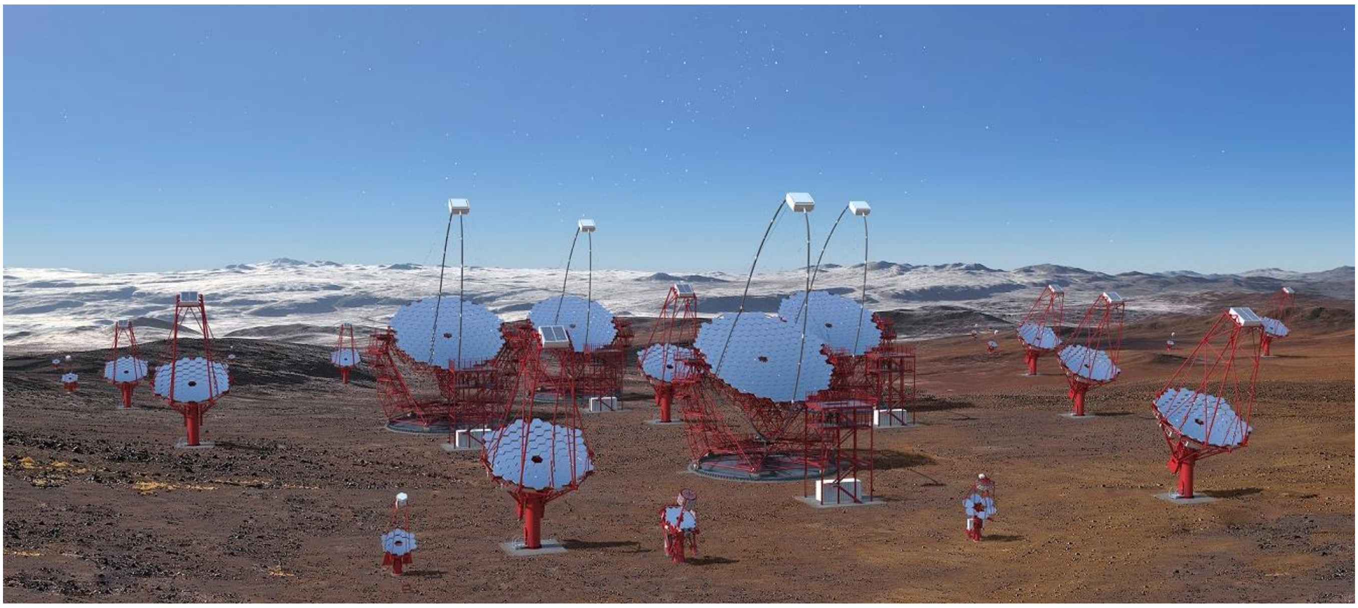
CITIROC 1A Gain Bandwidth Product (GBW) influence on the SiPM Optical Cross Talk (OCT)



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INDEX

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LIST OF ACRONYMS

OACT	Osservatorio Astrofisico di Catania
IFC	Istituto di Astrofisica Spaziale e Fisica Cosmica di Palermo
COLD	Catania astrophysical Observatory Laboratory for Detectors
PCB	Printed Circuit Board
SiPM	Silicon Photo-Multiplier
MPPC	Multi Pixel Photon Counter
SST-2M	Small-Size Telescope Dual-Mirror
PDM	Photon Detection Module
ASIC	Application Specific Integrated Circuit
FEE	Front-End Electronics
BEE	Back-End Electronics
FPGA	Field Programmable Gate Array
EASIROC	Extended Analogue Silicon-pm Integrated Read-Out Chip
CITIROC	Cherenkov Imaging Telescope Integrated Read-Out Chip
I/F	Interface
LCT	Low Cross Talk
PSAU	Power Supply and Amplification Unit
PDE	Photon Detection Efficiency
SCA	Switched Capacitor Array
OCT	Optical Cross Talk
LVR	Low Voltage Resistor
LVR2	Low Voltage Resistor 2nd Version
LVR3	Low Voltage Resistor 3nd Version
PHD	Pulse Height Distribution

1. INTRODUCTION

The scope of this work is to evaluate the influence of the CITIROC 1A input preamplifier Gain Bandwidth Product (GBW) on SiPM Optical Cross Talk (OCT) by using a WEEROC QFP and CITIROC 1A evaluation board. This document illustrates the experimental setup, based essentially in a continuous flux LED and an integrating sphere that illuminated a single 7x7 mm^2 SiPM.

For these measurements two 7x7 mm^2 LVR2 MPPC-7075 have been used:

- LVR2 7075 CS
- LVR2 7075 CN

To demonstrate the OCT dependency from the CITIROC 1A input preamplifier GBW product we carried out staircase measurements by operating the detector at 3 increasing gains in such a way to enhance the BW.

For the CS device we used the following HG values:

1. HG = 20
2. HG = 66.6
3. HG = 100

For the CN device we used the following HG values:

1. HG = 30
2. HG = 66.6
3. HG = 100

Three operating conditions have been selected:

- Dark
- Dark + about 3 MHz of continuous flux
- Dark + about 6 MHz of continuous flux

Furthermore, the measurements have been carried out at two different temperatures. One 10°C and the other 15°C (ASTRI camera working temperature).

The achieved results in the various operating conditions are here presented

We demonstrated that by increasing the HG (meaning decrease the BW), the OCT increases in all the three configurations.

In other words, the OCT, as expected, increases also when the SiPM is illuminated because the increase of the count rate.

As by now well known, this happens because the CITIROC 1A electronics (BWG of the chip ASIC) is unable to operate an effective signal baseline recovery.

At the end of this report a summarize table of the obtained results in all the three operating conditions and at the two temperatures is reported. In the same table the extrapolated achievable OCT when 25 MCnts/s (corresponding to a NBS) is also presented.

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2. Experimental Setup and operating conditions

The adopted experimental setup is shown in Figure 1. based essentially in a continuous flux LED and an integrating sphere that illuminated a single SiPM at a time.

In this way, the apparatus allows to illuminate the SiPM detector with a continuous source and we are able to set the illumination to obtain a desired count rate.

Figure 1. Experimental setup based on the use of a continuous light source that illuminates a single 7x7 mm^2 SiPM at a time.

We evaluated the influence of the input preamplifier GBW on OCT by using a QFP CITIROC 1A evaluation board and two 7x7 mm^2 with microcells of 75 µm SiPMs:

- LVR2 7075 CS
- LVR2 7075 CN

The selected operating condition for both devices are

1. Dark
2. Dark + ˜ 3 MHz of continuous flux obtained through the LED
3. Dark + ˜ 6 MHz of continuous flux obtained through the LED

3. Staircase measurements in different operating conditions

We carried out the staircase measurements of the two SiPMs above mentioned through a QFP CITIROC 1A evaluation board.

We selected three different gains of the input preamplifier HG:

- 20, 66.6 and 100 for the CS MPPC
- 30, 66.6 and 100 for the CN MPPC

Furthermore, we operated the devices at two temperatures 10°C and 15°C. This last tempearture is the ASTRI camera working temperature. The temperature of 10°C has been selected to have a sufficient low DCR to

In the following subsection we report the results

3.1 HG 20 staircase measurements for the LVR2 7075 CS

The CITIROC 1A **HG** gain has been set to **20** and the operating temperature is set to 10°C and to 15°C.

