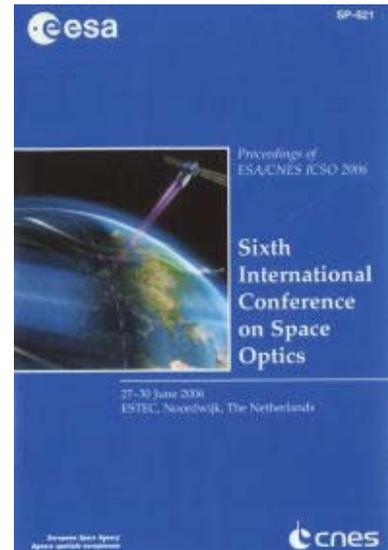


International Conference on Space Optics—ICSO 2006

Noordwijk, Netherlands

27–30 June 2006

Edited by Errico Armandillo, Josiane Costeraste, and Nikos Karafolas



Experience feedback on ccd detectors in orbit: focus on in-flight degradation of several cases of performance

A. Penquer, L. Lebègue, D. Herve, B. Fougnie



EXPERIENCE FEEDBACK ON CCD DETECTORS IN ORBIT: FOCUS ON IN-FLIGHT DEGRADATION OF SEVERAL CASES OF PERFORMANCE

PENQUER A.⁽¹⁾, LEBEGUE L.⁽¹⁾, HERVE D.⁽²⁾, FOUGNIE B.⁽¹⁾

⁽¹⁾CNES, 18 Avenue Edouard BELIN, 31401 TOULOUSE Cedex 9, FRANCE
Email: antoine.penquer@cnes.fr; bertrand.fougnie@cnes.fr; laurent.lebegue@cnes.fr

⁽²⁾SODERN, 20 Avenue Descartes, BP23 94 451 Limeil-Brévannes, France, Email: dominique.herve@sodern.fr

ABSTRACT

The performance stability of CCD detectors and video electronics during life time is an important issue for most of space missions. Several items are concerned, such as CCD dark signal increase, induced by space radiation environment (dose effects, proton hits, etc...). Ground tests are performed to predict on-board behaviour and end-of-life performance. But generally this approach cannot achieve a rigorous representation of mission conditions.

Experience feedback from in-flight measurements is therefore very useful in order to infer what really occurs and to allow comparison between actual findings and ground tests.

1. PIXEL DARK SIGNAL AND RADIATION EFFECTS

1.1 General

In darkness, the active pixels generate what is known as pixel dark voltage (also called pixel dark signal). This phenomenon depends on many factors, including:

- CCD technology,
- pixel size and type (photodiode or photoMOS),
- integration time (Ti),
- temperature (T),
- irradiation.

As a detector can be made up of several registers, the average pixel dark signal can be defined over the entire detector or over just one register (or a matrix row).

In addition, a non-uniformity parameter, known as DSNU (Dark Signal Non Uniformity) can be defined. This parameter represents the peak-to-peak pixel dark signal along a row or a register for linear CCD, or over an area for frame transfer CCD.

1.2 Radiation effects

Two effects stand out among the various causes of permanent damage to detectors:

-the accumulated dose effect, which causes an increase of the mean dark signal through interface states generation induced by oxide ionization.

-the effect of atomic displacement due to protons, which leads to a sudden, individual increase in the dark signal of the pixel concerned. This effect is therefore responsible for increased DSNU.

Figure 1 illustrates these two permanently damaging effects:

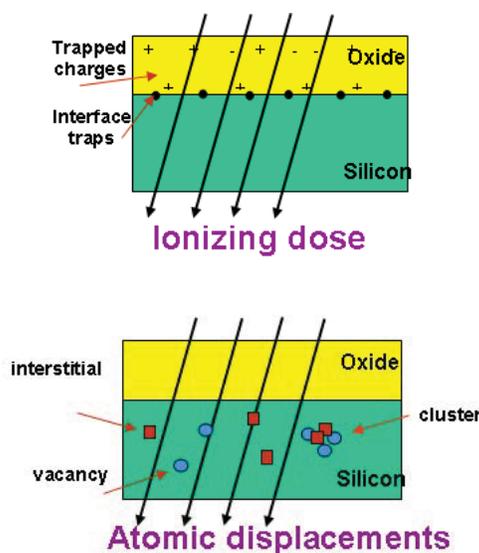


Fig. 1 : Permanent damage

2. DEFINITION OF PARAMETERS STUDIED IN FLIGHT

2.1 Available data

In-flight measurements can be used to monitor variations in pixel dark voltage in several detectors used on various missions.

