Temporal stability measurements of a cooled infrared type II superlattice (T2SL) focal plane array detector

Vignesh AROUNASSALAME
DOTA
ONERA
Palaiseau, FRANCE
vignesh.arounassalame@onera.fr

Jean NGHIEM
DOTA
ONERA
Palaiseau, FRANCE
jean.nghiem.xuan@gmail.com

Maxence GUENIN
DOTA
ONERA
Palaiseau, FRANCE
maxence.guenin@onera.fr

Eric COSTARD
IRnova AB
Electrum 236
SE 16440 Kista, Sweden
eric.costard@ir-nova.se

Philippe CHRISTOL
I.E.S, Univ. Montpellier
CNRS
F-34000 Montpellier, France
christol@ies.univ-montp2.fr

Isabelle RIBET-MOHAMED
DOTA
ONERA
Palaiseau, FRANCE
isabelle.ribet@onera.fr

Abstract* – *Type II Superlattice detectors (T2SL) showed promising achievements thanks to recent breakthroughs in its fabrication process. Following these evolutions, T2SL IDDCA (Integrated Detector Dewar Cooler Assembly) are now commercially available and their performances are evaluated with more advanced figures of merit to compare them to other detector technologies. Residual Fixed Pattern Noise (RFPN) is used to evaluate Focal Plane Array (FPA). However, this measurement is strongly dependant on the way to define defective pixels and some of them can have a flickering signal due to random telegraph signal (RTS) noise.

In this paper, a T2SL MWIR 320x256 pixels IDDCA is studied. We compare two data processing for defective pixels detection and the results obtained on RFPN over time. Then, we study RTS pixels with focus on their number of appearances and their classification

Keywords—Infrared Photodetector, T2SL, FPA RFPN, RTS

I. INTRODUCTION

Infrared detection knows a growing expansion in various markets, from aircraft enhanced vision systems to nondestructive control of skin cancer [1]. This is due, in part, to the continuous progress in the detector technology.

T2SL detectors emerged as a new field of infrared detection for high-performance imaging applications. One of its advantages is a tunable cut-off wavelength thanks to its particular structure of “Superlattice”. The good performances of the structure enabled to move on to the “system” stage. At the FPA level two important figures of merit are used to evaluate the detector: modulation transfer function (MTF) and stability over time. MTF describes how well a detector can reproduce spatial frequencies [2], whereas stability over time indicates how long time the calibration used is valid.

The stability over time is currently estimated through the RFPN. However, this figure of merit quickly shows its limits because of the conditions of application. Indeed, depending on the criteria used to set aside defective pixels, the results can change quickly, hence the importance of using common foundations in order to have pertinent comparisons between two different detectors. This problem is perfectly represented with some pixels affected by random telegraph signal (RTS) noise. The signal delivered by these pixels can oscillate between two or more levels at certain times, creating a particularly harmful blinking effect for image quality [3].

In this paper, a T2SL MWIR 320x256 pixels IDDCA (Integrated Detector Dewar Cooler Assembly) provided by IRnova is studied. We first describe our experimental protocol to evaluate the temporal stability of a FPA. We present the results of the evolution of the RFPN over time. Then we focus on random telegraph signal noise, and present the data processing and the experimental results.

II. RESIDUAL FIXED PATTERN NOISE

A. Principle of the RFPN

The Fixed Pattern Noise corresponds to the spatial fluctuations of the signal delivered between the different pixels composing a FPA when it receives a flux of uniform irradiance. The fixed pattern noise can find its origin in two different parts of the pixel: the first one is the detection circuit (the part responsible of the conversion of photons into electrons) because of differences in cut-off wavelengths for example. The second one is the Read Out Integrated Circuit (ROIC, the part making the link between the photoelectrons and the electronics processing the signal) for example if the output amplifiers have different offsets. The Residual Fixed Pattern Noise is calculated after a linear two-point calibration [4] is realized on the signal in order to reduce the Fixed Pattern Noise. This calibration is done by using two extended blackbodies at different temperatures. The corrected signal for one pixel (i,j) $S'_{i,j}$ is calculated using the two coefficients of the linear correction $G_{i,j}$ and $O_{i,j}$:

$$\begin{cases} S'_{i,j}(\phi) = G_{i,j}S_{i,j}(\phi) + O_{i,j} \\ S'_{i,j}(\phi_1) = \langle S(\phi_1)\rangle \\ S'_{i,j}(\phi_2) = \langle S(\phi_2)\rangle \end{cases} \qquad (1)$$

