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# SOFRADIR DETECTORS FOR MTG FCI APPLICATION

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## I. INTRODUCTION

For the last ten years, SOFRADIR space activity has considerably grown and strengthened relying on 25 years of experience in development and production of 2nd and 3rd generation MCT (Mercury Cadmium Telluride) infrared detectors. Indeed, around 60 persons are now full-time involved in IRFPAs development and/or manufacturing for space applications.

Space programs at SOFRADIR cover various applications such as earth observation, astronomy, universe exploration and meteorology, for civilian or military use. MCT detectors developed at SOFRADIR for space programs feature a large spectrum ranging from visible up to very long wavelength infrared (VLWIR). MCT technology initially developed between SOFRADIR and CEA-LETI is a standard n-on-p photovoltaic technology. This technology is the one used for space IR detectors having demonstrated by several years of operation on-board satellites that it is fully compliant with space environment and constraints (ageing, radiations …).

In the field of meteorology, it appears that the need of next operational missions is to have products of higher quality in terms of accuracy and resolution. In this context, SOFRADIR has been selected for the development and manufacturing of flight models for the FCI Mission (Flexible Combined Imager) on Meteosat Third Generation Imaging Satellite (MTG-I).

The MTG FCI needs for detector design will be first discussed in this paper. Then, the SOFRADIR proposed design to fulfill the specifications will be described. Finally, the first results in term of electro-optical and readout circuit performances will be presented.

## II. PRESENTATION OF THE APPLICATION NEED

In the frame of the Meteosat Third Generation (MTG) program for ESA and EUMETSAT, Thales Alenia Space is developing the Flexible Combined Imager (FCI). The mission principle is to make a complete multi-spectral image of the Earth area in 10 minutes, with a maximum East/West scan trip duration of 10 seconds at equator level.

The full description of FCI optical design and performance features can be found in paper referenced [4]. Each DA is ended by an hermetic connector which is connected to a dedicated front end electronic device. The relative arrangement of the 4 NIR/IR DAs, on the cold plate inside the cryostat is illustrated in the figure 1.
The cryostat assembly cools and maintains the NIR/IR detectors at a 60K operating temperature to reach radiometric performance, in particular for the longer wavelength infrared region.

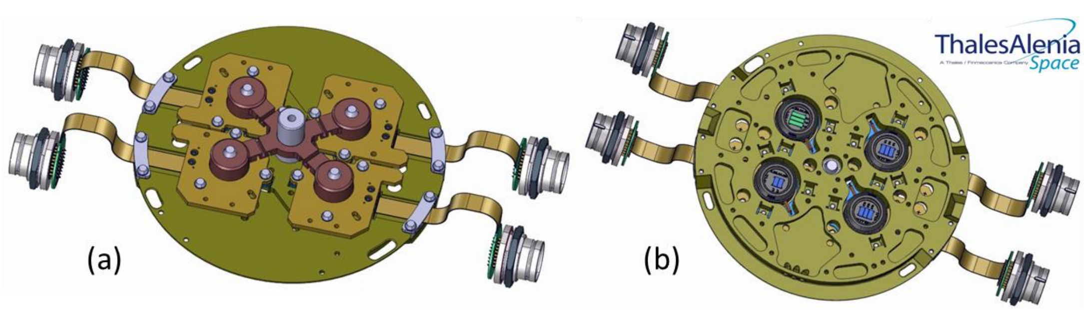


**Fig. 1.** The four FCI NIR/IR detection assemblies are integrated on a cold plate inside the cryostat assembly, and cooled down at 60K operational temperature. (a) Bottom view of the assembly on cold plate, with cooling braid. (b) Top view of the assembly on cold plate, above which the cold optics will be integrated.

The FCI integrates 11 spectral channels in the NIR/IR region from 1.3 to 13.6 µm. In association with the scanning strategy, each detection channel is designed among the same principle, which is a column of rhombus pixels. The number of pixels per channel and the pitch between pixels have been defined in order to cover the needed spatial sampling distance of 2 km down to 0.5 km for the higher resolution channels.

In order to answer the FCI high performance and high reliability needs, the detectors design includes redundancy of up to 4 pixels per line. There is therefore a best column mapping allowing no defects in the image, and redundancy to rectify any major pixel evolution in flight. Among other stringent spectral and MTF requirements, high SNR performance are needed for FCI on a large flux range (useful flux of the scene from 1.4 Me-/s/pixel at minimum flux for the NIR2.2 channel up to 107 Ge-/s/pixel at maximum flux for the IR12.3 channel). This implies the need at detector level of a very low readout noise in the NIR region for low flux detection and low dark current in the long IR region.

