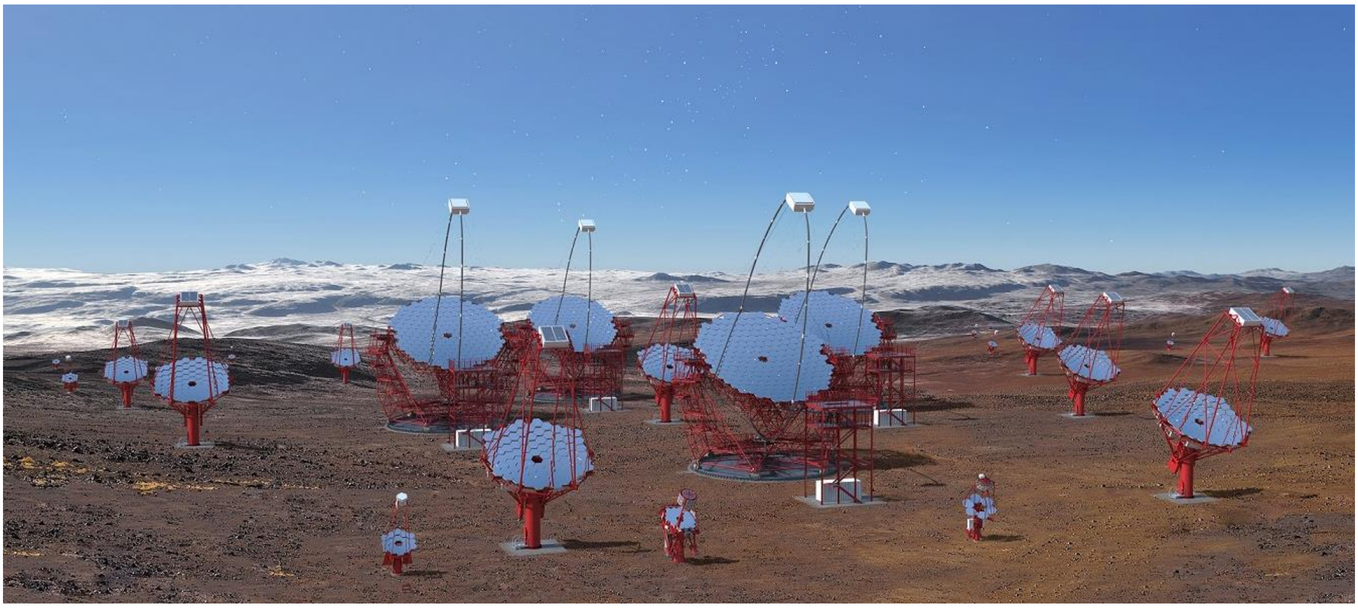
How a very high GBWP (>3.0 GHz) preamplifier and a high bandwidth of a front end electronics may solve the Optical Cross Talk issue



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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 on the Optical Cross Talk (OCT) when a very high GBWP (3.5GHz) preamplifier (TI OPA846) coupled to an amplifier and a digitizer are used. In such a way to evaluate the effect of a higher BW on the OCT respect to that of the Citiroc 1A (see report ASTRI-TR-INAF-3200-039).

We want to demonstrate that the BW of the input preamplifier is of crucial importance in obtaining low OCT and low pile-up even under sustained NSB conditions.

As digitizer we used an oscilloscope Teledyne Lecroy waveRunner 640Zi that allow to select the BW at four values: 20MHz, 200MHz, 1GHz and 4GHz.

This document illustrates the experimental setup, based essentially in a continuous light flux (an LED), a pre-amplifier TI OPA846, an amplifier Avantek AMG-502M (gain =23dB) and a digitizer to sample and acquire the SiPM signal.

The measurements are carried out on two 7x7 mm^2 LVR2 MPPC 7075:

- LVR2 7075 CS
- LVR2 7075 CN

We carried out count rates measurements at three different operating conditions:

1. dark
2. moderate NSB level illumination
3. near to about 0.7 NSB level illumination

For each operating condition we selected the oscilloscope bandwidth at:

- ✓ 20MHz.
- ✓ 200MHz
- ✓ 1GHz.

