HIGH SENSITIVITY GATED TV SYSTEM FOR IMAGE RECORDING

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A recording system based on a microchannel image-intensifier, a supervidicon, and a storage CRT is described. The system's quantum detection efficiency, its noise level, and the frequency-contrast characteristics are evaluated experimentally. The operational algorithm and the performance characteristics of the system are described.

When solving problems of technical imaging, weakly illuminated images often have to be recorded. For example, in spectroscopy such problem arise in the investigation of Raman scattering and the fluorescence spectra of various substances. Similar problems arise in plasma physics, astronomy, medicine, lidar remote sensing of the atmosphere, and in target observations through the atmosphere or dense scattering media.

Instrumental realization of high sensitivity systems may vary.[1,2] The widest capabilities would be demonstrated by a system in which the task of signal accumulation and processing is performed by a videoprocessor. However, in certain cases it would appear to be more advantageous to implement simpler and comparatively cheaper observation systems. The present paper describes a technical realization of operational algorithms and some of the technical parameters of such a simple system for image recording, functioning both in the current-measuring regime and the photon counting regime.

FIG. 1. The recording system assembly.

The recording system (see Fig. 1) was constructed on the basis of a microchannel image intensifier (II), a high-sensitivity transmitting TV tube (TT), and a storage CRT. The sensitivity of such a system to light attains the highest possible values as a result of the capacity of the II coupled to the TT to record single electron events. Temporal gating of the recorder is performed by gating of the microchannel plate (MCP) of the image intensifier. The minimum exposure, limited by the capabilities of the gating pulse generator, is 100 ns. The memory tube is capable of accumulating hundreds of TV-frame images, and of reading off the cumulative signal in the TV standard format.

This recording system was studied and tested in an arrangement presented in Fig. 2. An LPI-103 injection laser 1 started by the frame synchronizing pulses (FSP) generated radiation pulses at the wavelength $\lambda = 0.9$ μm, approximately 200 ns long ($\tau_p \simeq 200$ ns) with energy $E_p \simeq 50 \cdot 10^{-6}$ J, and divergence angle $2\alpha \simeq 40°$. After being reflected by the rotating mirror 13 this radiation then illuminates the test object 15 (of dimensions 435×170 mm), manufactured by Fukomira with a variable spatial frequency. The image of the test object at the II photocathode 2 was formed by a high-power objective 14 with clarified optics in the near-IR. The objective had a focal length of $F \simeq 148$ mm and diameter $D_{obj} \simeq 100$ mm. To reduce interference from the background visible radiation an IR bandpass filter 16 of IKS-1 (IR glass -1) was mounted in front of the objective. The microchannel II used in the setup had an electronic optical gain of 0.9–1.1 and a resolution of approximately 22.6 line pairs/mm in the center of the field of view in the static operation regime. It had a multialkaline cathode of operational diameter $D_{phcath} \simeq 17$ mm. During the entire time the laser signal was reflected by the test object onto the MCP-II, which was kept at a constant voltage $U_c \simeq 300$ V, a voltage pulse of $\tau'_p = 200$ ns ,duration and $U_p \simeq 700$ V amplitude was applied to the plate thus bringing the plate into the single-electron event recording regime. (For the current measuring regime such a voltage pulse had an amplitude of only $\simeq 450$ V). This voltage pulse was produced by the gate-pulse generator 12, also started up by the FSP. The delay unit 9 made it 'possible to compensate for time delays, which resulted from the finite time it takes the signal to travel to the test object and return, and also from the time it takes the laser pulse to form a pulse and the microchannel II to

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enter its nominal working state. The image formed on the II screen was transferred by the coupled "Helios-44-2" objectives to the LI-702-35 supervidicon cathode. A PTU-50 commercial TV system was used as the basic unit 4 in the construction of the supervidicon.

