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METHODS OF PHYSICAL EXPERIMENT

Study of the Temperature Stability of the High-Voltage DAC AD5535 for Powering Silicon Photomultipiers

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Abstract—In this paper we present the results of a study of a high-voltage 32-channel DAC AD5535 for powering silicon photomultipliers. Built-in high-voltage buffer amplifiers allow output voltage regulation in the range of up to 200 V, which provides application for a broad SiPM types, including their serial connection. The significant output current of 500 μA/ch allows biasing the SiPM arrays and assemblies. The documentation indicates a significant temperature dependence of ~200 ppm/C, which limits the use of DAC for SiPM powering. This work demonstrates the excellent temperature stability of the chip. Still, since the manufacturer does not guarantee this, an express method of channel-by-channel measurement of temperature dependence has been developed for a mass use of the AD5535 DAC

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1. SILICON PHOTOMULTIPLIERS BIASING

A silicon photomultiplier (SiPM) is a semiconductor avalanche photodiode consisting of many microcells operating in the Geiger mode. Currently, SiPMs are widely used in physical experiments and measuring, medical, and industrial equipment, etc., as photodetectors for recording light fluxes of low intensity. Modern particle detectors using SiPMs can contain thousands and tens of thousands of channels, which requires the use of multichannel powering systems. An additional reason for using a large number of channels in the power supply system is the spread of operating voltages of SiPMs, which in some cases reaches several volts for products of the same type. The typical value of a current consumed by SiPM ranges from units of nanoamperes to tens of microamperes. The operating voltage of such devices usually ranges from 25 to 100 V. For example, for the widespread Hamamatsu MPPC S13360, this value at room temperature is 50–60 V [1]. A typical SiPM connection circuit is shown in Fig. 1a.

The power supply for silicon photomultipliers must have high temperature and time stability of the output voltage. The problem of creating multichannel power supplies for SiPM can be solved by using integrated circuits of multichannel digital-to-analog converters (DACs) with sufficient resolution and stability. However, the output voltage of most DACs is not always

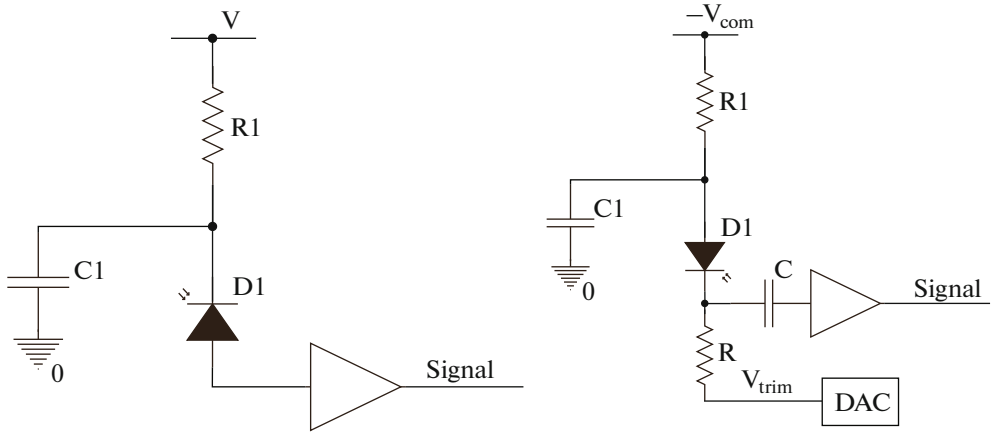


Fig. 1. Powering and readout layout of SiPM. The unipolar supply circuit is on the left. The supply circuit with cathode and anode bias is on the right.

