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Development of a detection block of a combined mode scintillator-photodiode system (counting-current) for azimuthal detecting complexes

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A small-sized gamma-detection block of scintillator-photodiodetem is reported. The block operates in the 0.05–3.0 meV energy range and the dose rate range from 10^{-6} to 10^{3} R/h and more. The detection block operates in a combined counting-current mode with spectrometry functions. Transition from the counting mode to the current mode and back is carried out automatically. The detection block is designed for use in azimuthal detectin g complexes of surveyor robots, in multifunctional dosimeters, direction-finding dosimete rs, etc.

Разработан малогабаритный блок детектирования γ–излучения системы сцинтиллятор-фотодиод, работающий в диапазоне энергий 0,05–3,0 меВ и диапазоне мощностей доз от 10^{-6} до 10^{3} Р/ч и более. Блок детектирования имеет совмещенный счетно-токовый режим с функцией спектрометрии. Переход со счетного режима на токовый и обратно происходит автоматически. Блок детектирования предназначен для использования в азимутально-обнаружительном комплексе робота-разведчика, многофункциональном дозиметре-пеленгаторе и др.

Advantages of the scintillator-photodiode (S-PD) system as compared with traditional ones, like gas counters, scintillator-PMT, semiconductor detectors, etc., have been described in detail in many publications [1–4]. However, as distinct from these systems with output signals of rather large amplitude (0.5–1.5 V and more), the S-PD system cannot be considered as a complete one, since the signal emerging at the photodiode output is very weak and requires further amplification and processing in order to reach amplitudes of ~0.5–1.5 V. The problem of amplification of weak signals is rather complex and requires special methods and ways. Moreover, high requirements are put to photodiode parameters, meeting which is also a difficult task. Nevertheless, if the whole problem is treated in complex, all difficulties related to realization of the possibilities offered by S-PD systems can be overcome. A complex approach means that limiting parameters of the whole chain are to be reached: crystal-photodiode-detector-circuitry. Such formulation of the research tasks allowed us to obtain positive results, one of which is presented in this paper.

An azimuthal-detecting complex (AzDC) is designed for automatic remote detection of local sources of γ-radiation for their safe storage or neutralization. AzDC is installed on a surveyor robot and comprises detectors of two types, operating in the current and counting modes, respectively. They are grouped into two blocks, 12 detectors in each. As counting detectors, gas counters are used, while current-mode detectors are SELDI-102 S-PD type detectors developed by the Institute for Single Crystals.

These detectors have a number of substantial drawbacks, among which one should note their large size and weight, low detection efficiency of high-energy particles by gas detectors, problems in combining information from the current and counting detectors in the 10^{-2} R/h range. The latter drawback is very important, as in this range gas detectors are reaching saturation, while current detectors did not ensure the required sensitivity. As a result, the surveyor robot in this crossover range lost his orientation in γ-fields, which caused negative effects on the operation quality.

We have developed a detection block (DB) operating in a combined counting-current mode with functions of spectrometry, which has no above-mentioned drawbacks. In the dose rate range of 10^{-2} R/h, DB has a certain overlapping of the current and counting modes, which allows carrying out continuous measurements. The detection block comprises a S-PD detector, a peak detector, a block for pulse amplitude measurement and spectra storage, a block for synchronization and exchange, a block for current measurement, and a RS-232 interface.

The detector includes:

— scintillator CsI(Tl) of 4.5 cm^3 volume;

— pin-photodiode 1 cm^3;

— charge-sensitive amplifier (CSA);

— 3.5 μs and 5 μs shapers;

— temperature sensor;

— commutator.

The peak detector block consists of:

— the peak detector itself, which "memorizes" the pulse shape;

— corrector of "0" line, which measures and stores the "0" line bias;

— comparator;

— digital variable resistor setting the comparator threshold;

— launching circuit for pulse amplitude measurement on a D trigger.

The block for measurement of pulse amplitudes and spectra storage consists of:

— a 12-digit analog-to-digit converter (ADC);

— microprocessor (MP);

— RAM for spectra.

The block for current measurement consists of:

— a 24-digit ADC, a microprocessor;

— communication circuit.

The block for current measurement is linked to the bias setting circuit — 50 V. The syn-chronization and exchange block is a microprocessor-manager controlling a system of several measurement channels. The RS-232 interface ensures connection with a computer via COM-port (for rapid exchange, communication via LPT-port).

