CM-P00067478

POSITION IDENTIFICATION OF GAMMA RAYS AND ELECTRONS WITH A MULTIANODE PHOTOMULTIPLIER

M. Salomon and J. Marans

TRIUMF, Vancouver, B.C., Canada V6T 2A3

Summary

We have studied the properties of a multianode photomultiplier coupled to a large scintillator and the capabilities of such a system to obtain position information of the impinging radiation. We found a position resolution of 7.0 ± 0.5 mm FWHM using a centre-of-gravity method.

Introduction

After many years of use, photomultipliers are still one of the best devices to convert photons from scintillators or Cerenkov radiators into electric pulses. The large gain, good linearity, high speed, good efficiency and excellent signal-to-noise values have made photomultipliers a standard component in many radiation detectors.

Despite these advantages, there are two main drawbacks of photomultipliers which need to be addressed: their sensitivity to magnetic fields and their inability to provide position information. Both problems have been considered over the years and many ingenious partial solutions have been developed, in particular, to provide position information.¹⁻⁴

We have investigated the properties of a modified version of a commercially available photomultiplier R1652,* which consists of 10 anode wires instead of the standard single anode. Some of the properties of this device, including response to point light sources and timing characteristics, have been measured previously by our group and will be published.⁵ We found in that work that the position resolution of this photomultiplier for point light sources was 1.8 mm and 1.3 mm FWHM using two different centre-of-gravity methods. We also measured a very good timing resolution of the order of 0.5 ns FWHM. In this paper we will report on our first attempts at studying this tube when coupled to a large scintillator, and its ability to provide position information for a collimated beam of electrons of 1.5 MeV average energy.

The main purpose of this study was to find out if the geometrical distribution of scintillation photons could be used successfully with a single position-sensitive photomultiplier. The principle of position determination in a large scintillator using the photon distribution is well known,⁶ and by using a single position-sensitive phototube it should be possible to simplify the electronics and reduce the cost of the overall system. Furthermore, a very good position resolution would be obtained.

Experimental Set-up

Several measurements with gamma-ray sources indicated that not enough collimation could be achieved with a single detector, to measure accurately the position resolution of the system. Consequently we used a collimated electron source instead, where the position and beam size was accurately known. To translate our results to gamma-rays it is necessary to include the light distribution produced by the Compton and pair-production effects.

*Manufactured by Hamamatsu Photonics, Hamamatsu City, Japan.

†Manufactured by Bicron Co., Newbury, Ohio, USA.

We used a collimated ^{106}Ru source which emits electrons with a maximum energy of 3.5 MeV and average energy of 1.6 MeV. These electrons impinge on plastic scintillators (BC-412)[†] of 25 mm and 13 mm thick and 150×150 mm in size. The edges of the scintillator were unpolished and blackened with india ink to reduce scintillator photon reflection. The source could be moved by means of a calibrated calliper with an accuracy of 0.3 mm. The scintillator was adjacent to the photomultiplier as shown in Fig. 1. No optical coupling was used. The photomultiplier contains 9 transmission mesh dynodes followed by 10 anode wires perpendicular to the plane of the figure and to the direction of motion of the source. The anode wires separation is 5 mm. Behind the plane of anodes there is one last reflective dynode. This tube and the biasing electronics have been described in our previous paper.⁵

With this geometry, a narrow cone of approximately 22° contains the photons reaching the photocathode, which are only 4% of all the scintillation light produced. The rest of the photons are either absorbed on the scintillator sides and front, or escape in the interface between the scintillator and the phototube. The whole assembly was contained in a darkened box with absorbing walls. In this way we can simulate approximately the photon distribution of events produced in a NaI(Tl) scintillator by 0.5 MeV gamma rays. As the collimator has a diameter of 2 mm and a length of 10 mm, the source of photons had a projected size of 3 to 4 mm corresponding to gamma-ray events in which a Compton process is followed by photoelectric absorption. The total number of scintillator photons is also similar, as a plastic scintillator has 5 times less photoefficiency than NaI(Tl).

The signals of the individual anodes are amplified $\times 10$ and fanned out in two groups. One group is fed to a CAMAC ADC (LRS2249W) and the other linearly added to trigger a discriminator whose output produces the event strobe and the gate signal for the ADC (Fig. 2), which in turn is read by a computer (DEC 11/34). The ADC signals are digitized and histogrammed individually.

Fig. 1 Experimental arrangement used for the measurements described in this paper. All distances in mm. The collimator - scintillator separation was 0.5 mm.

Fig. 2 The electronics used in these measurements. Delays between the amplifiers and the ADC are not indicated. A1, A2 etc. are the anode wires in the phototube.

Measurements with a Point Source

We repeated first a previous measurement⁵ without the scintillator but with a light source and an optical fibre to determine the response of the phototube to point light sources as a function of source position. The results are shown in Fig. 3. They indicate a somewhat reduced gain in the central part of the PM and also that the extent of the electron shower at the anodes has a FWHM of approximately 13 mm. Furthermore, the shape of the shower distribution is not Gaussian due to the multiplication at each stage of the electron cascade.