SOFRADIR is in charge of developing these 4 NIR/IR DAs answering the specific needs for MTG FCI instrument.

## III. MTG FCI DA DESIGN

### *A. General*

Four DAs (NIR, IR1, IR2 and IR3) allow addressing the 11 spectral channels as summarized in the following table :

| **DA** | **NIR** | | | **IR1** | | | **IR2** | | **IR3** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Central waveband (µm)** | 1.3 | 1.6 | 2.2 | 3.8 | 6.3 | 7.3 | 8.7 | 9.7 | 10.5 | 12.3 | 13.3 |

**Tab. 1.** Wave band distribution according to the DAs

. Each DA is composed of three main assemblies:

– The retina:

– The package :

– The flex-connector assembly :

All parts have been fully designed specifically for the MTGFCI program. They are described in the following paragraphs.

Figure 2 illustrates the detector assembly. The four DAs have similar designs.

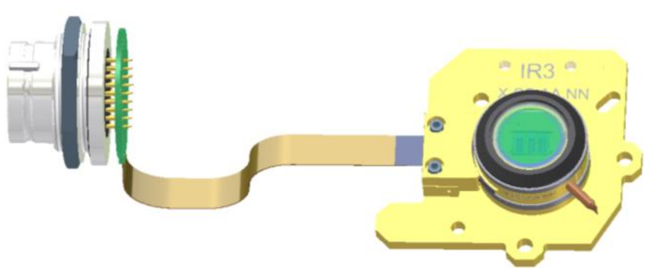


**Fig. 2.** Illustration of the IR3 DA : On the left, the flex with its connector, on the right the package where the three bands can be distinguished by transparency through the window.

### *B. The package*

The package is constituted by the assembly of four main parts: a kovar base, an hermetic ceramic, a filter-holder assembly and a window holder assembly. The retina is integrated on the Kovar base and bonded to the hermetic ceramic via gold bondings. The package provides a good thermal interface with the cooling system in order to reach cryogenic temperature, and the electrical interface by routing the electrical output of the ROIC to the outside of the package, to enable the connection with the flex. The filter-holder together with the window holder assembly, constitute the optical interface of the detector.

In order to guarantee the best positioning precision of the retina, it is glued on a Kovar baseplate where the mechanical references are machined. On the rear side of the baseplate a cylinder guarantees the thermal interface to the FCI cryostat.

The hermetic ceramic is welded on the Kovar plate and supports the window holder. It ensures electrical connexion and hermeticity function for the packaging. Inside the package, the filters are precisely positioned on a dedicated blackened filter holder as close as possible to the retina in order to limit parasitic flux.
Each channel has a dedicated filter optimized for the use-full wave band. Combined with the window (one per DA) it guarantees the needed spectral template.

The Kovar part of the package is covered with gold in order to limit radiative thermal loss. The upper part of the package (the window holder) is blackened to avoid parasitic reflections.

*C. The flex - connector*

The flex establishes the electrical link between the instrument electronic device and the DA package. It is composed of two main parts:

- The connector is a space grade airtight connector (Deutsch custom RSM family). This connector has 61 pins. The connector is brazed on the flex with plated through holes using classical and space qualified process.
- The flexible cable based on rigid-flex technology, is separated in 3 areas: a rigid area on the connector's side, a flexible area and a bonding area above the fixation part on the package side. Low emissivity (<0.05) is guaranteed by a dedicated design.

*C. The retina*

The retina is constituted by a MCT detection layer, which aim is to detect an incident photon flux, hybridized onto a ROIC, which aim is to enable the processing of the signal detected by the MCT diodes. For MTG FCI project, each detector (NIR, IR1, IR2, IR3) has an optimized MCT detection layer, in order to guarantee the best performances for each channel. The input stage of the ROIC is tailored to the required flux to be processed. Two types of ROICs are needed for the four DAs: one for the low flux specific to the NIR channels, and one for the other IR channels. The MCT detection layer is hybridized on its specific ROIC through the standard SOFRADIR hybridization process. For some DAs (IR1, IR3), a multi-hybridization process is used in order to have two detection layers on the same ROIC.