Transformation of the optical signal was carried out in the following way: γ-quanta are converted into photons; in the pin-diode, the photons are converted to an electric charge, which, in turn, is converted into voltage in the charge-sensitive amplifier, and the voltage difference is shaped into a pulse. Then the pulse comes (through the commutator, i.e., the output of one of the shapers) to the peak detector that stores the maximum pulse value. The peak detector can operate in two modes: watching and storage. Switching over between the modes is made by the microprocessor. In the initial state, the peak detector is in the watching mode, and the signal at the detector output repeats the input signal. When an input pulse passes over a specified threshold (the threshold is set by the microprocessor using a digital resistor), the comparator functions. When the comparator passes over from "0" to "1", the peak detector goes to the storage mode and records the pulse maximum. After a time interval equal to the shaper time plus one microsecond (controlled by the microprocessor), an ADC launching signal is formed, and the peak detector goes back to the watching mode and waits for the next pulse. The result of ADC transformation is written to RAM under control of the microprocessor. The data stored in RAM (spectra) are trans-ferred to the computer using a RS-232 port.

To make the results less dependent upon the load, correction of the '0" line is envisaged in the peak detector. The correction is ensured by measurement of the "0" line bias and introducing this correction in an analog form through the summator. In measuring spectra under high loads, some pulses are not recorded (load >35 kHz). For measurements under such loads, a counting channel is provided that ensures operation up to 250 kHz. The current measurement is carried out in the photodiode bias circuit. The photodiode current goes through a current-measuring resistor R_i = 50 kΩ, and the voltage fall on this resistor is measured by the 24-channel sigma-delta ADC. The result

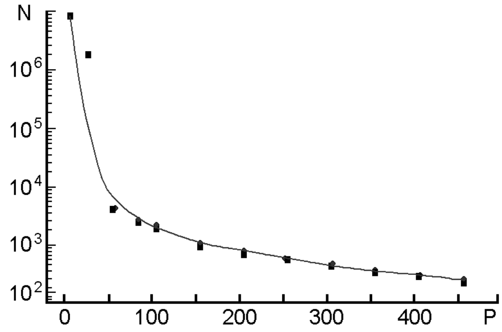

Fig. 1. Pulse counting as function of the comparator threshold level (channels number P).

is sent to RAM and further to the computer. ADC is controlled by its own microprocessor. The R_{2i}, R, C circuit of the meter is designed to compensate for current oscillations related to the bias source instability. To account for current variations related to changes in the photodiode temperature, the latter is measured and, using a known dependence of current on temperature, a correction is made to the measurement result.

Using the measurement channel of AzDC, the measurement is carried out in the same way, but there is, in addition, a microprocessor-manager that synchronizes operation of all the channels and periodically reads out the data (spectra and currents), writing them into the computer. In checking-up, readout goes through the RS-232 port, and in the real time scale operation — through LPT-port.

RS-232 is slow (up to 14.4 kbyte/s) at distances up to 10 m; LPT is fast (500 kbyte/s) at distances up to 2 m.

Technical characteristics of the detection block in the counting operation mode:

1. Energy range, MeV — 0.05–3
2. Maximum pulse frequency in the counting mode, kHz — 250
3. Output pulse amplitude (for ^{137}Cs), V — 0.4–0.6
4. Temperature sensor V/°C — 0.6/20. Transformation coefficient, mV/°C — 2
5. Power supply voltage, V — +5
6. Consumed current, mA — 2.5
7. Overall dimensions, mm — 21×21×42.

Technical characteristics of the detection block in the current measurement mode:

1. Current measurement range, μA — 5.10^{-5}–50
2. Mean square error in 1 s averaging, nA — 0.1
3. Current measurement discreteness, nA — 3
4. Power supply voltage, V — ±5.

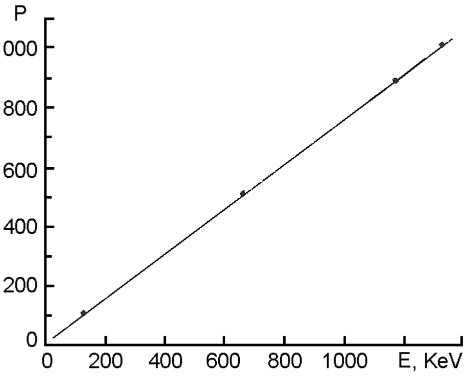

Fig. 2. Energy dependence of the detection block signal amplitude.

In the course of experiments, DB noise characteristics were studied in the counting and current modes, counting rate as function of the maximum exposure dose (MED) in the counting mode, the measured current as function of MED in the current mode, DB operation under temperature variations. In Fig. 1, the number of DB counts per second is shown as function of the comparator threshold. It can be seen that in the threshold region of 50 channels, the number of counts is sharply increased, which shows that noise pulses make a predominant contribution to the counting channel. The noise contribution is felt starting from the 450-channel threshold, with a smooth increase towards 100 channels. Thus, the comparator level should be set around the values of 400–450, adjusting it individually for each DB.

