COBRA: a CMOS space qualified detector family covering the need for many LEO and GEO optical instruments

Michel Bréart de Boisanger

Olivier Saint-Pé

Franck Larnaudie

Saïprasad Guiry

et al.
cobra, a cmos space qualified detector family covering the need for many leo and geo optical instruments

michel bréart de boisanger(1), olivier saint-pé(1), franck larnaudie(1), saiprasad guiry, pierre magnan(2), philippe martin gonthier(2), franck corbière(2), nicolas huger(2)

neil guyatt(3)

(1) eads astrium 31 av des cosmonautes 31402 toulouse cédex 4 france, michel.breartdeboisanger@astrium.eads.net

(2) isae-cimi 10 avenue edouard belin bp 4032 31055 toulouse cédex france, pierre.magnan@isae.fr

(3) e2v, 106 waterhouse lane, chelmsford, essex, cm1 2qu, england, neil.guyatt@e2v.com

abstract

visible and nir space imaging applications are today taking advantage from the availability of cmos arrays offering excellent electro-optics performances thanks to the use of processes dedicated to imaging applications. astrium and isae have developed a family of cmos detector based on umc 0.35 microns foundry from a sound r&t program which has enabled the design a wide toolbox and subsequent qualification of associated technology bricks. from these elements, many detectors were developed, among them a 2 million pixels detector was fully space qualified in 2007. this will be one of the first cmos detector operated in an operational mission on the geostationary orbit. the back-end processing of cobra 2m was carried out to e2v technologies. e2v will also industrialize the multi linear sensor of the multi spectral instrument of the low earth orbit sentinel 2 mission for which cobra family was selected. performances and qualification results will be presented in this paper as well as the development of test benches to improve accuracy and efficiency for extensive detectors characterisation and advanced technology works to extend the cobra family capabilities.

1. introduction

fig. 1-1 illustrates the cobra detector roadmap conducted from 2002 to 2007 to produce both space qualified 2d and multi linear arrays, with high spectral detection efficiency, for geo and leo earth observation missions. four main goals were reached during these years: high electro-optical performances, linear swing improvement, low noise readout by pixel correlated double sampling and conversion gain adjustment.

2. cobra2m: a 2 millions pixels detector fully space qualified in 2007 for an operational geostationary ocean colour mission

2.1 geostationary ocean color mission [1]

the detector cobra2m has been developed for the geostationary ocean color instrument (goci), see fig. 2-1, implemented on the coms spacecraft to provide multi-spectral data to detect, monitor, quantify, and predict short term changes of coastal ocean environment around korea, see fig. 2-2, for marine science research and application purpose, in eight spectral narrow bands, see fig. 2-3.

fig. 2-1: geostationary ocean color instrument (goci) implemented on coms satellite interface.

fig. 2-2: goci target area around korea in coms application. 16 slots are used to cover 2500*2500 km2

<table>
<thead>
<tr>
<th>band</th>
<th>center</th>
<th>bandwidth</th>
<th>main purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>412 nm</td>
<td>20 nm</td>
<td>chlorophyll absorption maximum</td>
</tr>
<tr>
<td>2</td>
<td>443 nm</td>
<td>20 nm</td>
<td>chlorophyll and other pigments</td>
</tr>
<tr>
<td>3</td>
<td>490 nm</td>
<td>10 nm</td>
<td>turbidity, suspended sediment</td>
</tr>
<tr>
<td>4</td>
<td>555 nm</td>
<td>10 nm</td>
<td>base of fluorescence signal, chlorophyll, suspended sediment</td>
</tr>
<tr>
<td>5</td>
<td>605 nm</td>
<td>10 nm</td>
<td>base of fluorescence signal, chlorophyll, suspended sediment</td>
</tr>
<tr>
<td>6</td>
<td>630 nm</td>
<td>10 nm</td>
<td>atmospheric correction and fluorescence signal</td>
</tr>
<tr>
<td>7</td>
<td>745 nm</td>
<td>20 nm</td>
<td>atmospheric correction and baseline of fluorescence signal</td>
</tr>
<tr>
<td>8</td>
<td>865 nm</td>
<td>40 nm</td>
<td>aerosol optical thickness, vegetation, water vapor profiles over the atmosphere</td>
</tr>
</tbody>
</table>

fig. 2-3: goci spectral bands and main purpose.
2.2 Detector heritage

2.2.1 Array heritage

A prototype of 1 million pixels was developed in 2002-2004 to confirm UMC 0.35µm excellent radiometric performances [2] in term of Spectral Detection Efficiency (SDE) and Modulation Transfer Function (MTF), see Fig. 2-4 and 2-5.

