CURRENT STATUS OF MODELING OF POINT SOURCES TRANSIENT RESPONSE FOR LW-ISOCAM

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ABSTRACT

The ISOCAM Long–Wavelength detector is a Si:Ga matrix array of 32×32 pixels dedicated for IR observations between 5 to 16 μm. Under quasi uniform illumination it has been shown that the transient response of each pixel can be described with a very good accuracy by a Fouks model, except for the pixels close to the edges of the matrix. As a direct consequence of the use of this model, some deviations from this model become evident : Long Term Drifts (LTD), Small Amplitude Oscillations (SAO) and the specific Point Source transient response.

A first model of Point Source transient response has been developed. A more complicated one is under preparation, closer to the effective geometrical and electrical design of the LW-CAM array. These models are based on physical approach.

In this paper we presents ground based and in-flight point sources transients. Theoretical examples are given. We also explain why empirical methods cannot be used.

Key words: ISO-CAM, transients, point sources, crosstalk, ground based tests

1. Introduction

For all the Si:Ga detectors on-board ISO (PHT S & P, SWS b2, LW-CAM), transient responses are the systematic effects who gives the major systematic error on the observations (see references in Coulais et al. (2000)). It has been shown that for uniform illumination the Fouks theory (Vinokurov & Fouks, 1991; Fouks, 1992, 1995; Fouks & Schubert, 1995) can describe those transients with a high accuracy, even at very low level. PHT-S transients were described at % level during ground based tests over 4 decades of incoming flux by one of the Fouks models (Schubert, 1995; Fouks & Schubert, 1995). This Fouks model was re-used with success for LW-CAM (Coulais & Abergel, 2000) then for SWS band 2 (Kester, 1999).

Deviations from the Fouks model also appear clearly. For raster maps observations with LW-CAM, the current major systematic error comes from inaccurate description and correction of the point source transient[1] (Miville-Deschênes et al., 2000; Blommaert et al., 2000). The change of transient shape for point source comes from two simultaneous effects : non uniform illumination of the pixel surface and gradient of illumination between adjacent pixels who give electrical crosstalk. It should be noticed that another supplementary non-linear effect for SWS is currently studied by Kester and Fouks.

We try to address this problem for LW-CAM from a physical point of view similarly to the uniform illumination case. The model we are developing could also be used for SWS and PHT Si:Ga detectors since they also are affected by non uniform illumination of the pixel surface and by electrical crosstalk between adjacent pixels.

This paper is a review of the current status of the current work on this problem. We present experimental data, both from ground based tests and in-flight observations. We explain several difficulties which occur when these data are used for comparison with models. We will also present outputs of the first model with explanations. The paper can be seen as an annex with figures and comments of the SPIE paper (Coulais et al., 2000) where the analytical model was fully developed.

In Sect. 2, we explain which kinds of experimental data are useful in order to study point source transients and to allow accurate comparison with models. In Sect. 3, we describe the ground based tests of CAM. In Sect. 4, some example of in-flight observations of point source are shown and commented. In Sect. 5, we present some outputs of the first model which has been developed specifically for LW-CAM point source transients. Since this model is insufficient, we present the new model in Sect. 6, which is currently under development. In last Sect. 7, we discuss empirical methods.

2. What are the ideal data ?

For LW-CAM it has been shown that the transient response under uniform illumination is accurately described by a non-linear model which is strongly sensitive to the initial and final levels (Coulais & Abergel, 2000). As a consequence the offset level of the observations must be very accurately corrected before transient correction, es-

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[1] For LW-CAM CVF, the error budget is different because of optical ghosts (Okumura, 2000)

pecially at low level. This is done by the LW CAM dark correction (Biviano et al., 2000) which is applied before any transient correction.

This difficulty remains the same for point source since the new models are only 3D generalization of the 1D Fouks model. Then the point source transient response will depend on the source amplitude and width but also on the background level[2] and on illumination history. In order to characterize this transient response, the first test to be done is to superimpose a source on a stabilized background [3]. The source should be added as fast as possible to reduce any other experimental effects. The parameters are the background level, the point source amplitude, the point source width and also the position of the point source center on the pixel surface.