This chapter presents a focus on different detectors in orbit: the SPOT5 detectors (SPOT5_XS for multispectral detectors, SPOT5_PAN for panchromatic detectors and SPOT5_ST for SPOT5 Star Tracker), and the PARASOL detectors (PARASOL_Payload for the Observation CCD array and PARASOL_ST for the Star Tracker). The set of analysed data covers a period of three years for SPOT5 and one year for PARASOL.

2.2 Relative drift in dark signal

Usually, dark signal variation ΔV is written versus initial dark signal V_0 and total dose as follows (1):

$$\Delta V_{(dose, T_i, T)} = V_0(T_i, T) + A \cdot Dose \quad (1)$$

where A represents dark signal slope versus total dose. In order to ease comparison between data taken with various operating conditions, the relative drift ΔV_r between dark signal variation ΔV and the initial dark signal V_0 has been preferred (2).

$$\Delta V_r = \frac{\Delta V_{(dose, T_i, T)}}{V_0(T_i, T)} \quad (2)$$

Assuming that dark signal drift and initial dark signal are proportional to integration time and temperature, then relative drift only depends on received dose (3).

$$\Delta V_r = f(dose) \quad (3)$$

Therefore, drift values on board different satellites can be compared simply by calculating the values at the same received dose (a proportionality factor is assumed: the greater the dose, the greater the drift). Relative drift is expressed as %/kRad.

2.3 Study of dark signal jumps

A jump is a sudden increase in a pixel dark signal after proton-nuclear interaction. Jump amplitude can vary with proton energy and interaction properties. **This study focuses only on the maximum in-flight amplitude.**

Jumps, expressed as the number of electrons generated, must therefore be compared at:

- the same integration time,
- and the same temperature.

DSNU drift is not constant. If one pixel is impacted by a proton hit and exceeds the maximum dark signal value previously observed in a register, then the DSNU significantly increases.

However, many pixels can be impacted without exceeding the maximum dark signal value. This means that the DSNU increases in a random manner over time. Similarly, if one severely damaged pixel (thus imposing the DSNU in the register) shows evidence of annealing (gradual and partial decrease in darkness level after impact, see Fig. 2), then the DSNU decreases significantly.

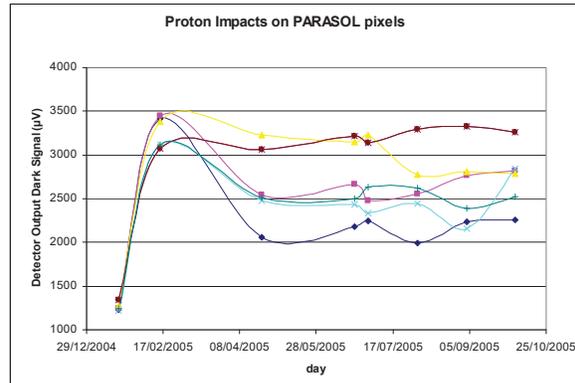


Fig. 2. Proton hits observed on PARASOL_Payload pixels in orbit : several pixels present a partial annealing.

Assuming that a pixel can only be significantly impacted once, it can be assumed that DSNU increase is limited by the maximum_jump. The only way to reach the maximum DSNU increase would be for a pixel with a near-maximum initial dark voltage to undergo a jump roughly equivalent to the maximum observable jump.

The study of jumps gives then an idea of DSNU increase worst case.