A new prototype COBRA1MP with various ionic implantations was tested in 2005 to maximize output voltage swing [3], offering improved charge handling capacity necessary for photonic noise dominated application as Geostationary Ocean Colour Imaging.

Fig. 2-4: COBRA 1M device): 8 inch wafer (left); COBRA1M in package (top right); COBRA1M pixels (bottom right).

2.2.2 Packaging heritage

Experience gained in the frame of LOLA mission [4] with the development of a 750x750 airborne APS [5] was used to define the COBRA2M package, using the same concept of Interstitial Pin Grid Array (IPGA) connected to a PCB Flex with multiple flexible parts, see Fig. 2.6, anticipating a Focal Plane Array with the detector back glued on a SiC part to offer excellent thermal control.

Fig. 2-5: COBRA 1M performances

2.3 Detector development

2.3.1 Design phase

From the radiometric performances extrapolated from COBRA1M and the increased performances of the readout circuit in term of output voltage swing, tested on COBRA1MP, accurate modelling of the COBRA2M performances was possible, especially in term of elementary integration time and the number of cumulated images necessary to meet specified SNR of 1000 for each of the eight spectral bands.

For the band of maximum flux and maximum Spectral Detection Efficiency, a minimum elementary integration time of 100msec was necessary to collect 100ke-. The frame period for this value is 100msec and was provided by four outputs with a pixel rate of 5.3 MPixels/sec.

Row and column decoders, already developed in the frame of COBRA1M, were implemented, see Fig. 2-7.

Fig. 2-6: LOLA APS750FAST packaging

Fig. 2-7: COBRA2M Detector Architecture

2.3.2 Demonstrator Model (DM) manufacturing and test phase

A small number of devices were packaged by e2v and tested by Astrium.

Readout circuit performances were confirmed with respect to COBRA 1M_P test results, see Fig. 2-8, with a output voltage swing greater than 1.1V for a 3.3V power supply and a Readout noise in darkness of 500µV rms due to α²(2kT/C) hard reset noise and an estimated 200µV rms noise for sampling circuit.

MTF performances measured on COBRA1M were confirmed, using a specific Astrium test bench, see Fig. 2-9.
2.3.3 Flight Model (FM) manufacturing and qualification phase

DM test results presented at the Critical Design Review (CDR) authorized the FM manufacturing and qualification phase. A FM test bench was implemented in an Astrium clean room, see Fig. 2.11 to screen the 32 devices packaged and delivered by e2v and select Qualification models, Flight model and Flight spares, see Fig. 2.12. The qualification test results demonstrated only Dark Current increases with Total Ionizing Dose (5krad) and protons irradiations (2 \times 10^{10} p+/cm² 60MeV) as depicted in figure 2.13.

At the end of the DM phase, a COBRA2M device was soldered to a PCB Flex and connected to the Front End Electronic (FEE) to test compatibility, see Fig. 2-10. Electro-optical tests were repeated to validate FEE behaviour.

### Table 2.3.3

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply current (I(sat))</td>
<td>ISAT</td>
<td>mA</td>
<td>12.74</td>
<td>13.79</td>
<td>0.05%</td>
</tr>
<tr>
<td>Noise signal characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Charge to voltage factor</td>
<td>C/V</td>
<td>µV</td>
<td>6.00</td>
<td>5.99</td>
<td>0.07%</td>
</tr>
<tr>
<td>Mean Range at 1% of non linearity</td>
<td>U</td>
<td>µV</td>
<td>643</td>
<td>642</td>
<td>0.05%</td>
</tr>
<tr>
<td>Mean Voltage at 5% of linearity</td>
<td>V%</td>
<td>mV</td>
<td>1371</td>
<td>1086</td>
<td>0.57%</td>
</tr>
<tr>
<td>Mean Saturation Voltage</td>
<td>Vsat</td>
<td>mV</td>
<td>1125</td>
<td>1125</td>
<td>0.00%</td>
</tr>
<tr>
<td>Performance in Darkness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Dark Signal</td>
<td>DSNU</td>
<td>mV</td>
<td>2.33</td>
<td>0.33</td>
<td>30%</td>
</tr>
<tr>
<td>Dark Signal leakage (β)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Leakage in Electronics</td>
<td>IN</td>
<td>µV</td>
<td>54.1</td>
<td>53.1</td>
<td>2.00%</td>
</tr>
<tr>
<td>Offset in Darkness</td>
<td>MDB</td>
<td>mV</td>
<td>2.3</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Influence of charge on 2 million pixel</td>
<td>$\Delta$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2-13: electro-optical parameters before after proton irradiation ($2 \times 10^{10} p+/cm² 60MeV$).

