QWIP COMPACT THERMAL IMAGER: CATHERINE-XP AND ITS EVOLUTIONS

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ABSTRACT

Since 2005, The THALES Group is successfully manufacturing TV/4 format QWIP sensitive arrays in high rate production through THALES Research and Technology.

Sofradir has entered a full production of its VEGA-LW-RM4 IDDCA using a 25µm pitch, 384x288 QWIP Array which is the core of the very compact QWIP thermal imager CATHERINE-XP.

Serial production of CATHERINE-XP has now started in THALES Optronique in order to meet the delivery schedule of the various programs for which it has been selected. A review of the QWIP Production status, CATHERINE-XP achievements and current programs are presented.

As THALES Optronique has based its today strategy on very compact TI in order to address the largest panel of platforms and applications, THALES Optronique is working in cooperation with Sofradir and TRT on the evolutions of the product to take advantage of the new capabilities offered by QWIP technology like bi-spectral or polarimetric. The achievements of these developments are also presented

Keywords: QWIP, Infrared Detectors, Focal Plane Arrays, Thermal Imager, Bi-spectral, Dual Band, Polarimetric

1 INTRODUCTION

THALES Optronique has based its strategy on very compact TI (Catherine) to address the largest panel of platforms and applications. THALES Optronique, working in cooperation with Sofradir and THALES Research and Technology, presented the first operational prototype of QWIP Catherine in 2001 and build several pre-serial units to demonstrate the high performance of the product, to qualify it on different platforms and to win significant contracts.

Since 2005, TV/4 format QWIP sensitive arrays are successfully manufactured in high rate production by TRT and delivered to Sofradir for integration. Sofradir has entered a full production of its VEGA-LW-RM4 IDDCA using a 25µm pitch, 384x288 QWIP Array which is the core of the very compact QWIP thermal imager CATHERINE-XP.

Serial production of CATHERINE-XP has also started in Thales Optronique to meet the delivery schedule of all the program for which it has been selected. A review of the QWIP Production status, CATHERINE-XP achievements and current programs are presented.

All the successes already gathered are only the beginning of the Catherine-XP story. The capacity of evolution is still great: On one side, the ability of integration in many other platforms thanks to its compactness and versatility, on the other side, the advantages given by the new capabilities offered by QWIP technology. Thales in cooperation with Sofradir are currently working on multi-spectral and polarimetric imagery. The achievements of these developments are also presented

2 CATHERINE-XP STATUS

2.1 QWIP detector production Status

After development and LRIP phase in 2005, the first production phase of the VEGA-LW-RM4 (384×288 25µm pitch QWIP) detector has started beginning of 2006 for delivery to TOSA to equip the Catherine-XP FLIR.

The compactness of the CATHERINE-XP FLIR (less than three liters) required a compact and low power IDDCA. With dimensions less than 118 mm height and 73.7 mm width (Figure 2.1), the total IDDCA weights less than 0.55 kg (1.21 lb). Associated with the high cryogenic power of the RM4-7i microcooler, the VEGA-LW-RM4 IDDCA has high cryogenic performance: at 20°C ambient: cool down time to 75K is less than 3 minutes, with maximum cool down power less than 24 W_{AC} (Figure 2.2) shows 20.6 W_{AC} averaged value over the last 70 deliveries), and regulated power less than 8W_{AC} (Figure 2.2 shows 5.13 W_{AC} averaged value over the last 70 deliveries).
At 71°C ambient, the IDDCA is cooled down to 75K in less than 4 minutes, with a maximum cool down power of 27 W_{AC}, and is maintained at regulated FPA temperature with less than 17 W_{AC}.

