

Comparing the Signal from a Deep Dynode to the Anode

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Abstract

It is still not decided whether the PMTs for the ground array will be operated at low gain so the PMTs will be linear over the full required dynamic range or the PMTs will be operated at high gain and large signals will be measured with a deep dynode. A series of experiments were carried out to determine the relationship between the anode and a deep dynode signal for a PMT operated at high gain. We found that tapping a deep dynode at a PMT gain of 10^6 gives only moderate improvement in linearity and is nowhere near adequate for detecting large cosmic-ray air showers.

1 Introduction

There are two techniques in consideration for running the PMTs for the ground array. In the first technique, the PMTs are run at a gain of approximately 10^5 and small signals are measured using an amplifier on the last dynode signal. Large signals are measured with the anode signal which, at this gain, is at least approximately a linear function of incident intensity of light on the PMT. In the second technique, the PMT is operated at a gain of 10^6 or 10^7 . Measuring small signals with the anode is easy and large

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signals are measured using a deep dynode to avoid non-linearity caused by space-charge effects in the last dynode stages.

The first technique has the advantage that the system is linear over the entire range of interest. However, a fundamental calibration of the tanks in the Pierre-Auger detector is the response of the tanks to minimally-ionizing particles (MIPs), in particular through-going muons. Operating at low gains makes this harder to analyze even with the amplified last-dynode signal because of RF noise in the environment. (It is understood that under good conditions in a lab, studying PMT signals at a gain of 10^5 is an accomplishable goal. It is true also that there often unexpected sources of noise in the field.)

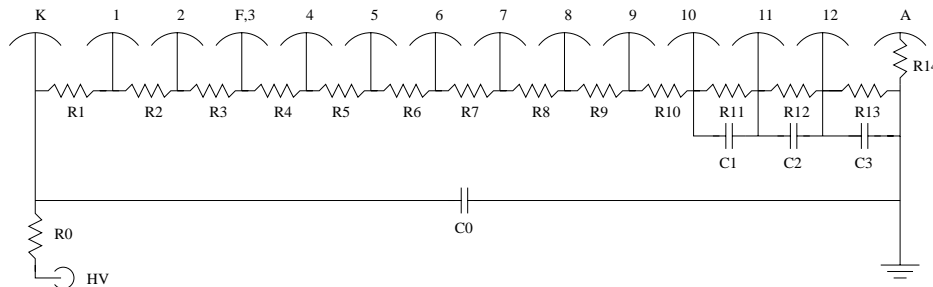
Thus operating at high gain presents an advantage, but it is necessary to obtain good linearity over the signal range of interest. Using the signal from a deep dynode has been considered as a way of obtaining better linearity at high gain.

We must define the maximum signal that is to be measured. B. Genolini [1] showed the photocathode current for a simulation of a 10^{21} eV cosmic-ray shower whose midpoint was 500 meters from a tank. This shows that the maximum cathode current in a PMT was 320 nA. For the purposes of this report, the linearity requirement is the ability to measure this cathode current with a maximum of 5% nonlinearity.

2 Apparatus

At UCLA, we ran a series of experiments to study the relationship between the anode and a deep dynode. We used the 12-dynode-stage ETL PMT 9353KB s/n#728 which was studied in detail in an evaluation of PMTs conducted over the summer and early fall of 2000 [2]. We used a base with negative high voltage at -1120V which gives an anode gain of 10^6 . The circuit, without the dynode tap, is shown in figure 1.

The testing described here was very similar to the linearity testing described in [2]. An LED, "A", was fired, then a second LED "B", and then the two were fired together. If the amplitude of the PMT signal for both firing is equal to the sum of A firing and B firing, then the PMT is linear for that range of cathode currents. If the PMT signal for both LEDs than the sum of the signal from A the signal from B the PMT is non-linear. More



R0	10 K	R1	1.097M	R2, R3	180K
R4 - R9	120K	R10	240K	R11	360 K
R12	480 K	R13	360	C0	4700pF
C1 - C3	0.01 μ F				

Figure 1: The base circuit without the dynode tap.

precisely,

$$NL = 100 \times \frac{\langle A \& B \rangle - \langle A \rangle - \langle B \rangle}{\langle A \rangle + \langle B \rangle} \quad (1)$$

where NL is the non-linearity expressed in percent, $\langle A \rangle$ is the mean charge when only LED A fired; $\langle B \rangle$, when LED B fired; and $\langle A \& B \rangle$, when both fired.

One difference between this measurement and the previous measurements of linearity is the data-acquisition system. Here we used a digitizing scope with a GPIB readout. The scope digitized at a rate of 1 sample per nanosecond. The 20 MHz bandwidth limit was applied on both the anode and dynode signals.

