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Author
Leskovar, B.

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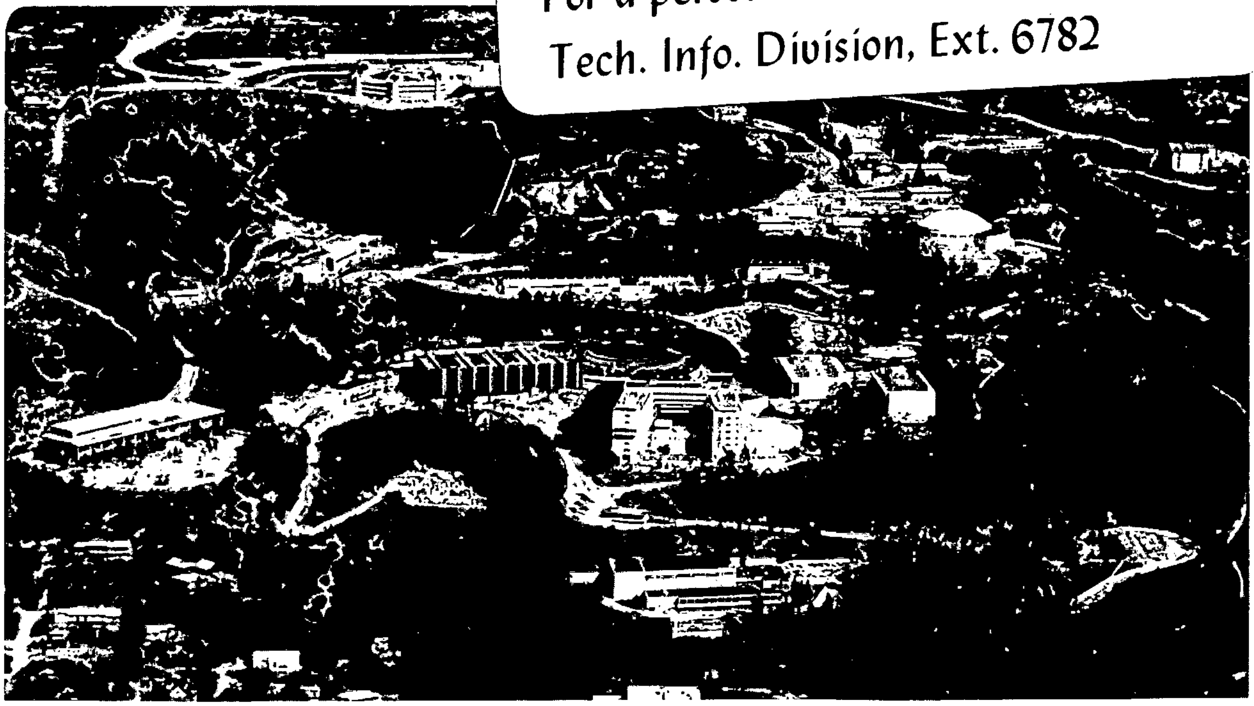

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Branko Leskovar

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720 USA

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PULSE-HEIGHT RESOLUTION PERFORMANCE STUDIES OF HIGH-SPEED PHOTON DETECTORS

Branko Leskovar
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720 USA

The pulse-height resolution capabilities of prototype microchannel plate high-gain photon detectors have been investigated. Specifically, the device studied included LEP HR350, PM 137 and ITT F4129--proximity focused high-gain microchannel plate photomultipliers. The experimental data have been compared with results obtained on conventionally designed RCA 8850 high-speed photomultiplier.

Introduction

The pulse-height resolution capabilities of high-speed photon detectors are important for the detection and measurement of very low light level scintillations in which only a few photoelectrons are produced, or where a discrimination against high-noise background count rate is necessary. Because of the statistical variations inherent in the conversion of photons to photoelectrons and the statistical nature of the secondary emission process, the photomultiplier output signal varies from one pulse to the next, even for an equal number of incident photons. These fluctuations can be reduced by using the maximum attainable photocathode quantum efficiency and high multiplier stage gain. The high resolution permits the elimination of a large number of single-electron dark pulses from the low level scintillations.

