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TIME RESOLUTION PERFORMANCE STUDIES OF HIGH SPEED PHOTON DETECTORS

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The time resolution capabilities of prototype microchannel plate and static crossed-field high gain photon detectors have been investigated. The devices studied included the LEP HR350 and PM 137-proximity focused high gain microchannel plate and VPM-154A/1.6L static crossed-field photomultipliers. Measurements were made of electron transit time, rise time, time response, single photoelectron time spread and multiphotoelectron time spread. The experimental data have been compared with results obtained with conventionally designed RCA 8850 and C31024 high speed photomultipliers. Descriptions are given of the measuring techniques.

The time resolution capability of high speed photon detectors has been the subject of intensive experimental and theoretical investigations, and a comprehensive survey of the literature has been given by the author, (1). The time characteristics of these devices are becoming increasingly important in a multitude of research areas, such as: atomic and molecular subnanosecond fluorescence decay time measurements, (2)-(4), nuclear research (5)-(6), optical ranging experiments (7)-(11), optical communication (12), and photon statistics experiments (13). The high speed photon detectors time resolution capabilities are essentially determined by the deviations in transit time of electrons travelling from the photocathode to the collector and in the possible spread of electron emission times.

The purpose of this research has been to investigate time resolution capability of the LEP HR350 and PM 137 prototypes high gain photon detectors having microchannel plates for electron multiplication where proximity focusing is used for the input and collector stages. For the electron multiplication, the LEP HR350 and PM 137 photomultipliers use a high-gain curved channel microchannel plate and two microchannel plates, respectively. Both photomultipliers were designed and manufactured by the Laboratories d'Electronique et de Physique Appliqueé at Limelil-Brévannes, near Paris, France. Also, the resolution capability of the VPM-154A/1.6L high speed static crossed-field photomultipliers has been investigated. This photomultiplier was designed and manufactured by the Varian Associates, Palo Alto, California. The results are compared with conventional RCA 8850 and C31024 photomultipliers characteristics. The investigation is based on previous work, described in references (1), (6), (16)-(21).

As opposed to the conventional discrete dynode electron multiplier, a microchannel plate consists of a closely packed two dimensional array of very small diameter short channels. Each single channel serves as an electron multiplier. It is a continuous glass tube whose inside surface has a resistive semiconducting coating used as the secondary electron emitting surface, (14). Schematic arrangement of the LEP PM 137 photomultiplier and an appropriate voltage divider are shown in Fig. 1.

The static crossed-field photomultiplier utilizes static electric and magnetic fields to determine the electron trajectories between dynodes of the electron multiplier, (15). The arrangement of the electrodes for a cross-field photomultiplier is shown schematically in Fig. 2. The strong electric field between the dynodes and the field plate results in short secondary electron transit times. The device provides a combination of optimum secondary emission yields per dynode and short overall transit times (and hence small transit-time spread). Since secondary electrons emitted at the same time and with the same velocity from a given dynode arrive at the same time at the next dynode, the transit time spread is due mainly to initial velocity effects.

The measurements of the single photoelectron and multiphotoelectron transit time spreads were made with the specially developed measuring system described earlier in Ref. (18). The system has a time resolution of approximately 25 psec, FWHM.

RESULTS AND DISCUSSION

The results of the single photoelectron time spread measurements on the HR350 and PM 137 photomultipliers with full photocathode illumination are given in Figs. 3 and 4, respectively. For comparison purposes, Fig. 3 gives the results of time spread measurements for electrostatically focused photomultipliers with discrete dynodes (8850 and C31024). The supply voltage between the anode and cathode was 2500 V for the 8850, and 3500 for the C31024. It can be seen that the single photoelectron time spread is a montonically increasing function of the current pulse width supplied to the electroluminscent diode. It is linear for pulses longer than 1 nsec. In the case where the diode current pulse width is considerably shorter than the photomultipier single electron spread, the time spread curves show a decreasing dependence upon the current pulse width, particularly for electrostatically focused photomultipliers. When the diode pulse current width is considerably larger than the single electron time spread, the measured value of the time spread closely equals the width of the current pulse.