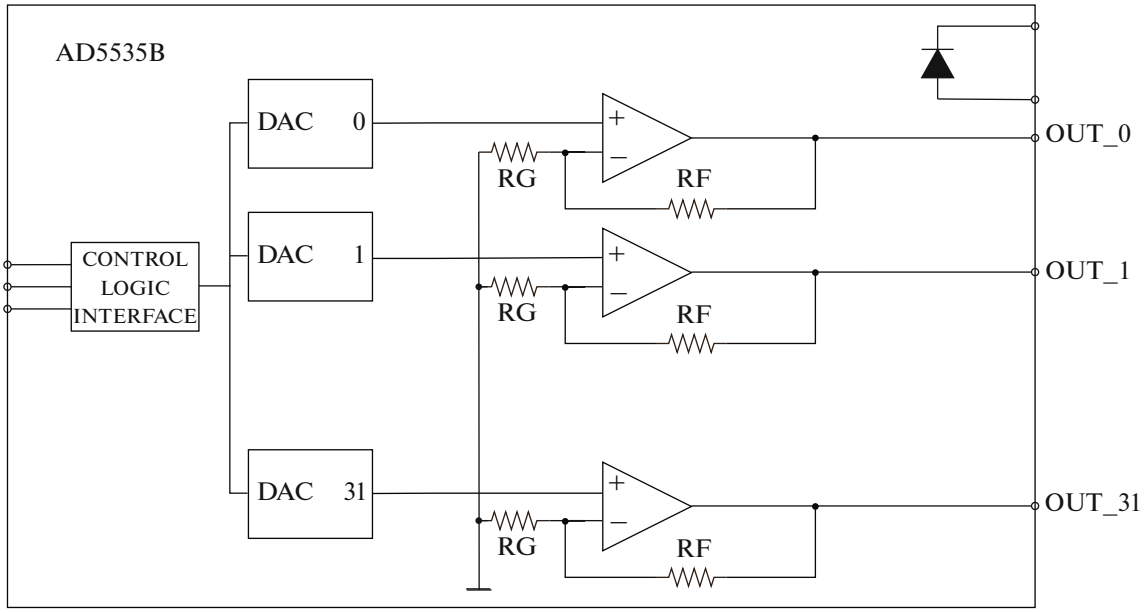


Fig. 2. Simplified block diagram of the DAC AD5535B.

sufficient for direct operation with SiPMs. This requires taking measures to expand the output voltage range by introducing additional external piping, which complicates the circuit and in some cases can lead to a deterioration in its performances. Another way to solve this problem is to use a multichannel low-voltage DAC, for example [2], along with a common bias source to power the SiPM group. In this case, high-resolution operating voltage adjustment is required only in a narrow range. Schematically, such a way to turn on the SiPM is shown in Fig. 1b. An example of using such a power supply scheme can be found in [3]. A constant negative voltage V_{com}, common to all channels, is applied to the cathode of the photodiode through the resistor R1. The voltage Vtrim is supplied to the anode from the output of the DAC through a subdividing resistor R. The photodiode voltage is adjusted within the limits ($V_{com} - V_{com} + V_{trim}$). Coupling to the AC input of the (external) amplifier is performed via coupling capacitor C, which is not always desirable when operating with high loads. In addition, connecting a DAC to the input of an amplifier can worsen the noise performances of the channel.

In some cases, it is expedient to use a unipolar power supply circuit (see Fig. 1a) and read the signal using DC. This approach has non of the disadvantages described above, but requires the use of a DAC with regulation in a wide voltage range that overlap the operating voltage of SiPM. A good candidate is a AD5535 DAC [4] by Analog Devices. However, the manufacturer guarantees temperature stability no worse than ~200 ppm/°C, which is about 10 mV/°C at a typical SiPM supply voltage. This can significantly limit the use of this device.

In this paper we study the temperature dependence of the output voltage of a 32-channel high-voltage DAC AD5535 and show that it is an order of magnitude better than that stated for most microchips. This makes it possible to use the AD5535 DAC to power SiPM, provided that chips with satisfactory parameters are chosen. The paper also presents an express method for selecting DACs for temperature stability for the mass production of power supplies for silicon photomultipliers.