Unfortunately only few in-flight data sets follow this ideal setup. For most of them, the stabilization is not achieved before adding the point source and sometimes the dark level accuracy is insufficient.

Moreover, to analyze the data, it has to be assumed that the point source position is constant. Unfortunately in-flight data are clearly affected by the satellite jitter[4]. It is also clear on the experimental data that the transient response depends on position of point source center on the pixel surface. When the point source is centered on pixel center then the curves of the four adjacent pixels will overlap themselves (see Fig 2a (centered) and Fig 1a (off-centered)).

Models of point source transients must take into account the width of the point source profile. The strongest possible gradient of the illumination profile is limited by the Point Spread Function (PSF) which depends on the lenses and filters. We consider that, at the beginning, it is more simple to study point source transients for the widest PSF in order to have the lower crosstalk between pixels. 1.5 arcsec filter and LW3/LW10 filters provide some of the widest PSFs. We have used theoretical point source profile provided by Okumura (2000).

3. Ground based tests

SW and LW CAM detectors have been extensively tested and calibrated during ground based tests. The experimental setup is described in Pérault et al. (1994).

A lot of ground based tests were done in order to characterize the transient response, both under uniform illumination and for point sources. At the present time, we have extracted only point sources data where the background level was changed at the same time as the sources. Three examples are plotted on Fig. 1. Despite the drawback of unstabilized background these data have a very high signal to noise ratio compared to in-flight data (See Fig. 2).

This is the first time that this kind of ground based data are shown. At the time of ground based tests, contrary to the PHT team, no accurate transient model was available for LW-CAM. If the model were available, less time would have spent on the uniform illumination case and more time for point sources and long term drift.

4. In-flight observations

Several calibration sources have been observed during ISO flight (Blommaert, 1998; Blommaert et al., 2000). These observations are used as test signals for our models. These data have several drawbacks : they are generally too short to ensure the stabilization is achieved for the brightest pixels, the satellite jitter gives a strong noise on the data, the stabilization before observing a source is rarely reached and data are affected by glitches.

Using the IDA software[5], we have extracted in the in-flight observations database all the point sources observations following these criteria :

- at least one hundred readouts at 2.1 s integration time;
- a wide PSF (see Sect. 2. This is achieved for example with lens 1.5 arcsec and filters LW 3 and LW 10);
- a limited amplitude of the source (in order to avoid extra non linear effect) below ~500 ADU for the brightest pixel. This limit was chosen because a very limited hook effect was observed during ground based tests under uniform illumination, when starting at levels very close to zero and going to levels above ~600 ADU (See Fig. 4 in Abergel et al. (2000)). We hope that beginning such a study in a limited range will avoid extra problem due to other non linear effects.

Interrogations of the IDA database was helped by using a table which gives the modeled brightness of IR references stars through LW-CAM filters. It remains about 20 data sets of good quality. Three examples (low, medium and high amplitudes) are shown on Fig. 2.

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[2] We define the background level as the quasi uniform level above the dark level (e.g. zodiacal light background). The dark level is defined as the (positive) level which remains when the entrance is closed (non incoming light). We recall that the Fouks model works only when levels are positive (See discussion in Coulais & Abergel (2000)).

[3] Transient responses include two simultaneous effects : memory effect and transient effect. Even we said that Si:Ga detectors are never stabilized, assuming stabilization significantly simplify transient studies.

[4] Relative pointing error specification for ISO was 2.7 arcsec, the effective value is 4 times better than the specified one (Salama, 2001).