It was previously shown that photomultipliers having dynodes with cesium-activated gallium phosphide secondary emitting surfaces exhibited significantly better resolution than photomultipliers having conventionally activated dynodes [1,2,3]. It was also shown that new high-gain photon detectors employing microchannel plates in cascade for electron multiplication [4,5] exhibit the highest pulse-height resolution ever obtained when operating conditions are properly optimized [6,7,8,9]. High resolution is contingent on operating microchannels in almost saturated mode. Furthermore, it assumes that the pulse rate is low enough to allow microchannel recovery between pulses.

The purpose of this research has been to investigate pulse-height resolution capability of the LEP HR350, PM 137 and ITT F4129 prototype high-gain photon detectors having microchannel plates for electron multiplication where proximity focusing is used for the input and collector. The HR350 photomultiplier uses a high-gain curved-channel microchannel plate and the PM 137 two-microchannel plates.

The photomultiplier HR 350 incorporates a microchannel plate having approximately 9 x 10^4 curved channels each 40 μm in diameter. The device has an S-20 photocathode with a useful diameter of 13 mm and has a coaxial anode. Since the photomultiplier is an experimental prototype, an ion pump is used to keep a high vacuum inside the glass envelope. The photomultiplier PM 137 incorporates two microchannel plates in cascade. The first microchannel plate has a channel diameter of 40 μm and a length-to-diameter ratio of 80. The second plate has channel diameters of 12.5 μm and a length-to-diameter ratio of 40. The device has KC_sSb photocathode of a useful diameter of 20 mm. An ion pump and a getter are provided to keep high vacuum in the glass envelope. Both photomultipliers were designed and manufactured by the Laboratoires d'Electronique et de Physique Appliquée at Limelil-Brevannes, near Paris, France [10]. The F4129 photomultiplier has an S-20 photocathode with a maximum usable diameter of 18 mm and three microchannel plates in cascade for electron multiplication [11]. The plates are in a Z-configuration to reduce the positive ion feedback. The plates are identical, having channel diameters of 12 μm and a length-to-diameter ratio of 40. The strip current of the microchannel plate assembly is 1.4 μA with 2400V across it. A getter is provided to maintain a high vacuum in the glass envelope. This photomultiplier was designed and manufactured by the Electro-Optical Product Division of ITT Corporation, Fort Wayne, Indiana, U.S.A.

The measurements of the pulse-height resolution were made with a measuring system which has been described earlier [8]. Measurements were made using the photomultiplier voltages suggested by the manufacturer. Schematic arrangements of HR350, PM 137 and F4129 and appropriate voltage dividers used in the measurements are shown in Figs.1, 2 and 3, respectively. Electrostatic voltmeters were used to measure all voltages.

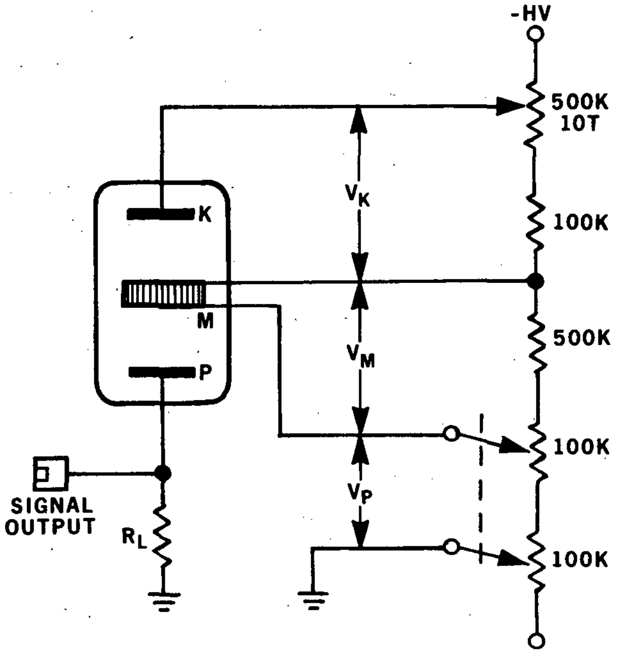

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Fig.1 Voltage divider used in the measurements of HR 350 microchannel plate photomultiplier