where $S_{i,j}(\phi)$ is the signal delivered by the pixel (i,j) for an incident power equal to ϕ minus the electrical offset of the pixel. $\phi_1$and ϕ_2 correspond to the reference incident powers of the two blackbodies used. $\langle S(\phi_1)\rangle$ (respectively $\langle S(\phi_2)\rangle$) represents the spatially averaged signal at the incident of power ϕ_1(respectively ϕ_2).The two correction coefficients are calculated from (1) assuming that each pixel has a linear response with the incident power:

$$G_{i,j} = \frac{\langle S(\phi_2)\rangle - \langle S(\phi_1)\rangle}{S_{i,j}(\phi_2) - S_{i,j}(\phi_1)} \tag{2}$$

$$O_{i,j} = \langle S(\phi_1)\rangle - G_{i,j}S_{i,j}(\phi_1) \tag{3}$$

The two-points correction (TPC) is very effective at the time it is implemented~~,~~ the corrected image is perfectly uniform at the two reference incident powers ϕ_1 and ϕ_2. However, the problem is to know if the correction used is appropriate for a long time. That is why, the Residual Fixed Pattern Noise is calculated. It indicates the effectiveness of the reduction of the Fixed Pattern Noise by its definition itself:

$$RFPN(\phi) = \sqrt{\frac{1}{N}\sum_i\sum_j\left(S'_{i,j}(\phi) - \langle S'_{i,j}(\phi)\rangle\right)^2} \tag{4}$$

where N is the total number of pixels of the FPA.

The effectiveness of the correction is not straightforward, because there is no absolute definition. One can use a relative definition to the temporal noise, which is defined as the temporal fluctuations of the signal delivered by a pixel. Indeed, fixed pattern noise and temporal noise are in general quadratically summed [5]. Therefore, the criterion that the RFPN must be inferior to the temporal noise in order to get a good image quality is reasonable.

B. *Data processing*

The RFPN is relevant only if it is used on pixels whose behavior follows a Gaussian statistic. But that is not the case for defective pixels. That is why, before evaluating the RFPN, a data processing has to be realized in order to detect the defective pixels and exclude them from the calculation of the RFPN. The RFPN is represented with the Well Fill (WF) of the detector. The WF can be defined as a function of the level of fullness of the ROIC capacity. Beyond 100% it is saturated and cannot be exploited. It is calculated from the incident power with the relation:

$$WF(\phi) = \frac{\langle S(\phi)\rangle}{\langle S_{sat}\rangle} \tag{5}$$

where $\langle S_{sat}\rangle$ corresponds to the average signal when the saturation is reached on the detector. For each pixel the electrical offsets have already been subtracted of the signal.

At this point, the analysis of the measurement consists of three main stages (these are successive steps)

- The detection of defective pixels
- The application of the two-points correction
- The calculation of the residual fixed pattern noise

As it was underlined in the introduction, the RFPN is a figure of merit subjected to important variations depending on the conditions used for the detection of defective pixels. As a way to highlight this problem, we will compare in the following two sets of conditions to detect defective pixels and compare the results obtained as a consequence on the RFPN.

The first set in TABLE 1, which will be further referred as reference algorithm, is applied on the averaged raw image at 50% of the well fill. This algorithm has four quantities exploited: continuous level, temporal noise, responsivity and noise equivalent temperature difference (NETD). For each pixel, if one of these quantities is too far from the corresponding average value, then it is set aside. The exact criteria and the number of pixels falling in each category are summarized in TABLE 1. The total number of defective pixels with this algorithm is 41, which corresponds to an operability of 99.95%. This total is not equal to the sum of the number of pixels in each category, because one defective pixel can have multiple defects and fall in the corresponding criteria.

TABLE 1 – Criteria used to classify one pixel as a defective one (reference algorithm), $\langle\mathbf{S}\rangle$ is the spatially average signal, $\boldsymbol{\sigma}_{\mathbf{i,j}}$ is the temporal noise of the pixel and $\langle\boldsymbol{\sigma}\rangle$ its spatially averaged value, $\mathbf{R}_{\mathbf{i,j}}$ is the responsivity of the pixel and $\langle\mathbf{R}\rangle$ its spatially averaged value, $\mathbf{NETD}_{\mathbf{i,j}}$ is the NETD of the pixel and $\langle\mathbf{NETD}\rangle$ its spatially averaged value

	Criteria	Number of pixels
Continuous level	$\lvert S_{i,j} - \langle S\rangle\rvert > 30\%.\langle S\rangle$	31
Noise	$\lvert \sigma_{i,j} - \langle\sigma\rangle\rvert > 30\%.\langle\sigma\rangle$	25
Responsivity	$\lvert R_{i,j} - \langle R\rangle\rvert > 30\%.\langle R\rangle$	34
NETD	$\lvert NETD_{i,j} - \langle NETD\rangle\rvert > 100\%.\langle NETD\rangle$	37
Total		41

The second algorithm, which will be called advanced algorithm, is based on the same principle, except that the two-point correction is applied before the detection of the defective pixels (except for the noise which is still applied on the raw image) and the first criterion on the continuous signal is different.

