

COBRA CRYOXs: NEW COMPACT & LIGHTWEIGHT IDDCA CONFIGURATION FOR HYPERSPECTRAL & SPECTRO-IMAGING SPACE APPLICATIONS

Quentin Chable^{1*}, Emmanuel Larique¹, Léa Junay¹, Frederic Mousseau¹, Sandra Eynard Machet¹, Antoine Genies¹, Diane Sam-Giao¹, Sebastien Aufranc¹

¹LYNRED, Actipole - CS 10021, 364 route de Valence, 38113 Veurey-Voroize, France

*quentin.chable@lynred.com

ABSTRACT

SWIR spectral range is of main importance in Earth observation applications. Spectro-imager, multispectral imager and hyperspectral imager instruments all use detectors operating in the SWIR domain. LYNRED has been proposing SWIR detectors for space applications for a long time. Many of them are currently used in operating missions, such as ESA SENTINEL 2, ESA MTG FCI, JAXA HAYABUSA, ASI PRISMA, ISRO CHANDRAYAAN ... Over the last 20 years, LYNRED has delivered more than 100 SWIR detector flight models.

More recently, LYNRED has developed a new generation of SWIR staring array detector for space applications named COBRA to address future hyperspectral and spectro-imaging applications. This detector has a larger format (1380x640, 20 μ m pitch) than previous generation, allowing a higher spatial and spectral resolution, as well as optimized gains and new functionalities to increase electro-optical performances (e.g. on chip CDS). In this paper, detector design is first recalled and then electro-optical performances and environmental validation are presented.

Additionally, LYNRED has been developing an Integrated Detector Dewar Cooler Assembly (IDDCA) architecture fitted for space environment in order to provide a ready to use solution compatible with COBRA detector for its customers. Detailed architecture is presented. Possible geometry variations such as cryocooler or optics alternative designs will also be discussed.

Keywords: SWIR, Detector, IDDCA, COBRA, spectro-imager, hyperspectral imager

INTRODUCTION

Environment monitoring has become a key element to better understand and adapt to climate change. Earth observation from space plays a major role in this field by using instruments that sample images at different wavelengths and thus allow separating and identifying details of Earth mostly using SWIR (0.9-2.5 μ m) or LWIR (8-15 μ m) bands. Three imaging solutions are mostly used:

- Multispectral imaging : a limited number of wavelengths is sampled to monitor particular parameters of Earth (e.g cloud type, gas signature...) and often relies on linear arrays coupled with bandpass filters;
- Hyperspectral imaging: image is decomposed in several narrow wavelength bands to get a large panel of information regarding Earth such as vegetation identification or ground composition. Staring arrays are preferred to get both high frequency operating point and resolution;
- Spectro-imaging: Composition of atmosphere is deduced from infrared absorption signature of imaged chemical species. In that case staring arrays are also mainly used as high spatial resolution and state of the art radiometric performances to correctly sample the low flux levels associated to this type of application.

In the past 20 years, LYNRED has contributed to several missions using SWIR imaging such as ESA Land Surface Temperature Monitoring (LSTM) or ESA Copernicus SENTINEL 2, which use linear arrays for multispectral imaging, ESA Copernicus SENTINEL 5 and CO2M missions [1] based on a NGP staring array to perform spectro-imaging or ASI

PRISMA using a SATURN detector for hyperspectral imaging. More recently, in order to prepare the next generation of SWIR hyperspectral and spectro-imaging missions, LYNRED has developed a new staring array named COBRA based on technical specifications discussed with spatial agencies. In parallel, LYNRED has also worked on developing an Integrated Detector Dewar Cooler Assembly (IDDCA) architecture compatible with space environment to provide a ready to use solution for its customers either for COBRA detector or for other LYNRED space detectors (CAPYORK, PEGA, NGP...).

This paper first presents COBRA InfraRed Focal Plane Array (IRFPA) design as well as its electro-optical performances and validation results. Then IDDCA architecture is detailed with the different sub-geometries available and environmental stress tests are discussed.