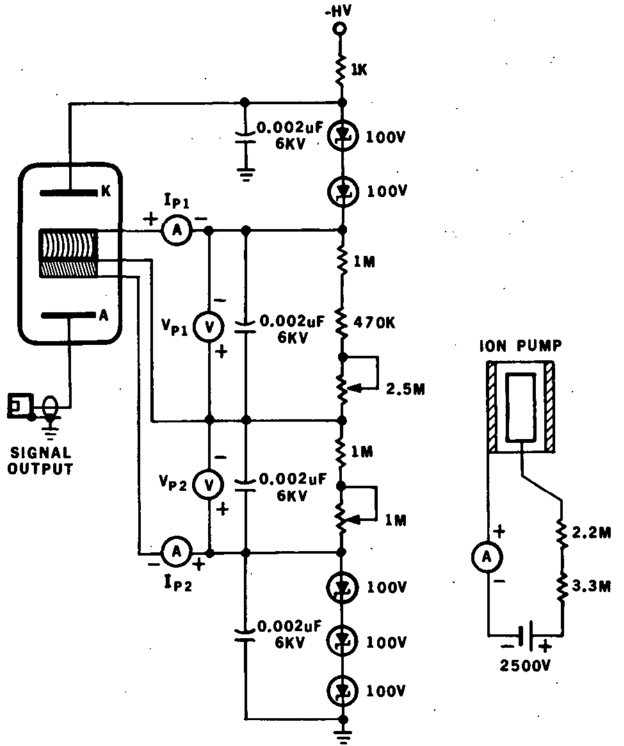

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Fig.2 Schematic arrangement of the PM 137 photomultiplier and voltage divider used in measurements

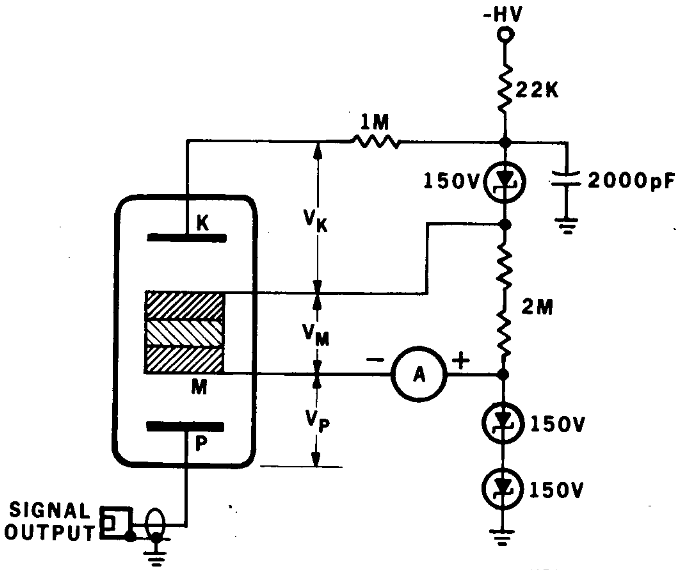

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Fig.3 Schematic arrangement of the F4129 photomultiplier and voltage divider used in the measurements

Results and Discussion

The results of the pulse-height resolution measurements on the HR 350, PM 137 and F4129 photomultipliers with full photocathode illumination are given in Figs.4, 5 and 6, respectively. In the resolution measurements of the HR 350 microchannel voltage, V_M, was set at 1600V and the light level of the light pulse generator was adjusted to yield one, two, three, four or more photoelectron pulses. The one, two and three photoelectron peaks were made to have the same height by varying the light pulse intensity during the measurement. The first peak-to-valley ratio and dark pulse counts in the 1/8 to 16 photoelectron range were 2.0:1 and 340, respectively. Similar measurements made on an RCA 8850 showed the photomultiplier had the first peak-to-valley ratio of 2:1 and a dark count rate of 145 pps.

