ON THE QUANTUM DETECTION EFFICIENCY OF A TV PHOTON COUNTER

L.P. Vorob'yeva, V.A. Chikurov, and V.M. Klimkin

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk
Received December 16, 1991

A simple procedure for evaluating the quantum detection efficiency of a TV photon counter on the basis of knowledge of the energy distribution of the photoelectronic scintillations, the employed image intensifier, the sensitivity of the picture tube for the single–exposure point images with well–known spectral composition and characteristics of the employed "transfer" optics is proposed.

The TV photon counters (TVPC) on the basis of microchannel image intensifiers (II), picture tubes (PT), and microcomputers are being increasingly used in spectroscopy, laser remote sensing of the atmosphere, and target observations through the atmosphere or dense scattering media. However, their basic characteristics have yet received only insufficient study. The simple procedure for evaluating one of the basic parameters of the TVPC – the quantum detection efficiency – is proposed in this paper.

The quantum detection efficiency which is determined through the ratio of the number of counts corresponding to single–electron events recorded in the RAM to the total number of photons striking the photocathode, can be given by the obvious relation

$$Q = \gamma\chi\Omega_k(1-P_0)\eta,$$

where γ is the quantum efficiency of the II photocathode, χ is the efficiency of the II barrier film being equal to the ratio of the packets of secondary electrons produced on the film back to the number of primary electrons incident on the film, Ω_κ is the load factor of the microchannel plate (MCP) with channels, $P_0=e^{-\delta}$ is the probability of the event that the primary electron collision with the channel wall results in no secondary emission[1] (δ is the secondary emission ratio), and η is the efficiency of scintillation counting from the II screen.

In the above–considered relation the coefficients $\gamma,\chi,\Omega_\kappa$, and δ are primarily determined by a system construction and technology of II and their usual values are $\gamma \simeq 0.1$, $\Omega_\kappa \simeq 0.63$, $\delta \simeq 1.5$–2 (Ref. 1), and $\chi \simeq 0.7$ (Ref. 2). The methods for their increase are given, for example, in Ref. 1. The coefficient η depending on the II and PT being employed as well as on the operating conditions and characteristics of the transfer optics may vary within wide limits and can be represented by the relation

$$\eta = \int\limits_{E_1}^{E_2} W(K,\ \mu,\ E_{sc})\mathrm{d}E_{sc},$$

where $W(E_{sc})$ is the energy distribution of the photoelectronic scintillation (EDPES), E_1 is the maximum sensitivity of the PT for point images, E_2 is the maximum recorded scintillation intensity, K is the sensitivity of the PT photocathode for the radiation from the II screen, μ is the efficiency of optical train between the II screen and PT photocathode.

It should be noted that this equation is valid given that load factor of the MCP is less than the critical, the probability of recording of two– and multi–electron events during the time of channel relaxation is low, and the PT is inertialless.

The form of the EDPES is primarily determined by the statistics of amplification of the single–electron events in the MCP channel. This statistics is assumed to follow the Poisson law.[1] Since the electron gain amounts to 10^4 and even more, it can be described by the Poisson law with large mean value, i.e., by the normal distribution. Such a distribution at the exit from the MCP was found experimentally in Ref. 3. The EDPES's of the microchannel II are shown in Fig. 1. Their deviation from the normal distribution is manifested in the shift of the single–electron peak toward the low–energy region and can be explained by the pressure of residual gases in the II tube. The resultant ion feedbacks limit the magnitude of electron gain[4] in the channel and give rise to a significant part of high–energy (noise) scintillations.[5] Taking into account the above–discussed circumstances the truncated normal distribution was assumed for the analytical model of the EDPES. The proximity of this distribution to the given experimental EDPES disregarding the high–energy scintillations was checked on the basis of the Pearson chi–square compatibility test.[6] The entire range of variation of the scintillation energy then was divided into 12 intervals for each curve. The obtained significance levels of the accepted hypothesis did not exceed $q \mid 0.2$ for all curves.

The scintillation count efficiency in the case of accepted hypothesis can be represented in the form

$$\eta \simeq \frac{C}{\mu K G_{sc}\sqrt{2\pi}} \int\limits_{E_1}^{E_2} \exp\left\{-\frac{(E_{sc}-\mu K E_{0sc})^2}{2(\mu K G_{sc})^2}\right\} \mathrm{d}E_{sc},$$

where G_{sc} and E_{0sc} are the standard deviation and the most probable value of the energy of scintillations on the II screen,

$$C = \frac{1}{\mathrm{F}\left(\dfrac{E_{max}-E_{0sc}}{G_{sc}}\right) - \Phi\left(\dfrac{E_{min}-E_{0sc}}{G_{sc}}\right)},$$

$\Phi(z)$ is the tabular error integral, E_{min} and E_{max} are minimum and maximum energies of scintillations, respectively.