The second difference concerned the light source. Like the previous measurements the system was carefully tested with a fine-mesh PMT that is known to be linear. This is necessary to ensure that the output of an LED is the same whether it is firing alone or at the same time as the other LED. The fine-mesh PMT run performed before and after the measurements described in [2] showed this to be the case. Since then, the problem as developed in the light source and there is some coupling between the two LED outputs. Thus a run with the fine-mesh PMT shows a non-linearity of 1.5 to 2% independent of light intensity. (We change light intensity with an optical filter wheel, not by changing the LED driving current.) Close examination of the

LED driving pulses shows that the pulses are in fact slightly coupled. In the non-linearity plots shown below, a shift of 1.5% is taken out from the plots. We have repeatedly checked the value of this shift and find it to be constant within 0.5% over the period of these measurements.

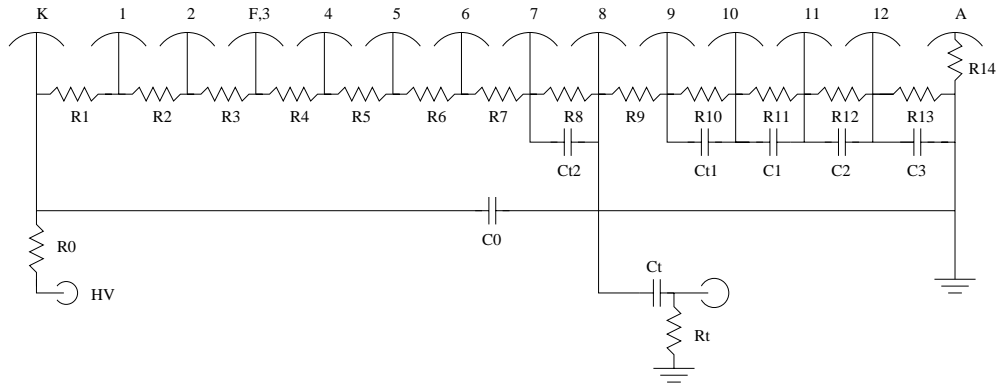
3 Testing Cycle

The dynode tap was applied to the PMT base. The base was mounted on the PMT in the dark box and the attenuator wheel was adjusted to give allow light intensity on the PMT -typically 20 mA peak anode current for both LEDs firing. In this region the anode is known to be linear. This run allows a direct comparison of the relative gain of the anode signal and dynode signal. Then runs with higher light intensity are performed and the linearity of the anode and dynode signals are measured.

4 Tap on Dynode 8

We chose a dynode that was deep in the chain for two reasons. Firstly, we wanted the gain to be lower than the anode by a factor of about 32 which corresponds to 5 bits on teh ADC. This allows 5 bits of overlap between the high-gain and low-gain signal. Secondly, we expected space-charge effects to be lower there. The base circuit used is shown in figure 2. There are a couple of points to be made. There are extra capacitors applied in parallel with the dynode chain resistors. This is necessary to avoid the dynode tap corrupting the anode signal. (When these are left out at low current the dynode signal is non-linear by +7%; that is to say the signal for both LEDs firing is larger than the sum of the two individual signals!) The blocking capacitor was chosen to be large such that the RC of the capacitor and the cable was large on the scale of the pulse duration. Were this not the case the RC would have acted as a differentiator. The value of the resistor after the capacitor was chosen to be 220Ω , in the range of 200 to 300 suggested by the Philips PMT handbook.

To obtain the difference in gain between the dynode and the dynode we used the run at lowest current and compared the integrated charge for the two signals averaged over all events. The dynode signal was reduced in gain by a factor of 69 compared to the anode.



R0	10 K	R1	1.097M	R2, R3	180K
R4 - R9	120K	R10	240K	R11	360 K
R12	480 K	R13	360	C0	4700pF
C1 - C3	0.01 μ F	Ct	0.02 μ F	Rt	220 Ω
Ct1	0.02 μ F	Ct2	2.2 nF		

Figure 2: The base circuit with the dynode tap.