3.1.1 Dark conditions

The dark condition is useful to evaluate the DAC values at 0.5 p.e. and at 1.5 p.e.. As the Over voltage (and thus the SiPM gain) doesn't change when the SiPM is illuminated, the corresponding DAC values at 0.5 p.e and at 1.5 p.e. will be used to evaluate the OCT under illumination condition.

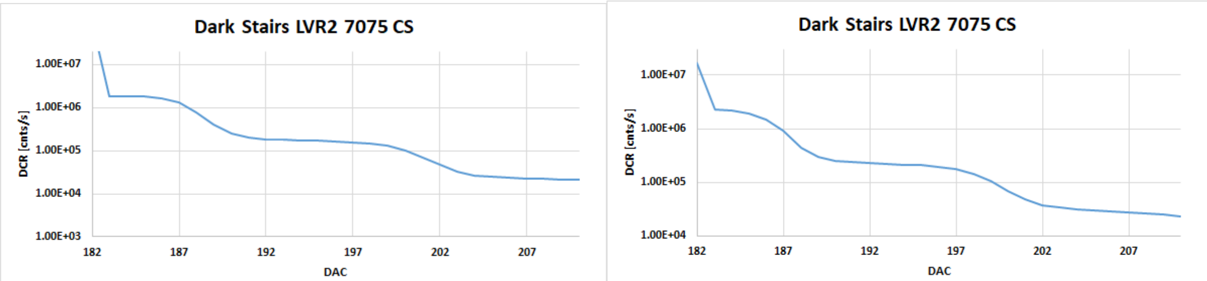

*Figure 2. Staircase of **CS** device under dark conditions at 10°C (left) and 15°C (right) working temperatures.*

The derivative method has been applied to accurately estimate the 1 p.e. and 2 p.e. in terms of DAC threshold and then to measure the DCR at 0.5 p.e and 1.5 p.e. For the HG=20 we obtain:

2 p.e. happens at **200 DAC** while **1 p.e.** happens at **187 DAC**. These threshold values are used for all other operating conditions and temperatures at **<u>HG = 20</u>**.

Thus at **<u>HG = 20</u>** we conclude that **1 p.e**. **corresponds at <u>13 DAC</u>**.

The $DCR_{0.5p.e}$. $DCR_{1.5p.e}$. achieved values are used to evaluate the OCT reported in the Table 1 section 5.

3.1.2 Dark plus 3 MCnts/s due to LED illumination

After the staircase measurements in dark condition the LED has been switched on to obtain a count rate of about **3 MCnts/s**. This is added to DCR.

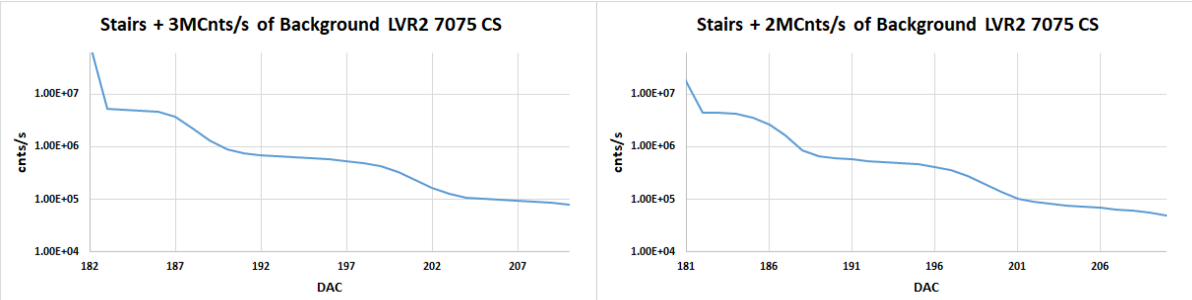

*Figure 3. Staircase of **CS** device under illumination conditions at 10°C (left) and 15°C (right) working temperatures.*

The $DCR_{0.5p.e.}$ $DCR_{1.5p.e.}$ achieved values are used to evaluate the OCT reported in the Table 1 section 5.

3.1.3 Dark plus 6 MCnts/s due to LED illumination

After the staircase measurements at a count rate of about 3 MCnts/s we increased the illumination to obtain a count rate of about **6 MCnts/s**. This is added to DCR.

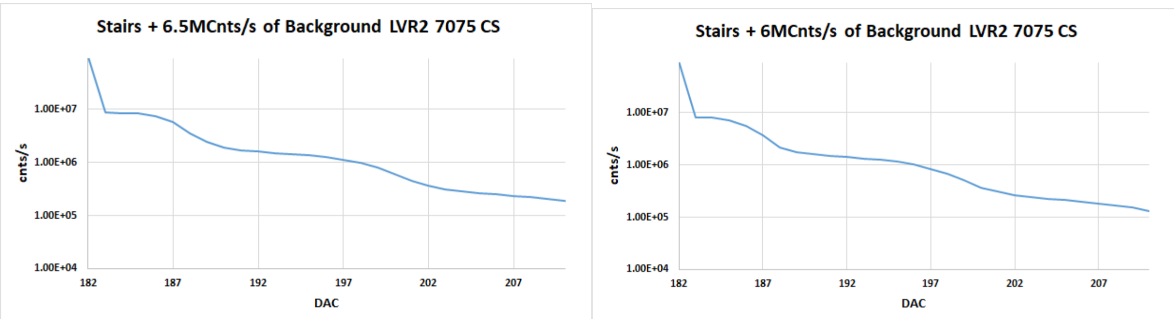

*Figure 4. Staircase of **CS** device under illumination conditions at 10°C (left) and 15°C (right) working temperatures.*

The $DCR_{0.5p.e.}$ $DCR_{1.5p.e.}$ achieved values are used to evaluate the OCT reported in the Table 1 section 5.

3.2 HG 66.6 staircase measurements for the LVR2 7075 CS

The CITIROC 1A **HG** gain has been set to **66.6** and the operating temperatures is set to 10°C and 15°C.

3.2.1 Dark conditions

Through the dark condition we evaluated the DAC values at 0.5 p.e. and at 1.5 p.e. (see subsection 3.1.1).

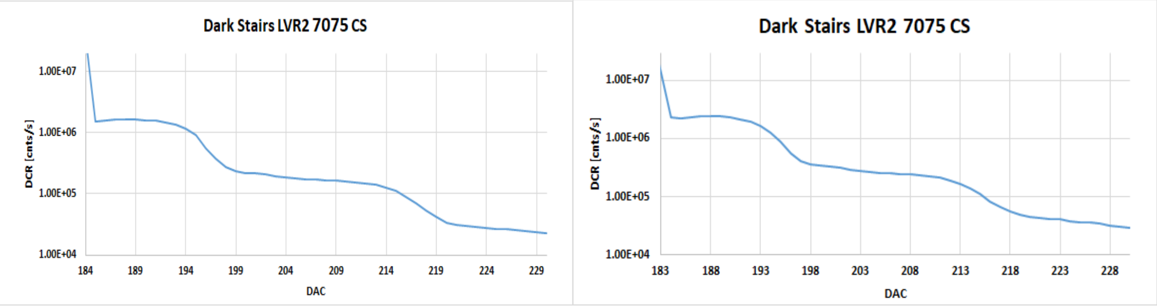

*Figure 5. Staircase of **CS** device under dark conditions at 10°C (left) and 15°C (right) working temperatures.*

2 p.e. happens at **215 DAC** while 1 p.e. happens at **195 DAC**. These threshold values are used for all other operating conditions and temperatures at **HG = 66.6**.