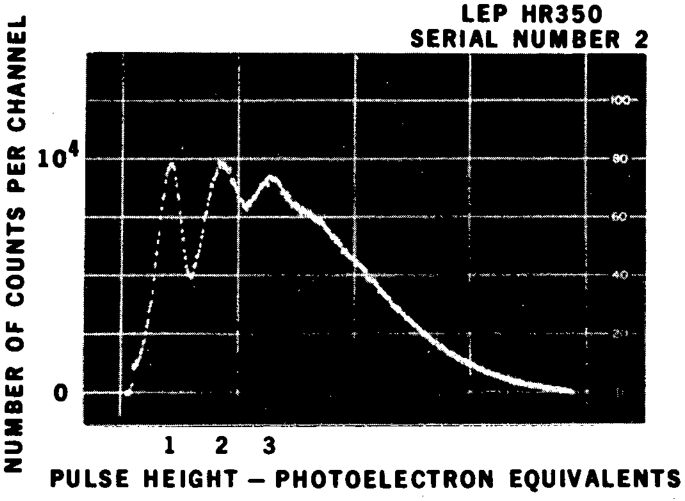

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Fig.4 Pulse-height spectrum, showing peaks corresponding to one, two and up to four electron peaks for HR 350 photomultiplier

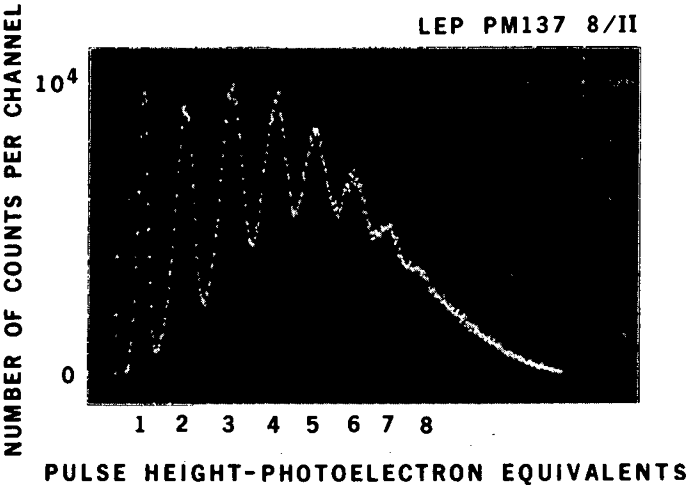

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Fig. 5 Pulse-height spectrum, showing peaks corresponding to one, two and up to eight electron peaks for PM 137 photomultiplier

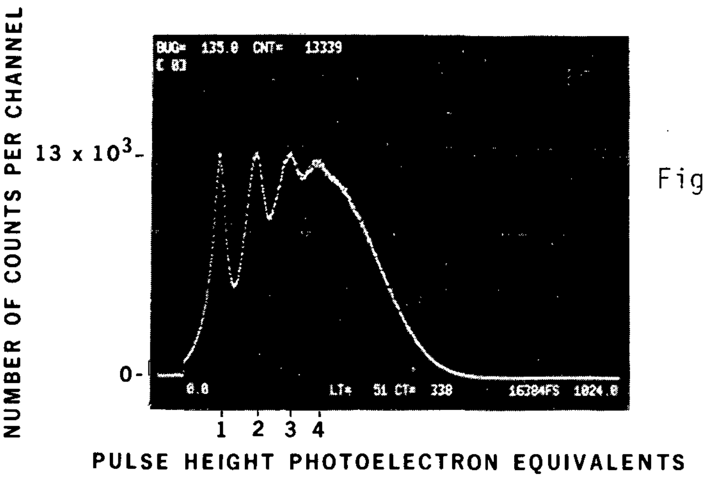

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Fig.6 Pulse-height spectrum, of the F4129 operating at microchannel plate cascade voltage of V_M=2710V

