Absolute Number Calibration of Photoelectrons of Photomultiplier Tubes using the Nature of Statistical Distribution

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Abstract

To obtain precise number of photoelectrons emitted from the photoelectric surface of photomultiplier tubes in short time simply and effectively is very important for experiments which use many photomultiplier tubes. The number of photoelectrons can be estimated from a formula which is made based on a statistical distribution. We have examined the precision of this formula by simulations and experiments. As a result, we found that the formula can be used very precisely after some corrections which depends mainly on the emission number of secondary electrons from the first and second dynodes of the photomultipliers.

1. Introduction

Photomultiplier tubes (PMT) have been used very often in various experimental fields to measure photons qualitatively. We will be able to know number of photons entered into the PMTs, if we know well the number of photoelectrons (p.e.) emitted from the photoelectric surface of the PMTs and their conversion efficiencies. To obtain the precise absolute number of the photoelectrons is, therefore, very important for experiments in which precise measurement of the photon number is required.

There are some methods to obtain the number of photoelectrons experimentally. We examined one of the simplest method which is to utilize the nature of statistical distribution of the photoelectrons emitted at the photoelectric surface of the PMTs, which we call '*photoelectron-statistics method*' hereafter [1,2].

It is possible to assume that the number of the photoelectrons is described by the Poisson ststistics with a mean number $\mu_{p.e.}$ and a standard deviation $\sigma_{p.e.}$, if the number of incident photons is constant. If the gain G is constant for any number of photoelectrons, the mean value μ_e and the standard deviation σ_e of charge distribution of the output signals from the PMT are expressed as

$$\mu_e = G\mu_{p.e.} , \quad \sigma_e = G\sigma_{p.e.} = G\sqrt{\mu_{p.e.}} . \tag{1}$$

The mean number of the photoelectrons is, therefore, expressed as

pp. 2871–2874

$$\mu_{p.e.} = \left(\frac{\mu_e}{\sigma_e}\right)^2 . \tag{2}$$

The number of photoelectrons is simply estimated from the distribution of output signals from the PMT by this formula which we call '*photoelectron-estimation formula*' hereafter.

However, the precision of this formula is not clear. Therefore, we have examined the precision of this formula by means of simulations and experiments in this paper.

2. Details of the Photomultiplier Tube

We used a Hamamatsu R3479 19mm diameter PMT which has 8 dynodes with the bialkali photocathode and a UV glass window for this experiment. Fig.1. shows a schematic view of the PMT. The photocathode and the housing of the PMT are grouded and positive high voltage is applied to an anode. High-voltage divider ratio is set to (7:1:1.5:1:1:1:1:1:1) which is recommended by Hamamatsu Photonics to achieve the optimal performance. When the photocathode receives photons, photoelectrons are emitted. They are accelerated by the electric field and produce some more electrons when they hit the first dynode. The electrons are multiplied at the successive dynodes.

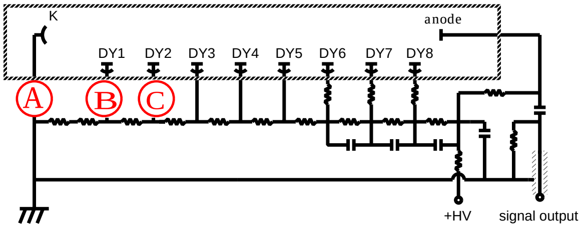

Fig. 1. Schematic view of the tested PMT with the high-voltage divider circuit

3. Simulation Method and Results

The formula based on the idea of the *photoelectron-statistics method* may be affected by the amplification factors at each dynode. Therefore we examined such effect by the Monte Carlo simulation with the following method.

Incident photons are assumed to have the Poisson distribution with a given mean value in the range from 1 to 100 photons. Photoelectrons are emitted at the photocathode with the quantum efficiency of 25%. Secondary electrons are emitted by assuming various combinations of amplification factors at the first and the second dynodes. Number of emitted photoelectrons can be calculated from the distribution of the output electrons using the *photoelectron-estimation formula* (2) which can be compared with actual number of input photoelectrons. Fig.2. shows the simulation results.