Thus at **HG = 66.6** we conclude that **1 p.e.** corresponds at **20 DAC**. The $DCR_{0.5p.e.}$ $DCR_{1.5p.e.}$ are used to evaluate the OCT reported in the Table 1 section 5.

3.2.2 Dark plus 3 MCnts/s due to LED illumination

After the staircase measurements in dark condition the LED has been switched on to obtain a count rate of about **3 MCnts/s**. This is added to DCR.

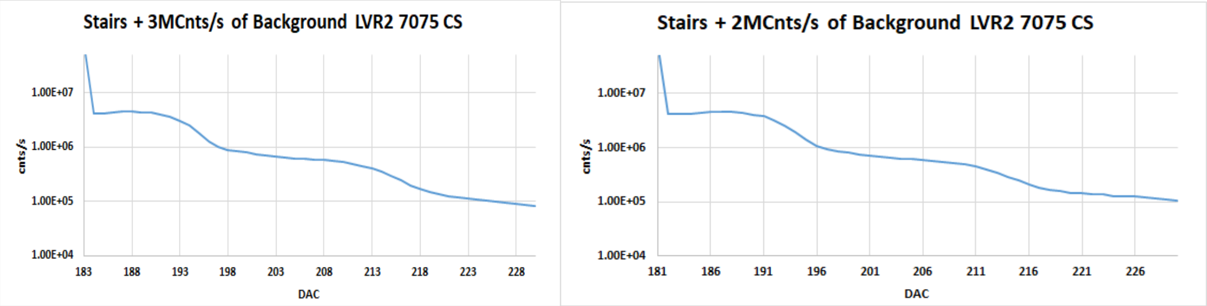

*Figure 6. Staircase of **CS** device under illumination conditions at 10°C (left) and 15°C (right) working temperatures.*

The $DCR_{0.5p.e.}$ $DCR_{1.5p.e.}$ achieved values are used to evaluate the OCT reported in the Table 1 section 5.

3.2.3 Dark plus 6 MCnts/s due to LED illumination

After the staircase measurements at a count rate of about 3 MCnts/s we increased the illumination to obtain a count rate of about **6 MCnts/s**. This is added to DCR.

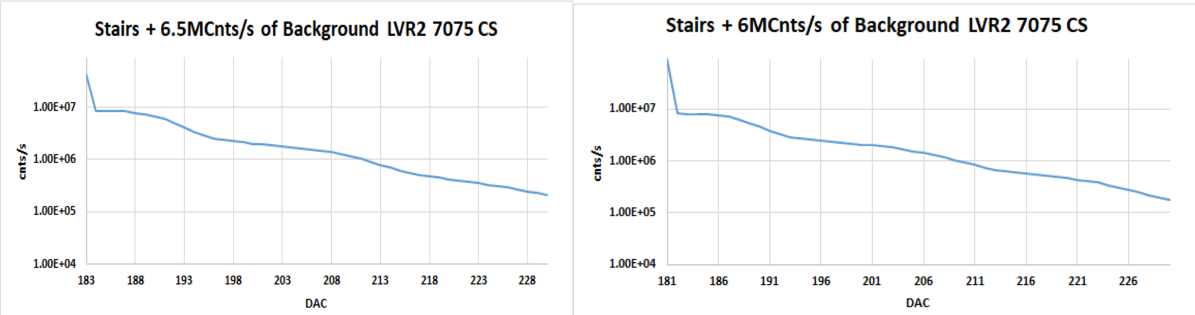

*Figure 7. Staircase of **CS** device under illumination conditions at 10°C (left) and 15°C (right) working temperatures.*

The $DCR_{0.5p.e.}$ $DCR_{1.5p.e.}$ achieved values are used to evaluate the OCT reported in the Table 1 section 5.

3.3 HG 100 staircase measurements for the LVR2 7075 CS

The CITIROC 1A **HG** gain has been set to **100** and the operating temperatures is set to 10°C and 15°C.

3.3.1 Dark conditions

Through the dark condition we evaluated the DAC values at 0.5 p.e. and at 1.5 p.e. (see subsection 3.1.1).

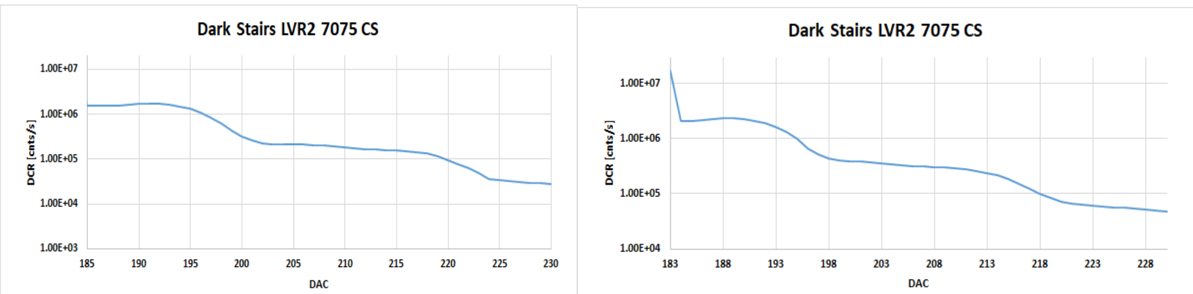

*Figure 8. Staircase of **CS** device under dark conditions at 10°C (left) and 15°C (right) working temperatures.*

2 p.e. happens at **219 DAC** while 1 p.e. happens at **195 DAC**. These threshold values are used for all other operating conditions and temperatures at **<u>HG = 100</u>**

Thus at **<u>HG = 100</u>** we conclude that **1 p.e.** corresponds at **<u>24 DAC</u>**. The $DCR_{0.5p.e.}$ $DCR_{1.5p.e.}$ are used to evaluate the OCT reported in the Table 1 section 5.

3.3.2 Dark plus 3 MCnts/s due to LED illumination

After the staircase measurements in dark condition the LED has been switched on to obtain a count rate of about **3 MCnts/s**. This is added to DCR.

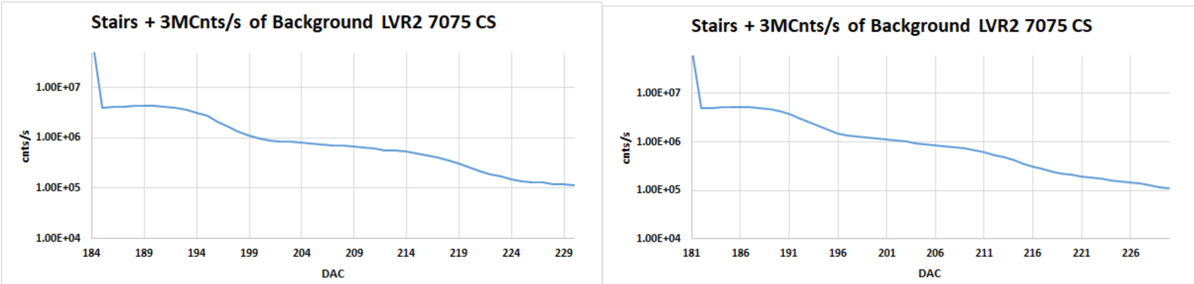

*Figure 9. Staircase of **CS** device under illumination conditions at 10°C (left) and 15°C (right) working temperatures*

The $DCR_{0.5p.e}$. $DCR_{1.5p.e}$. achieved values are used to evaluate the OCT reported in the Table 1 section 5.

