ON SPATIAL RESOLUTION OF A TV PHOTON COUNTER

V.A. Chikurov

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk

Received June 29, 1992

Relations for an engineering analysis of the width of the point spread function (PSF) and frequency–contrast characteristic of a TV photon counter with digital storage of normalized responses of single–electron events are described. The expression for estimating a potential value of the PSF width is presented.

Television photon counters (TPC) used for detecting extremely weak images (e.g., fluorescence spectra or Raman scattering spectra) are often constructed based on a microchannel image intensifier (II), linear photodetectors with charge coupling (LPDCC) or camera tubes (CT) and microcomputers. The point spread function (PSF) or its Fourier image, i.e., frequency–contrast characteristics (FCC) is a measure of spatial resolution of such counters. In spite of the available developments of TPC's there is a lack of published information about these characteristics.

This paper gives an estimate of the potential value of the PSF width as well as certain relations for calculating connections of the PSF width (FCC) and the characteristics of basic components of a composite photodetector of TPC for the case of centering normalized packets of pulses associated with single–electron events.

The PSF width which frequently has a bell–like shape[1] can be represented as the total error in determining true coordinates of single–electron events.

$$\Delta R \simeq \sqrt{\Delta R^2_{\mathrm{ecl}} + \Delta R^2_{\mathrm{mchp}} + \Delta R^2_{\mathrm{r}}}\ ,$$

where ΔR_{ecl}, ΔR_{mchp}, and ΔR_{r} are the errors introduced by an electrostatic cathode lens of the II, a microchannel plate, and a device for reading out scintillations, respectively.

The first component of the error is estimated by the diameter of the point of spreading at the electrostatic cathode lens of the II which can be represented as

$$\Delta R_{\mathrm{ecl}} = D = 1.2\ V/E\ ,$$

where V_0 is the initial energy of an electron leaving the II photocathode and E is the electrostatic field strength at the photocathode. The error introduced by a microchannel plate can be determined by the diameter of its channel $\Delta R_{\mathrm{mchp}} \simeq d_{\mathrm{mchp}}$. Without a preliminary choice of a video–signal processing device, the variance of an estimate of a coordinate (R_0) of the maximum value of the read out scintillation is evaluated as a lower limit of an unbiased estimate of the parameter according to the Rao–Cramer inequality[3]

$$D_{\hat{R}_0} \geq -\left(\frac{\mathrm{d}^2 q_F(R_0)}{\mathrm{d}^2 R_0}\right)^{-1}\Bigg|_{R_0=R_{00}} ,$$

where

$$q_F(R_0) = \frac{2}{N_0}\int\limits_0^r \left[F(R, R_0)\, F(R, R_{00}) - \frac{1}{2} F^{\,2}(R, R_0) \right] \mathrm{d}R\ ;$$

R_{00} is the true coordinate of the maximum of the read out scintillation, r is the scintillation extension, N_0 is the spectral density of the white–noise power, and $F(R)$ is the analytical expression for the read out scintillation intensity.

It is easy to show that for $F(R)$ in the shape of a Gaussian pulse

$$D\hat{R}_0 = \frac{4}{\pi}\, D^2_{\mathrm{sc}} \left(\frac{2E_{\mathrm{sc}}}{N_0}\right)^{-1}$$

where D_{sc} is the scintillation diameter and E_{sc} is the scintillation energy.

Assuming that the error of reading out follows the normal distribution law for which the width at the peak half–maximum is related to the standard deviation through the relation $\Delta R_{0.5} = 2.36\ \sigma$, the potential error is obtained in the form

$$\Delta R_{\mathrm{r_p}} = \frac{4.72}{\sqrt{\pi}}\, D_{\mathrm{sc}} \sqrt{\frac{2E}{N_0}}\ .$$