2. TEMPERATURE STABILITY OF OUTPUT VOLTAGE OF THE AD5535 MICROCHIP

2.1. AD5535 Microchip

The AD5535 microchip from Analog Devices is a 32-channel DAC with a resolution of 14 bit. It has built-in high voltage gain amplifiers with a gain factor of $A = 50$ (see Fig. 2). The AD5535 microchips are supplied in a 124-pin CSP_BGA package and have a built-in internal measuring diode (thermal sensor), which enables temperature monitoring of the crystal. The maximum output voltage U_{max}—from 50 to 200 V, depending on the selected reference voltage U_{ref} is calculated by formula (1). The maximum load current per one channel is 550 μA. The manufacturer guarantees the linearity of the output voltage in the range from 7 V to U_{max}. Typically, when operating in physics installations, the power supply may experience significant temperature variations, so it is important that the dependence of the output voltage on temperature is not significant. Temperature drift rating is –200 ppm/°C.

$$U_{max} = U_{ref} A, \quad (1)$$

where $A = 50$ is the gain of a high-voltage amplifier.

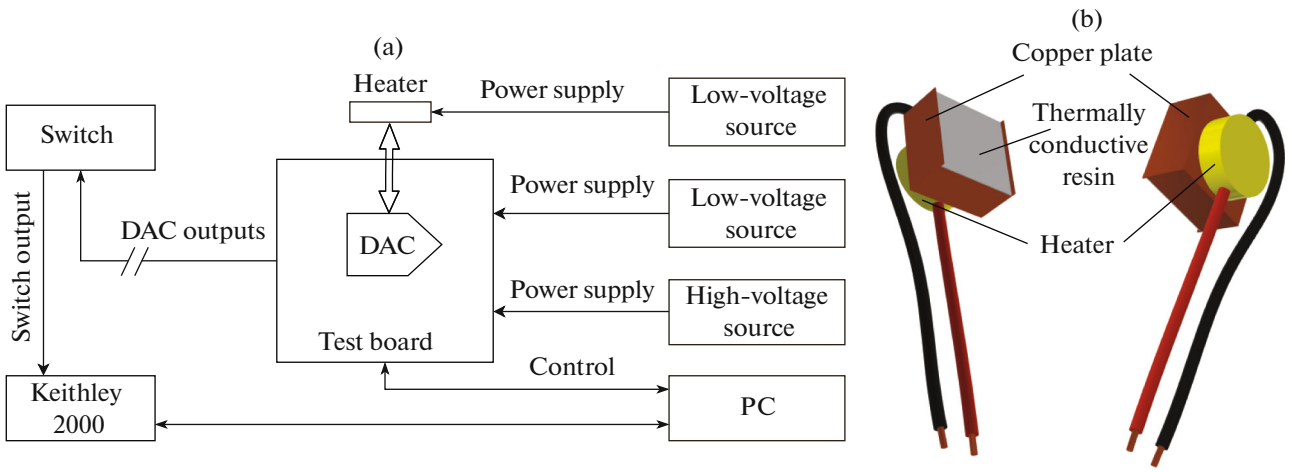


Fig. 3. (a) Block diagram of temperature tests of the AD5535 microchip; (b) heater used in the tests.

Silicon photomultipliers are characterized by a fairly low operating voltage of less than 100 V (for most market models). Thus, the operating voltage range (up to 200 V) of the AD5535 microchip indicates the possibility of its use in SiPM power supply systems using a unipolar power supply circuit and DC signal readout (see Fig. 1a). In this work, we studied the temperature performances of theAD5535 microchips and analyzed them for the possibility of using in SiPM power systems (see the following sections).

2.2. Studying the Temperature Stability of Output Voltage of the AD5535 Microchip

Performances of silicon photomultipliers strongly depend on temperature and bias voltage, which requires their stabilization during the operation of SiPMs. In practice, during the operation of SiPMs, their stable temperature is controlled with an accuracy of several °C. Thus, it is also necessary to provide a stable bias voltage for silicon PMs. Most modern silicon PMs operate at an overvoltage V_{OV}, which is 3–5 V higher than their breakdown voltage. Ensuring the SiPM stability at the level of 1% is acceptable for most applications. Accordingly, this requires the overvoltage stability of SiPM at the level of 30–50 mV. Thus, the requirements for the stability of the output voltage are imposed on the power supply systems of SiPMs.