<u>The Detection Circuit</u>

The channels sensitive areas respect the specified layout given in fig.3, the relative distance between the centres of two consecutive channel sensitive areas being equal to 2.5 mm. The pixel has a rhombus shape with different dimensions for X and Y axis.

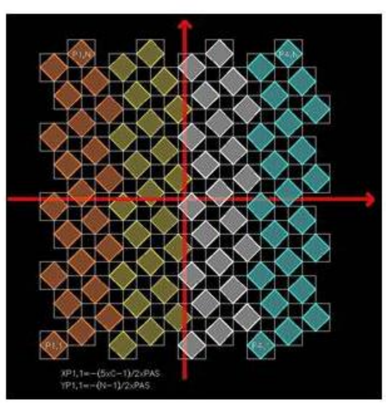

**Fig. 3.** Illustration of the pixel's shape and arrangement in the retina

Each channel sensitive area is composed of N lines x C columns, with its attached pitch grid as described in table here below:
Cut-off wavelength choice for MTG FCI retinas is basically driven by the level of dark current required, as well as the compatibility with the required channel bandwidth. Associated to the filter and the window the spectral response needs to be compatible with a specified narrow template.

| | **NIR** | | | **IR1** | | | | **IR2** | | **IR3** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B1 | B2 | B3 | B11 | B12 | B2 | B3 | B1 | B2 | B1 | B2 | B3 |
| **Spectral band (µm)** | 1.3 | 1.6 | 2.2 | 3.8 | | 6.3 | 7.3 | 8.7 | 9.7 | 10.5 | 12.3 | 13.3 |
| **# of lines (N)** | 224 | 224 | 448 | 224 | | 112 | 112 | 112 | 112 | 224 | 112 | 112 |
| **# of columns (C)** | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| **Pitch grid (µm)** | 25 | 25 | 12.5 | 12.5 | | 25 | 25 | 25 | 25 | 12.5 | 25 | 25 |
| **X dimension (µm)** | 53 | 49.5 | 21 | 20.1 | | 49.5 | 48.7 | 43.5 | 42.4 | 17.8 | 37.7 | 35.2 |
| **Y dimension (µm)** | 59.9 | 60.4 | 23.8 | 26.1 | | 58.9 | 59.4 | 53.9 | 53 | 24.4 | 50.1 | 48.3 |

**Tab. 2.** Detection circuit general characteristics

The Read Out Integrated Circuit

Two ROICs have been developed in the frame of the FCI program, one for the NIR DA and one for the IR DAs. Each active pixel converts into voltage the current from the photodiode to which it is connected by indium bump. This current-to-voltage conversion is done by integration into a capacitor within a CTIA (Capacitor Trans-Impedance Amplifier) stage which is also in charge to bias the cathode of the photodiode.

Integration time can be independently controlled through the serial word, and adjustable from 4% Tframe to 96%Tframe, by step of 1 TMC (where TMC is the master clock period). The conversion voltage is sampled and held at the end of the integration phase. This enables to start a new integration while conversion voltage is read-out (IWR mode: Integration While Read). One output (OUT) is shared by data from the bands.

Digital phases are internally generated by the digital part such as to control timing for integration and readout. Furthermore, the digital part also controls the pixel selection done either in hardware by the mean of selection table, or in software by the mean of the serial link whose input is SERDAT.

Selection-deselection of pixels enables to select one pixel by line.

As much active CTIAs as active selected pixel are biased (no bias if not selected), such as to save power, multiplexing from the pixels to active CTIA being controlled by values stored within the serial register.

Furthermore, the serial link enables to adjust:
- Biasing current of the input stage
- Biasing current of the output amplifier
- Biasing of anti-blooming function
- Voltage level of video during the extra readout cycles

The main characteristics of the two ROICs are summarized in the following table.