Figure 3 illustrates the supposed drift in DSNU:

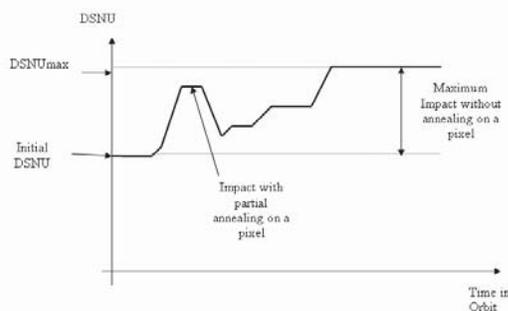


Fig. 3. Typical DSNU drift.

2.4 Study of the number of singular points

A cumulative approach is adopted to study variations in the number of singular points (pixel with a dark voltage beyond the average value + 3σ, where σ is the standard deviation inside a register): any point that has become singular once, continues to be counted as such during subsequent acquisitions, regardless of its later state.

Measurement frequency is seen to have an impact on the number of singular points count (see Fig. 4 and 5), as some pixels are annealed and become normal again. Consequently, the greater is the measurement frequency, the more likely we can count pixels of this type.

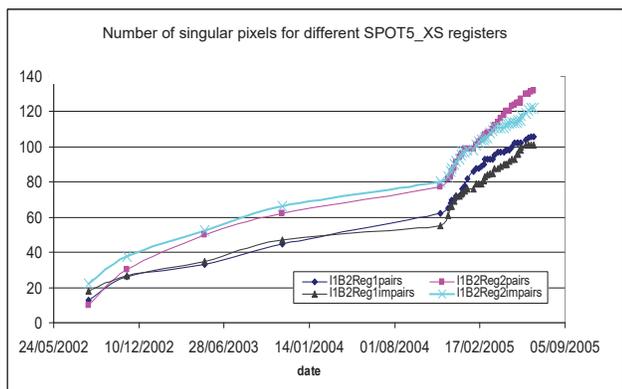


Fig. 4 : number of singular pixels evolution on several registers of SPOT5_XS. When the measurement frequency is higher, the evolution becomes faster

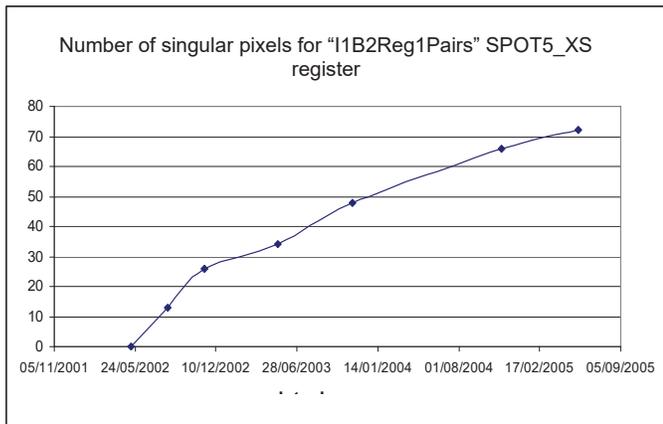


Fig. 5 : the evolution observed on a similar period but without any great change of measurement frequency: the evolution is almost constant

For this reason, a measurement frequency of one measurement per month (i.e. the measurement frequency of PARASOL detectors, the lowest available) has been adopted to be able to compare the results.

The number of singular points also depends on the received dose (the higher the received dose, the greater the probability of having a singular pixel) and on the pixel surface area (the larger the sensitive surface of a pixel, the greater the probability of having a singular pixel).

The following conditions must therefore be fulfilled to be able to compare results:

- same measurement frequency,
- same received dose (proportionality factor),
- same number of pixels and same surface area per pixel. The total sensitive surface area can also be defined by:

$$S_T = N.S_p \quad (4)$$

(where N is the number of pixels and S_p is the surface area of a pixel), in which case the results must be expressed for the same total sensitive surface area (proportionality factor).

It is important to know the variation in the number of singular points as it gives us an idea of the rate at which calibration should be carried out.