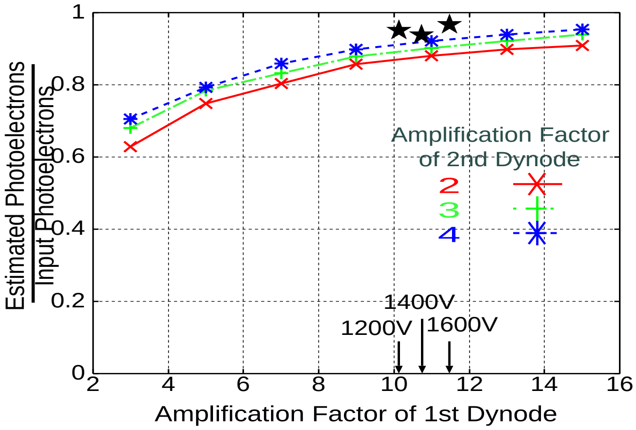

Fig. 2. Estimated photoelectrons/Input photoelectrons as a function of amplification factor of the first dynode for various amplification factors of the second dynode calculated by the simulation. Experimental results ($\star$) are also plotted.

From this figure it is found that the *photoelectron-estimation formula* has some estimation errors which mainly depends on the amplication factor of the first and second dynodes.

4. Measurements of Currents and Amplification Factors at Dynodes

To verify the simulation results we achieved some experiments. The amplification factors at the first and second dynodes can be obtained by measuring the electric current at the positions written as A, B, and C in Fig.1.. The currents are measured by an electrometer ADVANTEST R8240 with 10 fA resolution.

From these measurements the amplification factors at the first dynode and the second one are calculated. They are 10.2 and 4.2 at 1200 V, 10.8 and 4.7at 1400 V, and 11.5 and 4.9 at 1600 V, respectively.

5. Comparison of the Formula with Single P.E. Measurement

To verify the precision of the *photoelectron-estimation formula* we measured output charges from the PMT by an Analog to Digital Converter (ADC) and applied the formula to the measured ADC distribution for various input photon number. Obtaind results are shown in Fig.3.. It is found the obtained results are quite linear. To compare this results we measured the single photoelectron peak of the ADC distribution, which is also plotted in Fig.3.. For this high voltage of 1200 V (Estimated Photoelectrons)/(Input Photoelectrons) $= 0.95$, which we plotted in Fig.2. together with other HV=1400 V and 1600 V as a function of measured amplification factor.

Fig.2. shows the measured precision of the *photoelectron-estimation formula* agrees very well with the simulated one.

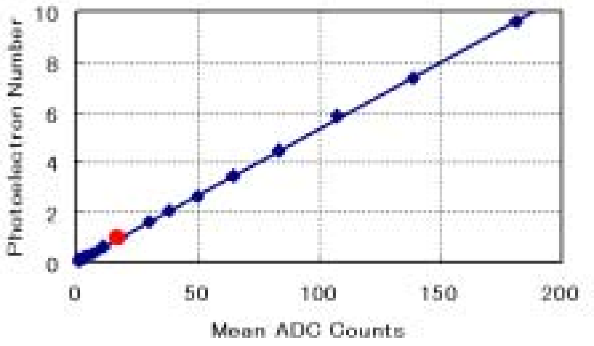

Fig. 3. ● : ADC count per 1 p.e. obtained from the peak value of the ADC distribution , ♢ : Photoelectron number obtained from the *photoelectron-estimation formula*

6. Conclusion

We have examined the precision of the *photoelectron-estimation formula* by means of simulations and experiments. The measured precision was found to agree with the simulated one. Therefore if we know well about the amplification factor at the first dynode and the second one, the *photoelectron-estimation formula* can be used with good precision after some correction. As this method is easy to use and the measuement is simple, there is a good possibility to use this method in experiments which use many PMTs with good accuracy.

7. References

1. Kabuki S. et al., Nucl. Instr. and Meth. A500 (2003) 318-336, arXiv:astro-ph/0210254
2. Baker M.A. et al., 2002, arXiv:hep-ex/0203001