[5] JAVA interface to ISO archive and database at `http://www.iso.vilspa.esa.es/ida/`

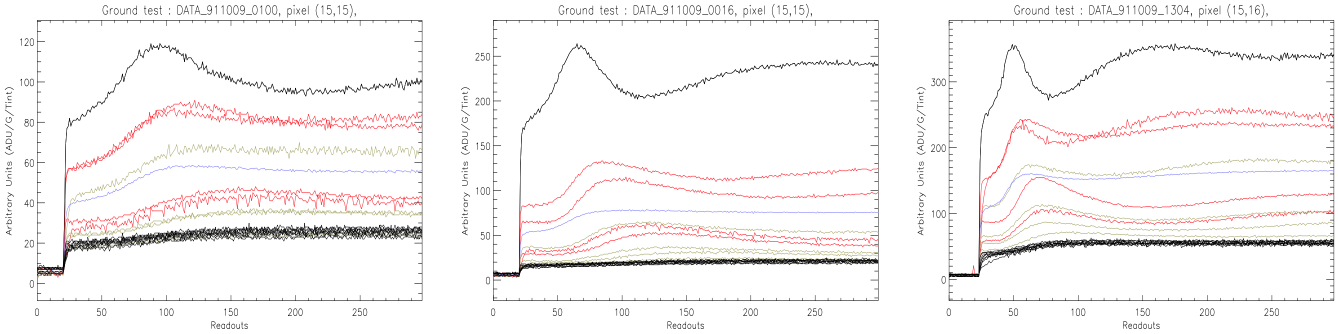

Figure 1. Three examples of point sources transients from ground based tests. These data present several interesting properties compared to the in-flight ones (see Sect. 4 and Fig. 2.) : they have a very low noise, they have very few glitches, they are not affected by satellite jitter and the all parameters are -in theory- well known (value of the background, width and flux of the source). These data have been corrected using a specific ground based dark. These data have the drawback to be affected by two changes at the same time : starting at a level close to the dark level, both the dark level and the source were added simultaneously. This configuration could give extra-complications for first comparisons to any transient models.

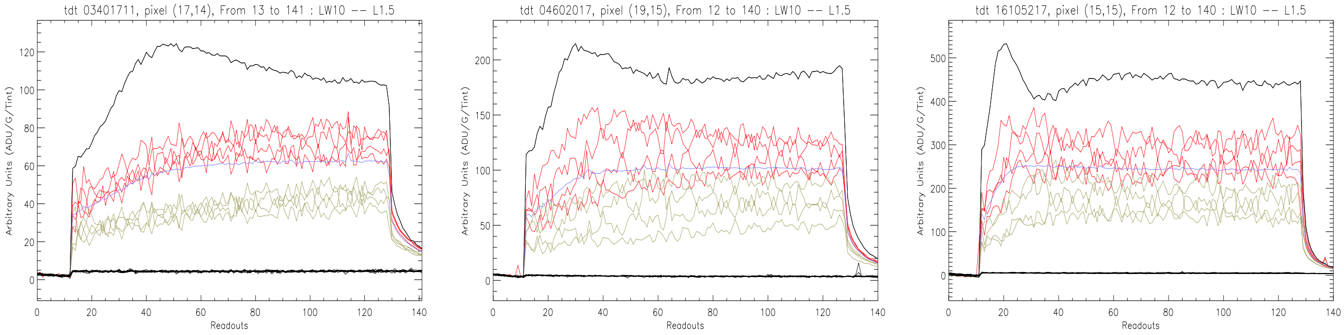

Figure 2. Three examples of point sources transients from in-flight observations. The glitched values have been replaced by median value after simple temporal median filtering. The dark level has been corrected. These data are clearly much more noisy than the ground based tests ones. The so-called noise on the point sources transient is generally much stronger than for uniform illumination transients. This difference is not observed on ground based data. Then, due to the observed anti-correlation in the noise behavior between two adjacent pixels, it is supposed that this special noise behavior is due to satellite jitter.