We demonstrated that by increasing the oscilloscope BW, the OCT decreases in all the three operating conditions.

It is well known that **the OCT is characteristic of each SiPM**, depends on:

- Optical trenches
- Coating on top of the surface
- SiPM dimensions
- Over-voltage

and **is unaffected** by the **Front-End Electronics (FEE).**

But, as demonstrated in this work, the FEE **BW affects** the pile-up and the **OCT**. The more NSB the more is the effect.

The paper “The front-end electronics and slow control of large area SiPM for the SST-1M camera developed for the CTA experiment”, NIMA 830(2016)219–232, reports (see table 1) a cut-off frequency of **120MHz** while the CTA requirement for this parameter is **>80MHz**.

Table 1.

Summary of the driving specification concerning the electronics on the photodetector plane and the corresponding measurements.

Parameters	Specification	Result
Rise time (5–95% ns)	<6	4.1
Fall time (95–5% ns)	<25	6.5
Cut-off frequency(MHz)	**>80**	**120**
Amplitude 1pe(mV)	2-3	2.4
Dynamic range(pe)	1-2000	1–600 (without saturation 600–2000 (in saturation)

2. Experimental Setup and operating conditions

The adopted experimental setup is shown in Figure 1. It is based essentially in a continuous flux LED that illuminated a single SiPM at a time, an OPA846 pre-amplifier evaluation board, an amplifier Avantek AMG-502M (gain = 23dB and BW = 500MHz) and a Teledyne Lecroy waveRunner 640Zi oscilloscope.

In this way, the apparatus allows to illuminate the SiPM detector with a continuous source simulating a NSB level from one side and, from the other side, we are able to set the illumination level to obtain a desired count rate.

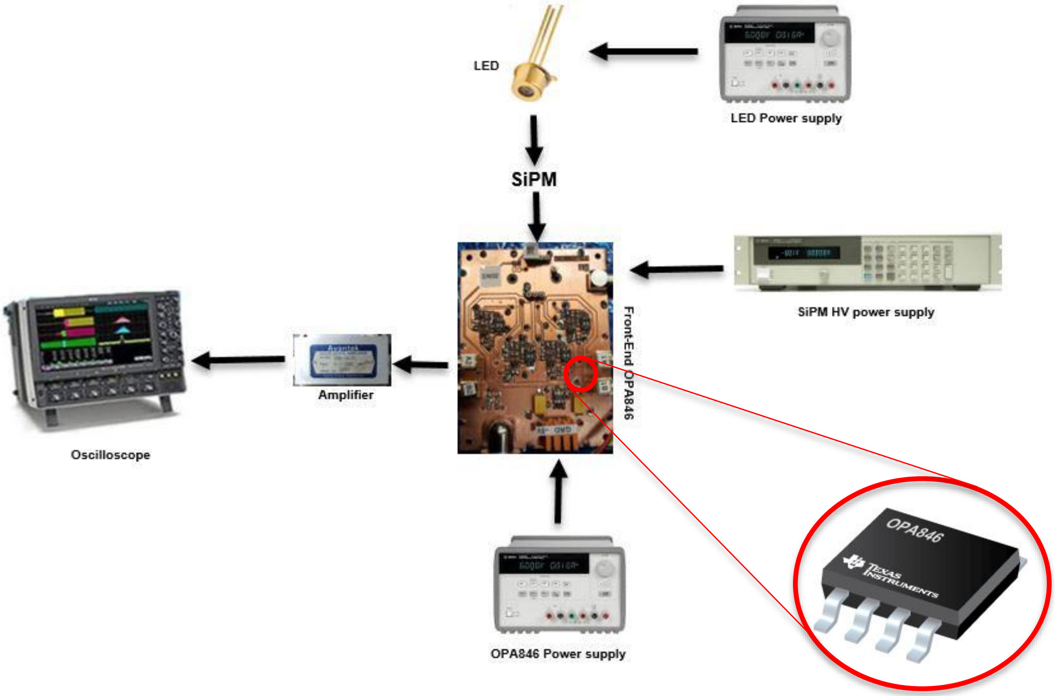

Figure 1. Experimental setup based on the use of a continuous light source that illuminates a single SiPM. As pre-amplifier a special circuit based on OPA846 pre-amplifier is used and as amplifier we used an Avantek AMG-502M (gain = 23dB and BW = 500MHz).