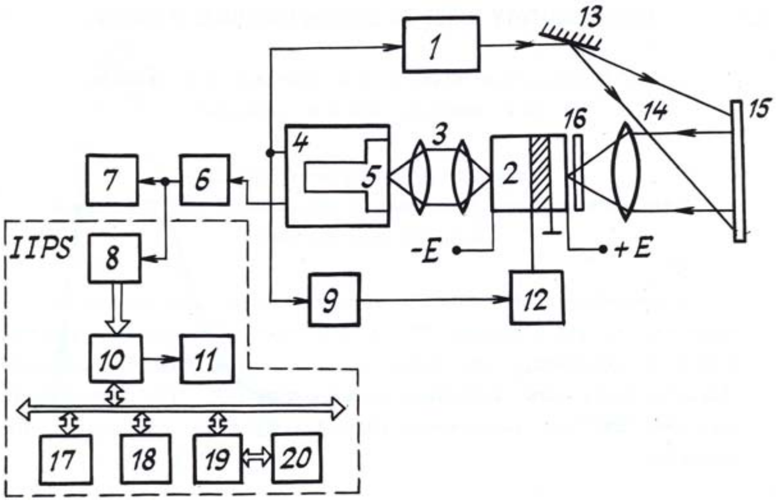

FIG. 2. Experimental setup: 1 — LPI-W3 injection laser; 2 — microchannel plate II; 3 — "Helios-44-2" objectives; 4 — PTU-50; 5 — LI-702-3; 6 — UP-6 storage device; 7 — TFD1; 8 — automatic printer; 9 — delay unit; 10 — frame memory; 11 — TFD-2; 12 — high-voltage pulse generator; 13 — rotating mirror; 14 — receiving objective; 15 — target; 16 — IKS-1 light filter; 17 — single-chip microcomputer; 18 — hard disk; 19 — DL-4 controller: 20 —SM-4 computer.

The system output signal was fed to the storage tube target which was an integral part of the UP-4 commercial storage device (see Fig. 2). This device could record, store, and reproduce (read off) TV signals both in the single- and multi-frame modes (up to 500 frames), using the Temporal Frame Device (TFD) 7. To process the experimental results, the system included an Image Input and Processing System (IIPS),[3] which could record up to four half-frames in the TV standard format (256×256×6 bits).

The energy incident upon the II photocathode, produced by a single laser pulse, was calculated using the following approximate expression:

$$E_{phcath} \simeq K_w K_{IR} K_{obj} \frac{E_p}{4\pi} S_{im} \left[\frac{D_{obj}}{2RF \operatorname{tg}\alpha} \right]^2, \tag{1}$$

where $K_{IR} \simeq 0.1$ and $K_{obj} \simeq 0.9$ are the transmittances of the IR filter and the objective; $K_w \simeq 0.35$ is the reflectivity of the test-object white band; $R = 8210$ mm is the distance between the receiving objective and the test object; $S_{im} = 0.6\ cm^2$ is the test-object image area at the II photocathode, whose contrast was taken to be equal to 100%.

Such an estimate yielded $E_{phcath} \simeq 0.9 \cdot 10^{-15}$ J, corresponding to the number of photons $N_{phcath} \simeq 45 \cdot 10^3$.

Since the experimentally recorded average number of single electron events per exposure is $N_{rec} \simeq 45$, the quantum efficiency of such an observation system ($\lambda \simeq 900$ nm) apparently does not exceed $Q = N_{rec}/N_{phcath} \simeq 10^{-3}$.

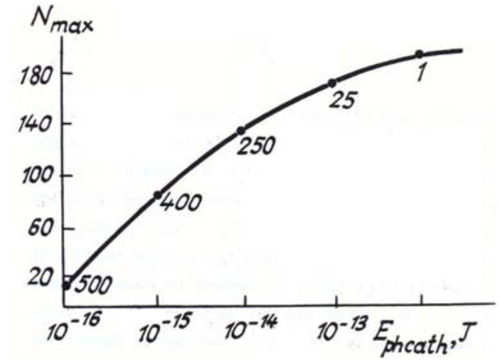

FIG. 3. Number of line pairs resolved at contrast $K \simeq 0.1$ vs the photocathode energy. The numbers on the graph show the number of TV-frames accumulated at a given energy.

The quantum efficiency of the II photocathode at its spectral sensitivity maximum ($\lambda = 550$ nm) increases by almost a factor of 50 (manufacturer's data), so that the quantum efficiency of the observation system is $Q \simeq 5.0 \cdot 10^{-2}$.

The experimental estimate of the number of noise counts produced by the II noise scintillations, which were above the supervidicon sensitivity threshold ($\simeq 2.4 \cdot 10^3$ phot/scint[4]) did not exceed 7 counts per 10 gate pulses, i.e., it was about

$1.5 \cdot 10^8$ counts $\cdot$ cm^2 $\cdot$ s^{-1} thus agreeing with the data from Ref. 5.

