AUTOMATIC STATION FOR CONTINUOUS SPECTROMETRIC MONITORING OF ENVIRONMENTAL RADIATION

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The problems concerning construction of an automatic station for continuous monitoring of the environmental radiation are discussed. The structure of the system and the implemented measurement techniques are described. The operation modes of the station, its basic parameters and its applicability are also presented.

1. INTRODUCTION

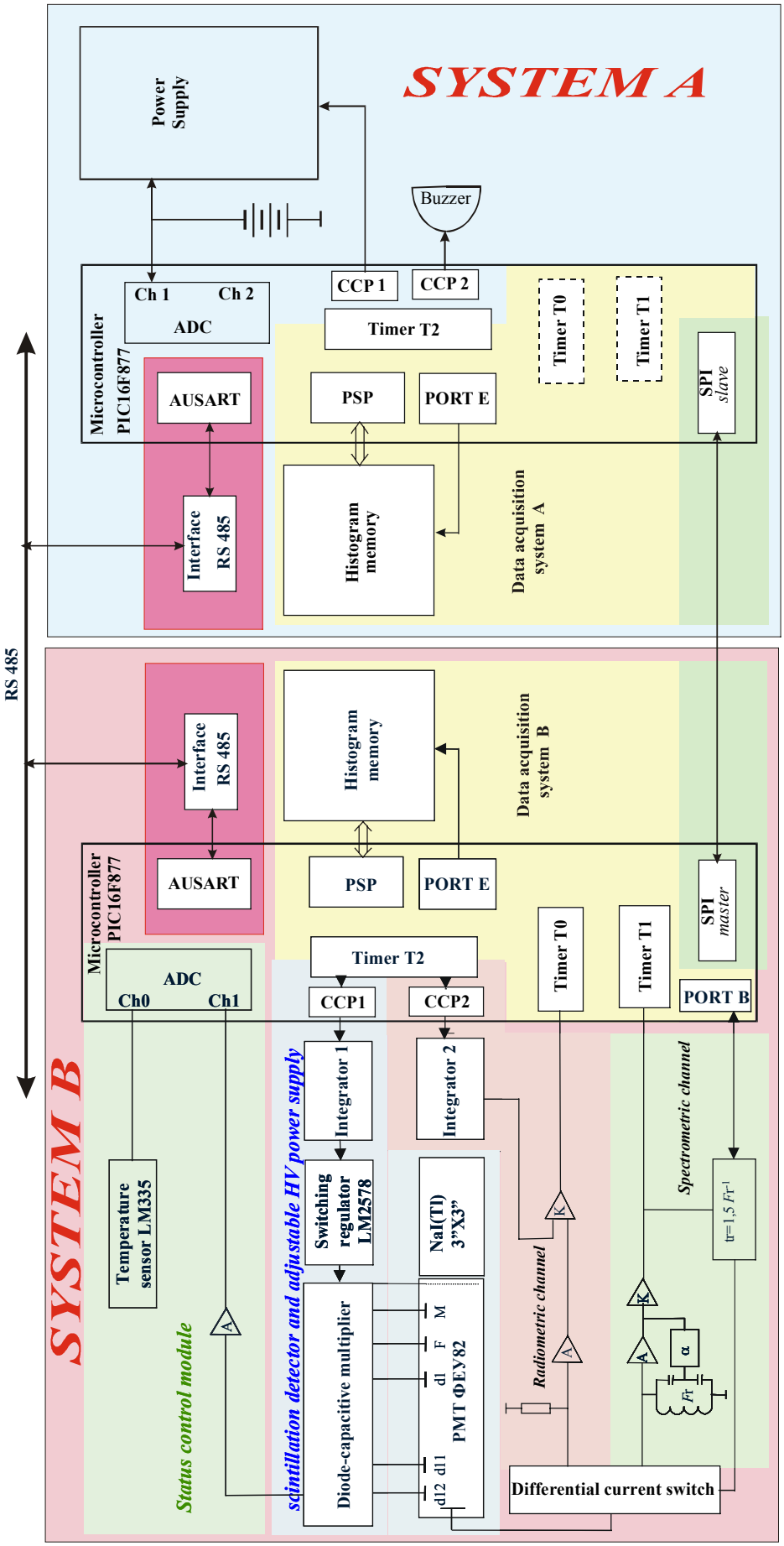
The problem for a continuous monitoring of the environmental radiation is going more and more actual in the recent years due to the frequently armed conflicts, threat of terrorists, possible nuclear accident etc. [1]. There are three main aspects of this problem:

- the shortage of equipment possessing high sensitivity and accuracy to determine nearly background radiation levels (for a precision measurement of the dose rate the energy distribution of the incoming radiation has to be taken into account);
- the very high demands to the equipment working in extreme atmospheric conditions;
- the high price of the equipment able to partially satisfy the above requirements.

