Abstract
This document analyzes the possible base line variations of the Auger Surface Detector photomultiplier base. It shows that measurements performed on the Orsay tank present a good agreement with the base electronic simulations, and that the base line variations are mostly due to the observed large pulses created by extensive air showers. 

Keywords: Surface detectors, photomultiplier, base line stability, electronic simulation, Orsay tank

1. INTRODUCTION

The base line stability is an important parameter for the Pierre Auger Observatory Surface Detector Electronics [1]. The photomultiplier tube (PMT) base [2, 3] was designed to ensure stability under the following two main requirements: a muon rate around 2 kHz and the largest signal to consider in the ultra-high energy events [4]. In May 2003, measurements were performed by X. Bertou at Malargüe [5] on surface detectors using the Auger front-end electronics. On the dynode, base line shifts of up to 10 ADC channels (20 mV) were observed over a duration of at least several hundreds of microseconds. A shift of 4 ADC channels seems to occur twice an hour. It could be the effect of large pulses created by extensive air showers (EAS).

This document reminds the electronic simulations of the base [2, 3, 6]. They are compared with measurements performed on the Orsay tank with the LED flasher and EAS.

2. ELECTRONIC SIMULATIONS OF THE BASE

The electronic simulations of the base have been presented several times [2, 3, 6]. The maximum signal to consider is the one coming from a $5\times10^{20}$ eV event at 500 m from the shower core [4]. It is modeled by a photocathode current with a triangular shape: a 0-100% rise time of 140 ns, a 100-0% fall time of 540 ns, a peak value of 200 nA (integrated charge of 430,000 photoelectrons) [6]. The results presented here refer to this signal. Simulations were carried out with SPICE under the Cadence Analog Workbench environment. The anode response is presented in Figure 1. The base line shift is less than 1 mV. For this kind of signal, the dynode output saturates. Its base line restoration is detailed in Figure 2. The main impulsion (negative polarity) is followed by a positive undershoot of 35 mV with a 300 µs decay time, followed by a negative overshoot with a maximum of 5 mV 700 µs after the pulse beginning. The base line is fully restored 1.5 ms after the pulse. This behavior is linear with the charge at the output of the amplifier and was estimated to be negligible because the main part of the signal (width of 500 ns) is considered in the case of large pulses. Besides, it is slow enough compared to muons signals to implement a base line calculation algorithm.

Figure 1 Simulation of the anode response to the largest pulse of interest. Left: part of the response useful for the data analysis. Right: base line restoration.
The base line restoration being a slow process, its shape depends mainly on the signal charge. For the dynode signal, it depends on the charge going through the amplifier capacitors. The undershoot caused by muon signals was calculated as a function of the anode amplitude for a triangular signal modelling a muon event in the tank: a 0-100 % rise time of 20 ns and a 100-0 % fall time of 200 ns. The results are presented in Figure 3. The slope change correspond to the saturation of the amplifier. The model does not include the photomultiplier saturation for the large anode amplitudes.

![Figure 2 Simulation of the amplified dynode output base line restoration after the largest pulse of interest at different time scales.](image)

![Figure 3 Simulation of the dynode undershoot as a function of the anode amplitude for a triangular signal with a VEM shape.](image)

### 3. MEASUREMENTS ON THE ORSAY TANK

#### 3.1 With the LED flasher

The signal simulations were confirmed by measurements with the LED flasher [8, 9] on the Orsay tank [3]. The LED flasher was used because it has a repetitive behavior, which enables to perform an average on the signal with the oscilloscope. It was set to reach two different anode amplitudes: 150 mV (see Figure 4) and 1.2 V (see Figure 5). It confirms the simulations concerning the undershoot and the overshoot. The observed undershoot amplitude fits well the plot presented in Figure 3. The ratio of 7 between the undershoot and the overshoot is confirmed.
3.2 Time over threshold measurements

In order to detect any additional source of base line shift, the oscilloscope trigger was set to detect signals on the dynode output of a $2 \times 10^6$ gain PMT on the Orsay tank with time of 100 µs over threshold of 5 mV (TOT). The IPN Orsay oscilloscope data acquisition was used during 21 hours to record the pulses. It only trigged on the overshoot due to a large pulse: a typical signal is shown in Figure 6. No other shape was observed. The trigger rate was less than $7 \times 10^{-4}$ Hz. With a threshold at 2 mV, the rate is around $2 \times 10^{-2}$ Hz. It means that at a PMT gain of $2 \times 10^6$ large signals create on the dynode output a positive base line shift of at least 14 mV followed by a negative base line shift of at least 2 mV following a Poisson distribution with a parameter of around 50 s, this event during around 1.5 ms.