The OPA846 pre-amplifier has a gain of 2 and a BW of about 1.8GHz while the Avantek AMG-502M amplifier has a gain of about 14 and a BW of 500MHz. Thus, the detector signal is amplified with a gain of about 28.

For the count rate measurements, the oscilloscope was operated in counting mode (see next section), and, as stated above, the measurements have been carried out by selecting three different BW:

- ✓ 20MHz.
- ✓ 200MHz
- ✓ 1GHz.

The 1GHz bandwidth really is not the effective one because is limited by the bandwidth of the Avantek AMG-502M amplifier which is 500MHz.

3. Count rates at 0.5 p.e. and 1.5 p.e. measurements in different operating conditions

We carried out the count rate measurements of the two above mentioned SiPMs through the setup described in the previous section.

The measurements have been performed by evaluating the amplitude of the signal pulse corresponding to one photon equivalent (p.e.) and then the two thresholds: 0.5 p.e. and 1.5 p.e. have been determined. As shown in Figure 2 we found in this particular case 7 mV as 1 p.e. and then we will have:

- 3.5 mV corresponding to 0.5 p.e.
- 10.5 mV corresponding to 1.5 p.e.

By selecting on the oscilloscope the edge@level function and with an appropriate sizing of the time base, we determined the value of the counting rates (Figure 2).

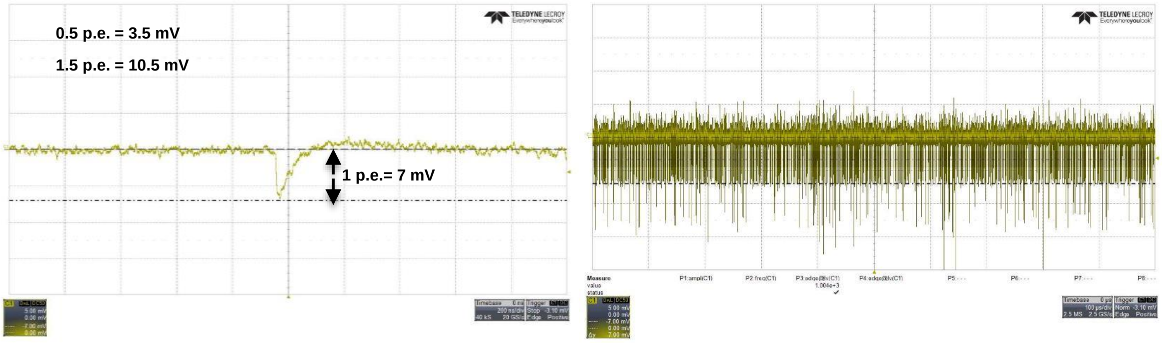

Figure2. Oscilloscope's screenshots. The left panel shows the amplitude of a single photon equivalent equal to 7mV. The thresholds for measuring the counts will then be positioned at 0.5 p.e. and 1.5 p.e., respectively at 3.5mV and 10.5mV. (the ratio between 1.5 p.e. and 0.5 p.e. gives the value of OCT). The right panel shows the sizing of the time base of the oscilloscope and the use of the "edge@level" function for the measurement of photon counting.

We carried out the measurements at three different operating conditions:

4. dark
5. moderate NSB level illumination
6. near to about 0.7 NSB level illumination

From the count rate measurements at thresholds of 0.5 p.e. and 1.5 p.e. we derived the OCT.

We selected the oscilloscope BW at 20MHz and measured the count rates in the three above mentioned operating conditions, then we repeated the same measurements at the other two bandwidths.

The results are discussed in the next section.