Figure 2.1 VEGA-LW-RM4 IDDCA with the "0.5W class" RM4-7i

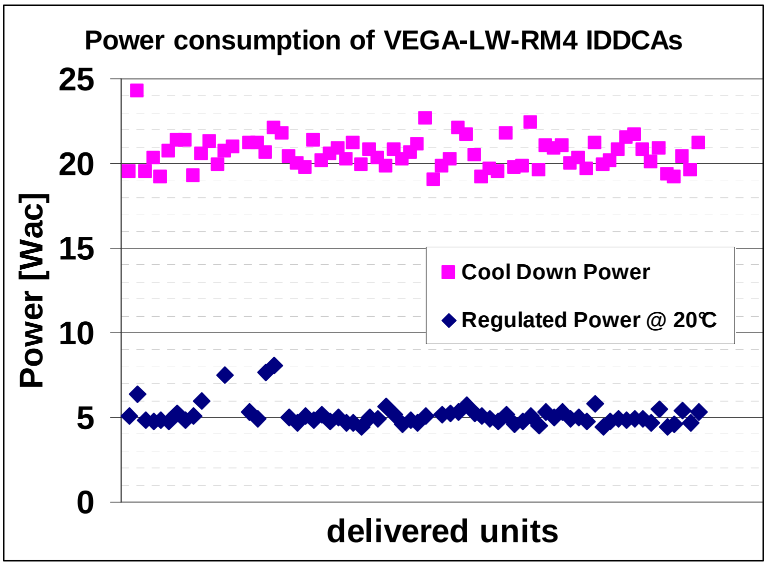

Figure 2.2: VEGA-LW-RM4 power consumptions

About one hundred detectors were already delivered to TOSA. Figure 2-3 and Figure 2-4 show the reproducibility of the sensitivity and NETD of the last 70 deliveries, for IDDCAs measured at 74K to 75K FPA temperature, with a f/2.68 aperture, in gain 2 (13.9Me-) in front of a 20°C blackbody, and with the integration time tuned around 4ms, at a value that ensures that the ROIC will not saturate in front of a 70°C blackbody (the instantaneous dynamic range is therefore guaranteed to be +50°C above ambient without any change of the integration time or skimming or gain settings).

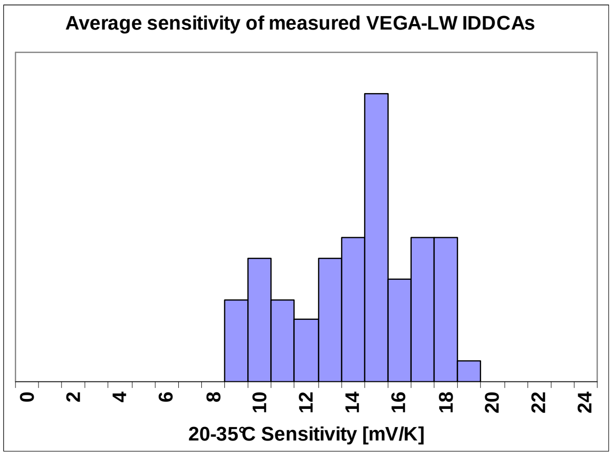

Figure 2-3: 20°C-35°C average Sensitivity over 70 IDDCAs, 75K, no FOV correction

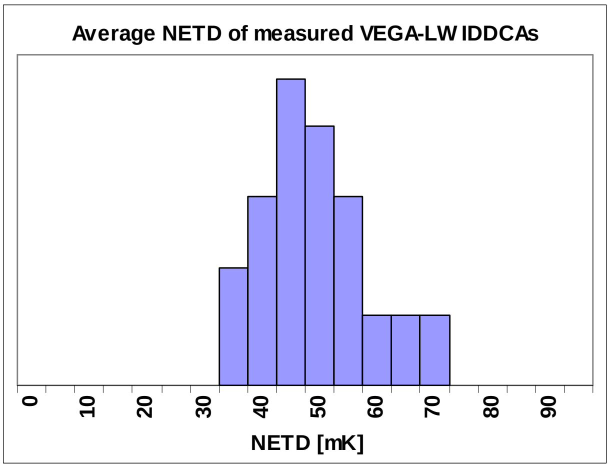

Figure 2-4: NETD over 70 IDDCAs, 75K, with FOV correction

The averaged Sensitivity over the array is measured by difference of the two DC level cartographies in front of 35°C and 20°C and is not Field-Of-View corrected (no $\cos^4\theta$ correction); over this delivered population, the mean value is 13.8mV/K (Figure 2-3). The NETD of the array (=noise/Sensitivity) is Field-Of-View corrected, and is corrected by the luminence variation between ΔT=15K and ΔT=1K. Over this population the mean value is 57mK (Figure 2-4).

Sofradir is today in full production of this detector.

2.2 Catherine-XP achievements and program review

The current programs are addressing mainly two types of platform and associated applications:

Recce Payload

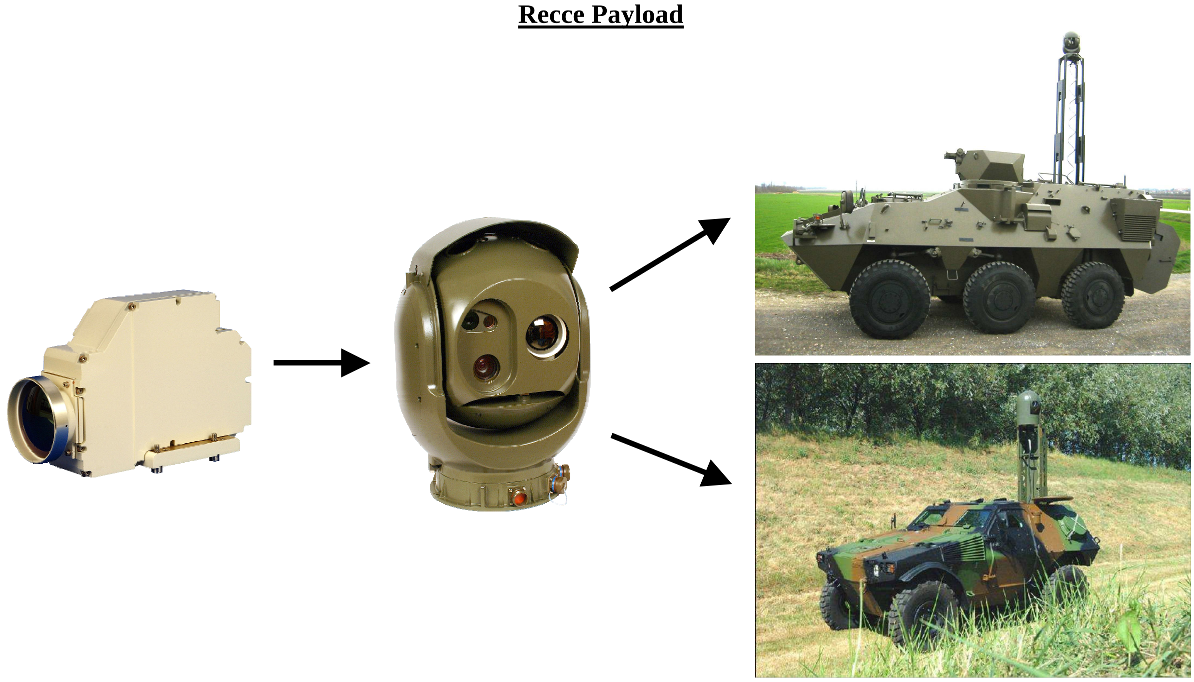

Figure 2.5: Pandur (Belgium) and VBL Source (France) equipped with MANON Payload

Gunner sight platform

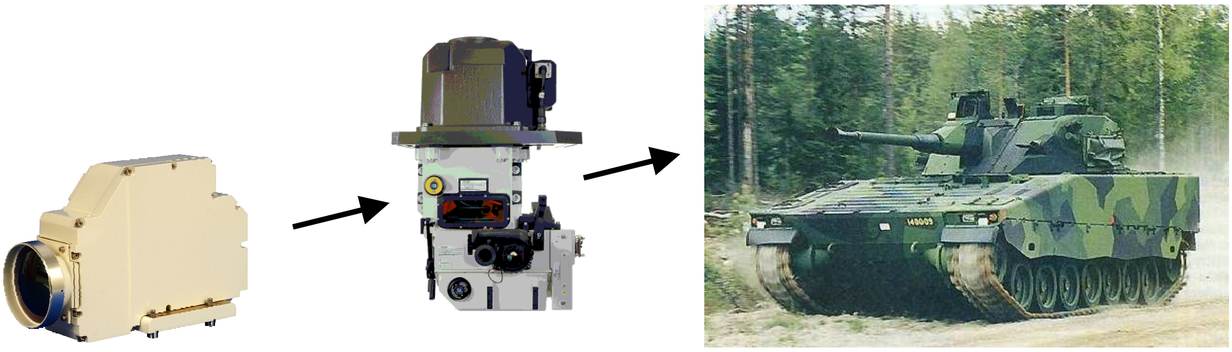

Figure 2.6: IGV program (The Netherlands & Denmark)

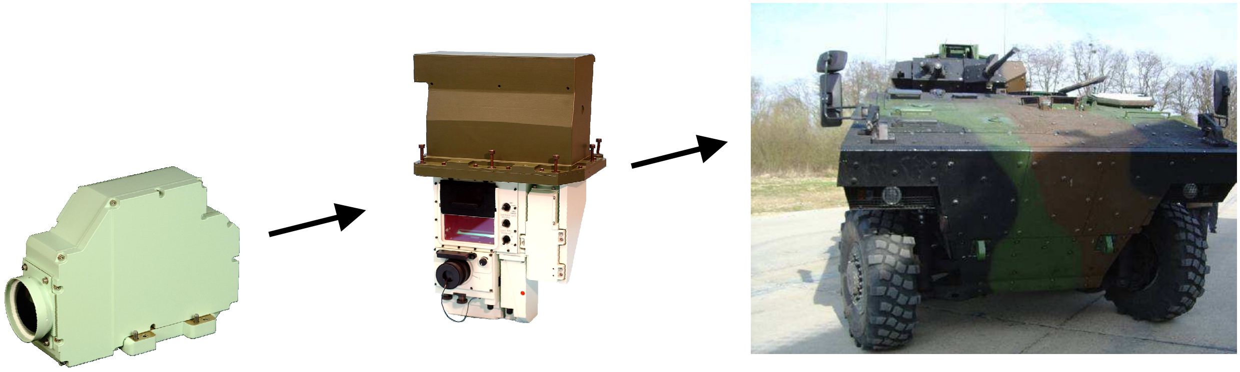

Figure 2.7: VCI program (France)

Qualification of the product has been pronounced and more than 40 serial units have been already delivered for these programs since end of year 2006. Production rate is planned to be10 to 20 units /month

Thanks to highly integrated electronics and compact optics, the Catherine-XP can easily be offered in various version keeping inside the same core modules. The Figure 2.8 shows an adaptation of the Catherine-XP for dedicated sight system. Only the housing has been redesigned and of course software has been adapted to the system needs.