TABLE 2- Criteria used to classify one pixel as a defective one (advanced algorithm), $\langle\boldsymbol{\sigma}_{\mathbf{S'}}\rangle$ is the spatial standard deviation of the continuous corrected signal in the FPA

	Criteria	Number of pixels
Continuous level	$\lvert S'_{i,j} - \langle S'\rangle\rvert > 10.\langle\sigma_{S'}\rangle$	43
Noise	$\lvert \sigma_{i,j} - \langle\sigma\rangle\rvert > 30\%.\langle\sigma\rangle$	25
Responsivity	$\lvert R'_{i,j} - \langle R'\rangle\rvert > 30\%.\langle R'\rangle$	34
NETD	$\lvert NETD'_{i,j} - \langle NETD'\rangle\rvert > 100\%.\langle NETD'\rangle$	37
Total		49

The advanced algorithm detects 8 mores pixels, the 41 others are not necessarily the same as the ones detected in the reference algorithm. Indeed, applying the two-point correction before the detection of defective pixels cancels the dome effect which is due to a variation in the geometrical throughput between the center and the corner of the FPA. Thus, this effect which does not belong to the FPA problems hides some of the defective pixels and classifies some as defective while they are not.

Once the defective pixels have been set aside, the residual fixed pattern noise can be calculated on the corrected images (application of the two-point correction) thanks to equation (4).

C. *Results and discussion*

Fig.1 presents the temporal evolution of the ratio between the RFPN and the Temporal Noise (TN) at 50% well fill. For both algorithms, the RFPN/TN increases with time, but the advanced algorithm manages to keep the ratio lower than one, meaning than the temporal noise remains the predominant noise.

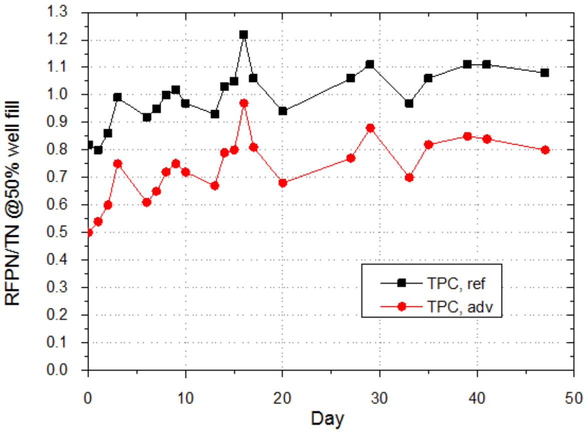

Fig.1- Temporal Evolution of the ratio between the RFPN and the Temporal Noise at 50% well fill, using the reference algorithm or the advanced one to detect defective pixels. The gain and offset coefficients used in TPC are those calculated on the first day of the campaign.

These results clearly show than the temporal stability of the T2SL MWIR FPA is excellent, even after seven weeks. They also stress the importance of the data processing phase with the criteria used to rule out defective pixels. Indeed by removing only 8 pixels, the ratio RFPN/TN decreased by 25%. The reference algorithm could not detect them, because their continuous levels were close to the average signal at 50% of the well fill mainly because of the dome effect. The application of the TPC enabled to detect them.

III. RANDOM TELEGRAPH SIGNAL NOISE

Pixels are considered as exhibiting random telegraph signal (RTS) noise when their signal oscillates between at least two levels, while the received power and operating conditions do not change. RTS noise can be harmful for image quality since the resulting blinking effect cannot be suppressed by TPC. That is why, it is considered as major problem that different technologies have to face [6-7].

A. *Experimental set up and data processing*

Acquiring data to study RTS noise requires long temporal acquisitions under fixed operational conditions (integration time, blackbody temperature…). A quick study shows that recording cubes of 5000 images with an integration time of 4 ms and a frame time (irreducible due to the detector used) of 16 ms is a good compromise between RTS pixels detection and data processing complexity.

In order to study the effects of RTS noise on the RFPN, the RTS data was acquired at the same time that the RFPN acquisition data. The blackbody was scanned in temperature between 10°C and 58°c with a step of 3°C. For each temperature, a cube of 5000 images was acquired, and a cube of 256 images was extracted from this big cube. Cubes of 5000 images were analyzed by an algorithm [8] for RTS detection while cubes of 256 images were used for calculating the RFPN. Then, pixels were defined as affected by RTS noise, if they were detected by both algorithms. Such measurements were repeated 24 times, representing a cumulated acquisition time of more than 9 hours. Some of the measurements were made within the same cooling, others after allowing the detector to return to room temperature.