Normally, two-detector systems are used to assure high sensitivity and accuracy in a wide range of dose rate change. The low (background) levels are measured by highly efficient detectors (e.g. NaI(Tl), while the high levels are determined by ionisation detectors [1]. The progress in the electronic circuitry stimulates development of portable spectrometric systems possessing high sensitivity, low energy consumption and low price [2,3].

2. STRUCTURE OF THE SYSTEM

The proposed automatic station for continuous monitoring of the environmental radiation is based on a portable multichannel analyser with a logarithmic energy scale [3]. A high efficiency scintillation detector of NaI(Tl) is used. The amplitude analysis of the detector signal is realised by a resonant charge-code converter. The resultant digital code (which contains information about the radiation energy deposited in the detector) is sent to two subsystems (B and A) working in parallel. A general structural diagram of the station is shown in Fig.1.


SYSTEM A
Power Supply
Buzzer
Microcontroller PIC16F877
Ch 1
Ch 2
ADC
CCP 1
CCP 2
Timer T2
Timer T0
Timer T1
AUSART
PSP
PORT E
SPI slave
Interface RS 485
Histogram memory
Data acquisition system A
RS 485
Interface RS 485
Histogram memory
Data acquisition system B
Microcontroller PIC16F877
AUSART
PSP
PORT E
SPI master
Timer T0
Timer T1
Timer T2
ADC
Ch0
Ch1
CCP1
CCP2
PORT B
SYSTEM B
Integrator 1
Integrator 2
Temperature sensor LM335
Switching regulator LM2578
NaI(Tl) 3"X3"
Status control module
scintillation detector and adjustable HV power supply
Diode-capacitive multiplier
PMT ФЕУ82
Radiometric channel
Spectrometric channel
Differential current switch

Фиг. 1

2.1. Logarithmic spectral analyser (SYSTEM B)

The first subsystem (SYSTEM B) acquires a 256-channel spectrum in a logarithmic energy scale. It provides a long term documentation of the environmental radiation spectrum in the whole range of interest (50keV-10MeV). The basic function of the SYSTEM B is to estimate the dose rate of the registered radiation. At lower dose rates (nearly to the background) this is done using the spectral information. At higher dose rate levels the system is automatically switched into radiometric mode (i.e. it works as a variable threshold integral discriminator).

The SYSTEM B consists of:

A. Detector block. A 3"x3" NaI(Tl) scintillation detector is used as energy sensitive detector. It is coupled to a ФЕУ82 photomultiplier tube (PMT).

B. Power supply for the detector. The supply voltage necessary for the PMT dynodes is provided by a diode-capacitance charge redistribution multiplier. A pulse voltage stabiliser LM2578 is used, which is able to stabilise negative voltage [4]. The dynodes potentials are controlled by varying a control voltage which results from integration of the output signal of the CCP1 generator of the used microcontroller. Hence, the PMT voltage can be regulated in a program way. The whole power consumption of the high voltage power supply is not more than 4mA at 12V.

C. Spectrometer. The shaping and the amplitude selection of the PMT output signal is performed by a resonant charge-code converter [5]. It is based on a LC circuit used as a load in the anode chain of the photomultiplier. Fading oscillations are then generated in the circuit and the count of their periods (until they fall below a predefined voltage level) serves as a digital code for the logarithm of the energy deposited in the detector.

In order to increase the number of the useful channels of the spectrometer, a positive feedback is introduced to partially compensate the energy loss in the LC circuit. So the energy range of interest can be extended up to 256 channels in a logarithmic channel-energy scale.