4. Comparative analysis of achieved results

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

- Figure 3 for the **CN** device operated at a temperature of **15°C**.
- Figure 4 for the **CS** device operated at a temperature of **15°C**.

The two plots depict the OCT versus the count rate at three different BW allowed by the oscilloscope: 20MHz, .200MHz and 1GHz

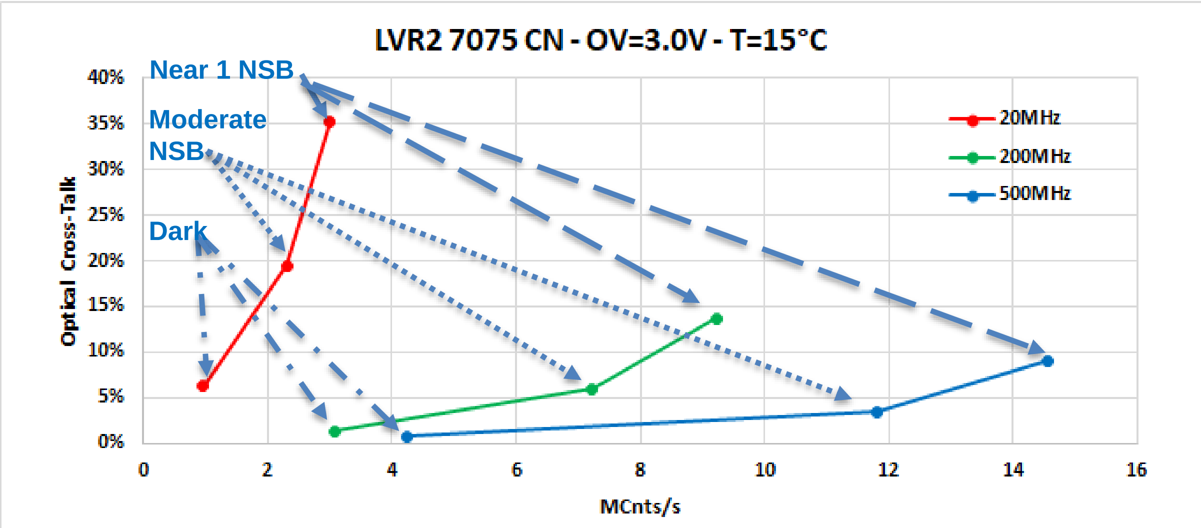

*Figure 3. OCT versus count rate at three different bandwidth of **CN** device under dark and illumination conditions at **15°C** working temperature.*

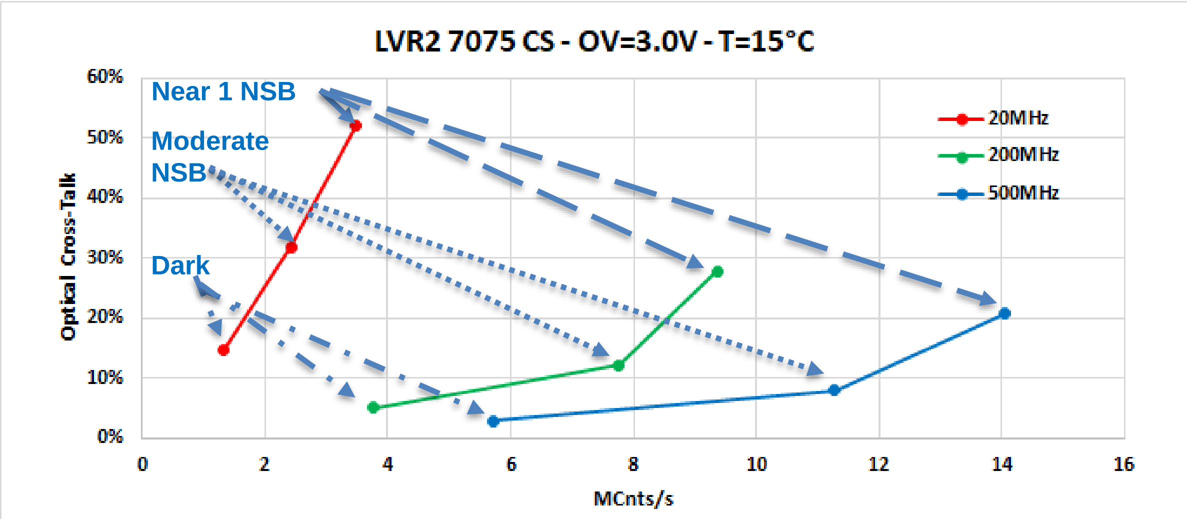

*Figure 4. OCT versus count rate at three different bandwidth of **CS** device under dark and illumination conditions at **15°C** working temperature.*