If we write down the derived relation in terms of the error integrals then we obtain

0235-6880/92/04 282-03 $02.00

$$\eta \simeq \frac{\Phi\left(\frac{E_2 - \mu K E_{0sc}}{\mu K G_{sc}}\right) - \Phi\left(\frac{E_1 - \mu K E_{0sc}}{\mu K G_{sc}}\right)}{\Phi\left(\frac{E_{max} - E_{0sc}}{G_{sc}}\right) - \Phi\left(\frac{E_{max} - E_{0sc}}{G_{sc}}\right)}.$$

Since virtually the values of E_2 and E_{max} do not fall within the interval 2 G_{sc} in length (see Fig. 1), we can assume

$$\Phi\left(\frac{E_2 - \mu K E_{0sc}}{\mu K G_{sc}}\right) \simeq \Phi\left(\frac{E_{max} - E_{0sc}}{G_{sc}}\right) \simeq 1.$$

Taking into account that $\Phi(-z) = 1 - \Phi(z)$ we obtain

$$\eta \simeq \frac{\Phi\left(\frac{\mu K E_{0sc} - E_1}{\mu K G_{sc}}\right)}{\Phi\left(\frac{E_{0sc} - E_{min}}{G_{sc}}\right)}.$$

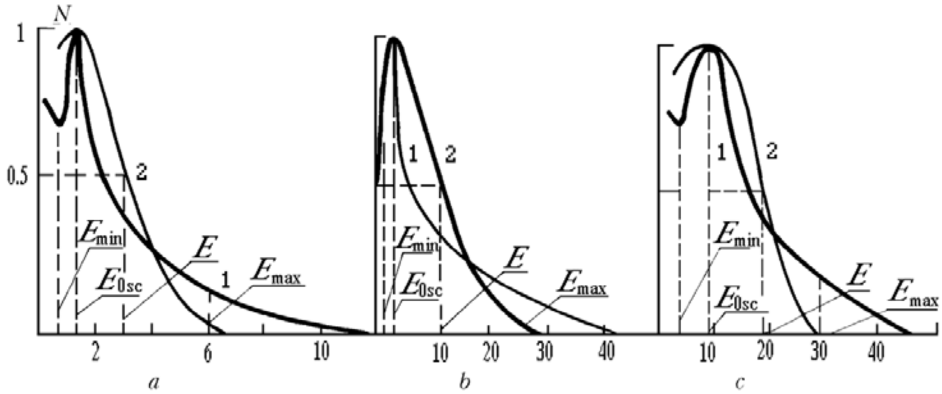

FIG. 1. The EDPES's of the microchannel II's (1), and their analytical models (2): a) PIM–104–2M; b) PIM–104B; and c) experimental II with the two MCP.

If we represent the standard deviation by the relation[7] $G_{sc} \simeq \frac{\Delta E_{sc}}{2.36}$, where ΔE_{sc} is the width of the Gaussian distribution at half–maximum, we obtain

$$\eta \simeq \frac{\Phi\left[\frac{2.36}{R}\left(1 - \frac{E_1}{\mu K E_{0sc}}\right)\right]}{\Phi\left[\frac{2.36}{R}\left(1 - \frac{E_{min}}{E_{0sc}}\right)\right]}.$$

In this equation $R = \Delta E_{sc}/E_{0sc}$.

Since the PT maximum sensitivity for the point images is $E_1 \simeq \mu K E_g$, where E_g is the minimum energy of scintillations on the II screen being recorded by PT with high probability, the resultant relation for the scintillation count efficiency can be given in the form

$$\eta = \frac{\Phi\left[\frac{2.36}{R}\left(1 - \frac{E_g}{E_{0sc}}\right)\right]}{\Phi\left[\frac{2.36}{R}\left(1 - \frac{E_{min}}{E_{0sc}}\right)\right]}.$$

It should be noted that the gate intensity E_{sc} must be chosen in the region of transition from exponential dependence to single–electron peak in order to maximize the signal–to–noise ratio for single–electron photodetectors. In this case $E_g \simeq E_{min} \simeq E_{sc}$ and, correspondingly, $\eta \simeq 1$. However, it is not always realizable in the TVPC.