3.3.3 Dark plus 6 MCnts/s due to LED illumination

After the staircase measurements at a count rate of about 3 MCnts/s we increased the illumination to obtain a count rate of about **6 MCnts/s**. This is added to DCR.

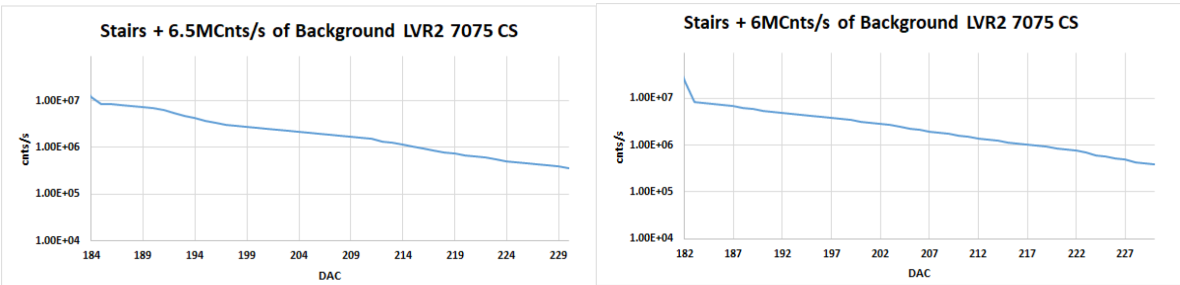

*Figure 10. Staircase of **CS** device under illumination conditions at 10°C (left) and 15°C (right) working temperatures.*

The $DCR_{0.5p.e}$. $DCR_{1.5p.e}$. achieved values are used to evaluate the OCT reported in the Table 1 section 5.

3.4 HG 30 staircase measurements for the LVR2 7075 CN

The CITIROC 1A **HG** gain has been set to **30** and the operating temperatures is set to 10°C and 15°C.

3.4.1 Dark conditions

Through the dark condition we evaluated the DAC values at 0.5 p.e. and at 1.5 p.e. (see subsection 3.1.1).

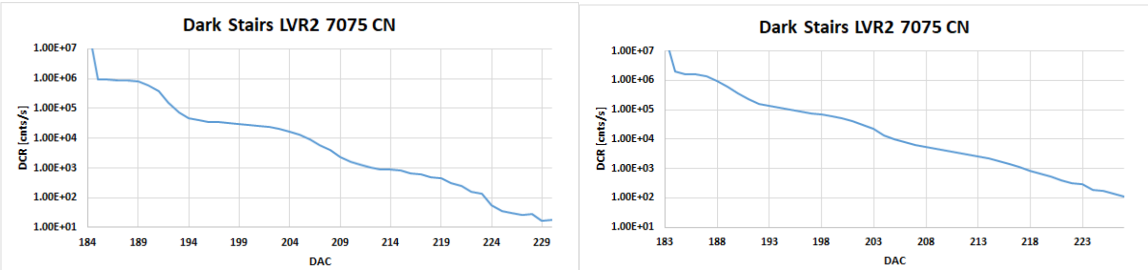

*Figure 11. Staircase of **CN** device under dark conditions at 10°C (left) and 15°C (right) working temperatures.*

2 p.e. happens at **XXX DAC** while 1 p.e. happens at **XXX DAC**. These threshold values are used for all other operating conditions and temperatures at **HG = 30**

Thus at **HG = 30** we conclude that **1 p.e.** corresponds at **XX DAC**. The $DCR_{0.5p.e.}$ $DCR_{1.5p.e.}$ are used to evaluate the OCT reported in the Table 1 section 5.

3.4.2 Dark plus 3 MCnts/s due to LED illumination

After the staircase measurements in dark condition the LED has been switched on to obtain a count rate of about **3 MCnts/s**. This is added to DCR.

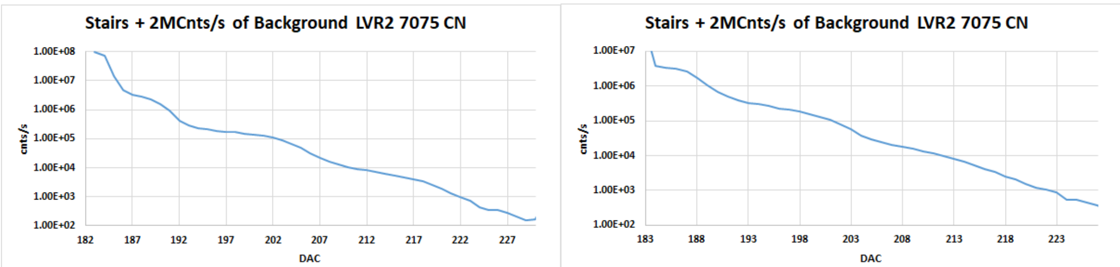

*Figure 12. Staircase of **CN** device under illumination conditions at 10°C (left) and 15°C (right) working temperatures.*

The $DCR_{0.5p.e.}$ $DCR_{1.5p.e.}$ achieved values are used to evaluate the OCT reported in the Table 1 section 5.

3.4.3 Dark plus 6 MCnts/s due to LED illumination

After the staircase measurements at a count rate of about 3 MCnts/s we increased the illumination to obtain a count rate of about **6 MCnts/s**. This is added to DCR.

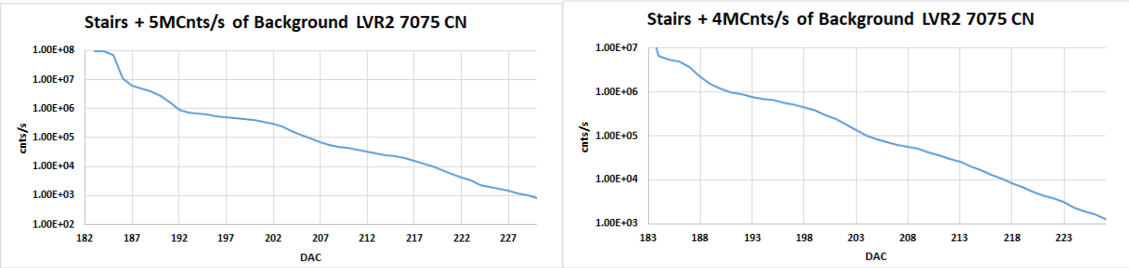

*Figure 13. Staircase of **CN** device under illumination conditions at 10°C (left) and 15°C (right) working temperatures.*

The $DCR_{0.5p.e}$. $DCR_{1.5p.e}$. achieved values are used to evaluate the OCT reported in the Table 1 section 5.

3.5 HG 66.6 staircase measurements for the LVR2 7075 CN

The CITIROC 1A **HG** gain has been set to **66.6** and the operating temperatures is set to 10°C and 15°C.