| | NIR | | | IR1 | | | | IR2 | | IR3 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B1 | B2 | B3 | B11 | B12 | B2 | B3 | B1 | B2 | B1 | B2 | B3 |
| **Charge handling capacity (fF)** | 34.9 | 53.9 | 5 | 31.8 | 508 | 27.8 | 29.8 | 1370 | 825 | 538 | 3922 | 3219 |
| **Frame frequency (MHz)** | 2.689 | | | 2.017 | | | | 0.672 | | 1.345 | | |
| **Total power consumption** | 28mW | | | 30.3mW | | | | 13mW | | 21.6mW | | |
| **ROIC Noise (µV)** | 560 | 374 | 1650 | 414 | 121 | 111 | 120 | 94 | 112 | 104 | 95 | 93 |
| **Nominal Integration time** | 0.363ms | | | | | | | | | | | |
| **Integration mode** | IWR | | | | | | | | | | | |
| **Input stage** | CTIA | | | | | | | | | | | |
| **Number of video output** | 1 | | | | | | | | | | | |
| **Output electrical dynamic range** | 2.8V | | | | | | | | | | | |
| **Non-Linearity** | <0.5% (5% to 90% of Well Fill) for all bands | | | | | | | | | | | |

**Tab. 3.** ROIC general characteristics

## IV. MTG FCI DA ELECTRO-OPTICAL PERFORMANCE

### *A. General*

First retinas have been manufactured and characterized. First results are presented in the next paragraphs. They are encouraging and allow giving confidence on the performance foreseen for flight models.

### *B. Radiometric performance*

The radiometric performances have been specified for three fluxes (Emin, Eref, Emax are specific to each channel) allowing covering the useful dynamic range of the pixels' output signal. In the next tables, average values for SNR, PRNU, QE are given.

| SNR | NIR | | | IR1 | | | | IR2 | | IR3 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B1 | B2 | B3 | B11 | B12 | B2 | B3 | B1 | B2 | B1 | B2 | B3 |
| **Emin** | 34 | 38 | 6 | 125 | 130 | 1942 | 1675 | 1576 | 1578 | 754 | 239 | 203 |
| **Eref** | 467 | 581 | 127 | 360 | 544 | 2817 | 2774 | 2927 | 1849 | 2045 | 850 | 598 |
| **Emax** | 698 | 857 | 192 | 700 | 3012 | 4829 | 4179 | 3960 | 3080 | 2383 | 1415 | 1002 |

**Tab. 4.** SNR for each channel at three different input irradiances.

The photo response uniformity (PRNU) is a key parameter, as it simplifies the calibration process and leads to high quality image with low residual fixed pattern noise (RFPN) drift under environmental condition changes.

Obtained results are given in the following table, showing a very well mastery of IR sensitive material manufacturing, enabling to answer MTG FCI DA requirements.

| | NIR | | | IR1 | | | | IR2 | | IR3 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B1 | B2 | B3 | B11 | B12 | B2 | B3 | B1 | B2 | B1 | B2 | B3 |
| **QE** | 0.75 | 0.77 | 0.79 | 0.78 | | 0.6 | 0.6 | 0.6 | 0.6 | 0.55 | 0.55 | 0.45 |
| **PRNU (%)** | 0.6 | 1.1 | 1.5 | 0.7 | 1.1 | 0.8 | 1 | 0.8 | 1.6 | 1.5 | 1.7 | 1.7 |

The QE is given for the useful wavebands of the final detector.

**Tab. 5.** QE and PRNU for each channel

As an example, output level and responsivity vs pixel number are shown for IR2 B2 band in figure 4 and IR3 B3 in figure 5. The four columns are shown. Signal show a high uniformity between columns and very small number of defects which will allow no defect retinas after de-selection (one out of four pixels to be selected). (see §C). For IR3, level of dark current is indicated, showing that even if remaining useful signal is low, homogeneity is not limited by dark current.

Overall radiometric performances for all channels were measured at values very close to expected. They will answer the instrument's need.