The performance of the given relation was tested experimentally using the following procedure. The given EDPES of the employed microchannel II was fitted by the truncated normal distribution (see Fig. 1). The values of $0.5\Delta E_{sc}$, E_{0sc}, and E_{min} were determined. Using the employed PT sensitivity for the point images with a well–known spectral composition and the characteristics of the transfer optics, the value of E was determined. The scintillation count efficiency was calculated on the basis of the obtained relation. The values of η calculated with the help of this procedure for different composite photodetectors are given in Table I in comparison with the experimentally measured values. As can be seen from Table I they are rather close in values.

If we assume that the scintillation count efficiency is related with the TVPC quantum efficiency in terms of the known constant coefficient

$$K = \frac{Q}{\eta} = \gamma\, \chi\, \Omega_k\, (1 - P_0)$$

then the above–described procedure gives the method for evaluating the TVPC quantum detection efficiency while the relation for this estimate has the form

$$Q = K\, \frac{\Phi\left[\frac{2.36}{R}\left(1 - \frac{E_g}{E_{0sc}}\right)\right]}{\Phi\left[\frac{2.36}{R}\left(1 - \frac{E_{min}}{E_{0sc}}\right)\right]}.$$

TABLE I

Serial number	Type of the composite photodetection	Voltage applied to the MCP, in kV	Scintillation count efficiency, in %		Quantum detection efficiency, in %		E_g, photons/sc	Refs.
			Experimental	Calculated	Experimental	Calculated		
1	the II with MCP + SIGNAL–2 + LI–801	1.0 1.5	–	0.21 1.0	 4 (λ = 460 nm)	1.0 4.4	$\simeq 4{\cdot}10^4$ $\simeq 4{\cdot}10^4$	8, 9
2	the II with MCP + GELIOS–40 + LI–706	1.3	–	0.86	5 (λ = 460 nm)	3.8	$\simeq 8{\cdot}10^4$	9, 10
3	the II with MCP + GELIOS–44–2 + + LI–702–3	1.3	–	0.69	0.08 (λ = 900 nm)	0.1	$\simeq 2{\cdot}10^5$ $\gamma \simeq 2{\cdot}10^{-3}$	9, 11
4	PIM–104–2M + SIGNAL–2 + LI–801	1.6	–	1.0	3	4.4	–	9

The comparative values of the experimentally measured and calculated scintillation count efficiency and quantum detection efficiency are summarized in Table I. The comparison of these data confirms the performance of the proposed procedure.

Thus, the TVPC quantum detection efficiency can be evaluated in a quite simple way if we know the EDPES of the employed II, the PT sensitivity for the point images with known spectral composition, and the characteristics of the employed transfer optics using the proposed procedure.

REFERENCES

1. A.G. Berkovskii, V.A. Gavanin, and I.N. Zaidel', in: *Vacuum–Tube Photoelectric Devices* (Radio i Svyaz', Moscow, 1988), 101 pp.

2. A.A. Dyatchenko, A.Ya. Kolenko, et al., Opt. Mekh. Prom., No. 1, 14–15 (1987).

3. A.A. Bashkeev and V.G. Dudnikov, Prib. Tekh. Eksp., No. 4, 77–81 (1989).

4. N.I. Pletneva, D.K. Sattarov, and E.P. Semenov, Opt. Mekh. Prom., No. 1, 63 (1976).

5. N.V. Zamyatin, V.M. Klimkin, et al., Atm. Opt. **2**, No. 6, 545–547 (1989).

6. P.V. Novitskii and I.A. Zograf, in: *Estimate of the Measurement Errors* (Energoatomizdat, Leningrad, 1991), pp. 192–195.

7. V.N. Lavrenchik, in: *Setting up a Physical Experiment and Statistical Processing of its Results* (Energoatomizdat, Moscow, 1986), 240 pp.

8. I.N. Zaidel', P.A. Lezhnin, et al., in: *Abstracts of Reports at the 12th All–Union Scientific and Technical Conference on the High–Speed Photography and Metrology of Transient Processes,* Moscow (1985), p. 49.

9. E.G. Sil'kis, "*Development and construction of multichannel system for photon counting in laser spectroscopy of Raman light scattering,*" Candidate's Dissertation in Technical Sciences, Moscow (1987), 148 pp.

10. V.A. Ganichev, S.K. Elkin, et al., Prib. Tekh. Eksp., No. 5, 152–155 (1987).

11. B.D. Borisov, V.M. Klimkin, V.A. Krutikov, et al., Opt. Atm. **3**, No. 10, 1003–1007 (1990).