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ABSTRACT

Characteristics have been measured of the Hamamatsu R1635 10 mm-diameter photomultiplier. Some typical photomultiplier characteristics—such as gain, dark current, transit and rise times—are compared with data provided by the manufacturer. Photomultiplier characteristics, generally not available from the manufacturer, such as the single photoelectron and pulse response time spread for full photocathode illumination were measured and are discussed.

INTRODUCTION

In many recently developed positron emission tomography systems, small scintillators and small diameter photomultipliers are used as detectors to obtain a high spatial resolution and sampling density.¹ Minimizing the coincidence resolving time is an important factor in the design of such systems to reduce the number of random coincidences. Also, in some recently developed systems, the time-of-flight information of the positron annihilation γ -rays is used in combination with the conventional projection data to improve the signal-to-noise ratio of the reconstructed image.²⁻⁴ In both cases the system requires a large number of fast scintillators and good time resolution photomultipliers.⁴

The R1635 is a 10 mm-diameter, 8-stage, head on, flat-face plate photomultiplier with a SbCs photocathode having a S-11 response. Because of its small size, the photomultiplier is particularly suitable for high spatial resolution tomography systems. The photocathode has a useful diameter of 8 mm and a peak response at 4200Å. The multiplier utilizes a box type structure and grid dynodes. Figure 1 shows a photograph of the R1635 photomultiplier.

GAIN AND DARK CURRENT MEASUREMENT

Gain and dark current measurements were made with a linear voltage divider which drew .9 mA with 1200 V across it. The measuring system has been previously described by the authors.⁵ The two R1635's measured had a gain of $1 - 1.2 \times 10^6$ at 1200 V and the average dark current at this voltage was 500 pA. Figure 2 shows the average gain and dark current as a function of the over all voltage between anode and cathode.

QUANTUM EFFICIENCY MEASUREMENTS

A calibrated RCA8850 with bialkali photocathode was used as the standard for the quantum efficiency measurements. The photocathode, masked to leave a 8 mm (the useful photocathode diameter of R1635) diameter area at the center, was placed in a marked position. The light source was adjusted to yield an output signal of 4 nA from the 8850 with 500 V between the photocathode and anode. With the same light level setting, the R1635 was connected as a diode and placed in a position with the photocathode exactly the same distance away from the light source as the photocathode of the 8850, and the output signal was measured. The average quantum efficiency was found to be 33±3% at 410 nm.

PEAK OUTPUT CURRENT MEASUREMENT

The peak output current of the R1635 photomultiplier was measured with a pulsed mercury light source capable of emitting enough photons per pulse to saturate the photomultiplier.

Calibrated neutral density filters were used to attenuate the light pulse intensity during the measurements. The results are plotted in Fig. 3. The peak linear output current was 14 mA and 18 mA respectively. The light pulse were 2.6 ns wide having a repetition rate of 60 pulses per second. The operating voltage on the two R1635 was 1200 V.

ELECTRON TRANSIT TIME MEASUREMENT

The description of the transit time measuring system has been published elsewhere by the authors.⁶ A LED light pulser was used to produce the light pulse, and the electrical pulse used to drive the LED was also utilized as the reference pulse. The electrical pulse was divided into two parts for calibration. An adjustable air line was used to bring the two pulses into coincidence on the oscilloscope, hence establishing zero time reference. The R1635 photomultiplier was then put in place and the delay of the output signal was measured.

The electron transit time as a function of anode-cathode voltage is plotted in Fig. 4. At 1200 V, the electron transit time through the R1635 photomultiplier was $9.5 \text{ ns} \pm .25 \text{ ns}$ for the two tubes measured.

SINGLE PHOTOELECTRON PULSE RESPONSE

The true characteristics of the pulse response of a photomultiplier can be observed with single photoelectron pulses. Since dark noise pulses are mostly due to single photoelectrons, they can be used to show the single photoelectron pulse response. However, in cases where a higher pulsing frequency is needed, either a low-level dc light source, or a very-short light pulser can be used to induce more single photoelectron pulses. The true pulse response of a photomultiplier can be observed only if the divider socket is properly designed to reliably transmit the output pulse to an oscilloscope or other monitoring device. Improper matching of the output circuit of the photomultiplier will induce ringing which in some cases will distort the results of the experiment.