Using the methods described above for the resolution measurement of PM 137, the with manufacturer's recommended operating microchannel plate voltages; namely: V_k=200V, V_{P1}=1700V, $I_{P1}=8\times10^{-6}$A, V_{P2}=700V, $I_{P1}=12\times10^{-6}$A, and V_A=300V, the first peak to valley ratio was 3 to 1 and the maximum resolvable number of peaks was three. The photomultiplier gain and dark current were 5×10^{6} and 5×10^{-9}A, respectively. The dark pulse count for the photomultiplier PM 137, when operating at a gain of 1×10^{6} was 400 counts per second in the pulse height range from 1/8 to 16 photoelectrons. The operating voltage of the first microchannel plate has the greatest effect on the collection efficiency and the pulse-height resolution. It was decided that the first plate voltage was to be increased to study the changes in the pulse-height spectrum of photomultiplier. As the first plate voltage was raised the dark current increased significantly; hence, the second plate voltage was lowered to keep the dark current within an approximate factor of two of its original level. By changing the voltage of V_{P1} to 2100V and V_{P2} to 525V, the first peak-to-valley ratio becomes 15:1, and the maximum resolvable number of peaks 8. At these operating voltages, the overall gain of the photomultiplier is 2×10^{6} and the dark current is 12×10^{-9}A. The time resolution characteristics of the device remained unchanged. Figure 5 shows a pulse-height spectrum of PM 137 under optimized operating conditions for best pulse-height resolution. To the author's knowledge this is the highest pulse resolution ever measured on a fast photomultiplier.

The pulse-height resolution measurements of the F4129 photomultiplier were made using the procedure described above. The present design of the cascade of the microchannel plates in a Z-configuration has considerable advantages with respect to fabrication, timing characteristics and application of the photomultiplier. However, Z-configuration without electrical connections to each microchannel plate does not allow full optimization of operating conditions of the individual microchannel plates for a maximum pulse-height resolution. As shown by the above given considerations, optimization of operating conditions of each microchannel plate is requied for a significant increase of pulse-height resolution capabilities of the photomultiplier. Minor modifications of Z-configuration would result in increased photomultiplier pulse-height resolution.

With the F4129 operating at V_M = 2400V (gain of 1×10^{6}), the dark pulse count of the photomultiplier was 1800 counts per second in the pulse-height range from 1/8 to 16 photoelectrons. The dark count was taken after the device had been in the dark for 48 hours. The photocathode quantum efficiency was approximately 19% at 410 nm. Back biasing the photocathode yields 5 counts per second indicating that most dark pulses come from the photocathode. With the microchannel plate configuration voltage, V_M, at 2400V, the device was unable to resolve separate photoelectron peaks. Voltage, V_M, was increased gradually to a maximum of 2760V. The ability to resolve different photoelectron peaks was drastically improved. Figure 6 shows the pulse-height spectrum of the F4129 operating at V_M = 2710V which was the optimized voltage yielding the largest first peak-to-valley ratio of 2.47. Figure 7 shows the first peak-to-valley ratio as a function of microchannel plate configuration voltage, V_M. With V_M = 2710V, the gain of the photomultiplier was 6.6×10^6.

Pulse-height resolution studies have shown that photomultipliers having two microchannel plates in cascade for electron multiplication, when operated under optimized conditions, surpass significantly photomultipliers of conventional design. If photomultipliers with Z-configuration of microchannel plates had electrical connection to each microchannel plate, it would allow full optimization of operating conditions, giving a significant increase in pulse-height resolution. Over an extensive period of time, the microchannel plate photomultipliers showed a decrease of photocathode quantum efficiency and microchannel plate gain. However, it is important to note that photomultipliers used in these studies do not have a protective Al film between the photocathode and the microchannel plate. Use of a protective film greatly improves the quantum efficiency stability of the photocathode [12].