With full photocathode illumination, and with a light pulse produced by a 200 psec electrical pulse, the single photoelectron time spreads were 250 psec and 270 psec FWHM, for the HR350 and PM 137, respectively. These values include the measuring system timing error. Assuming the LED light flash has a width of 100 psec, the time spread of the HR350 and PM 137 have, by extrapolation, upper limits of 180 psec and 200 psec, respectively. With only a 3 mm diameter area of the HR350 photocathode illuminated, the single photoelectron time resolution remains essentially the same as in the full photocathode case. The difference in transit time between photoelectrons leaving different points on the photocathode and the channel plate is negligibly small because of the proximity focusing used between the photocathode and the channel plate. It might be noted that the photoelectron transit time difference contributes significantly to the transit time spread of the conventional photomultiplier as shown by authors in Reference (1). Furthermore, as can be seen in Figs. 3 and 4, the time spread of the microchannel plate photomultipliers is at least two times smaller than that of the best commercially available conventional photomultiplier.

The multiphotoelectron time resolution was measured using the system described in Ref. (18). It is generally agreed that the variance, σ^2, of the photoelectron time spread of a photomultiplier is inversely proportional to the number of photoelectrons per pulse. This measurement was made using the mercury light pulse generator which was capable of producing thousands of photoelectrons per pulse from the photomultipliers. The number of photoelectrons per pulse was calculated by measuring the output pulse width and amplitude, and using the known gain of the photomultipliers involved, namely the RCA 8850, C31024, LEP HR350 and the VPM-154A/1.6L, for full photocathode illumination. Multiphotoelectron time response of VPM-154A/1.6L was measured at 904 nm using the injection laser light pulse generator described in Ref. (18). The photomultiplier was operated with a field electrode voltage of 560 V and the photocathode-output collector voltage of 3650 V. The time response was measured for full photocathode illumination (5.1 mm-diameter area). Fig. 5 shows the time resolution as a function of the number of photoelectrons per pulse from one photoelectron up to 6000 photoelectrons. The time resolution of single photoelectron pulses was 2.6 nsec, FWHM, indicating the light pulse was very close to 2.6 nsec wide. The time resolution decreases to approximately 36 psec, FWHM, with 6000 photoelectrons per pulse for the C31024, HR350, and VPM-154A/1.6L photomultipliers. There is no indication that a plateau of this transit time is reached with this number of photoelectrons. Measurement performed on RCA 8850 show that the multiphotoelectron transit time plateau of approximately 80 psec is obtained when the number of photoelectrons is larger than 1000, mostly due to saturation effects in the photomultiplier. Fig. 6 shows the plot of the time resolution as a function of the number of photoelectrons per pulse for the PM 137 photomultiplier. The time resolution tapered down to approximately 45 psec, FWHM, with 2300 photoelectrons per pulse.

Time resolution performance studies show that for input light pulses shorter than 200 psec, the time spread of microchannel plate and static crossed field photomultipliers is at least two times lower than for the best conventional photomultiplier. However, for input light pulses longer than 2 psec, the 5-dynode conventionally designed photomultiplier having dynodes with cesium-activated gallium phosphide secondary emitting surfaces, compares very favorably with micro-channel plate and static crossed-field photomultipliers. The measurement results obtained are shown in Table 1.

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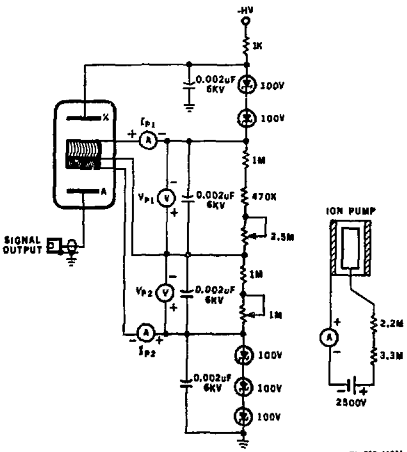

Fig. 1. Schematic arrangement of a microchannel plate photomultiplier and a voltage divider used in the measurements.

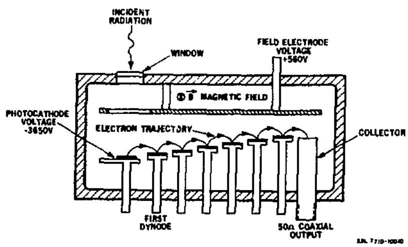

Fig. 2. Schematic arrangement of a static crossed-field photomultiplier.

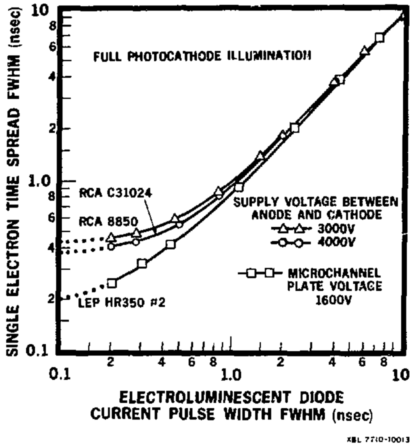

Fig. 3. Single electron time spread of RCA 8850, C31024 and LEP HR350 as a function of the width of the electro-luminsecent diode current pulse.