According to the documentation provided by the manufacturer of the AD5535 chip, the temperature dependence of the output performances of the DAC + buffer amplifier is –200 ppm/°C. Such a temperature drift of the microchip voltage is critical for the stable operation of SiPMs. Thus, before using AD5535 microchips as a power source for silicon photomultipliers, it becomes necessary to certify them for the stability of the output voltage, depending on the temperature regime of their operation.

This paper presents a method for studying the dependence of the output voltage of the AD5535 microchip on temperature, which allows one to efficiently and quickly[1] obtain the dependence U(t) within the operating temperature range of the microchip. Thus, it is possible to assess the stability of the output voltage of a single microchip. For the research, we have developed[2] a circuit board with mounted AD5535 chips and voltage references that allows one to control the chip using a serial peripheral interface (SPI) and has output pins for all DAC channels on a separate connector. An external multichannel switcher controlled from the PC was connected to this connector. In this way, the outputs of all DAC channels were connected in series to a Keithley 2000 precision multimeter to control the output voltage on each of the channels. The data by Keithley 2000 were read out using a PC. The crystal of microchip was heated to the required temperature using an external removable heater. The crystal temperature was read out from the internal thermal sensor (diode) of the microchip and transmitted to the PC. The scheme of measurements is shown in Fig. 3a.

The removable heater is a copper plate, which is tightly joined with the body of the microchip under study. The heating of the microchip crystal occurs due to heat exchange with the copper plate. Its heating is carried out using a heating element mounted on it (see Fig. 3b). An external power supply is used to power and regulate the current passing through the heating element, which ultimately leads to the heating of the chip + heater assembly to the temperature required in the current measurement. Such a scheme allows one to heat up a microchip to the maximum operating

[1] Compared to measurements in a temperature-controlled chamber.
[2] This product is designed for the manufacturing of multichannel SiPM power supplies [5]