B. *Results and discussion*

Measurements show that the number of RTS pixels of the MWIR T2SL 320x256 pixels FPA is very low. It varies between 0 and 10 pixels detected by acquisition of 5000 images. TABLE 3 presents a classification of the 52 pixels RTS detected out of 192 cubes, while Fig.2 shows the temporal—signal of a RTS pixel. For each RFPN measurement, only the first 8 temperatures were exploited for RTS detection, to ensure that RTS pixels would not be hidden by an increasing photon noise.

TABLE 3- Classification of pixels detected affected by RTS noise

Classification	Number of pixels
2 level – RTS pixels	19
Spikes	15
Atypical (low frequency fluctuations)	18

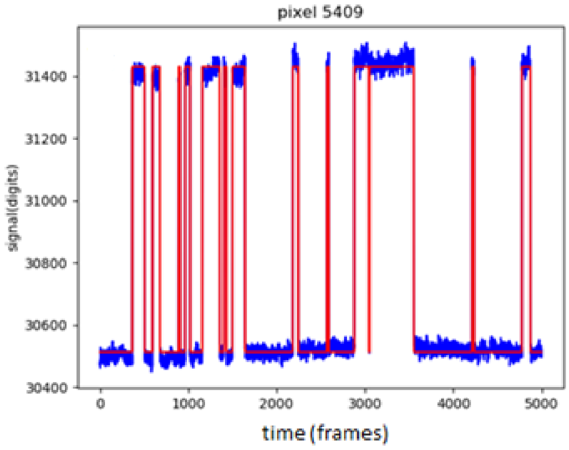

Fig.2- Signal as a function of time for one RTS pixel

Furthermore, we studied the cumulative number of RTS pixels as a function of the measurement number, in order to observe if a stabilization of this number of pixels happens.

In Fig.3, instantaneous and cumulative number (by cumulative we mean the number of pixels which flickered at least one time from the beginning of the measurements) of RTS pixels are reported. The cumulative number of RTS pixels increases rapidly and then slows down after 125 measurements where some stabilizing plates can be observed.

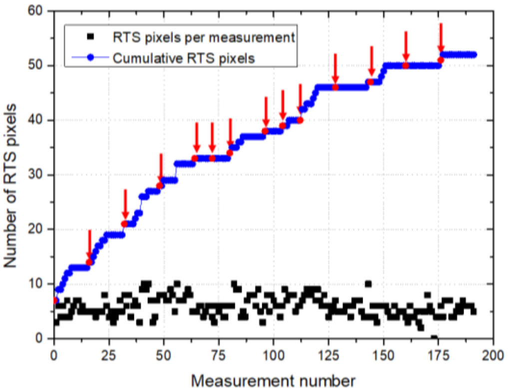

Fig.3 – Instantaneous and cumulative number of RTS pixels detected as a function of the measurement number. Red arrows indicate new cooling cycles.

After analyzing the RTS pixels detected by the advanced algorithm, a study was made in order to observe if some RTS pixels might have been not detected but have an effect on the RFPN. Therefore, we added to the list of defective pixels, the remaining pixels detected by the algorithm for RTS detection but not by the advanced algorithm. Fig.4 shows that there is no difference observed on the RFPN/TN ratio by adding the remaining RTS pixels to the list of defective pixels. It proves that the algorithm does not need improvements.

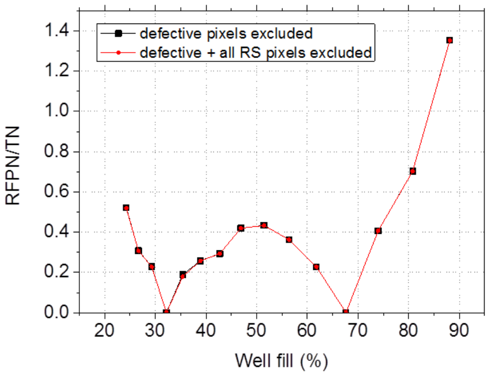

Fig.4- RFPN/TN ratio in function of the well fill. One curve represents the ratio obtained with advanced algorithm only, while the second one represents the result obtained by adding the remaining RTS pixels not detected by the advanced algorithm.

IV. CONCLUSION

In this paper, we described our protocol to evaluate the stability over time of an FPA and to count up/classify pixels with random telegraph noise. We presented the results obtained for a T2SL MWIR 320x256 pixels IDCA provided by IRnova. The stability over time is excellent over seven weeks. The observation made on the criteria used demonstrated the importance to define and state clearly the criteria used for the selection of operational pixels.

Furthermore, the study of RTS pixels enabled a classification in distinguished categories of the behavior of pixels affected by RTS noise. The count up of RTS pixels needs further measurements in order to conclude on the existence of a stabilization of the number of cumulated RTS pixels.

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