Fig.7 The first peak-to-valley ratio as a function of the microchannel plate configuration voltage for F4129 photomultiplier

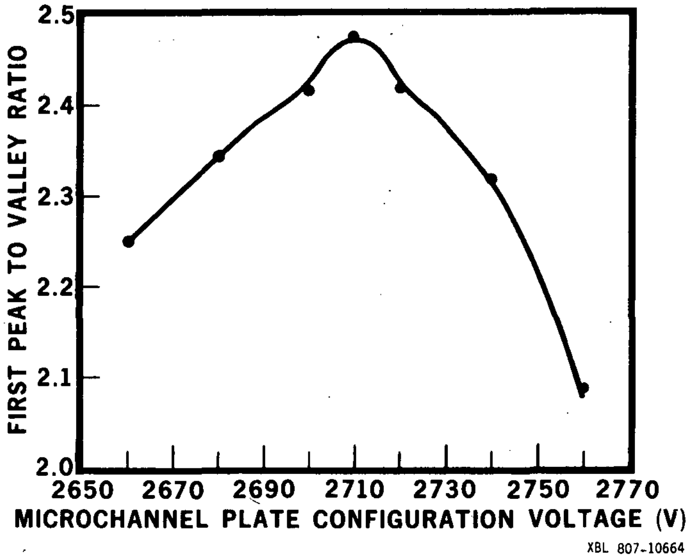

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Table 1 Summary of Pulse-Height Resolution Measurements of Conventionally Designed and Microchannel Plate Photomultipliers. Full Photocathode Illumination.

	RCA 8850	RCA HR 350	LEP PM 137	ITT F4129
DC Gain[a]	$>10^8$	$\approx 10^6$	$5\text{x}10^6$	$1.6\text{x}10^6$
Supply Voltage Between Anode and Cathode (V)	3000			
Microchannel Plate Voltage (V)		1600	V_{P1}=1700V V_{P2}=700V	2500
Rise Time[b] (ns)	2.4	0.64	0.64	0.35
Impulse Response[b], FWHM, (ns)	5.0	1.3	1.63	0.52
Peak-to-Valley Ratio of Pulse-Height Spectrum with Voltages Recommended by Manufacturer	2:1	2:1	3:1	not available
Peak-to Valley Ratio of Pulse-Height Spectrum with Optimized Operating Conditions[c]			15:1	2.47:1
Dark Pulse Count[d] (cps)	145	340	400	1800
Quantum Efficiency[e] (%)	31	20	10	20
Photocathode Diameter (mm)	51	13	20	18

[a] For PM 137: voltage between the photocathode and the input of the microchannel plate cascade V_k=200V; voltage between the output of the microchannel plate cascade and the anode V_A=300V. For F4129: V_k=150V; V_P=300V.

[b] These characteristics were measured for prototype packed photomultipliers.

[c] Optimized operating conditions for PM 137 were V_{P1}=2100V and V_{P2}=525V. At these operating voltages the overall photomultiplier gain was $2\text{x}10^6$. For F4129 optimized operating condition was V_M=2710V. In this case the photomultiplier gain was $6.6\text{x}10^6$.

[d] Dark pulse summation is defined by:

$$\sum_{1/8\ \text{Photoelectron}}^{16\ \text{Photoelectrons}} = \text{counts per second}$$

[e] The DC gain and quantum efficiency of PM 137 had decreased to $3.6\text{x}10^6$ and 4.8%, respectively at the end of extensive evaluation time. Similarly, the quantum efficiency of F4129 had decreased to approximately 5% after an accumulation of total anode charge of $27.5\text{x}10^{-3}$ Coulomb. Neither tube had a protective metal film between the photocathode and the input of the microchannel plate.

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