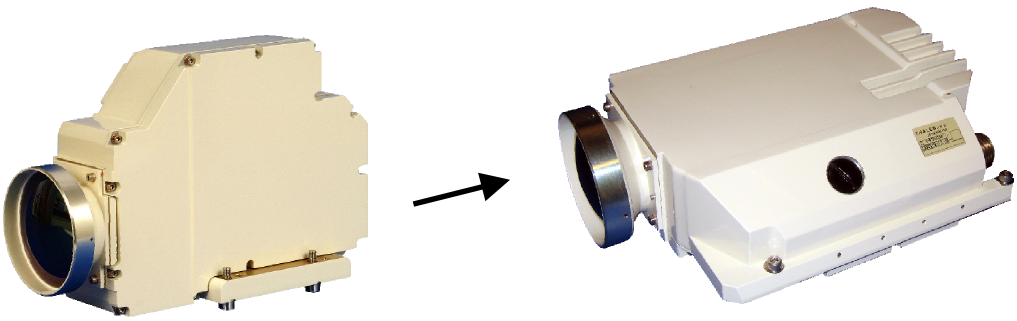

Figure 2.8: Catherine-XP adaptation

3 QWIP TECHNOLOGY NEW CAPABILITIES AND OPERATIONAL ADVANTAGES

The next step of infrared imagers, the so-called 3rd Gen imagers, will require “smart” detectors. The basic idea is to extract more data from the incoming signal in order to give more relevant information to the observer. We are currently exploring two different routes: polarimetric imagery (see [1]. in this conference) and multi-spectral imagery (see [2]. in this conference).

3.1 Polarimetric

Since human eye cannot detect the polarization of the incoming light, this feature was rarely addressed by IR imager manufacturers. Nevertheless, it has been demonstrated (see [3]) that the surface features of a target (shape and roughness) strongly influences the degree of polarization of its emitted radiation, independently both from intensity or spectral emittance.

The specific processing steps developed for the QWIP fabrication includes the realization of a diffraction pattern on the top of each pixel in order to couple the light to the quantum wells. The standard scheme uses 2D diffraction pattern, in order to maximize the response independently from the polarization, but implementing lamellar 1D structures allows to simply realize an monolithically integrated polarizer/detector assembly, within small pitches suitable for FPAs.

The FPA geometry is shown on Fig 3.1. The array is divided into 2x2 unit cells. Each pixel in the unit cell has a 1D lamellar structure etched on it, with four different orientations (0°, 90°, 45° and 135°). This geometry allows the full characterization of the first three components of the Stokes vector, related to the degree of linear polarization in the scene. The full resolution is recovered using a micro-scanning system (see [4]).

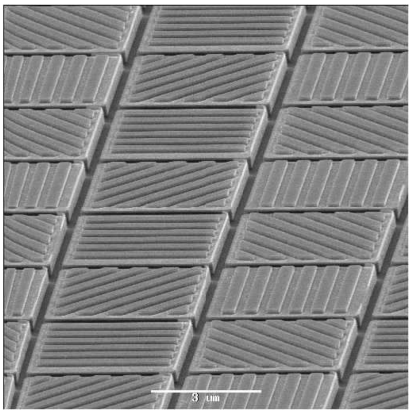

Figure 3-1: SEM view of a 2x2 pixel polarimetric array

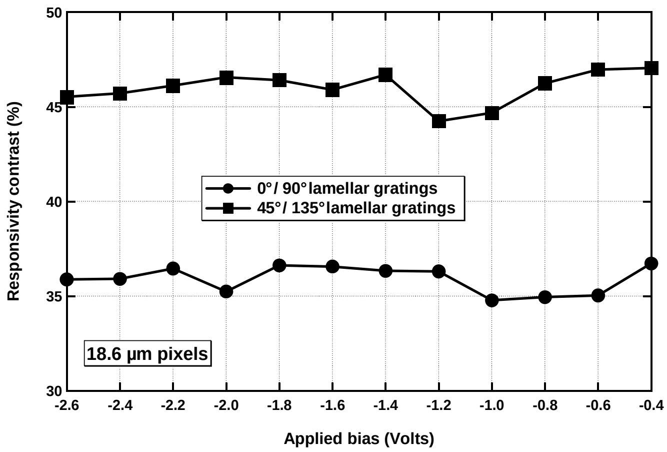

Figure 3-2: Responsivity polarimetric contrasts for 20µm pitch LWIR FPAs

The four polarizations being interlaced within the array, it is important to implement them on a large format array in order to image four spatially and temporally coherent sub-images having sufficient resolution. The first demonstrator of polarimetric QWIP was therefore developed with the challenging 20µm pitch 640×512 array format, in order to have four 320×256 polarized sub-images. The SIRIUS-LW-K548 IDDCA shown in Figure 3-3 (see [4]) was initially developed for the standard TV format QWIP and has been used without any modification to implement the polarimetric array (see [1] in this conference). The responsivity contrasts higher than 35% obtained with this 20µm pitch, are good enough for polarimetric imagery (see Figure 3-2)