As can be clearly noted in Figure 3,

1. in dark condition,
   - with a BW of 20MHz an OCT of about 6.0 % is obtained,
   - with a BW of 200MHz an OCT of about 1.0 % is obtained
   - with a BW of 500MHz an OCT of about 0.5 % is measured.

An impressive increase in OCT is found when from a BW of 200MHz (or 500MHz) we change to a BW of 20MHz. And we can extrapolate that at lower BW than 20MHz the situation worsens.

2. in moderate NSB level illumination,
   - with a BW of 20MHz an OCT of about 20.0 % is obtained,
   - with a BW of 200MHz an OCT of about 6.0 % is obtained
   - with a BW of 500MHz an OCT of about 4.0 % is measured.

The OCT difference between the case 200MHz (and 500MHz) and the 20MHz case is more evident when a moderate NSB illumination level is used. An OCT of about 20% is obtained at 20MHz while an OCT of about 4% is achieved at 500MHz.

3. in about 0.7 NSB level illumination,
   - with a BW of 20MHz an OCT of about 35.0 % is obtained,
   - with a BW of 200MHz an OCT of about 14.0 % is obtained
   - with a BW of 500MHz an OCT of about 10.0 % is measured.

The OCT worsens at unacceptable values of 35% at 20MHz when an illumination more than half NSB is used. Instead, an OCT of about 10% is achieved at 500MHz.

The Figure 4 shows that, as expected, the OCT obtained for the CS is higher than that of the CN device in all the illumination conditions and also in all the selected BW. We have:

1. in dark condition,
   - with a BW of 20MHz an OCT of about 15.0 % is obtained,
   - with a BW of 200MHz an OCT of about 6.0 % is obtained
   - with a BW of 500MHz an OCT of about 2.0 % is measured.

In this case, at a BW of 20MHz, the OCT is 15% and then unacceptable just in dark conditions, while at a BW of 500MHz the OCT is 2.0%. This result gives a remarkable idea of how the BW can heavily affect the OCT.

2. in moderate NSB level illumination,
   - with a BW of 20MHz an OCT of about 32.0 % is obtained,
   - with a BW of 200MHz an OCT of about 11.0 % is obtained
   - with a BW of 500MHz an OCT of about 8.0 % is measured.

Also in this case it is evident that the 20 MHz BW is insufficient to guarantee an acceptable OCT.

3. in about 0.7 NSB level illumination,
   - with a BW of 20MHz an OCT of about 52.0 % is obtained,
   - with a BW of 200MHz an OCT of about 29.0 % is obtained
   - with a BW of 500MHz an OCT of about 20.0 % is measured.

In this condition at all the BWs we have unacceptable values of OCT.

5. Conclusions

We demonstrated that a preamplifier with a high BWGP (>3.0GHz) allows us to understand how the BW of the other components of the front end electronics can heavily influence the OCT.

We found that a BW of 20MHz is too low to have reasonable OCT. The effect of the low BW is more evident when we illuminate the SiPM with a sufficient background rate.

A lower OCT dependence from signal count rate is obtained when the oscilloscope BW is set to 1 GHz, meaning, to 500MHz because the BW of the Avantek amplifier.

Thus we have to conclude that a FEE (preamplifier, fast shaper and so on) with at least 200MHz BW is mandatory to have an OCT not affected by the FEE itself. A preamplifier cut-off frequency **greater than 80MHz** is a stringent requirement for the FEE. On the other hands this value is a CTA requirement.

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