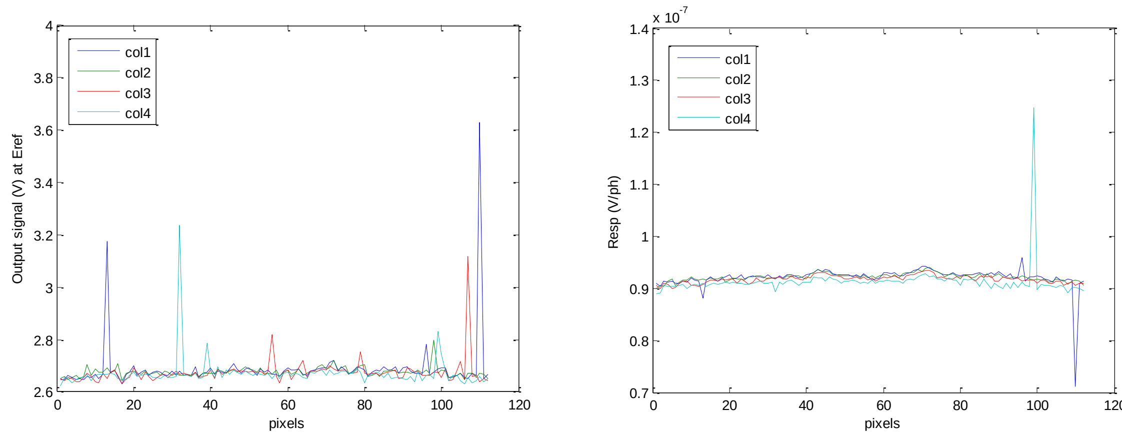


**Fig. 4.** Output levels (left curve) and responsivity (right curve) measured on B2 of IR2 retina in front of nominal input flux (Eref).

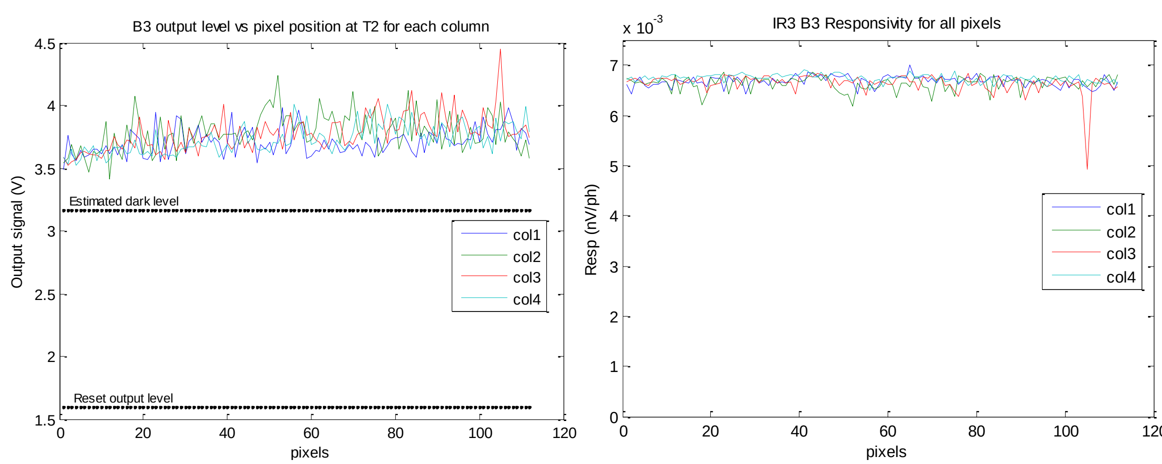


**Fig. 5.** Output levels (left curve) and responsivity (right curve) measured on B3 of IR3 retina in front of nominal input flux (Eref).

*C. Operability*

As mentioned above, pixel redundancy is implemented allowing selection of 1 pixel among up to 4 pixels. The benefit of this function is to be able to select the best pixel of each line and thus proposing zero defect channels for all FCI DA.

The figure 6 illustrates the efficiency of the pixel selection, measured by TAS on one of the first retinas manufactured for the IR3 Breadboard model. 100% operability is achieved on this model. This performance is obtained on a retina fully representative of expected standard performance for these channels (waveband between 12 and 14 µm).

