. The production line is mature and robust. Space detectors IRFPAs are produced on the same production line. As such they benefit from all the in-line

controls and monitoring that make volume production possible. Moreover LYNRED manufacturing facilities at Veurey-Voroize has recently been increased to reach 8000 m² of state-of-the-art clean room (see next figure), in order to secure volume production.

Regarding space detectors more specifically, LYNRED demonstrated its industrial capability through the flight model production of all the programs previously cited. On overview of the in-flight (or mission successfully ended) LYNRED detectors is presented in the next figure. Particularly, the FM production of S2 A/B and C/D demonstrated the production, fine testing and delivery of more than 50 flight models of the same detector. LYNRED put to good use the lessons learned from the S2 A/B and C/D programs. Main bottlenecks and specific actions were identified in the different parts of the organization: supplies, front end and back end activities, testing and validation, program management. LYNRED proposed industrial plan securing the B2CD phase of the S2NG program directly benefits from this experience, and is currently being validated through the S2NG AB1 phase.



Figure 8. LYNRED space heritage: in-flight detectors, or mission successfully ended (top). LYNRED development and production center (bottom).

6. CONCLUSION

In this paper, a full description of the S2NG SWIR detector is realized. Measured preliminary performances (@190K) are described. The detector power dissipation is 190mW. It offers three operational gains with CHC of 90ke-, 280ke- and 325ke-, and corresponding readout noises of 16e-, 37e- and 42e-. The non-linearity is measured well below 1%. The dark current density at operating temperature is evaluated at 0.2 fA/ μm^2 and the quantum efficiency higher than 0.8 with a flat response over the SWIR range. All these performances are fully compliant to ESA requirements for the mission. Characterization is on-going at LYNRED and will be completed by the end of 2026.

Moreover, LYNRED benefits from mature industrial capacities, recently increased by major investments in new facilities. Specific bottlenecks regarding supplies, manufacturing and testing are being resolved in the frame of the S2NG AB1 phase. LYNRED is thus in line to propose the S2NG SWIR detector: fully compliant to the performances requirement, as well as industrially mature to secure the delivery of the required number of flight models.

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