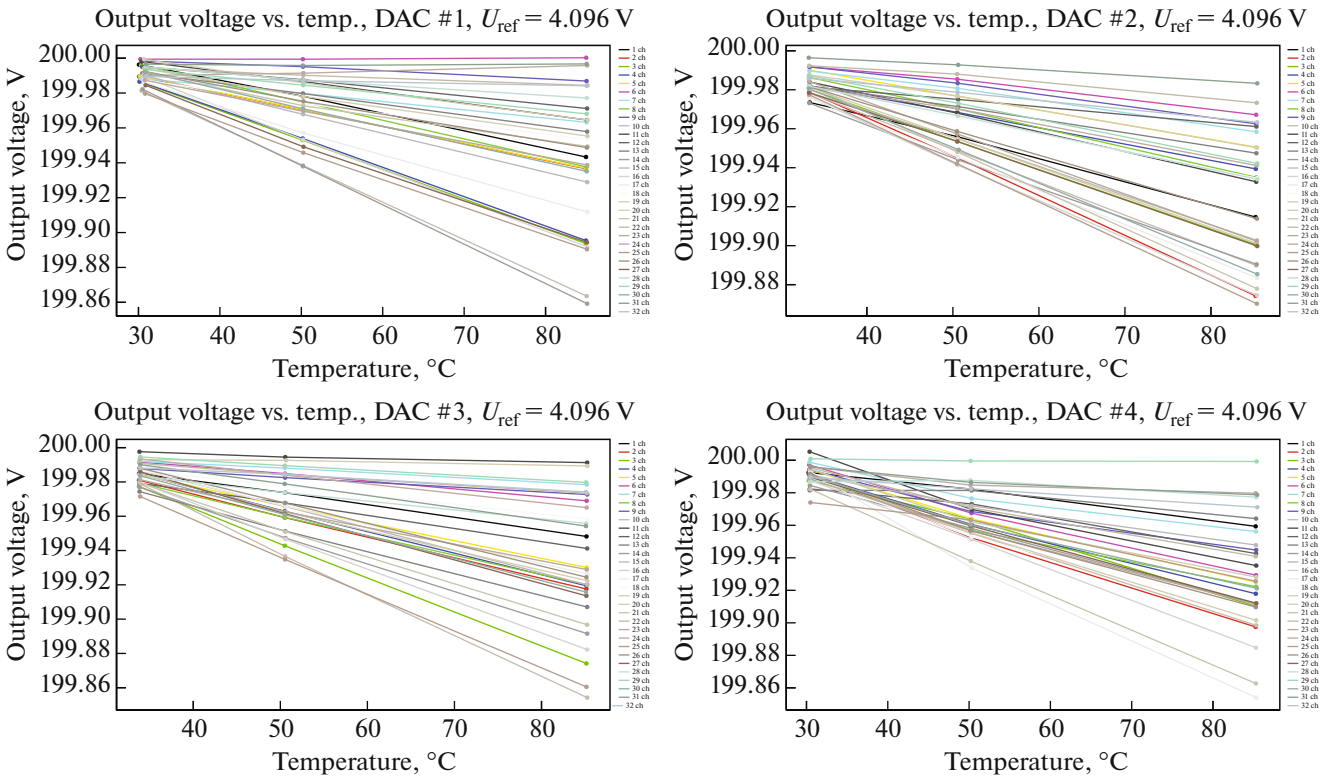


Fig. 4. Output voltage dependence on 32 channels of four AD5535 microchips.