1. COBRA IRFPA DESIGN

COBRA IRFPA is the successor of LYNRED NGP detector (1024x1024 pixels, 15 μ m pitch) and its design was driven by 4 main requirements to address future Earth observation missions:

- ✓ More spectral channels;
- ✓ Higher resolution of the images;
- ✓ Power saving design meaning focus on power consumption;
- ✓ Versatility to adapt to different applications with new ROIC functionalities.

The first two points are addressed with the chosen array geometry as COBRA is a 1380*640 pixels array with pixel pitch of 20 μ m and thus much larger than NGP detector as shown below :

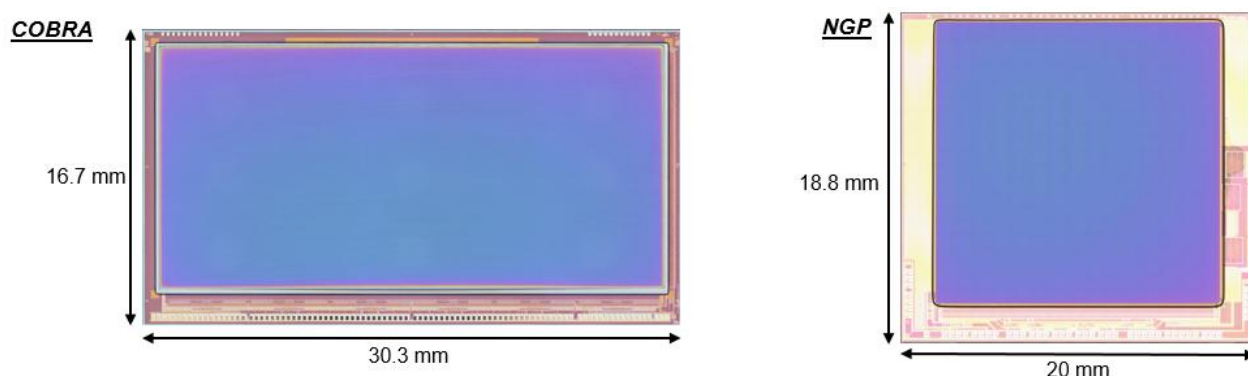


Figure 1 : COBRA IRFPA (on left) vs NGP IRFPA (on right)

Pixel has a CTIA input stage and two integration capacitances are available. Additionally an on-chip Correlated Double Sampling (CDS) functionality has been implemented with the high gain at pixel level to further reduce the readout noise. This flexible design allows to target different flux ranges and address low flux while keeping good Signal to Noise Ratio (SNR).

	Low gain	High gain
Integration capacitance (fF)	126	14.6
Charge Handling Capacitance (ke-)	1309	142

Table 1 : COBRA integration capacitance and CHC

ROIC nominally works at a pixel masterclock of 10MHz to reach a frame rate of 130Hz in Integration When Read (IWR) mode with 12 analog outputs. Integration Then Read (ITR) and non destructive multi-reading modes can also be used. A line selection functionality is also available to perform windowing anywhere on the image and increase frame rate if needed. For instance a windowing of 258 rows leads to a maximum frame rate of 325Hz. Additionally for power saving

considerations, an alternative output mode is available with only 6 of the 12 analog outputs being used for applications compatibles with lower frame rates.

Finally it is possible to adjust the electrical interface to reach a 2Me^- Charge Handling Capacitance (CHC) in low gain with an associated power consumption of 320mW.

2. COBRA PERFORMANCES

COBRA IRFPAs have been tested at LYNRED to evaluate electro-optical performances linked either to ROIC or MCT detection circuit. Most tests were performed with and without CDS mode for high gain full frame and with all 12 analog outputs used. Temperature of Focal Plane Array (TFPA) was set to 150K and two frame time were tested :

- Scenario 1 : frame time of 12ms with integration time of 10.5 ms for dark configuration
- Scenario 2 : frame time of 50ms with integration time of 48.5 ms for other test configurations

Please note that functional tests were also performed ensuring COBRA detector can be used up to 200K.

ROIC performances

Power consumption

Current of each power supply is measured. Power consumption 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.

Power consumption was measured at 220mW in 12 outputs full frame settings which is low considering format and frequency.