The pulses coming from the PMT anode during the conversion time of the spectrometer are switched to the radiometric channel by means of a differential current switch. In this way it is possible to count all events lost during the dead time of the spectrometric part of the system.

D. Radiometric channel. The radiometric channel includes a linear amplifier of the pulses coming from the anode chain of the PMT and a comparator which converts them to standard CMOS levels. The comparator's threshold is controlled by the output voltage of the second integrator connected to the microcontroller's CCP2 output. The spectrometric mode is used at low pulse intensity. A low threshold level is then given to the comparator in order to count all pulses having amplitude above that level and not registered by the spectrometer. If the PMT pulse intensity is high then the dose rate is determined only by means of the radiometric channel. Then the comparator's threshold is periodically varied with the time in a way to flatten the detector sensitivity in the whole energy range of interest.

E. Data Acquisition System. It is designed on the base of a microcontroller PIC16F877 of Microchip by an extensive use of its built-in periphery.

Timer2 is used to generate the main timing intervals of the system. It is used also to support the two PWM generators which provide the PMT voltage (CCP1) and the comparator's threshold in the radiometric tract.

The output shaped pulse burst coming from the spectrometric channel are counted by the Timer1 which works in burst mode. The timer output code is used as address for sorting the corresponding event into the spectrometric memory. The same code is sent by the serial peripheral interface (SPI, working in master mode) to the second subsystem (SYSTEM A) for a parallel processing.

The spectrometric (histogram) memory is 128 kbyte. Its schematics is designed to exchange up to 16 bytes in burst mode. The memory contains up to 240 spectrograms which allows a long time standalone work of the system.

Timer0 is used to register the pulses coming from the radiometric channel.

PortB is used in interrupt mode to receive end-of-burst signal from the spectrometric subsystem. It can also control the differential current switch to redirect all the PMT anode pulses to the radiometric channel.

F. Status control. A branch for controlling the current system parameters is provided in the automatic station for monitoring of the environmental radiation. The value of the PMT voltage is measured at the 12-th dynode (which is proportional to the whole voltage supplied) as well as the temperature close to the scintillation detector. For the last purpose a semiconductor temperature sensor type LM335 is used. The temperature is measured with 0.5 K resolution.

2.2. 8-channel spectrometer (SYSTEM A)

The second subsystem (SYSTEM A) provides a fast (within few seconds) reaction to a dose rate change. The statistical significance of that change is evaluated by comparison of the successive 8-channel records (using the χ^2 statistical test). An express estimate of the dose rate is made using the 8-channel spectrometric data.

The data acquisition system is identical with that of SYSTEM B. However, some of the functions delegated to the peripherals are changed because of the specific features of the problem.

The basic time intervals (e.g. acquisition time) are generated by Timer2. It is used also to feed a sound generator (piezoceramic beeper). The latter is switched on if a statistically significant deviation from the measured local stationary level has occured.

The data registered by the spectrometric system (SYSTEM B) are used as input data for SYSTEM A. They enter via the SPI operating here in slave mode. The incoming 8-bit codes are reduced to 8 wide energy channels. This 8-channel histogram is saved into the built-in microcontroller memory during the relatively small acquisition time.

The spectrometric memory is 128 kbyte and a 16 bytes burst exchange mode is implemented. Over 8000 8-channel records can be stored in the memory which means almost one daynight standalone work at 10s acquisition time.

2.3. Common subsystems

A. User interface. All data collected by the SYSTEM A and SYSTEM B of the automatic station are transferred to a higher hierarchy control level in NRZ format via the serial communication interface (SCI) embedded into the microcontroller. All electrical signals are made RS485 compliant. The latter interface is preferred by two reasons:

- it ensures stable operation at relatively long distances to the archiving station;
- it allows parallel operation of several units (such as a meteostation, for example).

B. Power supply of the station. The continuous operation mode of the automatic station sets strong requirements regarding the power supply module. All necessary voltage supply is taken from a pulse DC-DC converter powered by 9-24V DC. The total energy consumption of the station does not exceed 105 mA at 12V. The power for the DC-DC converter is received from a 220V~/12V= AC-DC converter backed up by a lead 12V/3.2Ah accumulator. In case of power net failure the automatic station can work more than 24h with the backup accumulator.