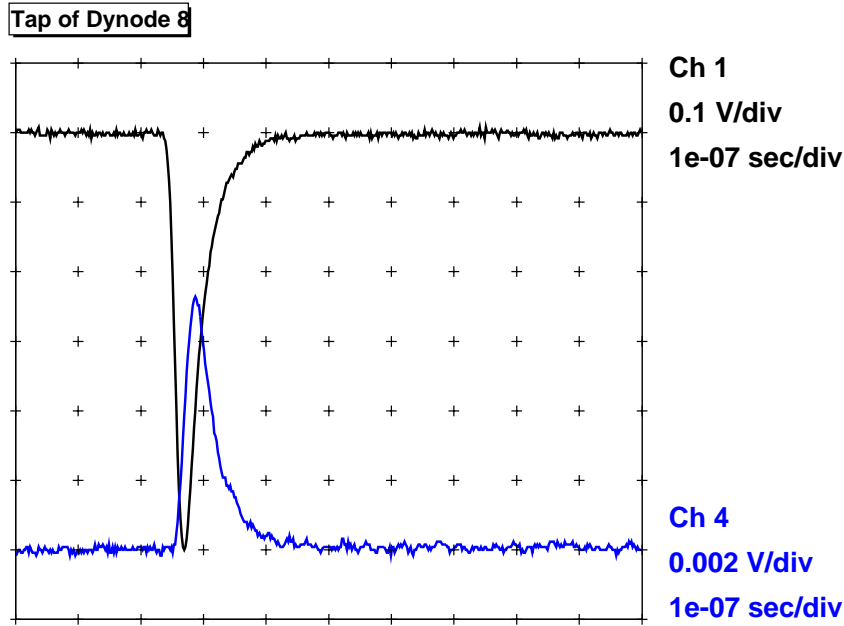


Figure 3: The anode (top) and dynode (bottom) pulses are shown for a run at a low intensity. Note that the input impedance of the scope was 50Ω .

A sample scope trace is shown from a low-intensity run in figure 3.

The results with this dynode tap were disappointing. Figure 4 shows the non-linearity as a function of peak cathode current plotted for both the anode and the dynode. The dynode only gives slightly improved linearity and is nowhere near the requirement of less than 5% nonlinearity at 300 nA cathode current. Also plotted are non-linearity measurements taken at a gain of 10^5 for comparison.

5 Conclusions

For the ETL PMT we were unable to use a tap on a deep dynode to obtain a sufficiently linear measure of photocathode current. We note that in tests performed at a gain of 10^5 , the anode signal was sufficiently linear over the range of interest. Current data suggest low-gain operation is a better choice.

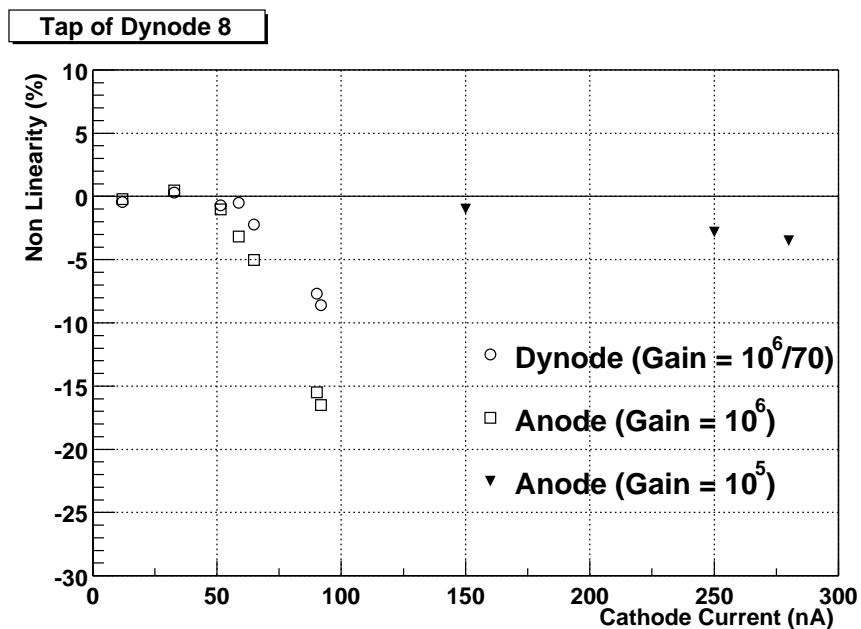


Figure 4: The non-linearity is shown for the anode and for a tap of dynode 8 for ETL PMT 728. Note that while the linearity of the dynode signal is better than the anode signal, the improvement is not large. Full scale on the x-axis is chosen to be the largest current at which we require less than 5% non-linearity. Also plotted are the linearity data plotted at a gain of 10^5 .

References

- [1] from a talk given 2000-08-24, conference unknown, B Genolini, transparency privately communicated.
- [2] Study of 8" PMTs at UCLA for Pierre-Auger Surface Detectors, GAP 2000-xxx, Arun Tripathi and the usual suspects.