The image transmission quality of the considered observation system was estimated from the maximum number of line pairs N_{max} resolved at a given contrast. The value of N_{max} was then determined from the test-object spatial period, and the contrast was estimated from the well-known expression

$$K = \frac{U_w - U_b}{U_w + U_b},$$

where U_w and U_b are the videosignal amplitudes from the centers of the white and black bands, respectively, averaged over their lengths. It was noted during the experiment that, depending on the radiation energy incident upon the II photocathode, both N_{max} and the minimal number of accumulated TV-frames N_{TV} needed to obtain such a value of N_{max} (see Fig. 3) varied. In addition, it was also noted that the observation system was characterized by the threshold energy $E_{thresh} \simeq 10^{-16}$ J. Below that energy the image did not form, presumably because in this case charge leakage processes in the memory tube target dominated over the processes of potential profile formation. The experimental results shown in Fig. 4 provide an estimate of the maximum number of line pairs resolved by the system (curve 1) and also characterize the dependence of the Frame Frequency Characteristic (FFC) on the number of accumulated frames (curves 2–4).

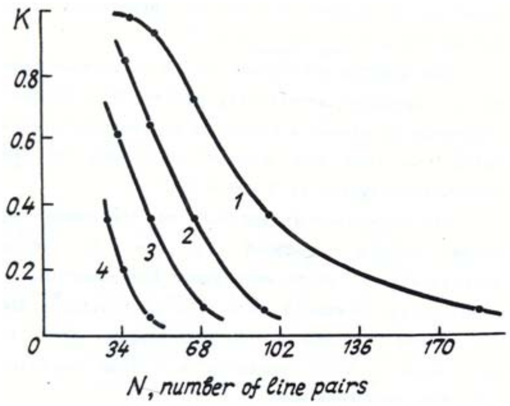

FIG. 4. Frequency-contrast characteristics of the recording system. Curves 2, 3, and 4 correspond to 500, 400, and 100 TV images accumulated respectively; and, $E_{phcath} \simeq 0.9 \cdot 10^{-15}$ J. Curve — the current-measuring regime, $E_{phcath} \simeq 2.5 \cdot 10^{-12}$ J.

To illustrate the capabilities of the observation system Fig. 5 shows images of the test object observed at the TFD without (upper image) and with (lower image) accumulation of 500 TV-frames. The radiation energy at the photocathode was close to its threshold level.

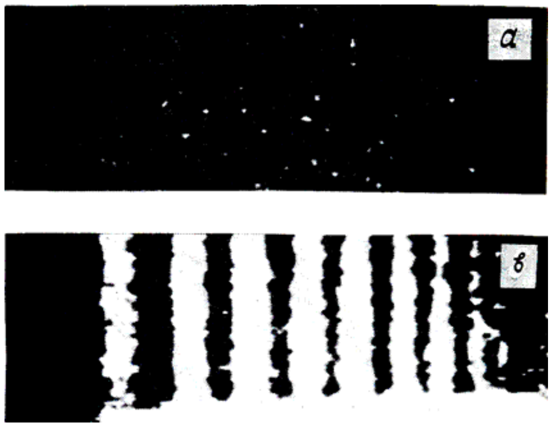

FIG. 5. Test-object image: a — no frames accumulated; b — 500 frames accumulated.

The exposure time T_{exp} in that experiment $T_{exp} \simeq 2N_{TV}\tau'_p$ was significantly shorter than the image "registration" time $T_{reg} \simeq 2N_{TV}T_g$, where T_g is the gate pulse repetition period. Thus, we obtain for $N_{TV} = 500$: $T_{exp} \simeq 2 \cdot 10^{-4}$ s and $T_{reg} \simeq 2$ s, respectively. However, if lasers with high pulse repetition frequency ($\simeq$ 10 KHz) are employed to illuminate the test object (for example, metal vapor lasers), the registration time may be reduced to approximately $5 \cdot 10^{-2}$ s. This result will, in all probability, lead to higher measurement speeds and to an improved image quality, as well as reduce the value of E_{thresh} determined by the charge leakage processes in the memory tube target. The supervidicon target might be used as such a target. It should be noted that the pulsed regime of MCP operation, when gate pulses follow at a frequency $F_g \leq 10$ KHz, does not result in any deterioration of the single electron characteristics of the II.[6] This result apparently follows from the low probability for one and the same channel in the MCP to react to each gate pulse.

Experimental testing of the system allows us to note the following peculiarities:

1. Image transmission quality depends on the energy at the II photocathode and the number of accumulated TV frames. It becomes possible, therefore, at low levels of illumination of the Investigated object or when it is necessary to gate out the background to improve significantly the quality of the recorded image by accumulating TV-frames and by matching the repetition frequency and the duration of the illuminating pulses with the respective characteristics of the gate pulse generator. On account of all these circumstances and the dynamics of the investigated image an optimal regime of system operation can be selected with regard to the number of TV-frames needed and' the quality of the image (or its recording time).

2. The sensitivity of the observation system and also the exposure time are determined by the threshold energy of the potential profile formed in the memory tube target.

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