Measurements were carried out simultaneously for two shaping times — 3 μs and 6 μs; however, the BD noise practically was not dependent upon shaping time. The DB dark current was measured in the current mode, with measurements carried out for 10^3 s (6000 measurements). As a result, the highest current was I_d = 2.822 nA, the lowest — I_d = 2.63 nA. The maximum scatter was 0.39 nA, and the average value — 2.63 nA. The DB dark current did not depend upon the comparator threshold and the shaping time. Then we studied the DB energy dependence in the spectrometric mode. In our measurements, we used OSGI standard radiation sources, measurement time — 100 s, shaping time — 3 μs. The sources were located against the side surface of the detector. The measurements results are presented in Table 1.

Thus, counting over energy begins from the 24th channel (which corresponds to the 0 keV energy). The point value of one chan-

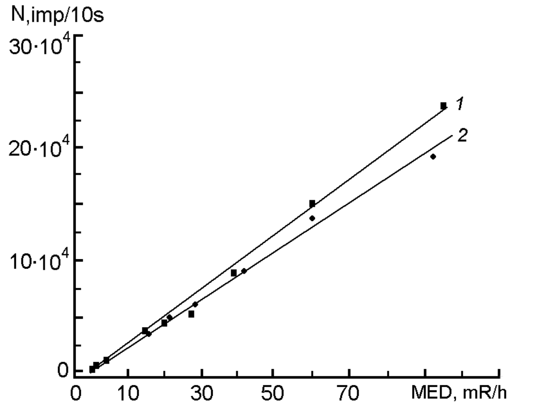

Fig. 3. Counting rate of the detection block as function of exposure dose rate (^{137}Cs source):

1 — shaping time 3 μs, *2* —shaping time 6 μs

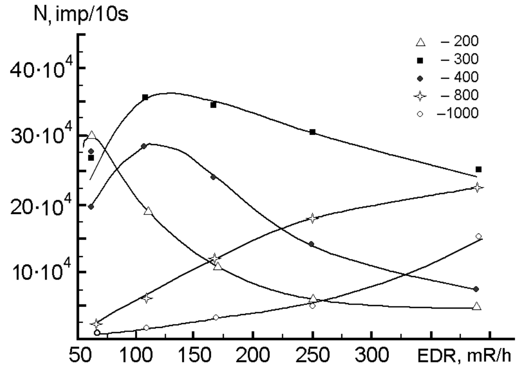

Fig. 4. Counting rate of the detection block as function of exposure dose rate for different comparator thresholds P.

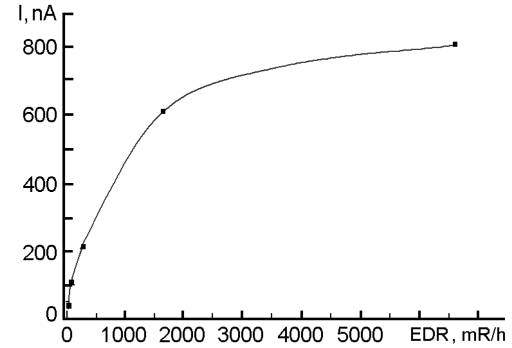

Fig. 5. Detection block current as function of exposure dose rate (Cs^{137} source).

nel is ~1.35 keV. The ^{241}Am line (59.6 keV) lies in the noises (at the threshold of 25 channels, only the right-hand slope of the photopeak can be observed). The photopeak maximum should presumably be in the 68th channel, with energy resolution of ~45 %. For the OSGI source, the signal to noise ratio is ~25 % at the photopeak maximum. Fig. 2 shows the energy dependence of the DB signal amplitude. As it can be seen, signal amplitude is linearly dependent upon γ-radiation energy, and the spectrometric mode of DB operation begins from 100 keV.

After that, we studied the effect of the comparator threshold and pulse shaping time multiplied by counting rate as function of the exposure dose rate (EDR). The ^{137}Cs source of an OSGI set was fixed in the collimator at the beginning of a dosimetric detector array and was not moved. DB was fixed on a rotating table with its base side directed to the source. DB is designed in such a way that at large loads (above 35 kHz) some pulses are not recorded in spectrum measurements. Therefore, linear dependence of the counting rate upon EDR for the ^{137}Cs photopeak is preserved only with the comparator threshold ~450 channels and corresponds to the energy of 576 keV. In spite of the fact that at large loads shorter shaping times are recommended to be set, the shaping time does not practically affect the counting rate at high EDR.

In Fig. 3, counting rate vs, EDR is shown at the comparator threshold of 450 channels. In Fig. 4, DB counting rate is shown as function of EDR for different comparator threshold values (shaping time 3 μs). It can be seen that when the threshold is higher than 400 channels, the number of counts sharply increases due to contribution from noise. DB current vs. EDR studies were carried out using the ^{137}Cs source No.368. The temperature was measured using a thermometer, increasing from 19.8 to 20.5°C in the course of measurements. The measure-ment time was 10 s. Sampling time from the computer to microprocessor is 2 s. Results of the measurements are presented in Table 2, showing that the shaping time and the comparator threshold do not affect the current going through the photodiode. The range where current vs. EDR linearity is preserved is 100 mR/h. When EDR rises above this value, the current continues to grow, but the linearity is violated (Table 3). The minimum EDR value at which current begins to noticeably (by 20 %) differ from the dark current value is ~100 μR/h. The maximum EDR value at which our experiments were carried out was 6500 R/h (measurements with three ^{137}Cs sources: No.378, 393, and 396).