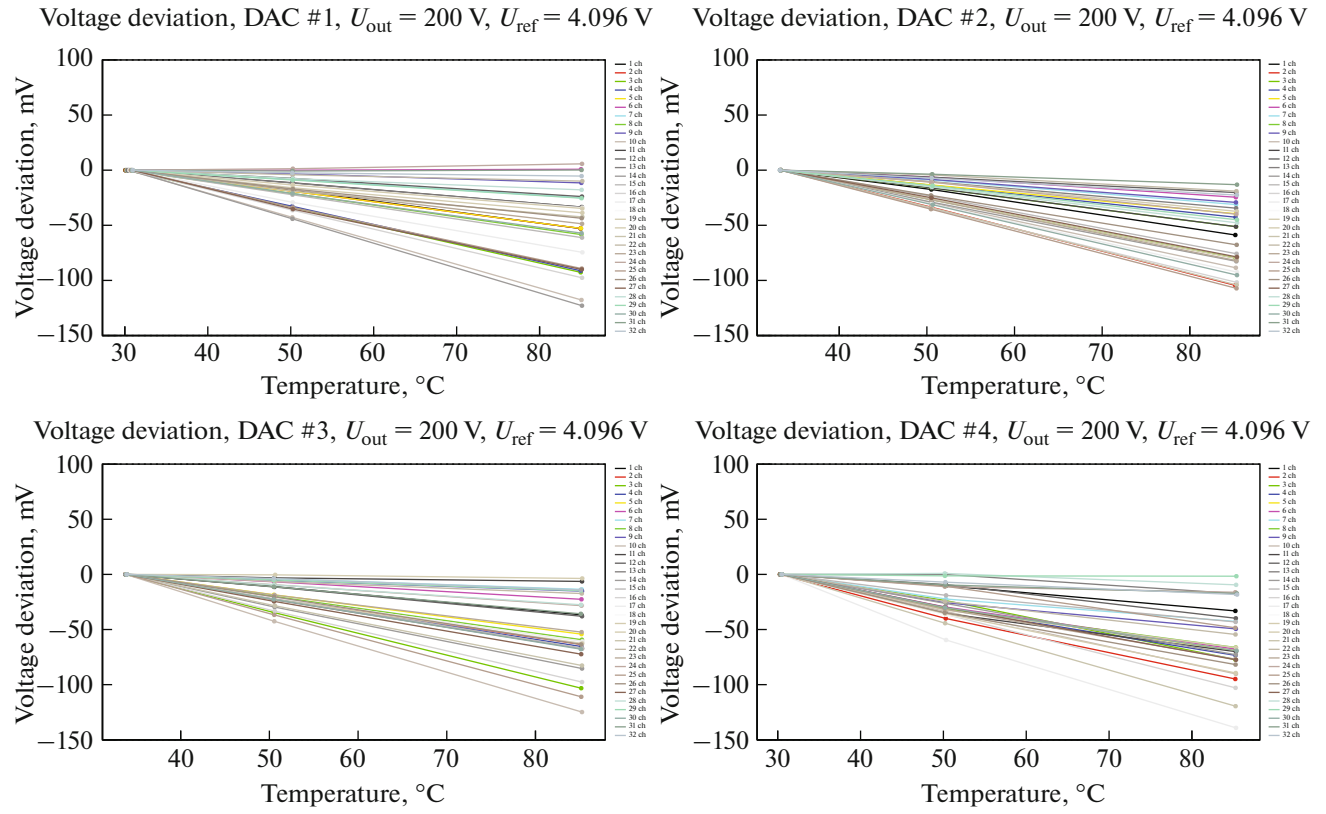


Fig. 5. Deviation of the output voltage on the channels of four AD5535 microchips depending on temperature. The initial output voltage was obtained at room temperature.

