DEVELOPMENT OF AN INTELLIGENT PREAMPLIFIER FOR SEMICONDUCTOR DETECTORS

by

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The results of engineering an intelligent preamplifier for high purity germanium gamma-detectors are presented. An intelligent preamplifier is a low-noise, high speed resistive feedback charge-sensitive preamplifier with a built-in microcontroller and additional units that enable control of preamplifier and detector parameters. It also allows the performance managing of the internal testing pulser, sensor of liquid nitrogen level in a Dewar, humidity, pressure and temperature sensors in a sealed preamplifier section. Intelligent preamplifier operation, set-up, and parameter measurements are controlled by a software.

Key words: intelligent preamplifier, charge sensitive preamplifier, HPGe detector

INTRODUCTION

Charge-sensitive preamplifiers (CSPA) are widely used in ionizing radiation spectrometers with semiconductor detectors (SCD) based on high purity germanium (HPGe) and other semiconductor materials [1-4]. The main purpose of the preamplifier is to convert a charge formed in the SCD as a result of ionization, into an electrical voltage signal, whose amplitude is proportional to the energy of the ionizing radiation. The theory of constructing the CSPA is well developed [1-3, 5] and CSPA are produced by many instrument-making firms.

In the last decade, due to progress in digital nuclear electronics, the demands on CSPA capacities have increased significantly. First of all, this relates to the possibility of real-time remote control of preamplifier and detector parameters, and to the ability to display the measured data in a report. Interest in a deeper integration of the CSPA with other devices consisting of the gamma spectrometer, for example, a multichannel analyzer (MCA), a liquid nitrogen level sensor, *etc*., has also grown.

In [6], Canberra Industries/Mirion presents the characteristics of an intelligent preamplifier (iPA) for HPGe detectors, capable of controlling the temperature of the detector and its leakage current, along with the operating voltages at checkpoints. Made in the form of a separate unit connected to the detector, the intelligent preamplifier has an internal test pulser, an integrated flash memory for parameters and status logging. The included "iPA Control Panel" software allows the control of parameters of the preamplifier and the detector [4]. However, no technical aspects of preamplifier development are presented.

In [7], another approach is proposed: a single intelligent system combining the detecting unit, the detector high voltage (HV) control module and the multichannel analyzer. The described technology by Ortec/Ametek was named SMART-1. This technology allows the control of a number of parameters of the spectrometric system (detector temperature, preamplifier supply voltage, detector HV value, *etc*.). The analyzer checks the condition of the detector before measurement starts and constantly monitors it during the measurement. In case of parameter deviation from the established norm, a warning message is displayed on the screen of the analyzer equipped with the *Maestro* software. The system works only with Ortec-branded analyzers. The authors also do not report on the technical aspects of the development.

This paper is devoted to the development and research of characteristics of our proprietary intelligent preamplifier's version with control and parameter setting functions useful for spectrometric measurements. From the very beginning, we have been focused on designing an intelligent preamplifier that can work as part of HPGe gamma-spectrometers with multichannel analyzers by any manufacturer. The engineered intelligent preamplifier is constructively an electronic module dimensioned 55 mm 63 mm 23 mm, installed under the cover of the electronic section of the standard Baltic Scientific Instruments (BSI) cryostat

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instead of a conventional CSPA, and is designed to ensure the production of spectrometric equipment based on HPGe detectors [8].

FUNCTIONAL DIAGRAM OF THE INTELLIGENT PREAMPLIFIER

The intelligent preamplifier SHP-01 (State-of-Health Preamplifier, hereinafter referred to as SHP-01) is a low-noise, high speed resistive feedback CSPA with a built-in microcontroller and additional units that enable control of the detector and CSPA parameters, as well as allow performance managing of the internal test pulser and sensor of the liquid nitrogen level, humidity, pressure and temperature in the preamplifier sealed section. The SHP-01 intelligent preamplifier is designed to work as a part of X-ray and gamma-radiation detectors based on HPGe and other spectrometric detectors.