![Figure 6](image)

**Figure 6** Typical signal shape observed on the Orsay tank with a 5 mV 100 µs TOT trigger, a 2.5 MSPS sampling rate and a PMT gain set to $2 \times 10^6$. 
3.3 Extensive air showers

Large pulses were recorded with the IPN Orsay oscilloscope data acquisition. The measurements were performed with two tubes on the Orsay tank: a tube (PMT1) at a high gain ($2 \times 10^6$) triggering the oscilloscope, and a tube (PMT3) at the Auger working gain ($2 \times 10^5$). The tubes were calibrated in vertical muon (VEM) by triggering the measurements with the coincidence of two scintillators: one above and the other under the tank. The amplitude VEM corresponds to 21 mV for PMT1 anode, and to 2.9 mV for PMT3 anode. The charge VEM corresponds to 60 photoelectrons for PMT1 and around 80 photoelectrons for PMT3. For the study of large pulses, the threshold was set at 70 amplitude VEM (i.e. 70 times the peak amplitude measured on the oscilloscope during a calibration in vertical muon) on PMT1, in order to make sure to trigger only on extensive air showers (EAS). Typical signal shapes are shown in Figure 7. All the pulses are sharp: the full width at half maximum of the 1 700 recorded event is less than 80 ns (for the signals that did not saturate the oscilloscope). The widest pulses are signals with a decay time corresponding to the measurement of light diffused in the tank. In order to ensure that the pulses are not due to electromagnetic compatibility problems, the anode signals of a tank independent PMT were recorded. It was an Auger PMT placed in a light tight box inside the buildings, 15 m away from the tank. Over 1 700 events, only 15 happened in coincidence with the tank (relatively low amplitude; 20 ns jitter - due to Cherenkov effect in the PMT glass?), the other events showing no signal.

<table>
<thead>
<tr>
<th>Anode of PMT 1</th>
<th>Anode of PMT 3</th>
<th>Dynode of PMT 3</th>
<th>Comments on the event</th>
</tr>
</thead>
<tbody>
<tr>
<td>(gain: $2 \times 10^6$)</td>
<td>(gain: $2 \times 10^5$)</td>
<td>(gain: $2 \times 10^5$)</td>
<td>Both pulses have a rise time around 20 ns. The PMT 1 is wider probably because of the non linearity due to the high anode current.</td>
</tr>
<tr>
<td><img src="image1.png" alt="Anode of PMT 1" /></td>
<td><img src="image2.png" alt="Anode of PMT 3" /></td>
<td><img src="image3.png" alt="Dynode of PMT 3" /></td>
<td>The PMT1 pulse is very narrow, compared to the PMT3 pulse.</td>
</tr>
<tr>
<td><img src="image4.png" alt="Anode of PMT 1" /></td>
<td><img src="image5.png" alt="Anode of PMT 3" /></td>
<td><img src="image6.png" alt="Dynode of PMT 3" /></td>
<td>PMT1 has the width of a standard muon event whereas PMT3 is very sharp (opposite configuration a the previous event).</td>
</tr>
<tr>
<td><img src="image7.png" alt="Anode of PMT 1" /></td>
<td><img src="image8.png" alt="Anode of PMT 3" /></td>
<td><img src="image9.png" alt="Dynode of PMT 3" /></td>
<td>Pulses so high that both anodes saturate the oscilloscope, which may cause problems with the base line restoration of the oscilloscope amplifier.</td>
</tr>
</tbody>
</table>

*Figure 7 Representative shapes of large signals. PMT1 has gain of $2 \times 10^6$, PMT 3 a gain of $2 \times 10^5$. The sampling rate is 1 GS/PS.*
The histograms of the amplitude distribution are shown in Figure 8. The fit on the distributions (results shown in the figure) give close results to the equation for the EAS differential spectrum presented by J. Cronin [7]:

\[
\frac{dN}{dN_{\text{VEM}}} = 51.10^{-5}N_{\text{VEM}}^{2.5}
\]

where \(N\) is the counting rate and \(N_{\text{VEM}}\) the number of VEM in the tank. The results presented in Figure 8 are not accurate because of the small total number of events (1700). The rate is calculated from the differential spectrum of the charge distribution renormalized by the frequency of the events.