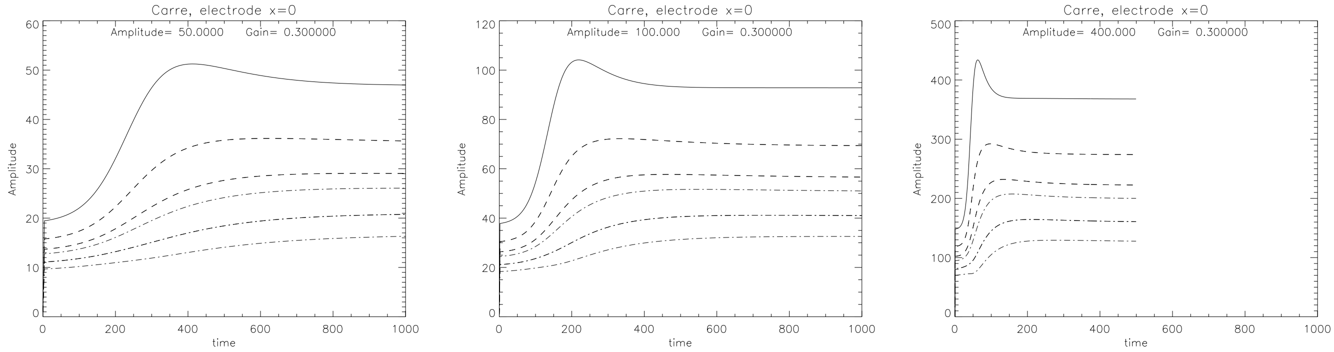

Figure 3. Three theoretical outputs from the first model for point source transients. On the same initial stabilized background level, an off-centered source is added at time t=0. The non linear effect of this model is clearly visible. The point source is off centered by (-1/4,-1/4) pixel. The source profile is pseudo-Bessel shape, half-width of the source is about 1/2 pixel size. Continuous line: central pixel, dashed line: closest 4 pixels, dashed-dot line: 4 diagonal pixels. Because of the symmetry, we have only 2 dashed lines and 3 dashed-dot lines.

5. First theoretical 3D model

B. Fouks has been invited during one month in IAS during Nov. 1999. He has developed a first 3D model of Si:Ga matrix detectors for computing transient response of each pixel in matrix array under non uniform illumination of this array.

This 3D model is based on the same physical equations as the 1D Fouks one, but with less simplifications. Basics equations of the Fouks model are described in Fouks & Schubert (1995). Equations of this 3D model were described in Coulais et al. (2000). Contrary to the 1D Fouks model this 3D model takes into account interaction between adjacent pixels in the matrix array. The 1D Fouks model was assuming that (1) the surface of the pixel is uniformly illuminated and (2) there is no interactions between adjacent pixels (no crosstalk). The electrical crosstalk always exists between adjacent pixels even they are physically separated (Vinokurov & Fouks, 1988; Fouks et al., 1994). This crosstalk is exactly compensated between two adjacent pixels which receive the same incoming flux. This is one of the reasons why the 1D Fouks model works well for matrix array under uniform illumination.

The 3D model was simplified assuming both contacts as continuous planes and therefore a circular symmetry of the detector. These simplifications reduce the computations.

Output examples of this model are shown on Fig. 3. Comparing with in-flight data, we clearly see that the response is qualitatively reproduced. However quantitatively the model fails. We believe that this model is limited by the simplified geometry used for the lower contact and by the circular symmetry simplification.

6. Second theoretical 3D model

A new 3D model based on the real geometry of the detectors is under preparation. The steps are similar to those of the first model (Sect 5). First we compute the field lines inside each pixel of the array assuming their lower contacts[6] as circular conductive islands. Second we compute the two kernels who characterized each contact side. Finally we compute, for a given illumination profile (uniform or not) of the matrix surface, the output current for each pixel. Major changes from the first model are (1) the geometry for the pixels is closer to the reality, (2) for the given geometry, we don't use the circular symmetry simplification and (3) one kernel depends on the illumination profile.

We are currently testing whether our new model can give the Fouks-Schubert transient response under uniform illumination. This is non trivial because computations are big and taking into account crosstalk between pixels will change the equivalent detector parameters β and λ (corresponding to the instantaneous jump and the time constant).

The main improvement comes from the change of the description of the lower contact. In our first model, both sides were supposed to be square and to fully cover the pixel sides. In reality, only the upper electrode of LW-CAM has a 100% filling factor. The lower electrode is a circular one, surrounded by a reflective plane (Vigroux et al., 1993).