3. RESULTS

3.1 General

The same trends are observed on all the detectors studied:

- the increase in average dark signal is almost linear over time,
- DSNU increase is random over time and displays a similar profile to that seen in Figure 4. In the worst case scenario, DSNU increase is on the same scale as the maximum impact observed,
- the number of singular points is linear versus time.

Figures 6 to 8 below illustrate these trends in the case of the PARASOL Payload, and Figures 9 to 10 show the case of SPOT5_XS.

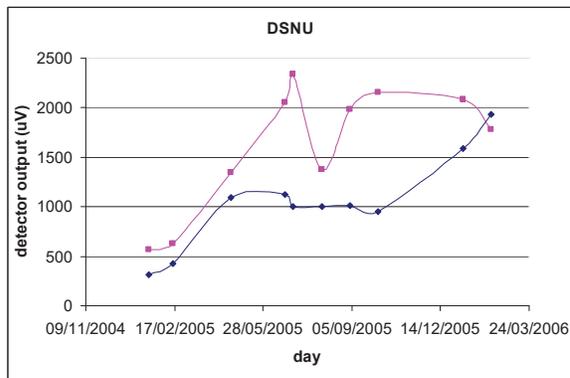


Fig. 6 : DSNU variations on two rows of the PARASOL_Payload matrix

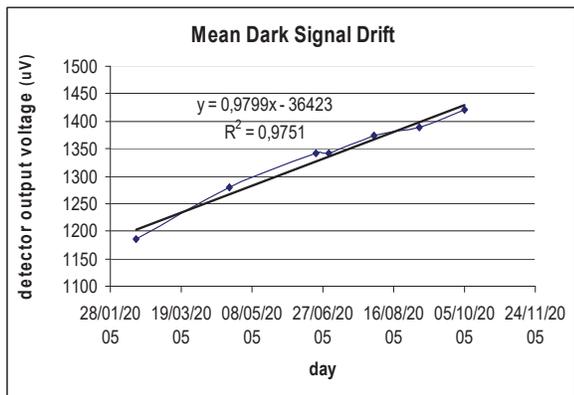


Fig. 7 : Mean dark signal drift on the PARASOL_Payload matrix

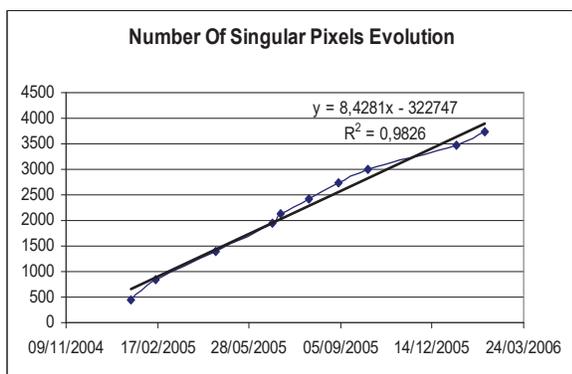


Fig. 8 : Variation in the number of singular pixels on the PARASOL_Payload matrix

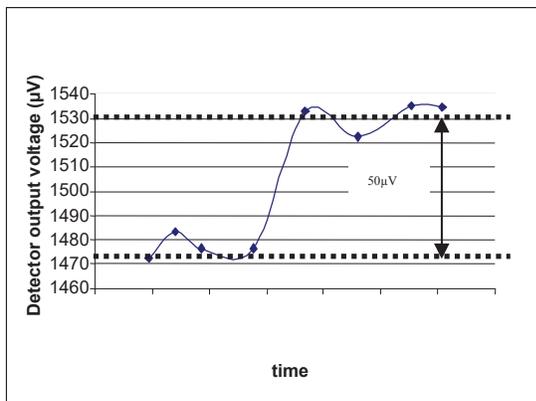


Fig. 9 : Maximum jump observed in three years of orbit on a SPOT5_XS pixel. Maximum amplitude is 50µV.