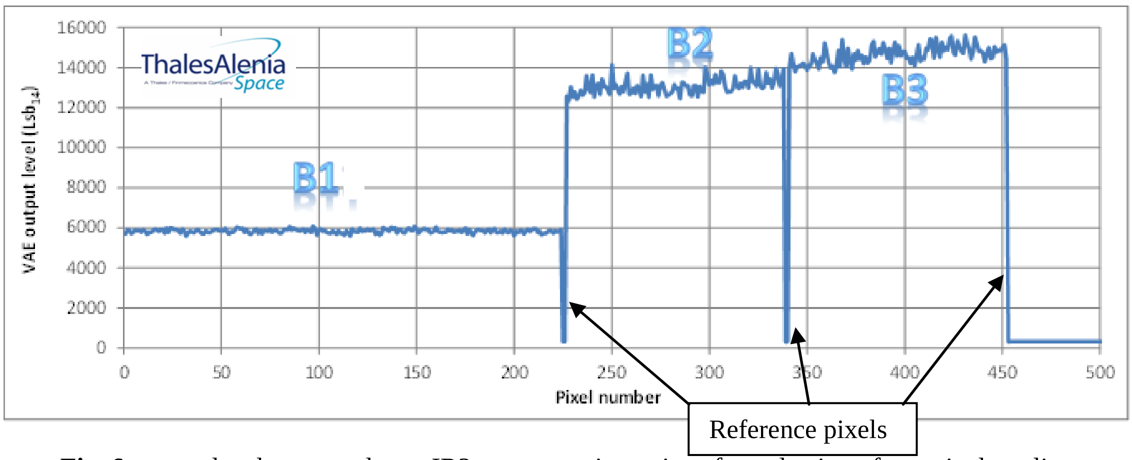


**Fig. 6.** output level measured on a IR3 representative retina after selection of one pixel per line

*D. Geometrical performance*

MTF measurements were performed on some pixels located on the centre of the retina for both axes.
For a square pixel, the MTF is compared to a sinc function. The theoretical value at Nyquist frequency is 0.64. For a rhombus pixel the MTF is compared to a squared sinc function. Therefore the value at Nyquist frequency is $(2/\pi)^2$. If one takes for example the NIR B1 band in the X direction, the value at 19 mm-1 should be at 0.4. As shown in figure 7, the measured value is close to the theory.

This excellent result is achieved thanks to the SOFRADIR's silicon-like planar implantation process which provides a well-controlled junction and diffusion lengths and enables sharp edge diode. For other channels, the same type of result is obtained and the MTFs measured are very close to theory.

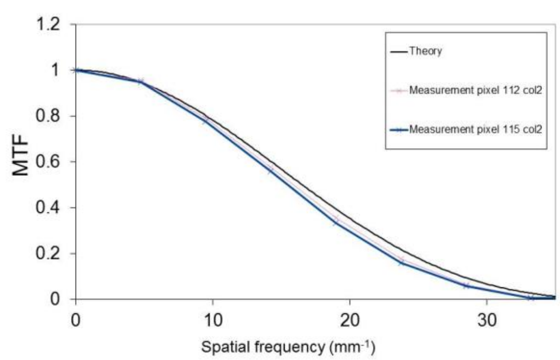


**Fig. 7.** NIR B1 MTF in the X direction : theoretical curve and measured MTF on two pixels.

## V. MTG FCI DA IRRADIATION CAMPAIGN RESULTS

Irradiation campaign has been performed on both ROICs for the MTG FCI program. The level applied has been summarized in the following table :

| Ion | Energie (MeV) | Range (µm(Si)) | LET (MeV.cm².mg⁻¹) |
|---|---|---|---|
| $^{15}N^{3+}$ | 60 | 59 | 3.3 |
| $^{20}Ne^{4+}$ | 78 | 45 | 6.4 |
| $^{40}Ar^{8+}$ | 151 | 40 | 15.9 |
| $^{84}Kr^{17+}$ | 305 | 39 | 40.4 |
| $^{124}Xe^{25+}$ | 420 | 37 | 67.7 |

UCL cocktail M/Q=5

| Ion | Energie (MeV) | Range (µm(Si)) | LET (MeV.cm².mg⁻¹) |
|---|---|---|---|
| $^{13}C^{4+}$ | 131 | 292 | 1.1 |
| $^{22}Ne^{7+}$ | 235 | 216 | 3 |
| $^{40}Ar^{12+}$ | 372 | 117 | 10.2 |
| $^{58}Ni^{18+}$ | 567 | 100 | 20.4 |
| $^{83}Kr^{25+}$ | 756 | 92 | 32.6 |

UCL cocktail M/Q=3.3

**Tab. 6.** Irradiation levels applied on MTG FCI ROICs

No SEL (single event latch up) were measured during test campaign. Some SEU (Single event Upset) and SEFI (Single Event Functional Interrupt) were monitored during the test campaign. They will have no impact since they are corrected by SERDAT (serial link input) refresh which is possible in a specific mode implemented both at ROIC and system level.

## VI. CONCLUSION

In the frame of MTG FCI, SOFRADIR has designed the NIR and three IR DAs. First results of MTG FCI DA retina performances show that they fulfill the mission needs. After closure of the PDR, the validation phase has started as well as activities linked to the next main milestone which is the delivery of MTG FCI DA Engineering models.
Bread board models have been delivered and tested by Thales Alenia space.

## ACKNOWLEDGMENTS

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