3.5.1 Dark conditions

Through the dark condition we evaluated the DAC values at 0.5 p.e. and at 1.5 p.e. (see subsection 3.1.1).

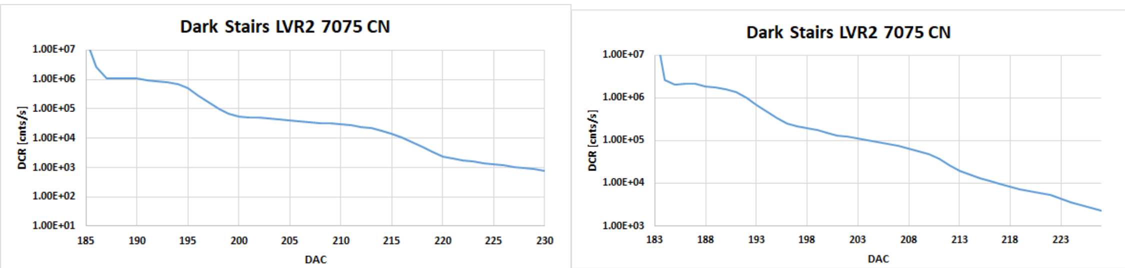

*Figure 14. Staircase of **CN** device under dark conditions at 10°C (left) and 15°C (right) working temperatures.*

2 p.e. happens at **XXX DAC** while 1 p.e. happens at **XXX DAC**. These threshold values are used for all other operating conditions and temperatures at **HG = 66.6**

Thus at **HG = 66.6** we conclude that **1 p.e.** corresponds at **XX DAC**. The $DCR_{0.5p.e}$. $DCR_{1.5p.e}$. are used to evaluate the OCT reported in the Table 1 section 5.

3.5.2 Dark plus 3 MCnts/s due to LED illumination

After the staircase measurements in dark condition the LED has been switched on to obtain a count rate of about **3 MCnts/s**. This is added to DCR.

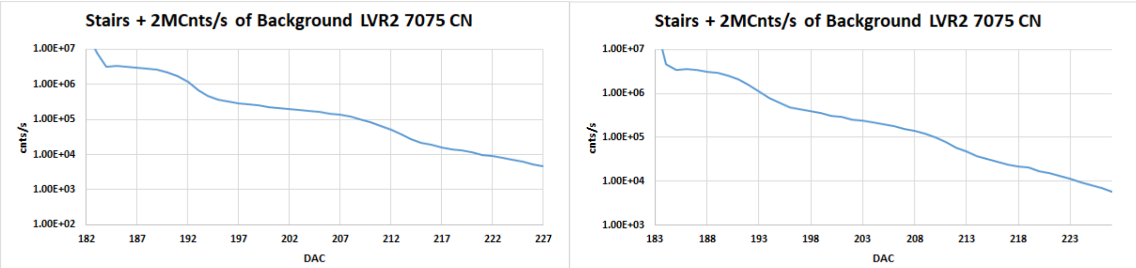

*Figure 15. Staircase of **CN** device under illumination conditions at 10°C (left) and 15°C (right) working temperatures.*

The $DCR_{0.5p.e.}$ $DCR_{1.5p.e.}$ achieved values are used to evaluate the OCT reported in the Table 1 section 5.

3.5.3 Dark plus 6 MCnts/s due to LED illumination

After the staircase measurements at a count rate of about 3 MCnts/s we increased the illumination to obtain a count rate of about **6 MCnts/s**. This is added to DCR.

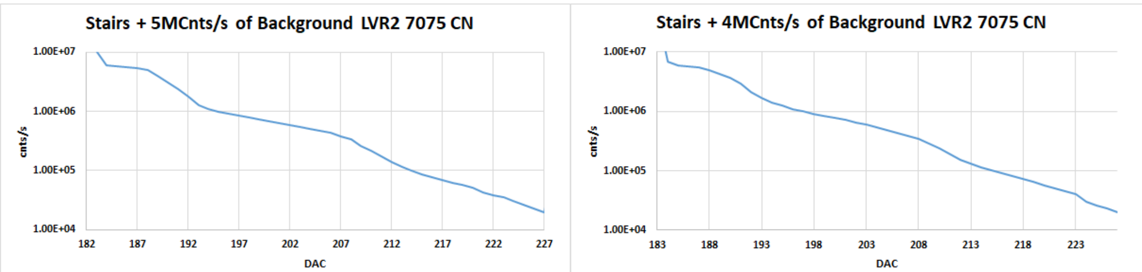

*Figure 16. Staircase of **CN** device under illumination conditions at 10°C (left) and 15°C (right) working temperatures.*

The $DCR_{0.5p.e.}$ $DCR_{1.5p.e.}$ achieved values are used to evaluate the OCT reported in the Table 1 section 5.

3.6 HG 100 staircase measurements for the LVR2 7075 CN

The CITIROC 1A **HG** gain has been set to **100** and the operating temperatures is set to 10°C and 15°C.

3.6.1 Dark conditions

Through the dark condition we evaluated the DAC values at 0.5 p.e. and at 1.5 p.e. (see subsection 3.1.1).

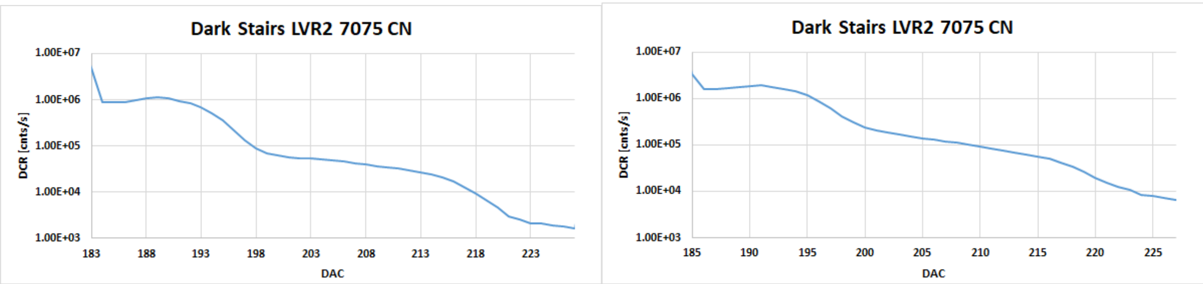

*Figure 17. Staircase of **CN** device under dark conditions at 10°C (left) and 15°C (right) working temperatures.*

2 p.e. happens at **XXX DAC** while 1 p.e. happens at **XXX DAC**. These threshold values are used for all other operating conditions and temperatures at **<u>HG = 100</u>**

Thus at **<u>HG = 100</u>** we conclude that **1 p.e.** corresponds at **<u>XX DAC</u>**. The DCR$_{0.5p.e.}$. DCR$_{1.5p.e.}$ are used to evaluate the OCT reported in the Table 1 section 5.

3.6.2 Dark plus 3 MCnts/s due to LED illumination

After the staircase measurements in dark condition the LED has been switched on to obtain a count rate of about **3 MCnts/s**. This is added to DCR.