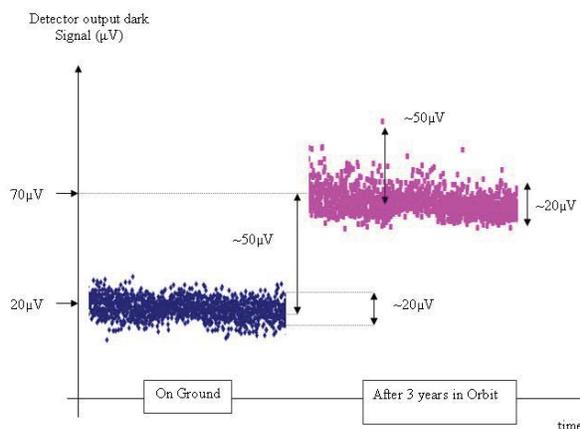


Fig.10 : Variations in a SPOT5_XS register after three years in orbit. Note that DSNU has not changed by more than 50µV.

3.2 Comparison of variations observed

By considering the parameters studied under equivalent conditions (calculation of received dose by considering the orbit and equivalent aluminium shielding), it can be seen that the trends observed in flight are on a similar amplitude (factor of 1 to 3) for all the detectors studied (see following table 1).

Parameter studied	Detector	In-flight drift measurement
Mean dark signal	(SPOT5_XS)	290%/kRad
	(SPOT5_PAN)	343%/kRad
	(PARASOL_Payload)	216%/kRad
	(SPOT5_ST)	116%/kRad
Jumps	(SPOT5_XS)	11e-/ms
	(SPOT5_PAN)	13e-/ms
	(PARASOL_Payload)	16e-/ms
	(PARASOL_ST)	16e-/ms
DSNU increase	(SPOT5_XS)	<50µV in 3 years
Singular points	(SPOT5_XS)	660 points/mm2/ kRad
	(PARASOL_Payload)	600 points/mm2/ kRad
	(PARASOL_ST)	820 points/mm2/ kRad

Table 1: comparison of in-flight variations

These similarities are surprising considering that the detectors concerned are very different in terms of type and use (matrix or linear array, integration time, etc...). The main similarities appear on singular points and jumps related to proton displacement effect. This shows clearly that the mechanisms involved seem to be independent on the CCD technology, and are rather intrinsic to the silicon-based material common to all the devices tested.

A spread of a factor 3 is observed on mean dark signal increase. As pointed in § 1.2, mean dark signal increase is related to total dose effect and oxide ionisation. In this case, an enhanced dependency on CCD design and process fabrication might be evidenced.

It should be underlined, however, that there is an uncertainty factor (even if it is less than 2) in the calculation of the in-flight dose received by the detector. This is because sectorial analysis are either missing or approximated.

3.2 Comparison with on-ground measurement

The results of ground measurement are available in the table 2.

Parameter studied	Detector	Ground prediction
Mean dark signal	(SPOT5_XS)	4800%/kRad
	(SPOT5_PAN)	650%/kRad
	(PARASOL_Payload)	272%/kRad
	(SPOT5_ST)	60%/kRad
Jumps	(SPOT5_XS)	-
	(SPOT5_PAN)	-
	(PARASOL_Payload)	-
	(PARASOL_ST)	-
DSNU increase	(SPOT5_XS)	140µV in 5 years
Singular points	(SPOT5_XS)	-
	(PARASOL_Payload)	-
	(PARASOL_ST)	-

Table 2 : ground measurement

It is observed, compared to table 1, that even if ground predictions are quite close to in-flight values, the predictions indicate a drift value that is 16.5 times greater than that actually observed in flight in the case of the SPOT5_XS detector.

4. CONCLUSIONS

Confirmation of these results by in-flight measurements on other detectors (other manufacturers, same type of orbit, etc.) would be very useful for end-

of-life predictions. An empirical model would give a clear idea of actual in-flight variation before testing (variations in DSNU and pixel dark signal, calibration rate, etc.).

In addition, ground predictions can prove very pessimistic compared with actual in-flight values (this is the case of TH7834B). In this case, a more realistic estimation would release some margin when adjusting certain parameters – detector temperature for example. Refined analysis of all the ground tests would be useful at a later stage to determine which come closest to these observations and possibly attempt to identify which test conditions offer the most realistic predictions.