This model depends on several parameters and their relative ratios :

- the intercontact distance (h=500 μm);
- the pixel pitch (d=100 μm);
- the radius of the circular contact connected to readout electronic through indium bumps ($a \sim 36$ μm)[7];
- the electrical voltage (E_0=28 V during ground based tests (Vigroux, 1991), 25 V in-flight (Vigroux et al., 1993)).

The reflective plane (the electrod at ~5 V surrounding the circular contact islands) is not considered for a steady state current, where its effect is very small, but is considered only for transient current, where it The reflective plane (the electrode at ~5 V surrounding the circular contact islands) isn't considered for a steady-state current, where its effect is very small, but is considered only for transient current, where it strongly affects the processes. This follows from the fact that the screening length in the detectors is very short at a steady state, but is very long under non-stationary processes (Fouks, 1995).

Most of physical values are now known except for the shape of the reflective plane. Nevertheless, it is possible that we will have to fine tune their effective values. For example, the effective value of the radius a will strongly depend on the way this electrode was implanted by lithography.

7. Alternatives to derive flux estimation

7.1. Use of the fast response

An alternative method to compute the stabilized value for point sources is to consider only the amplitude of the instantaneous response. In the case of uniform illumination, β does not depend on the initial and final levels. However in the case of point sources, we have not enough stabilized data to give definitive conclusion at the present time any. Also from physics it follows that β depends on the size of the point source illumination.

7.2. Use of the 3×3 mean pixel

From ground based and in-flight tests it is clear that the value of the mean of the 3×3 pixels –centered on the brightest one– stabilizes much more faster than the individual pixels. This is illustrated on Figs. 1 and 2. We conclude that this value can be used to correct at first order the point source data. However we don't have enough experimental data to build any table, since these data should cover the range of brightness observed by LW-CAM not only for sources but also for background levels.

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[6] This contact is the electrode which is in contact with electronics through Indium bumps.

[7] The value of radius a was not published and we thank LETI team who provided it.

8. Conclusion

The problem of accurate correction of point source transients for LW–ISOCAM is still pending.

During ground based tests, due to a lack of understanding of the memory effect and of the non linear behavior of these transients, no dedicated strategy of background change was used. Future design of ground based tests procedure of such point sources transient could be clearly improved using these experiences (sensitive not only to the source intensity but also to the background level, to the position of the source center on the pixel surface, to the source width and source profile, ...)

It has been explained in Sect. 4 why, in order to study point source transients, in-flight data are much less convenient than the ground based ones. Unfortunately, the electrical setups were different during ground based tests and in-flight operations. As a direct consequence, point source transients have changed and ground based tests cannot be used directly to study or to correct in-flight data[8].

It appears that for all the problems around transients (under uniform illumination, for point source, the LTD, ...) the better the transient modeling, the better the final instrument performance. If the Fouks model had been used for LW-CAM data during ground based tests, obviously the deviations due to non uniform illumination and drift would have become evident at that time. As a consequence, the ground based test strategy and also the operations during flight would have been optimized. The calibration phases of new instruments will benefit of the experience coming from ISO.

ACKNOWLEDGEMENTS

AC thanks CNES, CEA SaP and IAS for financial support. AC thanks the Paris XI university for the B. Fouks' one month invitation during Nov. 1999. First model was developed during this time. AC is grateful to B. Fouks who concepts these theoretical point source models. AC thanks A. Abergel, M. Pérault and G. Levanti for their helps for re-processing ground based tests. AC thanks K. Okumura who provides the point source profile used for first model, this profile is based on current knowledge of LW-CAM PSF. AC thanks LETI team who indicates the shape and radius size of the lower electrode after measurement on a spare array. BF is thankful to the Paris XI University and IAS for the invitation and to A. Abergel and AC for the fruitful cooperation.

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[8] Nevertheless comparisons are not trivial because the illuminations are often different. For example, ground based initial level is often much lower than in-flight ones. That could have strong consequences on point source transients, as it is the case under uniform illumination. On the other side, β was $\sim$0.65 during ground based test (V=28 V) and $\beta \sim 0.5$ during flight (V=25 V). In any case, ground based data will be very useful when we will adjust the parameters of the new model.

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