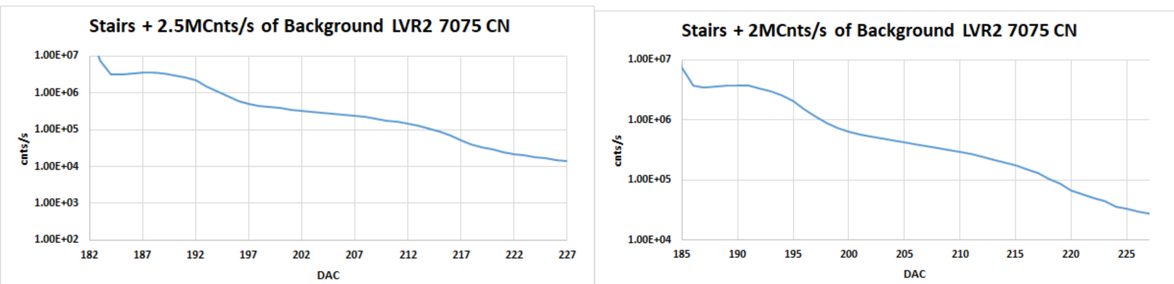

*Figure 18. Staircase of **CN** device under illumination conditions at 10°C (left) and 15°C (right) working temperatures.*

The $DCR_{0.5p.e}$. $DCR_{1.5p.e}$. achieved values are used to evaluate the OCT reported in the Table 1 section 5.

3.6.3 Dark plus 6 MCnts/s due to LED illumination

After the staircase measurements at a count rate of about 3 MCnts/s we increased the illumination to obtain a count rate of about **6 MCnts/s**. This is added to DCR.

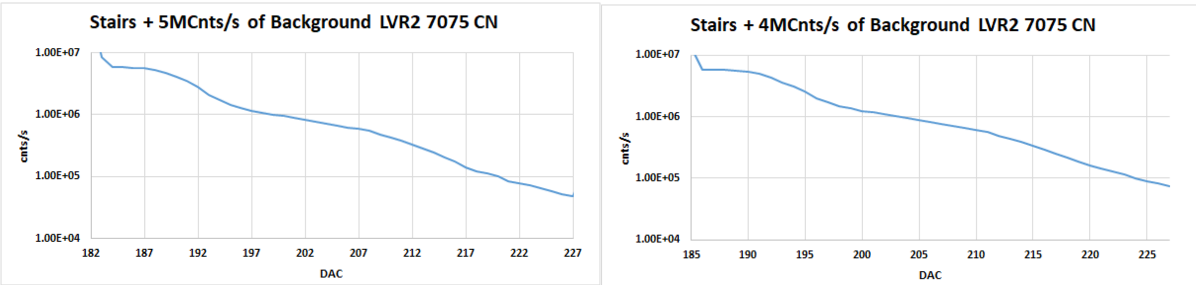

Figure 19. Staircase of ***CN*** *device under illumination conditions at 10°C (left) and 15°C (right) working temperatures.*

The $DCR_{0.5p.e}$. $DCR_{1.5p.e}$. achieved values are used to evaluate the OCT reported in the Table 1 section 5.

4. Comparative analysis of achieved results

The obtained results in the various operating conditions are plotted and compared in:

- Figure 20 for the **CN** device operated at a temperature of **10°C**,
- Figure 21 for the **CN** device operated at a temperature of **15°C**,
- Figure 22 for the **CS** device operated at a temperature of **10°C**,
- Figure 23 for the **CS** device operated at a temperature of **15°C**.

The four plots depict the OCT versus the count rate at 3 different HG gains:30, 66,6 and 100.

As can be clearly noted in Figure 20, **the OCT increases with the increasing HG value**. **And the OCT increases also when the background illumination increases**. Selecting HG=20 an OCT of 3.5 % is obtained, while with an HG = 100 an OCT of 5% is found. Even worst situation is observed when the SiPM is illuminated because the pile up of the $DCR_{0.5p.e.}$ or better to say, because **the CITIROC 1A electronics** (BWG of the chip ASIC) **is unable to operate an effective signal baseline recovery**. In this case with an illumination of about 6 MCnts/s and an HG=100 an OCT of 10% has been found, meaning that respect to the staring operating condition an OCT increase of 6.5% is observed. This leads to the consideration that **if the background increases a higher OCT is obtained**.

Instead it is well known that:

- ✓ **the OCT should not change if the HG preamp changes**
- ✓ **the OCT should not change if the background count rate changes**

Thus, it is evident that the BWG (of the preamplifier and of the fast shaper) influences the OCT and the pile-up of the SiPM- A higher bandwidth may solve the inconvenient.

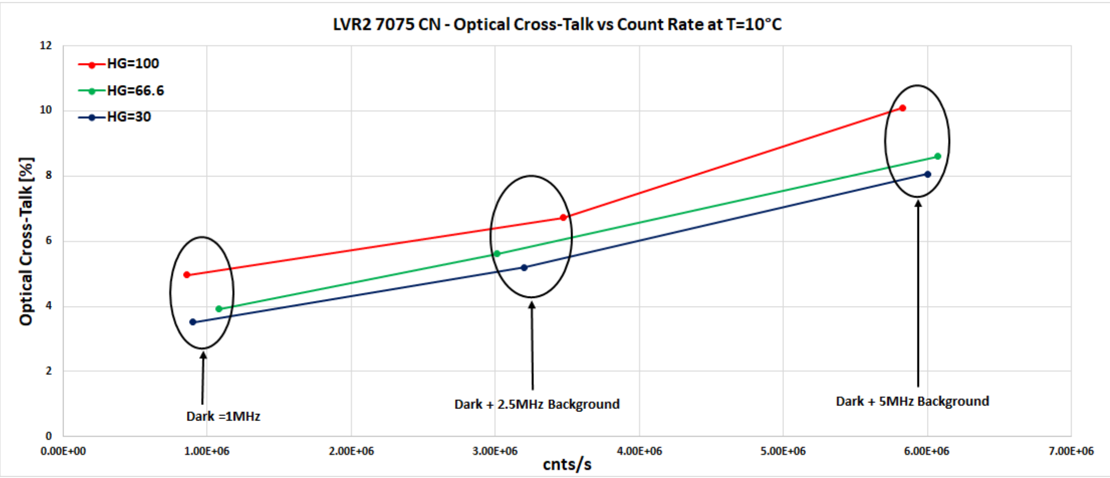

*Figure 20. OCT versus count rate at 3 different HG of **CN** device under dark and illumination conditions at **10°C** working temperature. The OCT increases with the increasing HG value and when the background illumination increases. With HG=20 an OCT of 3.5 % is obtained in dark conditions, while with an HG = 100 an OCT of 5% is found. When the SiPM is illuminated with an illumination of about 6 MCnts/s and an HG=100 an OCT of 10% has been found, meaning that respect to the staring operating condition an OCT increase of 6.5% is observed.*

As expected, at a working temperature 15°C, the situation worsens. In fact, in Figure 21 is clearly evident that the OCT at same HG=20 and at the same dark condition but at a temperature of only 5°C higher the OCT is higher because the $DCR_{0.5p.e}$ is higher and the pile-up increases. In this case from 3.5% obtained at 10°C, the OCT goes to more than 6% at 15°C. The OCT **difference** between the staring situation with **HG=20** and the final with **HG=100** (with the SiPM illuminated) **rises to about 10%.**