A structural diagram of the SHP-01 intelligent preamplifier is shown in fig. 1. The core of the SHP-01 is a microcontroller that controls all operating modes of the preamplifier, processes the measured parame-

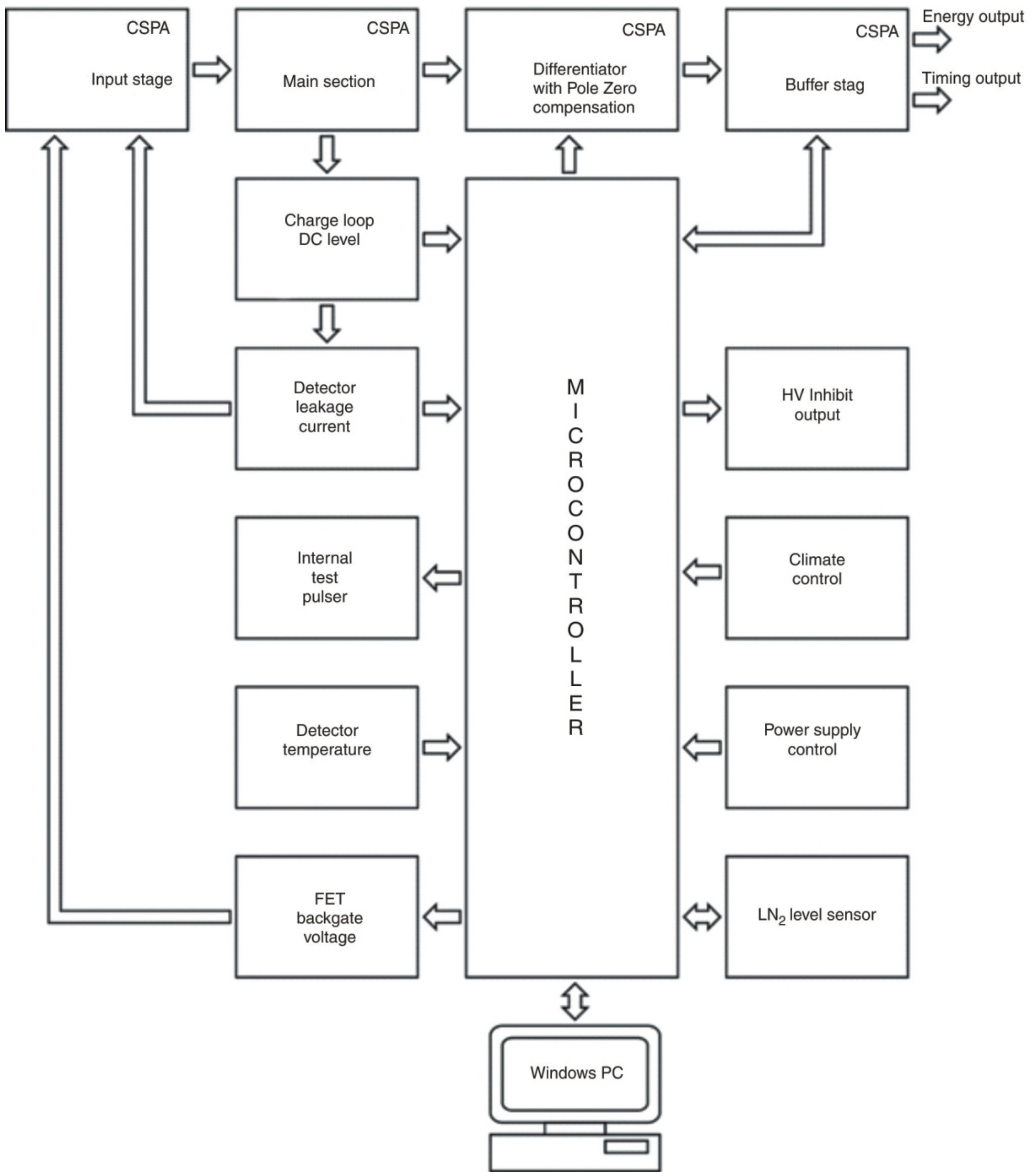

Figure 1. Block diagram of the SHP-01 intelligent preamplifier

ters and provides communication with a personal computer via the USB 2.0 port. The complex of tasks which are solved by SHP-01 imposes certain requirements on the type of controller used. It must have sufficient processing power; low level of electromagnetic interference; a wide range of peripheral equipment; low power consumption and be able to switch from the operating mode to the stop mode and *vice versa*.

As a result of research, for engineering an intelligent preamplifier the STM32L433 microcontroller by STMicroelectronics was chosen [9]. The 32-bit microcontroller architecture allows for the necessary amount of computation, operating at a low frequency and ensuring a minimum level of electromagnetic interference. The 12-bit analog-to-digital converters of the microcontroller allow taking measurements with sufficient accuracy, and the comprehensive port system makes it possible to control additional SHP-01 modules.