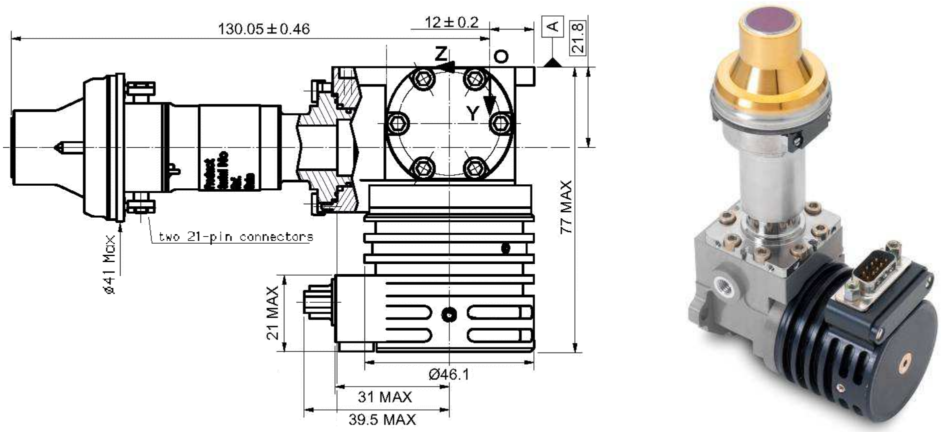

Figure 3-3: SIRIUS-LW-K548: 640×542 QWIP IDDCA

For Catherine XP, thanks to a larger pitch (25µm), expected contrasts should be higher than 50%.
This new function helping to differentiate natural objects from artificial targets will be proposed as upgrade for the future versions of Catherine.

3.2 Bi-spectral

In the field of defense and security, Thermal imager are mainly dedicated to the following applications:

- ☑ Detection, recognition, identification and tracking of targets
- ☑ Missile firing and tank gun firing
- ☑ Battlefield observation
- ☑ Search and rescue operations

In the beginning of thermal imaging story, only LWIR band was used because detectors had few discrete elements and the short integration time requested to be able to deliver video signal with enough resolution requested to use LWIR band where the IR flux for ambient temperature is much higher than in MWIR band.

With the availability of Staring Focal Plane Array, it has been possible to increase the integration time to some milliseconds and MWIR detector became an alternative.

In the past ten years, a permanent debate between pro LWIR and pro MWIR has animated the infra-red community and now, advantages and disadvantages of each band are well known (see [5]).

Until recently, taking advantages of each bandwidth by having bi-spectral device with spatial coherence needs to use two detectors with complex optical design. This leads to large system, very expensive with poor reliability.

The QWIP technology gives the possibility to get in the volume of a single band TI, both LW and MW thermal imager. Switching from one spectral band to another is as simple as changing the polarity. The operator can choose the infra-red band that will optimize the performance according to the environmental conditions (climate, atmospheric transmission, sunlight, reflection, clutter, smokes,…), the type of target (man, tank, aircraft, vessel, ..), the type or phase of the mission (observation, detection, identification, tracking, firing, …).

One prototype based on Catherine-XP has been manufactured and is described hereafter.

4 BI-SPECTRAL CATHERINE-XP: LWIR / MWIR

4.1 Dual-band Detector achievements

By taking advantage of the existing dewar of the Catherine XP LW detector, it was decided beginning 2006 to experiment a first demonstration of a dual-band camera. The modifications of the VEGA-LW-RM4 IDDCA were minimized to the window definition. Since a double band-pass window was not available, the initial Germanium window with LW-optimized antireflection coating has been replaced by a Silicon window with MW-optimized antireflection coating, in order to optimize the transmission in MW band while still ensuring a sufficient transmission in LW band.
The remaining dewar parts were unchanged and the IDDCA looks as described in Figure 2.1.

The ISC0208 Indigo ROIC has not been designed for dual band application, therefore this demonstrator can not be a temporally coherent MW-LW array: the MW band is output during some frames, and when required, the two QWIP biases are modified from ($V_{QWIP-MW}$; ground) to (ground; $V_{QWIP-LW}$) to output the LW band.

The QWIP dual band array structure (Figure 4.1) was described in [6] For this development, the QWIP wafers were processed with the 384×288 25µm pitch format of the ISC0208 ROIC.

Figure 4.2 illustrates the spectral response measured on the test detectors. For the MW band, the peak response is 4.6µm and the FWHM is 0.57µm. For the LW band, the peak response is 8.6µm and the FWHM is 0.9µm.
The optical crosstalk between the MW and the LW bands is close to zero.