A linear voltage divider was made with consideration given to the output matching. Two 0.01 μf capacitors, one from each of the last two dynodes were connected to the output coaxial cable shield with the shortest leads possible. By doing this, the last two dynodes looked like a ground plane to the fast pulses, and lowered the impedance of the output structure of the photomultiplier—achieving a better match to the 50 ohm external load. The pulse response under this condition is shown in Fig. 5. No objectionable ringing was observed.

The 10 - 90% rise time of a single photoelectron pulse from the R1635 was found to be $800 \text{ ps} \pm 50 \text{ ps}$ at 1200 V and the pulse width $1 \text{ ns} \pm 0.1 \text{ ns}$ at FWHM. The pulse amplitude was $15 \text{ mV} \pm 0.3 \text{ mV}$ with the same anode-cathode voltage.

SINGLE PHOTOELECTRON TIME SPREAD MEASUREMENT

The system described in Reference 7 was used for the time spread measurement. The light pulses were generated by an avalanche light emitting diode and had widths of 200 ps or less at half maximum. The system resolution was in the order of 30 ps, FWHM.

Figure 6 shows two single photoelectron time distributions spaced 3 ns apart. With full photocathode illumination and with a light pulse produced by a 200 ps electrical pulse, and average single photoelectron time spread was 869 ps FWHM.

MULTIPHOTOELECTRON TIME RESOLUTION

The time resolution measurement was made using a mercury light pulse generator capable of producing thousands of photoelectrons per pulse from the photocathode of the photomultiplier. The number of photoelectrons per pulse was calculated by measuring the output pulse width and amplitude and knowing the gain of the photomultipliers at the operating voltage. Figure 7 shows the plot of the time resolution as a function of the number of photoelectrons per pulse from one to 200 photoelectrons. The time resolution of the single photoelectron pulses was 2.25 ns FWHM. This number was the result of the light pulse width and the single photoelectron time resolution of the R1635 which was 869 ps. With 200 photoelectron per pulse, the time resolution of the R1635 was tapered down to approximately 0.3 ns, FWHM.

PULSE HEIGHT SPECTRUM MEASUREMENT

The pulse height spectrum of the R647 was measured by illuminating the full photocathode with a light emitting diode whose light output intensity was controlled by varying the amplitude of the driving pulse. The photomultiplier output pulses were stretched before they were processed by the pulse-height analyzer. The photoelectron peaks were calibrated with a RCA 8850 photomultiplier which could resolve 1, 2, 3 or 4 photoelectron peaks.

The pulse height spectrum of the R1635 is shown in Fig. 8 with the R1635 operating at 1200 V which corresponds to a gain of 1×10^6 . The average dark pulse count of the photomultipliers was found to be:

$$\sum_{16 \text{ photoelectrons}}^{1/8 \text{ photoelectron}} = 40 \text{ counts per second}$$

CONCLUSION

Our measurements have shown that basic characteristics of the R1635 photomultiplier agree closely with those given by the manufacturer. However, a good voltage divider must be made to provide a better matched output structure to reduce ringing in the output signal.

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Fig. 1 Photograph of the R1635 photomultiplier.

Fig. 2 Gain and dark current as a function of anode-cathode supply voltage.

Fig. 4 Electron transit time as a function of anode-cathode supply voltage.

Fig. 3 Peak anode output pulse current as a function of light intensity.

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Fig. 5 Single photoelectron pulse response.

Fig. 7 Multiphotoelectron time as a function of the number of photoelectron.

Fig. 6 Single photoelectron time spread of R1635 with full photocathode illumination.

Fig. 8 Pulse-height spectrum of R1635 photomultiplier.

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