The analog circuit of the CSPA for amplifying the detector signals is built according to the classical scheme and contains a cooled Input Stage with diode protection against breakdown of the input field-effect transistor (FET), the Main Section of the CSPA and the Buffer Stage [1-3]. The Buffer Stage has two analog signal outputs: an output for amplitude analysis and an output for timing measurements. To ensure the preamplifier's high input count rate, a Differentiator with a Pole-Zero Compensation is installed between the Main Section and the Buffer Stage.

An important characteristic of the detector that affects the energy resolution is the leakage current [10, 11]. The DC component of voltage from the CSPA Main Section output is used to measure the detector leakage current in the absence of an input count rate, as well as to monitor the baseline shift at the Main Section output when increasing the input count rate. When changing the detector leakage current, the change in voltage at the Main Section output is quite significant. Thus, with a feedback resistor of 1.0 G and a detector leakage current of 20 pA, the additional baseline shift is 20 mV, which allows it to be fed directly to the input of the microcontroller's analog-to-digital converter. In the process of tuning the preamplifier with a detector – the detector's bias voltage being low, the bias voltage at the Main Section output is measured and stored in the microcontroller's memory. The leakage current level calculated from this bias voltage is taken as zero detector leakage current. With a rise of the detector's bias voltage, its leakage current increases and, accordingly, the bias voltage of the baseline at the CSPA Main Section output rises as well.

The bias voltage is also used to control the CSPA input count rate. With an increase of the detector's input count rate, signals are overlapping and, as a consequence, the baseline at the *Main Section* output is shifted. At a high input count rate, the baseline shift can exceed the dynamic range of the output signals and, as a result, make it impossible to register the signals. The maximum input count rate of the CSPA for the HPGe detector, with a supply voltage of +/– 12V, C_{oc} = 1 pF, R_{oc} = 1 G and a gamma-quanta energy of 662 keV, is (450-480) 10^3 cps. The signal amplitude is 35.3 mV, or 53.3 mV $(MeV)^{-1}$. The baseline shift over the preset limiting threshold is displayed in the corresponding window of the *SHP Control* software (see the next sub-section) and an external LED indicator.

A small amplitude of signals at the preamplifier output imposes stricter noise requirements for the rest of the CSPA spectrometric chain. To increase the signal amplitude, an additional CSPA buffer stage with a gain of from 3 to 5 times is installed in the CSPA, which makes it possible to increase and normalize signal amplitude. The decay time constant of the output signal is selected in the range of 40 μs to 60 μs, which allows working with almost all types of multichannel analyzers.

With the buffer stage, the Main Section is connected through a differentiator with a pole-zero compensation. The scheme of the differentiating circuit with pole-zero compensation is shown in fig. 2. The circuit contains a $C_d R_d$ differentiating circuit, where an additional R_k resistor is connected in parallel to the capacitor through a voltage divider based on a digital-to-analog converter (DAC). Changing the turn-on ratio of this resistance provides overswing compensation at the output of the differentiating circuit. The resistance turn-on ratio is controlled using the software, by changing the code at the DAC digital input.

The SHP-01 intelligent preamplifier also contains a number of modules that control the detecting unit's parameters.

Detector temperature. The analog part of the detector temperature sensor is built based on a classical scheme [12]. A constant current of about 0.3-1.0 mA is passed through the PT-100 temperature sensor mounted on the detector holder. The voltage drop across the sensor resistance is amplified by the operational amplifier and fed to the input of the microcontroller's analog-to-digital converter. Once the temperature sensor has been calibrated, its data is displayed in the *SHP Control* operator program window and is used to generate a signal to prohibit the high bias voltage of the detector. The HV inhibit output provides a HV inhibit signal if the temperature of

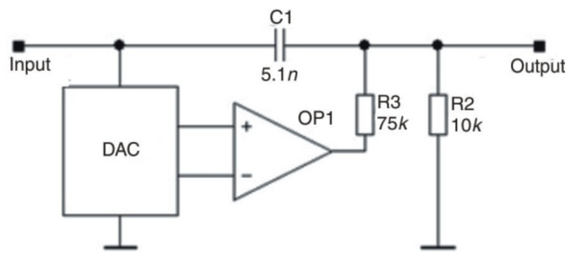

Figure 2. Pole-zero compensation in SHP-01

the detector exceeds a threshold level. The threshold level of the detector temperature is set at to the manufacture phase and is (–175 - –185) °C. The HV inhibit signal is a TTL logic signal, where the high-level signal allows to switch the HV.