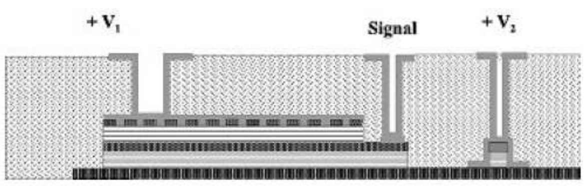

Figure 4.1: dual band QWIP structure

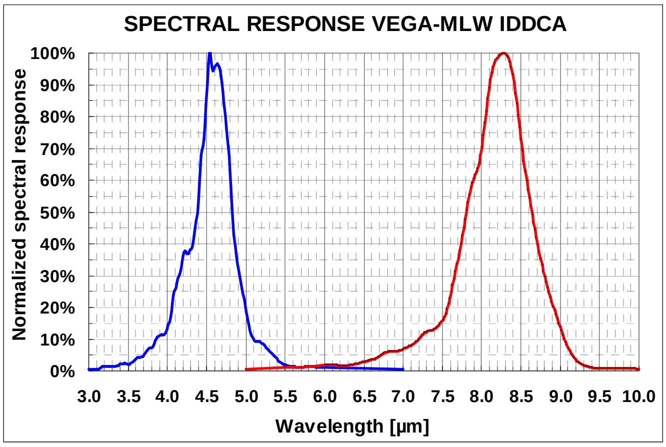

Figure 4.2: spectral response

With the following conditions: 73K operating temperature, f/2.68 aperture, in gain 2, in front of a 20°C blackbody, with the integration time set at 20ms for MW band and at 7 ms for the LW band, the performances of the dual band array are the followings:

- ☑ LWIR: NETD= 40 mK and Sensitivity = 14 mV/K
- ☑ MWIR: NETD= 47 mK and Sensitivity = 8 mV/K

The dual band prototype has been delivered to TOSA for camera integration.

4.2 Catherine-XP architecture

CATHERINE-XP and Bi-spectral CATHERINE-XP have been designed for low cost, low consumption, high performance and easy integration into very small sights. They are particularly well adapted to new infantry vehicles where space are limited, but are also capable of retrofit to older sights. The Bi-spectral version is able to provide the switching of the video between MWIR Band and LWIR Band controlled by the operator.

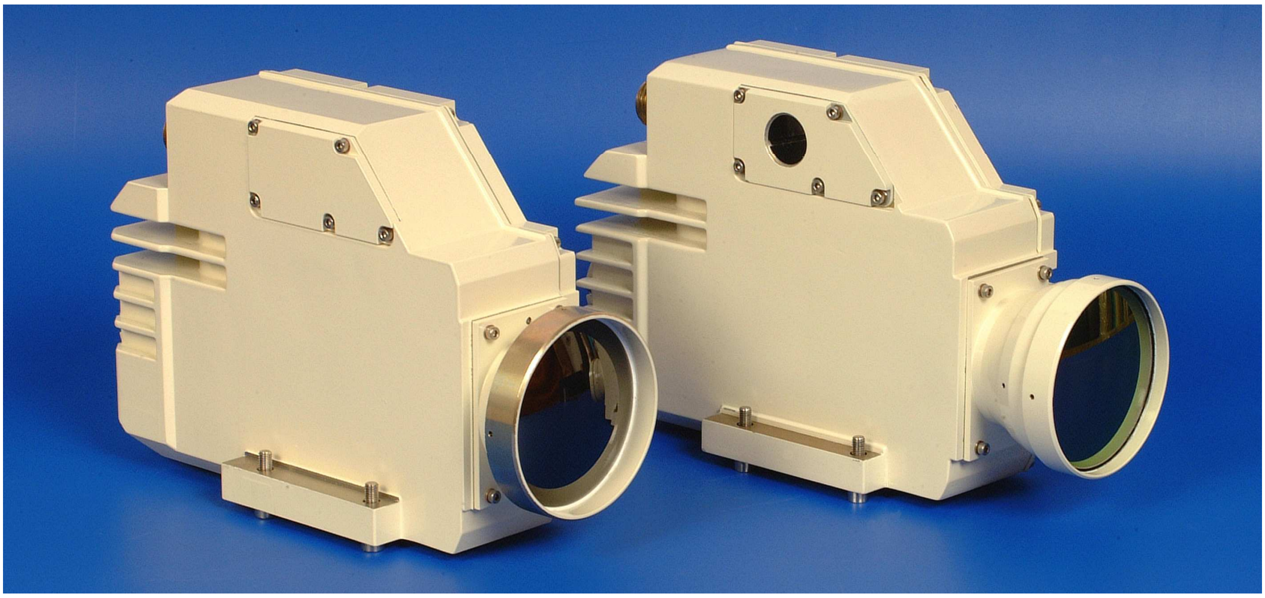

Figure 4.3: CATHERINE-XP and Bi-spectral CATHERINE-XP

Both thermal imagers are single box equipment sized to suit many types of ground vehicle, particularly armoured vehicles. With further environment protection, it can be installed on naval vessels. It is powered directly from a vehicle power supply (20V to 30V DC) compliant with MIL-STD1275B, delivers a standard UIT-R 625 lines video signal and is remotely controlled though an asynchronous serial data link (RS422 or CANBUS). Fire control is facilitated by a reticule displayed on the video signal, the position of this reticule depending on the initial values of boresighting. Both imagers can be synchronized by an external video (UIT-R 625 line).
Serial digital video output can be also implemented inside on optional board with additional dedicated connector.