TRON and electrical output video are given below. One can note that CDS mode for high gain gives a very low ($<50\text{e}^-$) readout noise with homogeneous behavior :

	High gain	Low gain	High gain with CDS
Median TRON (μV)	1094	428	335
Median TRON (e^-)	99	338	45
Electrical Output Vidéo (V)	1.254	1.182	1.147

Table 2 : Readout noise and electrical output video

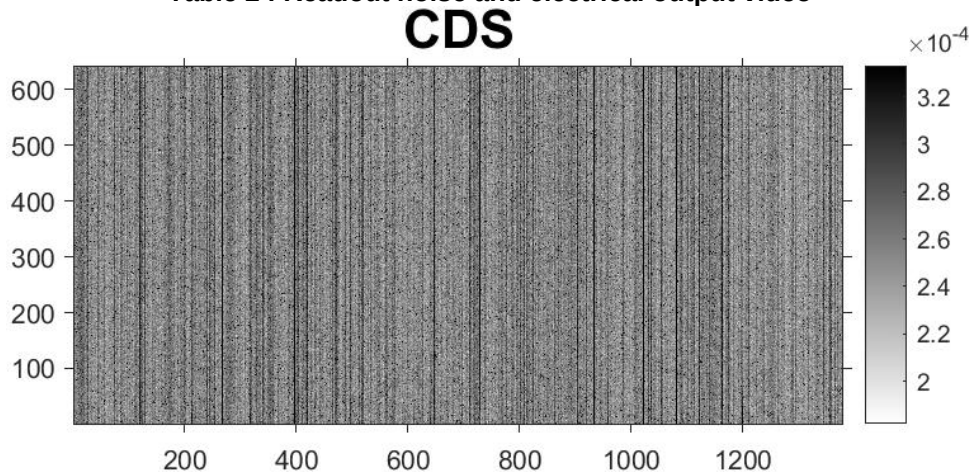


Figure 2 : ROIC noise (μV) cartography in CDS mode

Detection circuit and detector performances

Dark current density

Variation of the output voltage for different integration times in dark conditions. Expressed in current [$\text{fA}/\mu\text{m}^2$] using the Charge to Voltage Conversion factor (CVF) and integration capacitance. Dark current contributes negatively to the SNR through its shot noise. Standard deviation (in %) is the Dark Signal Non Uniformity (DSNU).

Signal to Noise Ratio (SNR)

SNR is the ratio of useful photonic signal over total noise, measured at a given irradiance.

Spectral Detection Efficiency (SDE)

SDE is the absolute response of the detector to an input irradiance. Standard deviation (in %) is the Photo-Response Non Uniformity (PRNU).

Non-linearity

Flux linearity is the response of the detector to a linear ramp of input irradiances. Non linearity is the gap to the perfect ramp.

Modulation Transfer Function (MTF)

MTF is a measurement of the detector capacity to resolve spatial frequencies. Measured on both axis for several pixels across the matrix.

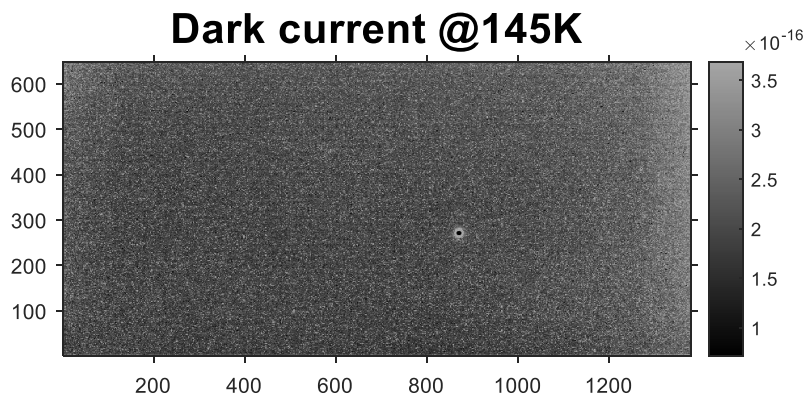
Temporal lag

Temporal lag is the residual level after an irradiance abrupt transition. Residual level is calculated by subtracting the level long after the transition (where there is no lag).