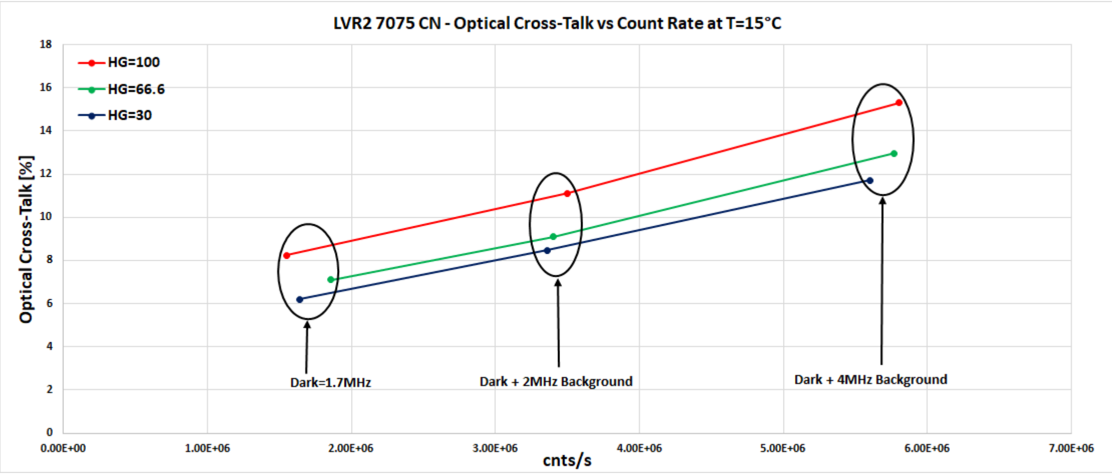

*Figure 21. OCT versus count rate at 3 different HG of **CN** device under dark and illumination conditions at **15°C** working temperature. The OCT obtained with HG=20 is about 6% in this case (1.5% more than the 10°C case) and this is due to the increasing* $DCR_{0.5p.e}$ *with the consequent increase of the pile-up effect. When the SiPM is illuminated with an illumination of about 6 MCnts/s and an HG=100 an OCT of 16% has been found, meaning that respect to the staring operating condition an OCT increase of 10% is observed.*

Figures 22 and 23 depict the same above mentioned situation but with higher OCT values.

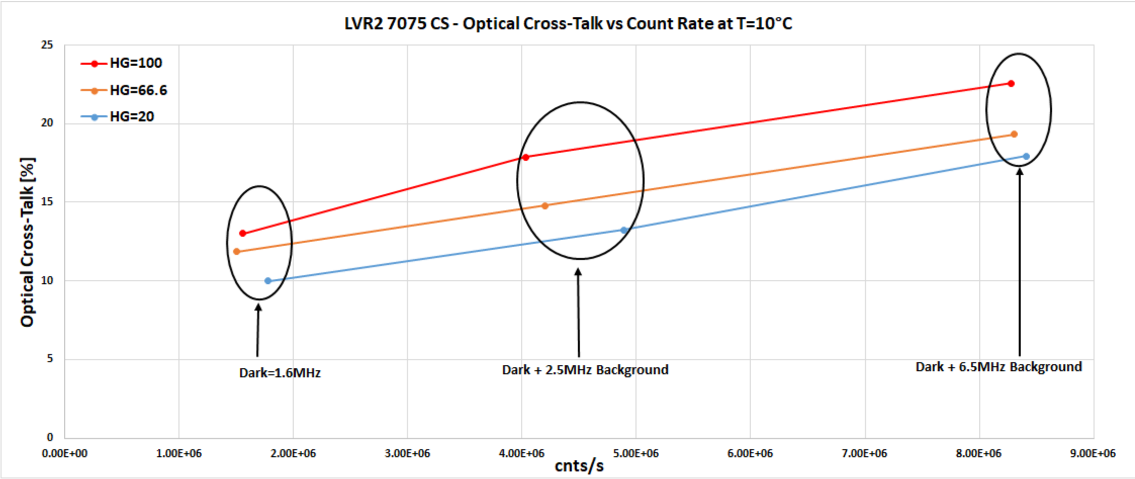

Figure 22. OCT versus count rate at 3 different HG of ***CS*** *device under dark and illumination conditions at* ***10°C*** *working temperature. The OCT increases with the increasing HG value and when the background illumination increases. With HG=20 an OCT of 10 % is obtained in dark conditions, while with an HG = 100 an OCT of 13% is found. When the SiPM is illuminated with an illumination of about 6 MCnts/s and an HG=100 an OCT of 23% has been found.*

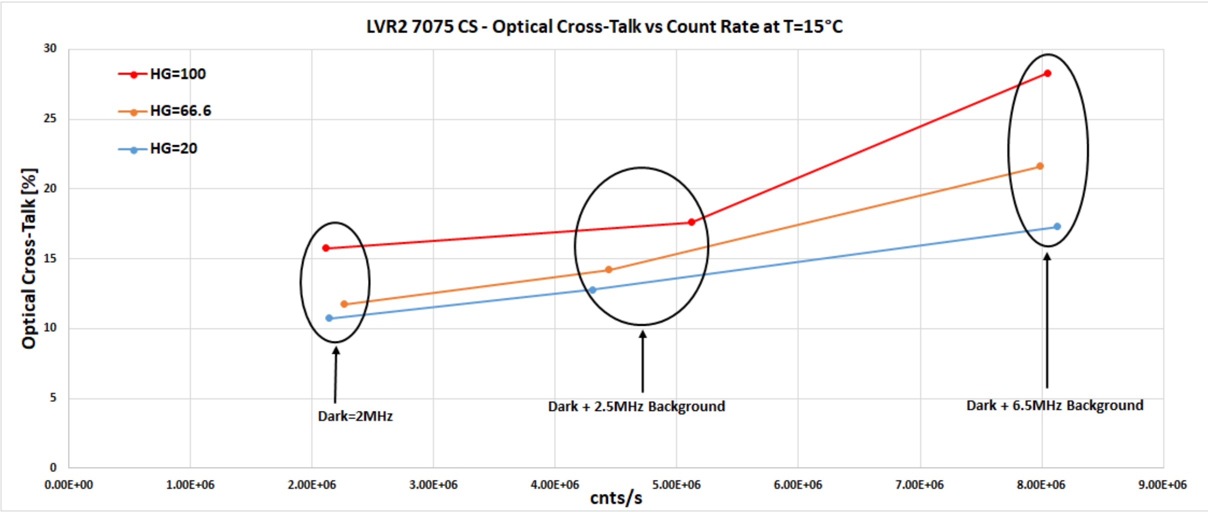

Figure 23. OCT versus count rate at 3 different HG of ***CS*** *device under dark and illumination conditions at* ***15°C*** *working temperature. With HG=20 an OCT of 11 % is obtained in dark conditions, while with an HG = 100 an OCT of 16% is found. When the SiPM is illuminated with an illumination of about 6 MCnts/s and an HG=100 an OCT of* ***28%*** *has been found.*

In the next section, a summarizing table of the obtained OCT respect to the HG in all the three operating conditions and at the two temperatures is reported. In the same table the extrapolated achievable OCT when 25 MCnts/s (corresponding to one NBS) is also presented.

5. Effects of the BGW on the OCT

As demonstrated in the previous section a higher OCT is obtained if the HG increases and if the background increases.