The Internal Test Pulser generates test pulses to control the amplifying chain of the spectrometer. The microcontroller provides regulation of the amplitude (0-1000 mV) and frequency (5-2500 Hz) of the pulses, and also stores the set parameters in the SHP-01 non-volatile memory. The pulser parameters are controlled from the corresponding window of the *SHP Control* operator software.

Liquid nitrogen level sensor. The principle of a liquid nitrogen level sensor's operation is based on measuring the capacity of the sensor immersed in liquid nitrogen. The nitrogen level sensor can be initiated at the customer's request during the production phase. Once the sensor is initiated, it can be turned on or off at any time at the operator's command. The nitrogen level value is displayed in the *SHP Control* window as a percentage. The sensor has an alert system for a critically low level of nitrogen in the Dewar. The alarm threshold is set by the operator and can be changed at any time.

The SHP-01 intelligent preamplifier also contains additional modules that provide control of temperature, humidity and pressure in the sealed preamplifier housing, control of preamplifier supply voltages, as well as voltage on the input field-effect transistor substrate.

The SHP Control Software

The SHP-01 intelligent preamplifier parameters are controlled by a specialized *SHP Control* software. The software does not need to be installed in the Windows operating system, but is simply installed on the operator's computer running under its control. The program offers to review the CSPA and the detector data, monitor their parameters in real time, as well as control the test pulser and different built-in sensors. All measured parameters are saved in separate files on the computer at the operator's discretion.

The *SHP Control* software can operate in two modes. The basic mode of operation is *Initialization on demand.* In this mode, after the initial setting of all parameters, the preamplifier controller is turned off. The operator can at any time use the slider in the software window to establish a SHP-01 connection with the computer, read the parameters and turn it off again.

Another mode of the software is the *Constant monitoring of parameters*. In this mode, the preamplifier controller is constantly in operation, measuring various parameters. The choice of the processor operating mode is carried out by the operator at his own discretion at any time using the slider in the software window. The list of controlled and settable parameters of the SHP-01 intelligent preamplifier is given in tab. 1.

Table 1. The list of controlled and settable parameters of the SHP-01 intelligent preamplifier

Main settings	SHP-01
Detector leakage current	Measurement
Charge loop DC level	Measurement
Output stage DC level	Measurement
FET back-gate voltage	Setting
FET drain voltage	Setting
Detector temperature	Measurement
Ambient temperature	Measurement
Ambient humidity	Measurement
Ambient pressure	Measurement
+12V supply	Measurement
–12V supply	Measurement
Liquid nitrogen level sensor	+
Internal test pulser	+
Ability to stop the microcontroller	+
Connection to the computer	USB 2.0
Signal output for amplitude analysis	+
Signal output for timing analysis	+
Signal HV inhibit output	+
External indicator of prohibition of HV switching	+
External overload indicator	+
Detector serial number/authentication code	+
Power supply	+12 V, 60 mA
	–12 V, 25 mA

INTELLIGENT PREAMPLIFIER PERFORMANCE RESEARCH AND ANALYSIS OF RESULTS

Currently, provision of CSPA spectrometric characteristics in accordance with modern requirements [13] is not a problem for professionals. However, embedding a significant number of digital devices into the analogue CSPA circuit can affect its operation and lead to deterioration of measurement characteristics, first of all – the energy resolution. Therefore, during development and research, much attention has been given to controlling the influence of the digital part of the intelligent preamplifier over the analog one.

To perform spectrometry performance research, the SHP-01 intelligent preamplifier was connected to the GCD20180 and GCD50190 coaxial HPGe detectors having known spectrometric characteristics, measured with a BSI serial reference CSPA. For the spectra acquisition and their subsequent analysis, we used an MCA Boson equipped with the GammaPro software package [14]. The spectra were acquired in different energy ranges with the Microcontroller turned on and off. Measurement results are shown in tab. 2, and the spectra of ^{241}Am and ^{60}Co, registered by the GCD50190 detector with the designed SHP-01 intelligent preamplifier, are shown in fig. 3.

As can be seen from tab. 2, the energy resolution of both detectors does not deteriorate when using an intelligent preamplifier with the controller being both on and off. No distortions of the spectra shape caused by parasitic signals from the digital part, or their influence on other parameters of the CSPA, were noticed, either.

CONCLUSION

Thus, embedding a microcontroller into the HPGe detector CSPA leads to a new quality and an increase in the functionality of such an intelligent preamplifier. The built-in microcontroller allows the operator to control parameters of the detector and the preamplifier itself, as well as the operation of the internal test pulser, liquid nitrogen level sensor and other built-in units. As our results have shown, the digital part of the intelligent preamplifier does not have a visible effect on the characteristics of the CSPA itself and the spectrometric characteristics of the HPGe detector. The intelligent preamplifier operation is controlled by the appropriate software.

