Absolute calibration of the sensitivity of photodetectors using a biphotonic field

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The combined influence of a monochromatic flux of pumping photons and quantum noise on a medium that is not centrally symmetrical results in the appearance of rigorously time-correlated pairs of photons in the spontaneous parametric scattering (SPS) process. The presence of a field of such photon pairs (biphotons) makes it possible to develop a fundamentally new method of determining the absolute quantum efficiency of photodetectors. [1–3]

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The presence of quantum noise in a medium with a nonzero quadratic susceptibility results in the appearance of a scattered field in a broad spectral band. The photons in parametrically coupled modes of the field (for which the conditions

$$\hbar\omega_0 = \hbar\omega_1 + \hbar\omega_2, \quad \hbar\mathbf{k}_0 = \hbar\mathbf{k}_1 + \hbar\mathbf{k}_2 \tag{1}$$

are satisfied, where the "0" subscript refers to the pumping photons, while the subscripts "1" and "2" refer to the photons of the secondary radiation, $\hbar\omega$ is the photon energy, and $\hbar\mathbf{k}$ is its momentum) appear only as pairs. The delay Δt of the moment of escape of one photon in the biphoton from a nonlinear medium relative to the moment of escape of the second photon is determined by the optical path lengths to the boundary of the medium; in the absence of marked absorption at the frequencies ω_0, ω_1, and ω_2 and for sample dimensions of the order of a few centimeters $\Delta t \leqslant 10^{-12}$ sec it is insignificant for most photodetectors. However, the probability of the simultaneous appearance of two photons in one mode at low pump powers is negligibly small. Such rigidly pairwise-coupled photons make it possible to make an absolute calibration of photodetector sensitivity without using a standard. (The method can be used for the absolute calibration of photodetectors both in the visible as well as the IR and UV.)

This method is based on the following principle. Assume that the detector 1 records the photon flux N_1 with energies $\hbar\omega_1$ while detector 2 records the photon flux N_2 with energies $\hbar\omega_2$. The number of photocount pulses from each detector is

$$M_1 = \eta_1 N_1, \quad M_2 = \eta_2 N_2, \tag{2}$$

respectively, where η_1 and η_2 are the quantum efficiencies of the detectors. If the pulses from the photodetectors enter a coincidence circuit, then the number of coincidence pulses will be

$$M = \eta_1\eta_2 N = \eta_1\eta_2 N_1 = \eta_1\eta_2 N_2, \tag{3}$$

where N is the number of photon pairs, which is exactly equal to the number of photons arriving at each photodetector in the case of a biphotonic field. It follows from Eqs. (2) and (3) that the η value of one detector can be determined from the number of coincidence pulses and from the number of photocounts of the other detector

$$\eta_1 = \frac{M}{M_2}; \quad \eta_2 = \frac{M}{M_1}. \tag{4}$$

The parameters of the second reference channel should not affect the measurement results, and the quantity η contains in product form the transmission coefficients of the optical elements of the measured channel and crystal, which can be measured independently.

The quantum efficiency of the photodetectors (type FEU-79 and FEU-51 photomultipliers) was measured on a two-channel apparatus, whose block diagram is shown in Fig. 1. The pumping source was a cadmium-vapor laser with a 5-mW radiation power at a wavelength of 325 nm. A biphotonic field appeared with SPS in a lithium-iodate crystal. The crystal orientation was chosen in such a way that the scattering angles were 1-3° in the degenerate scattering regime ($\omega_0 \approx 2\omega_1 \approx 2\omega_2$). The parametric converter provided a biphoton flux of 10^6 pairs/sec in a 0.1-nm spectral band over the entire solid angle. The number of field modes recorded by the receivers was determined by the angular width of the tuned parametric scattering curve (the curve of the maxima determined from the condition $dp/d\theta|_{\omega_1,\omega_2=\mathrm{const}=0}$, where P is the intensity of scattered light and θ is the scattering angle), which did not exceed 30′, and by the spectral widths of the passbands of the receivers, which could be varied within the limits 0.03-2.00 nm. The completely identical electronic systems for processing the signals from the photodetectors included a radiation detector (photomultiplier), a wide-band amplifier with a 280- to 300-MHz passband, a high-speed discriminator-shaper, and electronic pulse counters. The pulses arrived simultaneously at the coincidence circuit. After passing through the discriminator-shaper, the duration of the pulses, which were locked-in with the time of arrival of

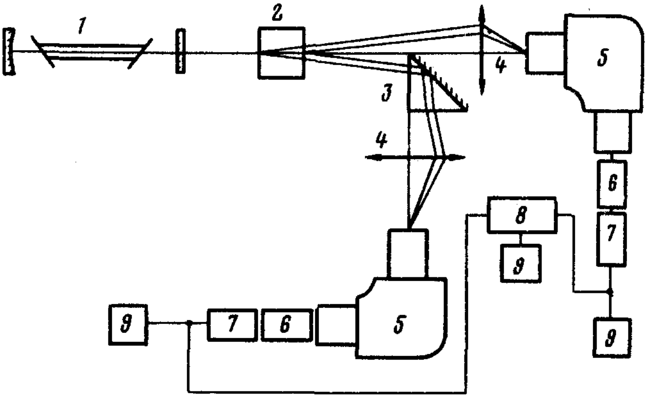

FIG. 1. Block diagram of experimental apparatus for absolute calibration of photodetectors: 1–He-Cd laser; 2–crystal; 3–reflecting rotating prism; 4–lenses; 5–ISP-51 spectrographs; 6–photomultipliers; 7–high-speed amplifiers; 8–coincidence circuit; 9–counters.