![Figure 8 Amplitude histogram of the large pulses. Recording trigged by a voltage threshold on PMT1 (70 amplitude VEM).](image)

As shown in Figure 2, there are two kinds of base line variation: the undershoot (positive polarity) that lasts for around 300 µs, and the overshoot (negative polarity) that lasts for 1.2 ms (after the undershoot). The rate of each events was calculated by the extrapolation from the electronic simulations (Figure 3) and the EAS rate on PMT3 (gain of \(2 \times 10^5\)), as a function of the variation. The results for several values are shown in Table 1. The PMT saturation was not taken into account in the simulations. It limitates practically the anode amplitude to 10 V. Thus, the base line variation will be mostly limited to 5 mV for the overshoot, and to 35 mV for the undershoot.

<table>
<thead>
<tr>
<th>Dynode base line variation (mV)</th>
<th>2</th>
<th>4</th>
<th>8</th>
<th>16</th>
<th>32</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undershoot rate (Hz)</td>
<td>0.5</td>
<td>0.1</td>
<td>(8 \times 10^{-3})</td>
<td>(9 \times 10^{-4})</td>
<td>(2 \times 10^{-4})</td>
</tr>
<tr>
<td>Anode amplitude (mV)</td>
<td>50</td>
<td>100</td>
<td>800</td>
<td>3000</td>
<td>8000</td>
</tr>
<tr>
<td>Overshoot rate (Hz)</td>
<td>(10^3)</td>
<td>(3 \times 10^3)</td>
<td>(3 \times 10^4)</td>
<td>(3 \times 10^5)</td>
<td>PMT saturation</td>
</tr>
<tr>
<td>Anode amplitude (V)</td>
<td>3</td>
<td>7</td>
<td>2</td>
<td>7</td>
<td>30</td>
</tr>
</tbody>
</table>

![Table 1 Rates of negative and positive dynode base line variation for a PMT at gain of \(2 \times 10^5\). The definition of the base line variation is given in Figure 2. The corresponding anode amplitude is given for a signal which shape corresponds to the model used in the plot of Figure 3. Values in gray are questionable because of the PMT saturation.](image)

For all the cases calculated in Table 1, the variations are slow enough compared to the signal total width: as is shown in Figure 7, even the total width of EAS signals is less than 500 ns. At this time scale and with the undershoot and overshoot limitations, as can be concluded from the simulations shown in Figure 2, the base line variation is a constant compared to the order of magnitude of the signals. Besides, the rates are negligible compared to the muon rate (around 2 kHz): it will have a negligible influence on the PMT calibration from the muon signal. Therefore, it is sufficient to calculate it with a few points preceding the pulse.

4. **CONCLUSIONS**

The large signals observed on the Orsay tank create base line variations accordingly to the electronic simulations. The base line variation occurs on the dynode output after a large signal (negative polarity) because of coupling capacitance recovery. It consists in an undershoot (positive polarity) with a decay time of around 300 µs followed by an overshoot.
(negative polarity). The ratio between the undershoot and overshoot amplitudes is around 7. The baseline is fully re-
stored 1.5 ms after the original pulse. The amplitude of the undershoot is proportional to the charge on the last dynode
output. The effect on the anode is negligible. The maximum expected values are around 30 mV for the undershoot and
4 mV for the overshoot. The measured rate seems compatible with observations of X. Bertou at Malargüe. It is negligi-
ble enough to have no effect on the calibration based on the muon buffer. The preliminary estimate of the differential
spectrum is compatible with that of extensive air showers (EAS). Since the base line variations due to the base are slow
enough compared to muon and even EAS signals, it is sufficient to calculate the actual base line using a few points be-
fore the signal.

5. REFERENCES

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