### Fig. 2-11: COBRA2M FM test bench in clean room with class 100 flux and device regulated at 17°C.

### Fig. 2-12: location of Qualification and Flight Models on the wafer processed by e2v.

**2.2.4 COBRA2M development lessons learnt**

A learning curve is always necessary when using a new foundry and that some prototypes are necessary before producing flight models. Developing an efficient fully
automated test bench greatly assists the conduction of testing during an FM production phase, securing both schedule and quality of test results, especially for the repeatability of test before and after qualification tests. The selected Flight Model was delivered in June 2007, two years after project kick off, to be soldered on the Flight PCB Flex and then glued onto the Focal Plane Array Sic part, before to be mounted on the Instrument telescope.

3. **S2 VNIR: A MULTI LINEAR SENSOR OF THE MULTI SPECTRAL INSTRUMENT (MSI) FOR THE LOW EARTH ORBIT SENTINEL 2 MISSION [6]**

3.1 **Sentinel 2 mission, instrument and VNIR focal plane**

Sentinel 2 is a LEO Earth observation mission in the frame of Global Measurement Environment and Security (GMES) program. The instrument is equipped with VNIR and SWIR Focal Plane Arrays, Each Focal Plane Array is made of twelve detectors in staggered configuration, see Fig. 3-1. The VNIR detector offers tens spectral bands with 10m, 20m and 60m resolution, and the SWIR detector offers three spectral bands with 20m and 60m resolution, see Fig. 3-2.

For each spectral band, a SNR corresponding to a reference flux and the maximum integration time is specified. A maximum flux is also specified for each spectral band. The detector sensitivity has to be adjusted band per band through Charge to Voltage conversion Factor (CVF) adjustment to meet SNR specification for a reference flux with avoiding saturation for maximum flux.

To help meeting SNR requirement, a Correlated Double Sampling readout circuit is implemented to eliminate photodiode reset noise and provide total readout noise lower than 200µV

3.2 **Detector heritage**

3.2.1 **Array heritage**

A multi linear array prototype COBRA NxK providing two lines with 10m resolution and nine lines with 20m resolution associated to two outputs was developed and tested in 2006 and beginning of 2007, see Fig. 3-3. This prototype validates the Correlated Double Sampling readout circuit with the expected readout noise reduction, due to photodiode reset noise suppression.

Specific test vehicles (COBRA CVF) were developed and tested to validate conversion gain adjustment.

Fig. 3-3: COBRA NxK prototype

3.2.2 **Test bench and method heritage**

The detector development took also advantage of know-how gained in the frame of the COBRA2M development, in term of test bench architecture, definition and implementation, see Fig. 3-4.

The same test methods and processing were mastered, providing high accuracy in test results, see Fig. 3-5.
Fig. 3-5: typical SDE, CVF and RON estimation with non linear estimation method [7]

3.2.3 Black coating heritage
As for COBRA2M, e2v works on the S2 VNIR back end manufacturing. Due to VNIR reflectivity requirements, a post process step is needed in order to strongly reduce the die global reflectivity. A black coating will be deposited on the non photosensitive area of the die to meet reflectivity requirements. This process has been still validated on COBRA NxK wafers, although black coated COBRA NxK devices have been packaged by e2v, see Fig. 3-6. Fig. 3-7 illustrates reflectivity measurements. Very low reflectance is achieved.

Fig. 3-6: COBRA NxK black coated device

Fig. 3-7: black coating reflectivity

3.3 S2 VNIR Detector development status
3.3.1 End of Design and validation phase
Today the design and validation phase is nearing completion, concluded by a Preliminary Design Review (PDR)

Fig. 3-8 presents the retained architecture:
- Pixels lines associated to the different spectral bands are read through three outputs at a sample rate of 4.8MHz enabling to read the 10m resolution bands in less than 1.51msec
- Each group of lines associated to one output are selected by a row decoder. Readout circuit sampling capacitances are addressed by shift registers

Fig. 3-9 shows a breadboard of the S2 VNIR device using COBRA NxK die to demonstrate required photosensitive flatness better than 10µm.

Fig. 3-9: breadboard of the S2 VNIR detector using COBRA NxK die.
3.3.2 EM and FM phases

Finally, on chip signal processing (within or outside the pixel) is a field that can strongly improve CMOS performances for specialised applications, such as lightning imagers, requested for future meteorological space missions.

Fig. 4-1: COBRA2M thinned and backside illuminated developed by Astrium, ISAE and E2V team.

5. REFERENCES


5. M. Bréart de Boisanger et al., Développement d'un sensor d'acquisition et de poursuite (ATS) pour un terminal de liaison optique, OPTRO 2005 conference proceedings, Paris