The Position Information

The position information is obtained using a centre-of-gravity method

$$G_n = \frac{\sum_{i=1}^{10} x_i (C_i Q_i)^n}{\sum_{i=1}^{10} (C_i Q_i)^n}, \quad (1)$$

where Q_i are the charges collected in each anode i and digitized in the ADC, C_i are correcting coefficients that deal with irregularities of the device, and x_i are the anode i positions. The exponent n was varied from 1 to 4 but only $n=1$ and 2 produced reasonable results. In our previous paper⁵ we had found that for a point light source $n=2$ produced a better resolution than $n=1$ (1.3 mm FWHM and 1.8 mm FWHM, respectively). This is not the case for an extended light source as will be shown later.

Fig. 3 The anode charges collected in each anode in arbitrary units, as a function of the position of a point light source at the photocathode.

Fig. 4 Histogram of G_1 for 3 different source position separated by 5 mm. The discriminator setting was -0.80 V.

The computer calculated expression (1) for $n=1$ and 2 simultaneously and on line, and histogrammed the functions G_n for each ^{106}Ru source position. The results are shown in the next section.

After several trials we used values of C_i obtained from point light source response by setting them to values proportional to the inverse of the peak height of Fig. 3. These values produced good results, but were later modified slightly to improve the range of positions with linear response. This point will be explained in a subsequent section.

Measurements with a Source and a Scintillator

With the source and scintillator arranged as shown in Fig. 1 we tried several biasing voltages and discriminator values. The best position resolution was obtained for a bias of 1500 V between anodes and cathode, and with a discriminator setting equivalent to 200 keV gamma-ray energy in the plastic scintillator. The gate length in the ADC was 40 ns.

Measurements were first done using a 12.5 mm thick scintillator, but in order to simulate the parameters encountered in positron emission tomography we increased the scintillator thickness to 25 mm. We started the measurements by computing on line event by event the Eq. (1) for $n=1$ and 2, using a set of C_i obtained from Fig. 3. Several values of the discriminator were used and the results are shown in Fig. 4. For $n=1$ we obtained a FWHM resolution of 6.5 mm and for $n=2$, 7.4 mm. We found in all cases that the results with $n=2$ were somewhat worse than for $n=1$. This is the reverse from what we observed⁶ in our previous measurements with a point source, and is due to the larger number of photons involved in the former measurements. The discriminator level was equivalent to 200 keV of γ rays in plastic scintillator.

With a lower value of discriminator setting equivalent of 100 keV the resolution was somewhat worse, as shown in Fig. 5 with a FWHM of 7.5 mm for $n=1$ and 8.8 mm for $n=2$.

Measurements of Linearity of Response

When the source is moved over larger distances on the scintillator surface, we found that the peak position of G_n and the real position of the source are no longer linearly related. This effect is shown in Fig. 6 where edge effects are apparent. As the anode wires extend over 50 mm in the phototube it was hoped to extend the linear region to about that size. We accomplished that by modifying the values of C_i from the

Fig. 5 Histogram of G_1 for 3 different source positions separated by 5 mm. The discriminator setting was -0.60 V.

Fig. 6 The peak position of G_1 (full line) and G_2 (dashed line) as a function of several source positions using a modified set of parameters C_1 .

Fig. 7 The peak position of G_1 (full line) and G_2 (dashed line) as a function of several source positions using a modified set of parameters C_1 .

ones used in the previous section. Several sets of C_1 were tested, and the best results were obtained by keeping the central values (C_3 to C_7) close to the original values and decreasing the edge values (C_1 , C_2 , C_8 , C_9) by up to a factor of 2 in a gradual way. With this new set of C_1 the linearity improved as is shown in Fig. 7. With the new set of C_1 the resolution FWHM was 7.0 mm for $n=1$ and 8.2 mm for $n=2$.

Conclusions

We measured the capability of a specially designed photomultiplier to obtain position information of radiation falling on an extended scintillator. The results indicate that for energies of about 2 MeV in plastic scintillators (or equivalent 0.4 MeV in NaI(Tl) scintillators), it is possible to obtain a position information of the order of 7 mm FWHM.

There are, however, several important shortcomings that need to be addressed. A two-dimensional device must be built if one wants a useful device. This is presently under construction and we hope to test it soon. For medical applications the total area has to be increased, either by a single large tube or by tiling smaller ones. This last alternative would require a square cathode design. The total gain of the tube ($\sim 10^5$) is somewhat small and two more dynodes should be added; we expect no significant degradation in space resolution.

We believe this device to be an important step towards an inexpensive solution to low-level photon detection with position information, with applications to medical gamma-ray detectors, as well as several high-energy devices as Cerenkov imaging devices, hodoscopes and scintillating fibre detectors. Also important to point out are the very good time response of these devices and their decreased sensitivity to magnetic fields. Both properties are due to the very short path of the electrons between the cathode and the anodes.

References

1. J. Ditta et al., Nucl. Instrum. Methods **220**, 343 (1984) and references therein.
2. K. Oba et al., IEEE Trans. Nucl. Sci. **NS-26**, 346 (1979).
3. H. Kume, S. Suzuki, J. Takeuchi and K. Oba, IEEE Trans. Nucl. Sci. **NS-32**, 355 (1985) and **NS-32**, 448 (1985).
4. Report from: Instrument Technology Ltd., Imaging photodetector, St. Leonard-on-Sea, East Sussex, U.K.
5. M. Salomon and S.S.A. Williams, TRIUMF preprint TRI-PP-85-24 (submitted to Nucl. Instrum. Methods).
6. H.O. Auger, IEEE Trans. Nucl. Sci. **NS-13**, 380 (1966).