In S-PD systems, dependences of DB characteristics upon temperature are very important. To study this dependence, DB

Table 1.

Nuclide	E, keV	Threshold, channels	Pulses per 100 s сек	Resolution, %	K, channels	$K_{calc.}$, channels
^{241}Am	59,6	–	–	–	–	68
^{57}Co	123	70	174551	31,0	114	115
^{137}Cs	662	450	54176	8,7	516	–
^{60}Co	1172	800	38047	8,7	890	891
	1333			7,0	1013	1010

Note: K is the channel number corresponding to the γ-line photopeak maximum, K_{calc} – calculated channel number. Approximation for DB:: $K_{calc.}$ = 24+0,74pE.

Table 2.

R, m	2.00	1.50	1.20	1.00
EDR, mR/h	61.63	109.56	171.19	246.52
t, °C	19.8	19.9	20	20.1
Current, nA	1.180	1.414	1.667	1.930

Note: R is the distance from the source to the detector

Table 3.

R, m	1	2	5	10	20
EDR, mR/h	6579.6	1644.9	263.2	65.8	16.4
Current, nA	802.8	613.8	218.5	111.2	41

Table 4.

Parameter	Temperature			
	25	40	50	60
Average dark current value, nA	0.94	9.51	40.21	123.05
Mean square deviation σ, nA	0.0313	0.2514	0.4228	0.5169
Relative deviation δ, nA	3.33	2.64	1.05	0.42
Average counting value for 30 s, pulses.	664	1199	2281	218721
Mean square deviation σ, pulses.	175	421	884	48146
Relative deviation δ, %	26.5	35.0	38.7	22.0

Table 5.

Parameter	Tempearture			
	25	40	50	60
Average current value, nA	1.35	9.84	41.48	141.63
Mean square deviation σ, nA	0.07	0.68	0.83	1.28
Relative deviation δ, nA	5.24	7.00	2.02	0.91
Average counting value for 30 s, pulses	75344.9	1725670.0	169039.0	1142930.0
Mean square deviation s, pulses.	685.7	10189.5	11095.5	4666.5
Relative deviation δ, %	0.91	0.59	0.66	0.41

was heated in a muffle furnace. The temperature was measured with a mercury thermometer. The dark current was measured, as well as number of counts without gamma-source and with a ^{137}Cs source of 350 kBq activity (1993). In Table 4, measurement results are presented for the dark current I_d and the number of counts as function of temperature without gamma-source. In Table 5, data are shown for current and DB counts as function of temperature with a ^{137}Cs source.

As a result of our studies, the following conclusions can be made. With increased loads, the energy resolution begins to deteriorate. In measurements with a source or without a source, substantial increase is observed in the counting rate close to the comparator threshold. In the counting mode, for preservation of linearity over EDR for different (as for their energies) sources, different comparator thresholds should be set. For measurements in the counting mode with a ^{137}Cs source, the optimum comparator threshold is 450 channels. With such threshold, the counting rate vs. EDR linearity is preserved up to 110 mR/h. The linearity range for current is from 100 mR/h to 100 R/h. Thus, there is a certain overlapping of the ranges of counting and current modes. When EDR rises above 100 R/h, the current continues to increase, but its linearity over EDR will be violated. The dark current dependence on temperature is similar to that characteristic for Hamamatsu S3590-01 photodiodes. In the counting mode, substantial increase in load with temperature is also observed.

Thus, we have developed and produced a detection block operating in a combined counting-current mode (with a function of spectrometry), which can be successfully used in an azimuthal-detecting complex. The DB has small size and weight at high sensitivity in a broad range of gamma-radiation doses.

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Розробка блока детектування системи сцинтилятор-фотодіод сполученого режиму роботи (лічильно-токовий) для азимутально-виявного комплексу

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Розроблено малогабаритний блок детектування γ-випромінювання системи сцинтилятор-фотодіод, що працює у діапазоні енергій 0,05-3,0 МеВ і діапазоні потужностей доз від 10^{-6} до 10^{3} і більш Р/год. Блок детектування має суміщений рахунково-струмовий режим з функцією спектрометрії. Перехід з рахункового режиму на струмовий і назад проходить автоматично. Блок детектування призначено для використання у азимутально-виявляючому комплексі робота-розвідник, багатофункціональному дозиметрі, дозиметрі-пеленгаторі та ін.