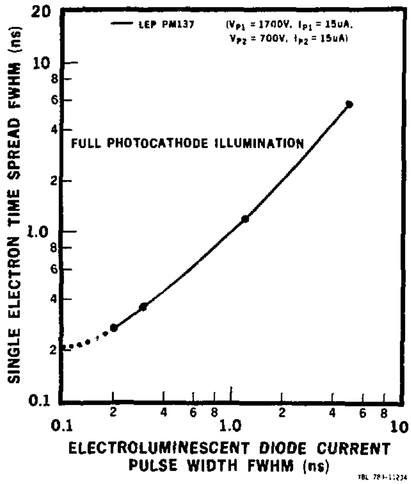

Fig. 4. Single photoelectron time spread of the PM 137 as a function of the width of the electroluminescent diode current pulse.

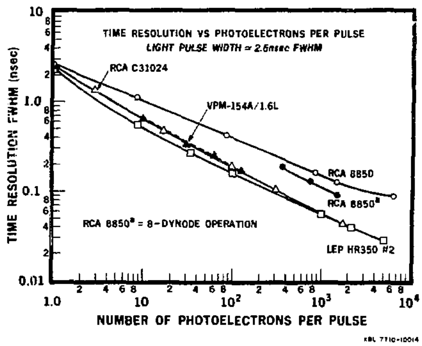

Fig. 5. Multiphotoelectron time resolution of RCA C31024, 8850, VPM-154A/1.6L and LEP HR350 as a function of the number of photoelectrons per pulse, measured with 2.6 psec light pulse width.

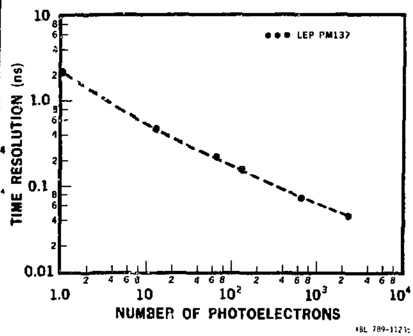

Fig. 6. Multiphotoelectron time resolution as a function of the number of photoelectrons per pulse, measured with a 2.6 nsec light pulse.

Table 1. Summary of Time Characteristics Measurements of Conventionally Designed, Microchannel Plate and Static Crossed-Field Photomultipliers. Full Photocathode Illumination

	RCA 8850	RCA C31024	LEP HR350	LEP PM137*	Varian VPM-154A/1.6L
DC Gain	$>10^8$	$>10^6$	$\sim 10^6$	5×10^6	2.5×10^5
Supply Voltage Between Anode and Cathode (V)	3000	4000			
Microchannel Plate Voltage (V)			1600	V_{p1}=1700V V_{p2}=700V	
Field Electrode Voltage (V)					560
Photocathode-Output Collector Voltage (V)					3650
Electron Transit Time (nsec)	31.2	16.2	3.4[a]	2.5[a]	8.9[a]
Rise Time (nsec)	2.4	0.8	0.64	0.64	0.26[b],0.25[c]
Impulse Response, FWHM, (nsec)	5.0	1.0	1.3	1.63	0.4[b], 0.3[c]
Single Electron Time Spread[d], FWHM, (psec)	450	400	<200	<200	Not Available
Multiphotoelectron Time Spread[e], FWHM, (psec)	400[f],150[g]	190[f],58[g]	160[f],56[g]	<45[h]	190[f]
Photocathode Diameter (mm)	51	51	13	20	5.1

[a]These characteristics were measured for prototype packaged photomultipliers.

[b]Measured using a 904 nm gallium arsenide injection laser.

[c]Measured using a 60 psec impulse excitation from the mode-locked Nd:YAG laser and a 530 nm frequency doubler. The laser light was focused onto approximately a 3 mm diameter area (22).

[d]These values include the measuring system timing error. Measured using 200 psec light pulses.

[e]Measured using 2.6 nsec light pulses with repetition frequency of 60 Hz.

[f]Measured using 10^2 photoelectrons per pulse.

[g]Measured using 10^3 photoelectrons per pulse.

[h]Measured using 2.4×10^3 photoelectrons per pulse.

*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. The DC gain and quantum efficiency had decreased from 5×10^6 to 3.6×10^6 and from 10% to 4.5%, respectively at the end of extensive evaluation time.