Both cameras use common design approaches: The same housing, the same electronics boards, mechanisms and cooler engine. The basic elements are as follows:

Telescope, Standard or Bi-spectral
Two telescope with 2-position zoom objective can be fitted in the housing. Both are very compact and provide a narrow field of view of 3°x2.25 and a wide field of view of 9°x6.75. Bi-spectral version is described hereafter in 4.3

Microscan
The micro-scanner is a dual-axis piezo-electric device which translates the last lens of the telescope to produce a half pixel size motion in order to increase resolution of the image.

Integrated Detector cooler Assembly (IDCA), Standard or Bi-spectral
Both detectors are a 384x288, 25µm pitch QWIP (made by THALES Research and Technology) indium bump bonded to a ROIC by Sofradir. The cooling engine is an integrated Stirling rotary micro-cooler from THALES Cryogénie. Sofradir manufactures the whole assembly. A view of the IDCA is shown in Figure 2.1.
Only the QWIP array structure and coating are different for Bi-spectral version.

Processing electronics

Two analogue outputs from ROIC are digitized to 14 bits. The proximity Electronics includes the processing of the focal plane temperature sensor and provides all bias voltages required by IDCA.

Camera Processing

The processing electronics, based a powerful FPGA (XILINX VIRTEX 4) and DSP, performs the following functions:

- Spectral band switch control,
- Telescope control (micro-scanning, focus and field of view change),
- Cooler engine control,
- Non uniformity correction (factory calibration setting and scene based update of offset),
- Video Gain and Level adjustment with automatic or manual control,
- Two-dimensional edge enhancement,
- Bitmap overlays,

Power supply and interface board

The power supply is designed to handle incoming voltage according to MIL-STD1275B and STANAG 4236 (LEMP), and provides voltage to the other boards.

Cooler engine control and micro-scanning board

The board provides the high voltage for the microscan module and includes the drivers to control the cooler engine.

CATHERINE-XP and Bi-spectral CATHERINE-XP have nearly the same mechanical and electrical characteristics. Their general characteristics are compared in Table 1 below:

Table 1 - CATHERINE camera characteristics

Camera:	**CATHERINE-XP**	**CATHERINE-XP Bi-spectral**
Detector:	LWIR QWIP	MWIR and LWIR QWIP
IDCA format:	384x288	
Array pitch:	25µm	
IDCA field rate:	100Hz	
Micro-scanning:	2 x 2	
Image format:	768x575 (UIT-R TV)	
Optical fields of view:	WFOV: 9°x6.75° and NFOV: 3°x2.25°	
Electronic Zoom:	x 2	
NUC:	Factory setting of gain and offset, plus scene-based update of offset.	Factory setting of gain and offset, plus scene-based update of offset for each bands.
Output:	2 analog UIT-R video	
Synchronization:	UIT-R video ± 200ppm	
Control:	RS422 serial link or CANBUS	
EMC:	MIL-STD-461E Ground Army	Not Qualified
Dimensions:	259 x 170 x 99	277 x 170 x 99
Weight:	3kg	
Power consumption:	20W	

4.3 Dual-band optics: optical design

A very compact, dual FOV telescope has been designed and patented for the new dual-band detector.

Two mechanisms (variator & compensator, see drawing below) are used to select FOV and waveband, and for focusing.

Color correction is achieved in each waveband but MWIR and LWIR focus are different. Switching from one waveband to the other waveband is possible by moving slightly the “compensator” lens.
In the NFOV configuration the main contribution to axial color is obviously the front objective group. It has been corrected by using the Germanium / ZnS / DOE (Diffractive Optical Element) triplet. Indeed the classical ZnSe / ZnS / Ge sequence has not been considered as pertinent because of the high relative power of each material, leading to splitting each materials into too many components, and to high sensitivity to manufacturing tolerances.
The lens has been further optimized by correcting residual lateral color aberration of the compensator in the MWIR. This is possible by adding a second DOE on the compensator, which slightly degrades LWIR’s lateral color, but greatly improves MWIR’s.

The DOEs are optimized for the diffraction order 1 in the LWIR band, and for the diffraction order 2 in the MWIR band. The diffraction efficiency is good in both wavebands (though better in the LWIR band) because the detector’s wavelengths used in the LWIR band are about 2 times larger than those used in the MWIR band.

DOE parasitic diffraction orders contribution to ghost images has been analyzed. Although they do contribute to ghost images in the NFOV MWIR configuration, their influence on the three other configurations is negligible.