Instead it is well known that:

- ✓ the OCT should not change if the HG preamp changes
- ✓ the OCT should not change if the background count rate changes

As the OCT increase depends essentially on the increase of the $DCR_{1.5p.e.}$ and the decrease of the $DCR_{0.5p.e.}$ we have to conclude that **the CITIROC 1A electronics is unable to operate an effective signal baseline recovery when a sustained signal rate has to be amplified.**

From the other side, we observed that the OCT worsens if HG gain rises. A higher HG means a smaller BW (see Figure 24). This is the reason why the OCT is higher when the HG is higher. A large BW facilitates the **signal baseline recovery**.

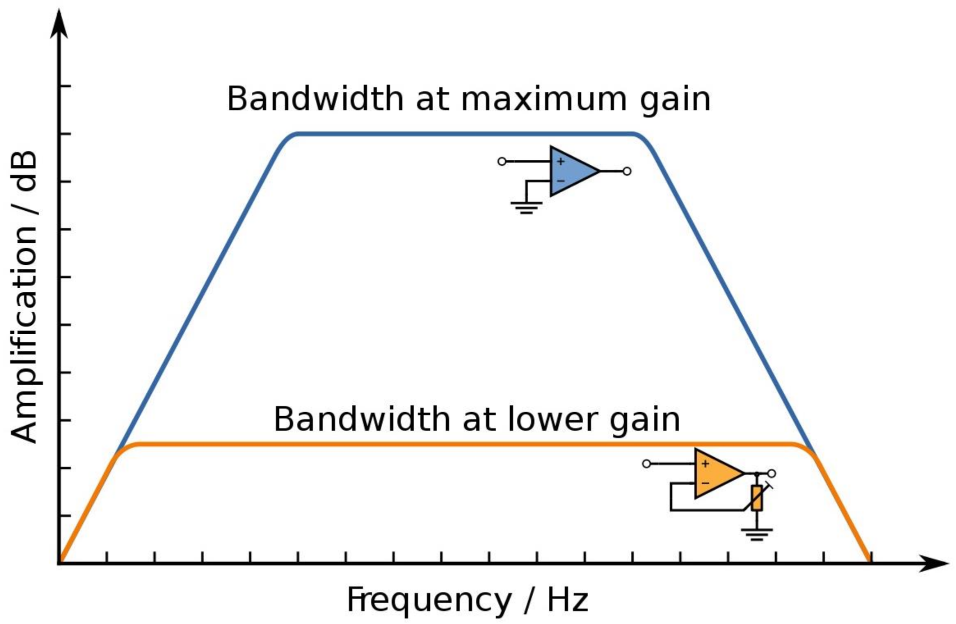

Figure 24. Bandwidth (BW) versus gain (G). A lower G implies a higher BW if the BWG. product is constant.

In Figure 25 the OCT versus the HG gain for the CN device is shown at the different background conditions. As can be seen the OCT depends on HG or, in turn, on the BW.

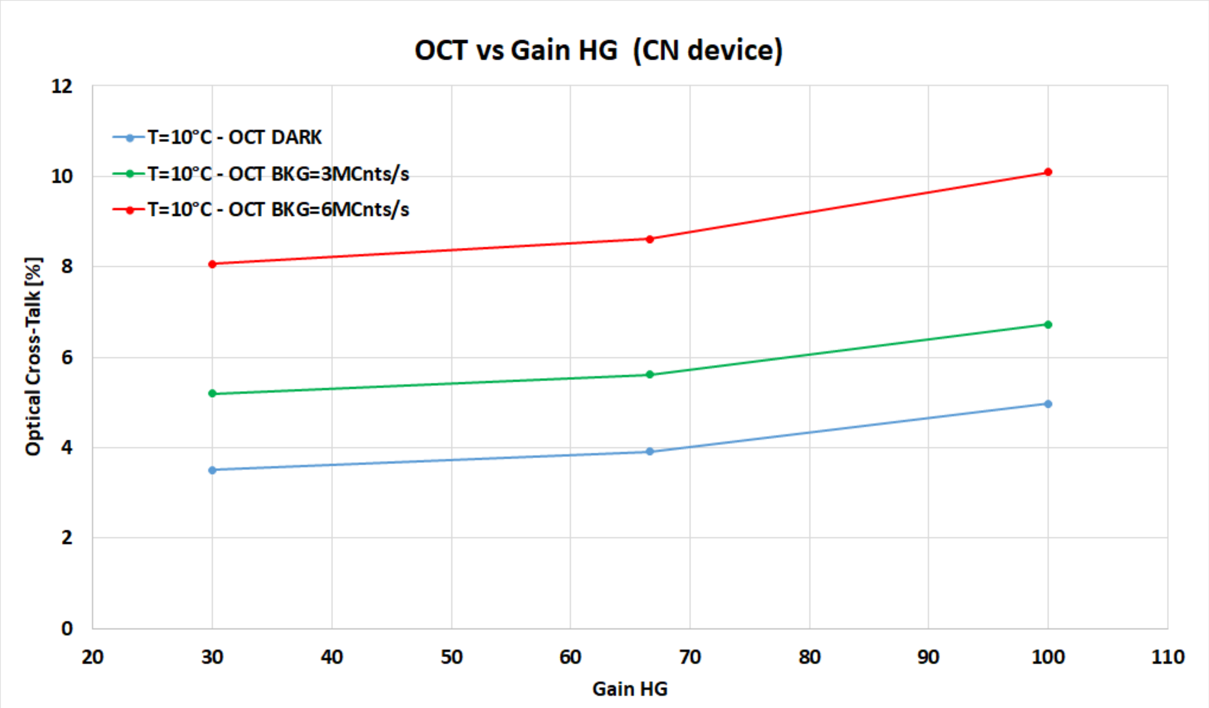

Figure 25. OCT versus HG for the CN device at the three different background conditions. As can be noted the OCT depends on HG or, in turn, on the preamplifier BW.

Finally, the achieved results for the CN device (that shows a low OCT) are summarized in table 1.

Table 1

Measured OCT (CN SiPM) at various HG and background conditions and at 10°C and 15°C

Working Temperature [°C]	Gain HG	OCT Dark [%]	OCT BKG=3MHz [%]	OCT BKG=6MHz [%]
10	30.0	3.51	5.2	8.06
10	66.6	3.91	5.62	8.61
10	100-0	4.97	6.73	10.1
15	30.0	6.2	8.47	11.72
15	66.6	7.11	9.1	12.97
15	100.0	8.23	11.1	15.3

4. Conclusions

We demonstrated that by increasing the HG (meaning decreasing the BW), the OCT increases in all the three operating conditions.

In other words, the OCT, increases not only by increasing the HG but also when the SiPM is illuminated because the increase of the background rate.

As widely demonstrated in previous reports (ASTRI-TR-OACT-3200-036 and ASTRI-TR-OACT-3200-037), OCT dependence from signal count rate is due to the CITIROC 1A electronics (BWG of the chip ASIC) not cable to operate an effective signal baseline recovery.

A wider BW of both preamplifier and fast shaper will greatly mitigate the effect.

All files related to the experimental measurements presented in this report, are located in the database on the PC-LAB (COLD) site Astrophysical Observatory of Catania, path C:\Users\CCDLab1\Desktop\Romeo\Misure