3. OPERATION MODES

3.1. Determination of the dose rate in the spectrometric mode

The dose absorbed within the detector volume is determined by means of the spectral distribution of the registered gamma-rays. The charge appearing at the PMT anode is proportional to the energy deposited in the detector and it is independent on the kind of the interaction. The dose absorbed for the time interval of the measurement is:

$$D = k_d \cdot \sum_{I_{\min}}^{I_{\max}} N(I).E(I) \qquad (1)$$

where *N(I)* is the number of counts registered in the I-th channel;
E(I) is the average energy corresponding to the I-th channel;
k_d is a coefficient to account for the detector mass and geometry.

An advantage of this method is its high accuracy and sensitivity which are superior to any other methods at low dose rates (i.e. close to the natural background). A drawback of this mode is the relatively large acquisition time (typically several minutes)necessary to collect statistically significant events in the 256-channel histogram.

3.2. Determination of the dose rate in the semi-spectrometric mode

In this mode all incoming events are sorted into a limited number of channels (8 in the present system). So, it is possible to acquire statistically significant results within a few seconds. They can be then processed using the method described in the previous section. Of course, the dose rate uncertainty is now larger than if all 256 channels are used. This mode is especially suitable for real time measurements with a dynamics in the seconds region, e.g. for car-borne exploration systems.

3.3. Determination of dose rate in the radiometric mode

At higher count rates the dead time of the resonant charge-code converter becomes rather high and causes considerable measurement errors. It is provided to use the radiometric channel in this case, when all PMT signals are redirected to that channel (by the differential current switch).

In this case, the method of the so called spectral weight function G(E) is used for dose calculations [6]. G(E) is indeed a conversion operator connecting the absorbed dose with the pulses distribution by:

$$D = \int_{E_{\min}}^{E_{\max}} F(E).G(E)dE \qquad (2)$$

where F(E) is the spectral distribution of the registered events in the energy range E_{min} - E_{max}.

In the measurement, the operator G(E) is replaced with a time dependent operator G(t), which repeats its characteristic during the integration time interval. This is made using the programmable threshold of the integral discriminator (the comparator in the radiometric channel):

$$D = k_d \int_{E\min}^{E_{\max}} N(E).G(E)dE = k_d^t.\sum_{t_{\min}}^{t_{\max}} N(t).G(t) \qquad (3)$$

Here again k_d^t accounts for the detector characteristics.

In this case the automatic system works as a single-channel analyser. So, the length of the integration time interval $t_{\max} - t_{\min}$ should be sufficiently short (several seconds) to follow the dynamics of the radiation field. In fact, the time cycle in (3) is continuously repeated.

This method allows measurement of dose levels which are considerably higher than those achievable by the multichannel spectrometric method without replacing the detector system.

4. CONSTRUCTION FEATURES

The used non-standard spectrometer design makes possible to assemble the whole automatic system inside a single hermetic cylindrical container of magnetic soft material with outer dimensions $\varnothing 140 \times 400 mm$ (including the scintillator). It has a 4-wires connection: two for the DC power supply and two for the interface.

5. CONCLUSION

Usually, the systems for radiation monitoring are based on doubled detector system – one high sensitive detector is used for the low doses and another – for elevated doses.

Combining a spectrometric method with that of the pulse height weighting function [6] makes possible to use the same detector for both high and low radiation fields keeping good accuracy and sensitivity in a large dose scale.

System parameters:

Detector system background	< 20 nGy/h
Energy range	50 keV – 10 MeV
Pulse height analysis	resonant charge-code converter at 1MHz, 256 channels
Conversion time	(6.6 + N.1) μs – N is the channel number
Histogram memory A	128kB, 2^{16}-1 counts per channel, up to 240 256-channel spectra
Histogram memory B	128kB, 2^{16}-1 counts per channel, up to 8190 8-channel records
Dead time correction	counting the lost pulses
Energy resolution	FWHM – 7% at 662keV (2"x2" crystal)

Adjustments
Automatic acquisition cycle – 0.01s to 167772s, step 10 ms
(separately selectable for SYSTEM A and SYSTEM B)
Hardware adjustment of the energy scale slope
HV adjustment – programmable, 500-2000 V, 1024 steps

Control interface - RS485

Power supply – 12V DC

Power consumption – < 110mA.

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