Assuming also that the diameter of the point of spreading at the electrostatic cathode lens overlaps the interval ±3σ, the potential value of the PSF width at the level of the peak half–maximum takes the form

$$\Delta R_{\mathrm{p}\ 0.5} = \sqrt{K_0^2 \left[\left(0.47 K_{\mathrm{e}} \frac{V_0}{E}\right)^2 + d^{\,2}_{\mathrm{mchp}} \right] + (2.67\ N_{\mathrm{sc}})^2\, \frac{N_0}{2E}}\ ,$$

where K_0 is the scale of image transfer of matching optics of a composite photodetector and K_{e} is the coefficient of the optico–electronic amplification of the II. For most widely used values $V_0 \simeq 1$ eV, $E = 50$ V/mm, $d_{\mathrm{mchp}} = 10$ μm, $D_{\mathrm{sc}} = 0.1$ mm (Ref. 2), $K_0 = K_{\mathrm{e}} = 1$ (Ref. 4), $2\,E/N_0 = 10^3$, and $\Delta R_{\mathrm{p}\ 0.5} = 16$ μm.

When the scintillations are read out from a screen of the II using the LPDCC or CT the error in determining the center of scintillations is found based on the method of video–signal processing and the raster stability. When centering the packets of normalized pulses related to the read out scintillations, the centers of scintillations are found with the error corresponding to the distance between the neighbor pulses within the packet[4]

$$\Delta R_{\mathrm{cal\ p}} \simeq 0.6\ K_0\, K_{\mathrm{e}}\, \frac{d_{\mathrm{pc}}}{N_{\mathrm{r}}}\ ,$$

where d_{pc} is the size of a photo–sensitive surface of a CT photocathode in the direction of the frame scanning or the size of a photo–sensitive surface of the LPDCC, N_{r} is the number of lines of the CT raster or a number of photosensitive elements of the LPDCC. The error caused by the instability of the CT raster can be estimated by the relation[5]

0235-6880/92/11 764-03 $02.00

$$\Delta r_{\mathrm{r}} \simeq \sqrt{(R_y\,\delta E_{\mathrm{s}})^2 + \left(\frac{R_y}{2}\,\delta E_{\mathrm{a}}\right)^2 + \left[\left(R_x + \frac{B}{2}\right)\gamma\right]^2}\,,$$

where δE_{s}, δE_{a} are the relative instabilities of supply voltages of scanning and anode, respectively, B is the side of the raster, γ is the raster rotation angle determined primarily by an instability of power–supply sources of a focusing coil and a focusing electrode, and R_x and R_y are the coordinates of the center of a read out scintillation at the CT photocathode. When $\delta E_r = \delta E_{\mathrm{a}} = 0.1\%$, $\gamma = 10^{-3}$ rad, $B = 15$ mm, $R_x = 10$ mm, and $R_y = 7.5$ mm the raster instability gives the error $\Delta r_{\mathrm{r}} = 19$ μm.

Assuming that the PSF has a Gaussian envelope the expression for the PSF halfwidth takes the form

$$\Delta R_{\mathrm{c}\ 0.5} \simeq \sqrt{K_0^2\left[\left(0.47K_{\mathrm{e}}\frac{V_0}{E}\right)^2 + d^2_{\mathrm{mchp}}\right] + \left(0.6\frac{d_{\mathrm{pc}}}{N_{\mathrm{r}}}\right)^2 + \Delta \mathrm{r}_{\mathrm{r}}^2}\,. \quad (1)$$

In the absence of signal centering there occurs almost three–fold increase of the PSF width[4] and correspondingly we have

$$\Delta R_{\mathrm{w}\ 0.5} \simeq 3\Delta R_{\mathrm{c}\ 0.5}\,,$$

where $\Delta R_{\mathrm{w}\ 0.5}$ is the $R_{\mathrm{c}\ 0.5}$ PSF width without centering.

It should be noted that when the LPDCC is used as a photodetector with a constant position and size of its photo–sensitive elements it is possible to assume that $\Delta r_{\mathrm{r}} \simeq 0$.

Depicted in Fig. 1 is a plot of $\Delta R_{\mathrm{c}\ 0.5}$ on the number of lines of the CT raster N_{r} calculated by formula (1) for the above–calculated parameters entering into this expression. As can be seen from the figure, when $N_{\mathrm{r}} \le 300$ the PSF width changes negligibly, therefore it is expedient in this case to use basic characteristics of a video signal common for TV broadcasting where a number of half–frame lines $N_{\mathrm{l}} = 312.5$.