Detection circuit is made of an active layer of Mercury Cadmium Telluride (MCT). Its dark current density at 145 and 150K results are close to expected results, based on LYNRED SWIR technology knowledge, verified on other SWIR detectors, and associated DSNU and Dark Signal Fluctuation (DSF) are also at expected level. Additionally Random Telegraphic Signal (RTS) [2] pixels were also evaluated in dark configuration and detected number is very low, about 0.1%, with a threshold set at 3 times the median RMS noise :

Tfpa (K)	Dark current density ($\text{A}/\mu\text{m}^2$)	DSNU (%)	DSF (%/K)
145	5.59e-19	23.5	19.4
150	1.75e-18	23.1	/

Table 3 : COBRA dark current density, DSNU and DSF



RTS cartography Operability : 99.9%

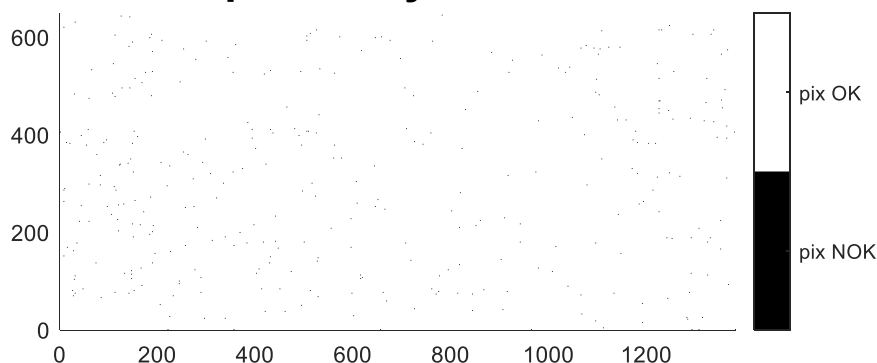


Figure 3 : Dark current cartography @145K and RTS operability

COBRA IRFPA radiometric performances are summarized below with responsivity and Photo-Response Non Uniformity (PRNU) showing a very good uniformity and very low number of defects (defined as pixels outside of median value $\pm 30\%$ range) and thus very good SNR operability:

	Median	Mean $\pm 80\%$	$\sigma \pm 80\%$	Defect number
Responsivity (V/ph) @2 μm	8.32e-6	8.32e-6	2.4	609 (0.07%)
PRNU (%)	1.6	1.5	48.9	834 (0.09%)

Table 4 : Responsivity and PRNU

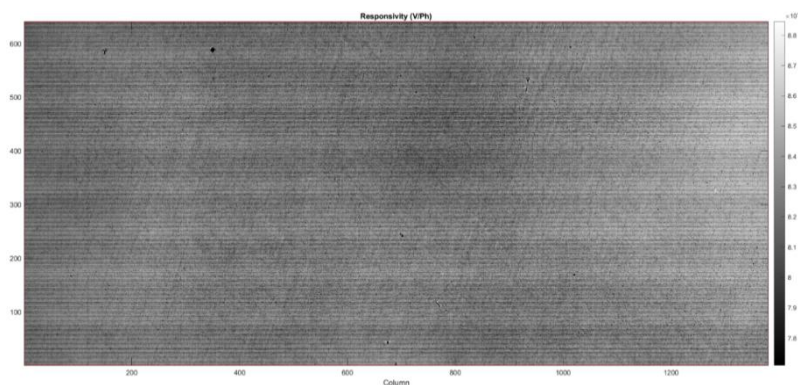


Figure 4 : Responsivity cartography

Spectral response was measured and used with the measured responsivity to evaluate absolute Spectral Detection Efficiency (SDE) giving a value of 75% at 1.6 μm on this tested IRFPA:

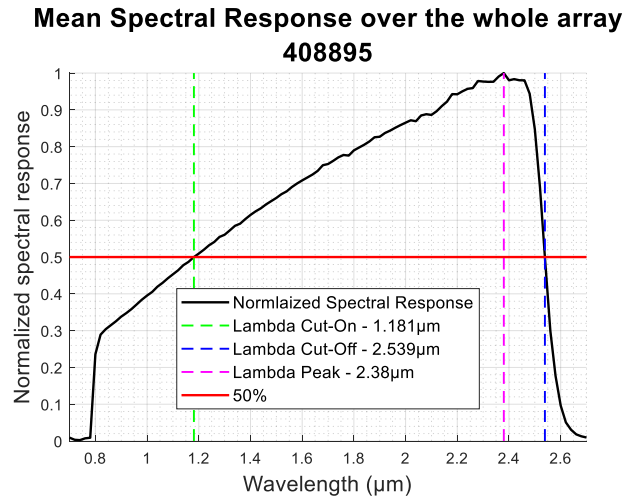
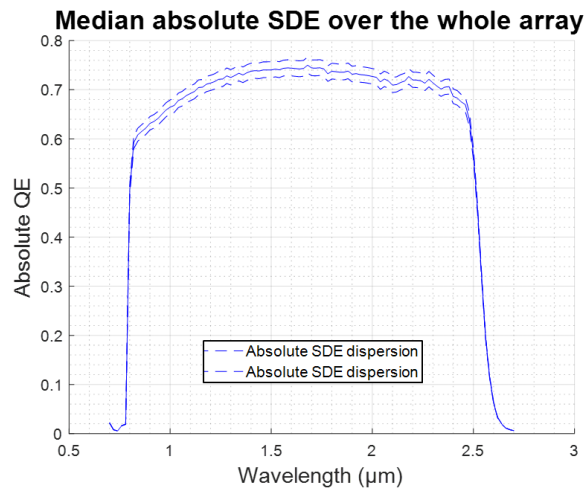


Figure 5 : COBRA spectral response and SDE

Flux non-linearity as a function of well-fill is indicated in following figure and is well below 1% :

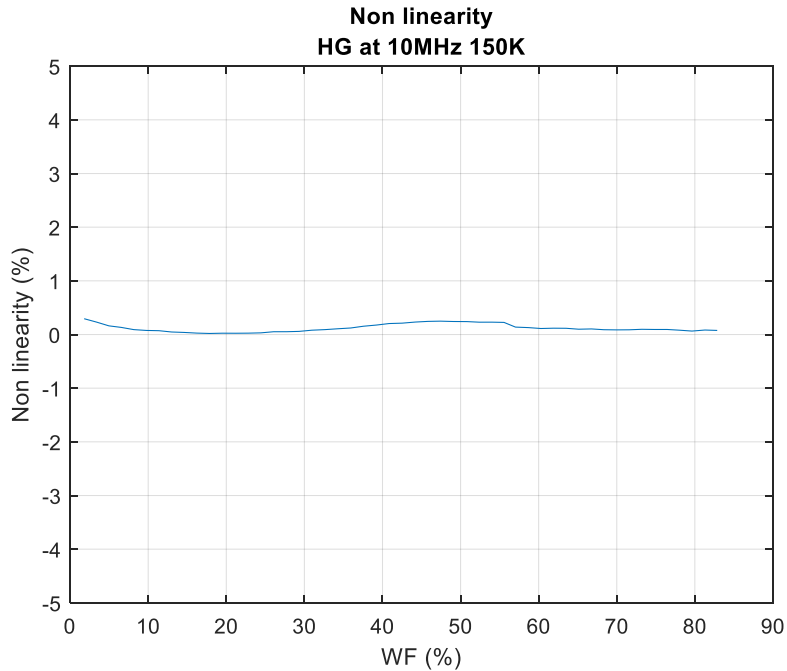


Figure 6 : Non-linearity

Finally Modulation Transfer Function (MTF), measured with knife edge method [3], and lag measurements are presented below. Remarkable MTF performance is obtained with a value of 0.53 at Nyquist frequency, and lag is very good as it is inferior to 0.15% (-56dB) on first frame after transition:

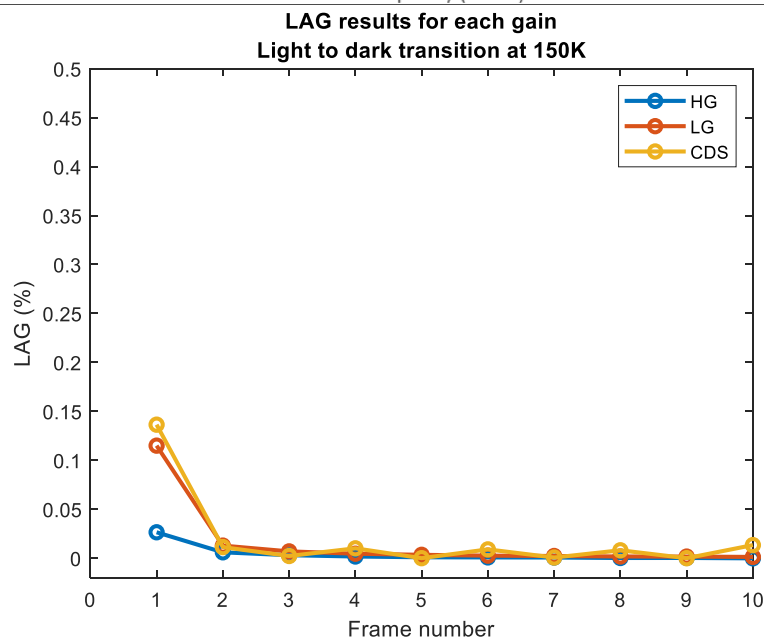
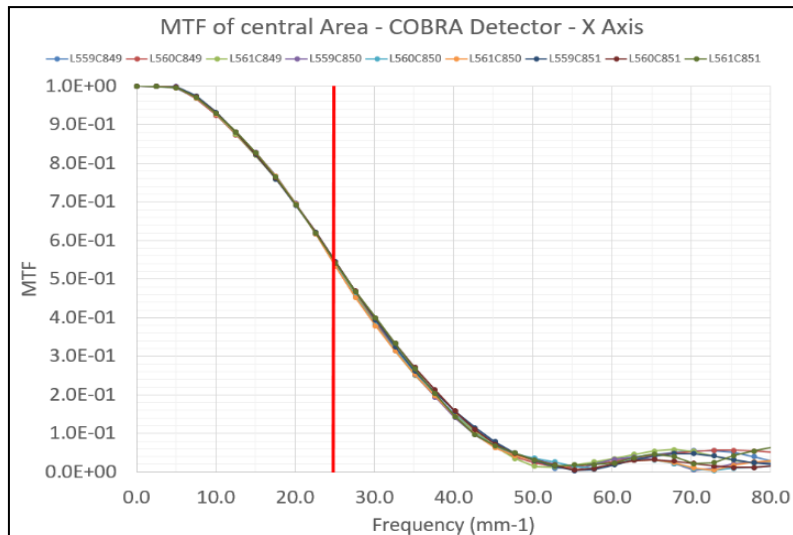


Figure 7 : COBRA MTF and lag

Overall COBRA detector shows very good electro-optical performances, with low readout noise and lag for instance, and high operability.

Environmental stress validation has also been performed :

- Heavy ions radiations on ROIC;
- ElectroStatic Discharge (ESD) on ROIC;
- Thermal cycling on IRFPA;
- High Temperature Storage (HTS) on IRFPA.

Heavy ions test shows that COBRA ROIC is latch-up free and availability rate calculated based on typical mission profile are acceptable. Regarding ESD test, COBRA ROIC is class 2. At IRFPA level no evolution were observed after thermal cycling and HTS on typical mission profile.

3. CRYO XS IDDCA ARCHITECTURE

CRYO XS design was thought to be versatile to address several mission profiles using LYNRED detectors depending on required lifespan, power consumption, weight and optical configuration. LYNRED has first developed CRYO XS-R version using COBRA detector with a THALES RM3 rotary cryocooler (RICOR K508 cryocooler can also be used) and a non-telecentric optical aperture equipped with a bandpass window with a transmittance >90% in [0.9-2.5] μm range. A cold filter can be added on top of the cold shield if needed:



Figure 8 : CRYO-XS-R, non-telecentric version

First ICCDAs have been manufactured and initial EO tests performed before starting qualification.