AUTHORS' CONTRIBUTIONS

V. F. Kondratjev – development of the analogue section; V. S. Litvinsky – development of the digital section; S. S. Pohuliai – supervising and article writing.

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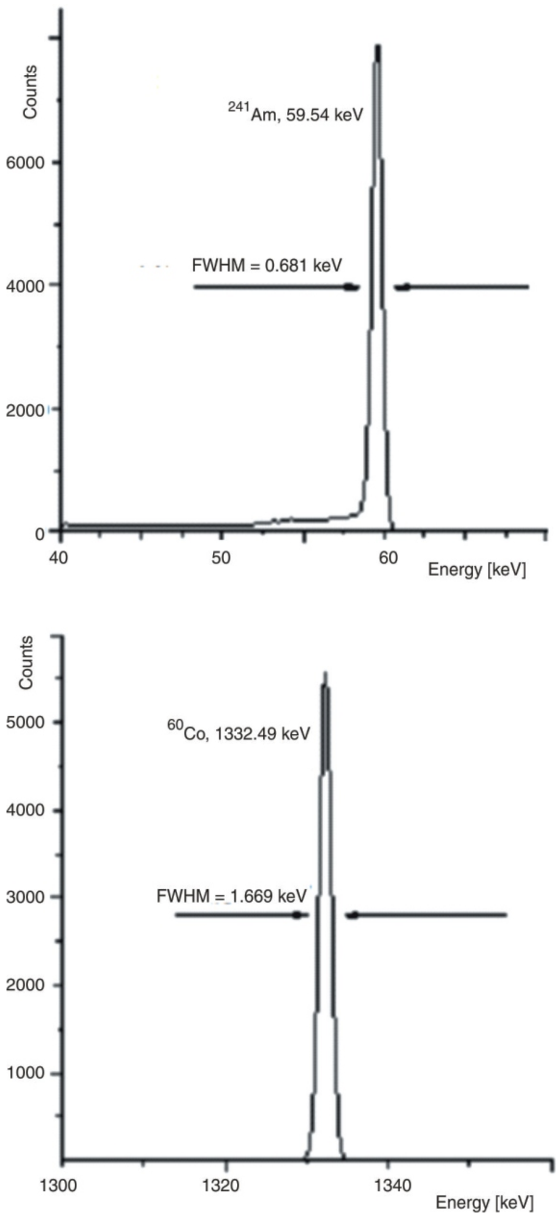

Figure 3. The ^{241}Am and ^{60}Co spectra, registered by the GCD50190 detector with the SHP-01 intelligent preamplifier

Table 2. Energy resolution of HPGe detectors with SHP-01 controller switch on and off

Radiation energy [keV]	Reference CSPA FWHM [keV]		SHP-01, controller off, FWHM [keV]		SHP-01, controller on, FWHM [keV]	
	GCD20180	GCD50190	GCD20180	GCD50190	GCD20180	GCD50190
Pulser	0.612	0.598	0.612	0.598	0.646	0.617
59.6 (^{241}Am)	0.688	0.685	0.688	0.683	0.698	0.681
122.0 (^{57}Co)	0.727	0.728	0.727	0.728	0.731	0.733
662.0 (^{137}Cs)	1.203	1.198	1.203	1.198	1.204	1.204
1332.5 (^{60}Co)	1.617	1.676	1.617	1.676	1.631	1.669
2614.0 (^{238}Th)	2.256	2.299	2.256	2.299	2.243	2.300

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РАЗВОЈ ИНТЕЛИГЕНТНОГ ПРЕТПОЈАЧАВАЧА ЗА ПОЛУПРОВОДНИЧКЕ ДЕТЕКТОРЕ

Представљени су резултати пројектовања интелигентног претпојачавача за HPGe гама-детекторе. Интелигентни претпојачавач је претпојачавач ниског шума, отпоран на повратне спреге, осетљив на пуњење великом брзином, са уграђеним микроконтролером и додатним јединицама које омогућавају контролу параметара претпојачавача и детектора. Омогућено је такође управљање перформансама интерног тестирајућег пулсера, сензора нивоа течног азота у Девару, сензора влажности, притиска и температуре у запечаћеном одељку претпојачавача. Рад интлигентног претпојачавача, подешавање и мерење параметара контролише софтвер.

Кључне речи: интелигентни претпојачавач, претпојачавач осетљив на пуњење, HPGe детектор