Under the assumption that the PSF has a Gaussian envelope the frequency–contrast characteristics being a Fourier transform of the PSF (Ref. 2) can be represented as

$$T(\nu) = \exp\left[-3.5(\Delta R_{\mathrm{c}\ 0.5}\,\nu)^2\right]\,,$$

where the dimensionality of ν is [lines/mm]. The frequency–contrast characteristics calculated based on this relation for the potential value of the PSF width and PSF widths with and without centering of pulse packets are given in Fig. 2 (curve *1* is for $\Delta R_{\mathrm{p}\ 0.5} = 19$ μm, curve *2* is for $\Delta R_{\mathrm{c}\ 0.5} = 35$ μm, and curve *3* is for $\Delta R_{\mathrm{w}\ 0.5} = 105$ μm).

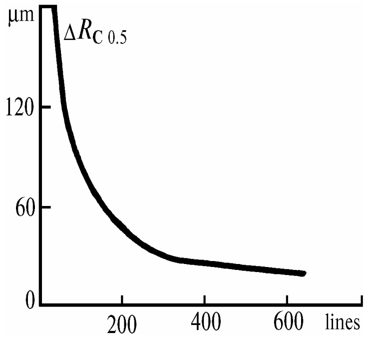

FIG. 1.

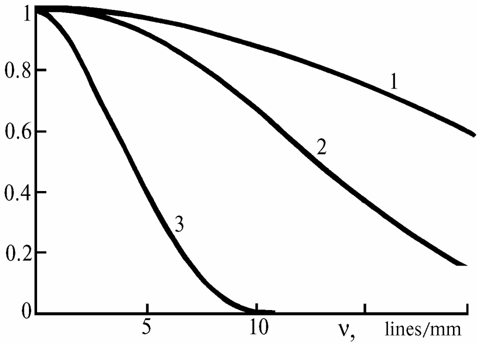

FIG. 2.

Finally, the table lists the comparative PSF widths experimentally measured (published data) and calculated based on expression (1) for different composite photodetectors. The results presented in the table confirm the efficiency of the relations proposed in this paper which can be used for a justified selection of components of a TPC composite photodetector.

TABLE I.

Type of composite photodetector	Image intensifier				Point Spread Function (PSF) Width, μm				Ref.
	Operating diameter of photocathode (mm)	Coefficient of opto–electronic amplification, K_{e}	Scale of image transfer of matching optics, K_0	Size of photo–sensitive surface of CT, mm·mm	With centering		Without centering using every third pulse of a packet		
					Experiment	Calculation	Experiment	Calculation	
PIM–104 MP+ +signal 2+LI–805	8	2	1	24×32	40	55.8	–	–	Ref. 4
EOP with MKP+ +signal 2+LI–801	15	1.5	1	24×32	50	52.5	–	–	Ref. 4
II with MKP+ +Gelios 44–2+ +LI–702–3	14	1	1	15×20	42	37.6	297	338	
EOP with MKP+ +Gelios 40+LI–706	15	1.5	1	15×20	40	41	–	–	Ref. 4
PIM–104 MP+ +VOP+1200 TsM2	8	2	1	8.6×12	–	32	–	–	

REFERENCES

1. V.L. Afanas'ev and I.I. Tsukkerman,Tekhn. Sredstv Svyazi. Ser. Tekhn. Televideniya **5**, 3–12 (1987).
2. M.M. Butslov, B.M. Stepanov, and S.D. Fanchenko, *Opto–Electronic Converters and Their Application in Scientific Research* (Nauka, Moscow, 1978).
3. V.I. Tikhonov, *Statistical Radioengineering* (Sov. Radio, Moscow, 1966).
4. E.G. Sil'kis, "*Development and construction of a multichannel photon counting system for laser Raman spectroscopy*", Candidate Dissertation in Engineering Sciences, Moscow (1987).
5. V.V. Aprelinov and B.A. Granovskii, Vopr. Radioelektron. Ser. Tekhnika Televideniya **5**, 81–90 (1967).