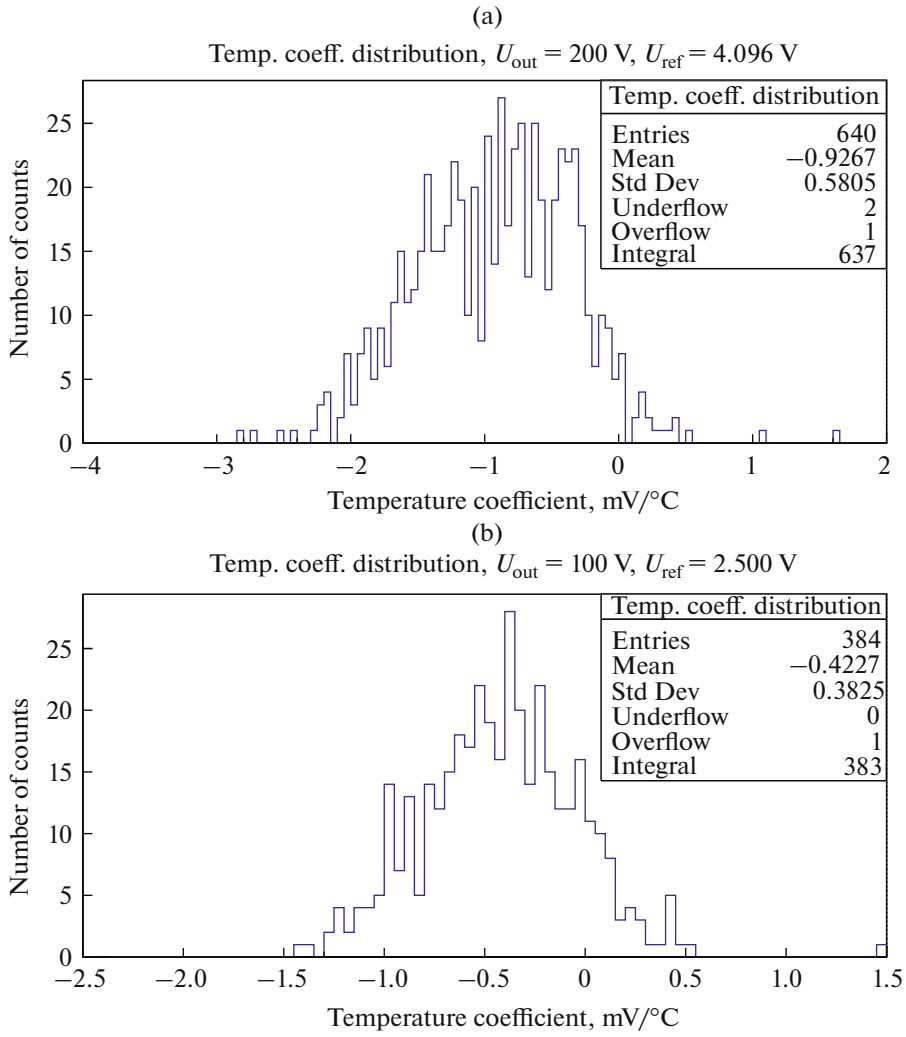


Fig. 6. Distribution of temperature coefficients for (a) U_{out} = 200 V and U_{ref} = 4.096 V; (b) U_{out} = 100 V and U_{ref} = 2.5 V.

temperature of 85°C, as is indicated in the passport data.

In this work, we studied the stability of the output voltage $U(t)$ depending on temperature for 32 AD5535BKBCZ microchips manufactured by Analog Devices. The operating voltage range of the AD5535 chip depends on the value of the external reference voltage U_{ref} fed to it. We used two reference voltage sources (RVS) U_{ref} = 2.5 V and U_{ref} = 4.096 V in the setup, which corresponds to 125 and 200 V of operating voltage range of the microchip and completely covers the operating voltage range of all widely used SiPMs. The range of temperatures under study was about 55°C. Initially, the temperature and voltage at 32 microchip outputs were measured at room ambient temperature. The last measurement was carried out for a microchip heated to 85°C. Based on the measurement results, we obtained a curve of the voltage-temperature dependence on each channel of microchip (see Fig. 5). For a more clear data representation, the deviation curve of the output voltage of each channel of microchip from the voltage set at room temperature was plotted (see Fig. 6). Part of the chips was studied using a voltage of U_{ref} = 2.5 V, and the other part with U_{ref} = 4.096 V. The value of the output voltage in the measurements was chosen individually for each microchip and depended on the value of the RVS used.

To analyze the stability of the output voltage of a single microchip, a linear approximation of the obtained dependences $U(t)$ was performed. Based on the results of linear approximation, the slope coefficients k of the curves were obtained, which characterize the change in the output voltage depending on the temperature. For each chip, 32 values of k were determined. Figure 7a plots the distribution of parameters k for 20 microchips measured for U_{ref} = 4.096 B at the preset output voltage U_{out} = 200 V. It should be noted

that for three channels of three microchips, the values of k turned out to be 5.54, –6.36, and –16.36 mV/°C, so they are out of the hystogram range (Fig. 7a). Figure 7b shows the distribution of k for 12 chips at U_{out} = 100 V and U_{ref} = 2.5 V. The value k = 11.67 mV/°C of one channel in Fig. 7b is out of the hystogram range.

3. CONCLUSIONS

To study the temperature dependence of performances of the AD5535 microchip, we created a setup and developed a method for express testing the dependence of the output voltage of microchip channels on its temperature regime. This allows one to efficiently and quickly obtain the temperature drift coefficient of each channel of the microchip.

We have shown that the temperature drift of the studied microchips samples does not exceed 3 mV/°C at a voltage of 200 V, which is 15 ppm/°C, and, in the case of voltages up to 100 V, it does not exceed 1.5 mV/°C or fall below 7.5 ppm/°C. It should be noted that some microchips have separate channels for which the temperature drift significantly exceeds the above values. The technique used in this work allows selecting the AD5535 DAC chips with the output voltage temperature drift determined by the requirements of a particular application.

The wide range of output voltages of the AD5535 microchip and the ability to individually set the voltage on each of its channels is a great advantage when using these microchips in SiPM power supply systems. However, it is necessary to guarantee the required temperature stability of the chip. Based on the data obtained in the work, the temperature drift for most of the investigated AD5535 microchips does not exceed 3 mV/°C. In the case of using selected AD5535 microchips (without anomalous channels) in power supply systems for silicon photomultipliers, it is necessary to stabilize their temperature regime within 10–15°C, which will ensure the stability of the SiPM performances at the level of 1%.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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