IDDCA characteristics are:

- Dimensions : 85 x 64 x 152 mm² ;
- Mass: 675g $\pm 10\%$;
- Power consumption : <4.5Wdc @22°C in steady state;
- Operating temperature : from -40°C to +71°C;
- MTTF: >20000h @24/7.

CRYO-XS design is also compatible with a telecentric aperture and cold filter close to IRFPA on demand. Other optical elements (window, cold filter) can also be tuned depending on customer need.

Finally for missions requiring long MTTF >60000h CRYO-XS could be used with Pulse-Tube (PT) cryocoolers with an adjustment of a few interface parts only to switch from CRYO-XS-R to -PT configuration.

Currently two designs with PT cryocoolers are available at LYNRED and could be proposed to customers:

- CRYO-XS PT with cryocooler LPT-9511 from THALES for SWIR & MWIR applications;
- CRYO-XS PT with cryocooler LPT-6510 from THALES for MWIR & (V)LWIR applications.

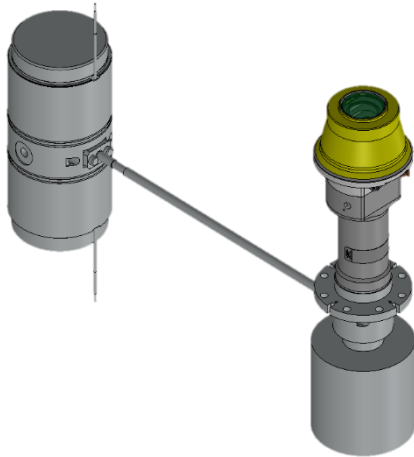


Figure 9 : CRYO-XS-PT with LPT-9511

CRYO-XS PT with cryocooler LPT-9511 is under development at LYNRED with a thermo-mechanical qualification planned in order to propose this configuration to customers.

Qualification for environmental aspects (shocks and vibrations) is currently ongoing on CRYO-XS-R configuration. Mechanical simulations were performed to validate proposed qualification levels and preliminary tests were successfully done on CRYO-XS-R as derisking activities.

Qualification levels are summarized in tables below :

Mechanical shocks		Random vibrations		Sinusoidal vibrations	
Frequency (Hz)	SRC (g)	Frequencies	PSD (g^2/Hz) Qualification	Frequencies (Hz)	Displacement (mm) or Amplitude (g)
[100 - 600]	+ 15 dB/Oct	20 - 100 Hz	+3 dB/Oct	[5-15]	10 mm
[600 - 4 000]	350 g	100 - 700 Hz	0.1 g^2/Hz		(zero-pic)
[4000 - 10 000]	- 6 dB/Oct	700 - 2000 Hz	-3 dB/Oct	[15-50]	10 g
		Overall 'g' RMS	11.8 g	[50-100]	6 g
		Duration	2 min per axis		

Table 2 : CRYO-XS-R qualification levels

4. CONCLUSION

LYNRED has developed and fully characterized a new large staring array named COBRA. The design was driven by the new mission requirements and the Lynred vision, which was consolidated by customer needs for the next generation of SWIR imaging . We achieved the electro-optical performance required by the design target and the mission needs. In parallel, a new generation of IDCDA with versatile designs to address several mission profiles has been developed and manufactured. The first EO and qualification tests have been successful, meaning that the COBRA CRYO-XS is now available for use in short-wave infrared (SWIR) Earth observation applications.

ACKNOWLEDGEMENTS

The authors thank the LYNRED COBRA team for their dedicated work, as well as the European Space Agency (ESA) and Centre National d'Etudes Spatiales for their support and fruitful collaboration.

REFERENCES

- [1] Gaucher A., Marchant A., Eynard-Machet S., Guichard J., Delannoy A., Duvert R., Berthoz J., Sanson E. "CO2M NGP SWIR DETECTOR: FLIGHT MODEL PERFORMANCES", ICSO 2024
- [2] S. Machlup, "Noise in Semiconductors - Spectrum of a 2-Parameter Random Signal" J. Appl. Phys., 25, pp. 341-343 (1954)
- [3] Berthoz, Jocelyn et al. "Modeling and Characterization of MTF and Spectral Response at Small Pitch on Mercury Cadmium Telluride." Journal of Electronic Materials 44 (2015): 3157-3162.