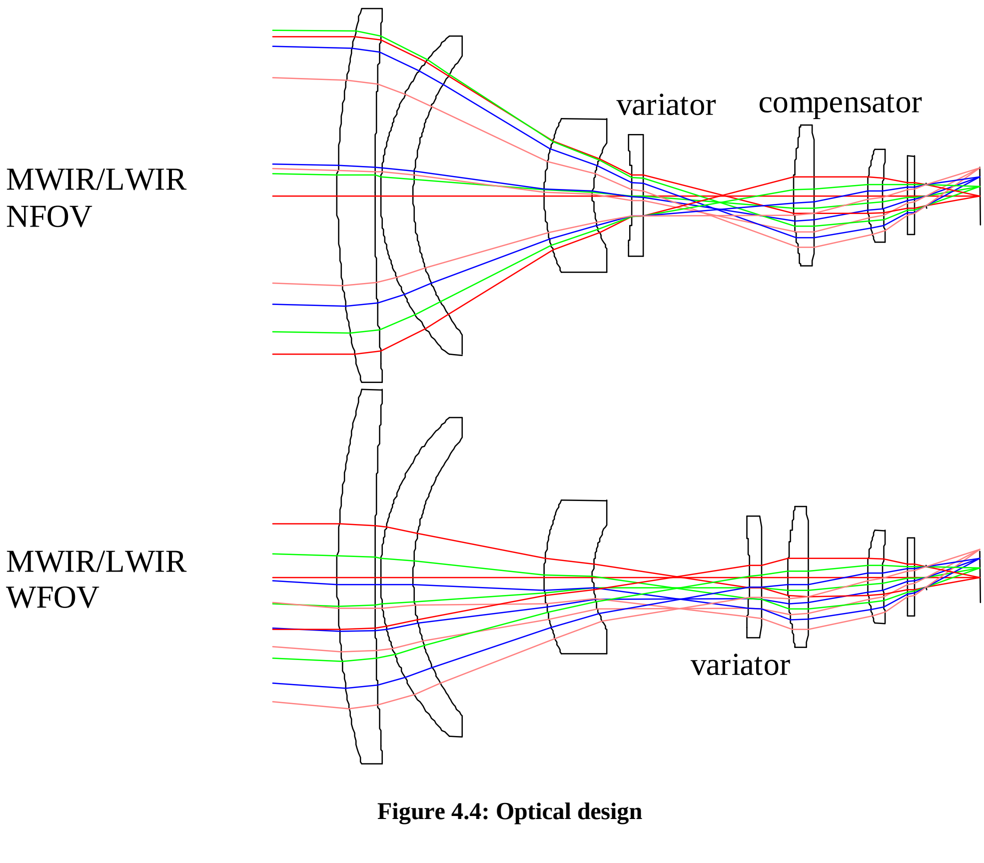

Figure 4.4: Optical design

4.4 Prototype results

First images of Bi-spectral Catherine-XP have been produced and they have confirmed our expectations.

Thanks to the versatility of the Catherine-XP architecture and quality of the detector, only 3 days have been necessary to assemble the bi-spectral detector, bi-spectral optics and common parts (electronics and mechanics) of standard Catherine-XP. After a two points calibration, it was possible to get a high quality pictures and to switch between MWIR and LWIR Band in less than 0.5 s.

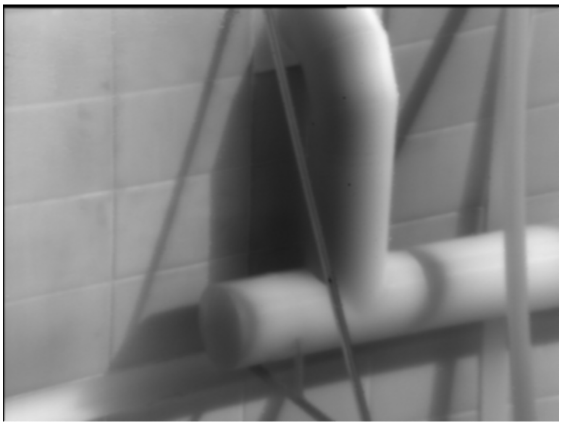

Figure 4.5: LWIR Picture

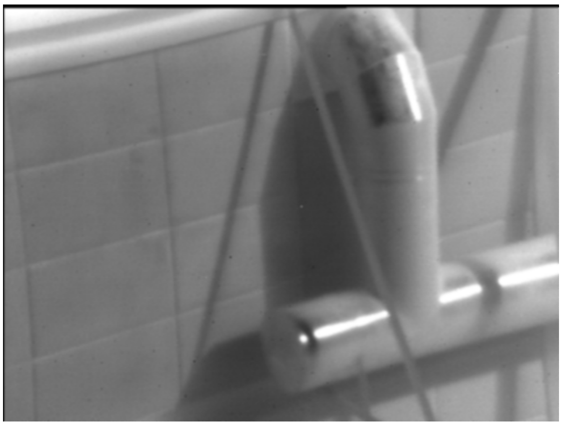

Figure 4.6: MWIR Picture

Figure 4.7: LWIR Picture

Figure 4.8: MWIR Picture

5 CONCLUSION

With the QWIP technology which has reached the highest level of maturity, it is possible not only to offer affordable, compact high performance thermal imager but also to offer differentiators to the traditional infra-red imaging product with polarimetric and multi-spectral capabilities.

The fast implementation of the bi-spectral Catherine-XP shows that a new step has been passed and that such functionalities will be available without needing complex or expensive devices. They will bring easily key advantages on the field.

Catherine-XP has now opened the way towards the true Third Generation Thermal Imager.

ACKNOWLEDGMENTS

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