photons at the photocathode, did not exceed 10–12 nsec with a rise time of 3–4 nsec; the intrinsic resolution time of the coincidence circuit was about 3 nsec, but with the duration of the input pulses taken into account the resolution time in the experiments was equal to 4-5 nsec. Because the time resolution of the system was much greater than the average time between the appearance of biphotons, we ignored the corrections due to the simultaneous arrival of two biphotons in the receiver system.

The performed measurements showed the reliability of using this calibration principle and the low sensitivity of the results to many of the instrumental parameters (the passband of the reference channel and the pumping intensity). The value of η varied by less than 1% for a more than twofold change in the pump intensity. Replacement of the PMT in the reference channel by a PMT with a different integral-sensitivity value did not affect the measurement results. The insertion of light filters, which attenuate the radiation several fold, into the reference channel did not affect the results within the error limits of the measurements. However, the insertion of a filter with a calibrated transmission resulted in a strictly proportional decrease of η.

A measurement of the correlation function of the coincidences from the accuracy of the tuning of the receiver systems in the recording of parametrically conjugate photons showed the necessity of broadening the passband of the channel being calibrated as compared with the reference channel. Figure 2 shows two curves representing the dependence of the measured value of η on the accuracy of the frequency tuning $\Delta\omega = (\omega_0 - \omega_1) - \omega_2$ for two ratios between their spectral widths. Curve 1 is obtained when they are equal, and curve 2 is produced when the width of the channel being calibrated is twice the width of the reference channel. It can be seen

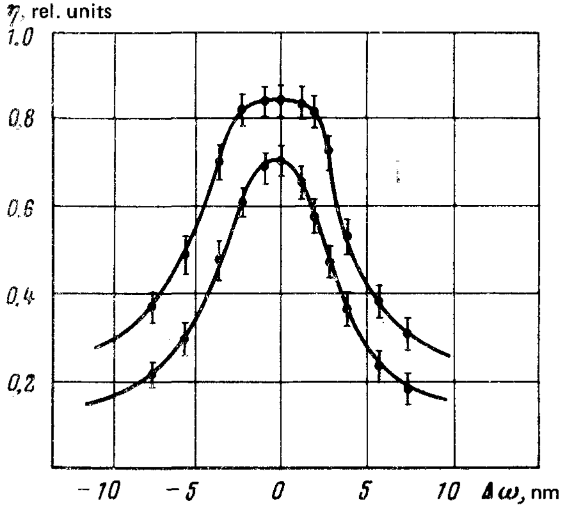

FIG. 2. Dependence of the measured value of η on the frequency detuning $\Delta\omega$ of channels 1 and 2 for equal spectral passbands of the channels (curve 1) and for a calibration-channel width that is twice as large as that in the reference channel (curve 2).

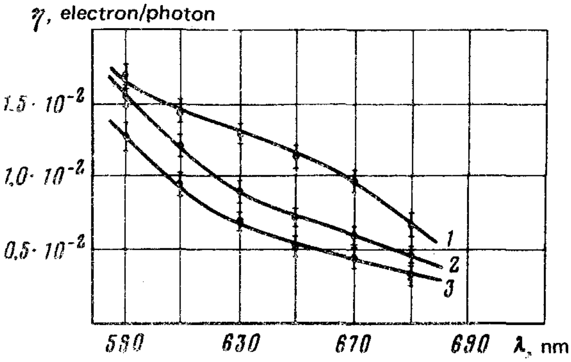

FIG. 3. Experimentally obtained spectral dependences of the quantum efficiency of three FUE-79 systems, 1–PMT integral sensitivity is $S_\Sigma = 306$ μA/lm; 2–$S_\Sigma = 210$ μA/lm; 3–$S_\Sigma = 143$ μA/lm.

in the figure that the requirements on the accuracy of the frequency tuning can be reduced in the second case.

The use of wide-band, scattered light due to parametric scattering made it possible to determine the absolute quantum efficiency in a certain spectral band. Figure 3 shows curves of the spectral dependence $\eta(\omega)$ for three FEU-79 systems with different certified values of the integral sensitivity.

The obtained results confirmed the correctness of the assumptions about the nature of the field that appears in the spontaneous parametric scattering process and showed the possibility of developing instruments based on the biphotonic field for measuring the absolute quantum efficiency.

1. D. N. Klyshko, Kvantovaya Elektron. 4, No. 5 (1977) [Sov. J. Quantum Electron. 7, No. 5 (1977)].
2. D. N. Klyshko, Kvantovaya Elektron. 7, No. 9 (1980) [Sov. J. Quantum Electron. **10**, No. 9 (1980)].
3. D. N. Klyshko, Fotony i nelineǐnaya optika (Photons and Nonlinear Optics), Nauka, Moscow, 1980, p. 138.

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