Compensation of the nonuniformity of sensitivity for the multielement infrared photodetector

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Abstract. Application of spectral devices for the detection of small concentrations of substances presents high demands on the signal dynamic range. Commonly used multielement photodetectors have a substantial nonuniformity of both sensitivity and dark signal that significantly narrows the dynamic range. For correction of such situation it was designed an amplifier with individual correction of gain and offset of a dark signal for each pixel that considerably enhances dynamic range and presents an ability to effectively detect weak signals.

1. Introduction
In optical spectrometers for the registration of radiation in the infrared (IR) region of a spectral range most commonly used are photodiode linear arrays based on InGaAs [1, 2]. Such photodiodes detect radiation in a spectral range 0.9–2.55 μm. These photosensitive arrays use CMOS (complementary metal–oxide–semiconductor) signal processing system with individual amplifiers for each photodiode and a multiplexer for the selection of a channel.

Application of spectral devices for the detection of small concentrations (several ppm) of substances presents high demands on the dynamic range of a signal. It is often necessary to record minor deviations of a signal for the lines of emission or absorption of analyte on the background level of a rather high intensity [3].

2. Development of the amplifier design for compensation of the nonuniformity of sensitivity
Multielement photodetectors of IR region, as a rule, are built using a double-crystal scheme, consisting of a linear array of InGaAs photodiodes and CMOS amplifiers with a control unit (figure 1).

![Figure 1. Internal structure of a multielement IR photodetector.](image-url)
In this design multielement photodetectors have the following disadvantages:

- nonuniformity of the sensitivity of photodetectors can reach 10–20 %;
- photodetectors have a significant nonuniformity of a dark signal, in addition depending on the temperature of a crystal.

Signal obtained using a multielement IR photodetector G9206-256W manufactured by Hamamatsu exposed to uniform illumination is shown in figure 2. It is obvious that with such irregularity of both dark signal and sensitivity the dynamic range of the photodetector is significantly narrowed.

Figure 2. Output signal of a multielement IR photodetector.

Preamplification of the output signal having such a significant nonuniformity leads to the fact that the constant component of a dark signal also increases; consequently the remaining amplitude of a useful signal is noticeably reduced. For example if a photodetector has a dark signal of 20 % compared to the minimum value, the gain ratio of 5 leads to a full saturation of the output signal, making registration of a useful signal using this photodetector unrealizable [4].

For correction of such situation it is possible to presubtract the dark signal level from the output signal before amplification using a differential amplifier. In the case of a multielement IR photodetector such compensation must be carried out individually for each photodiode. Nonuniformity of the sensitivity also should be compensated individually. Thus the structure of the output signal amplification scheme should have two cascades – compensation of the nonuniformity of a dark signal and an adjustable gain of the useful signal (figure 3).

Figure 3. Compensation of a dark signal in the absence of a useful signal.
Amplitude of the useful component of an output signal of a multielement IR photodetector usually does not exceed 2 V, but the signal itself is shifted by a DC (direct current) component on 1.5–2 V. Taking into account nonuniformity of a dark signal of about 10–20 %, the amplitude of the compensation signal reaches 200–400 mV on the background of a constant shift of up to 2 V.

In this case application of common digital-to-analog converters (DAC) becomes inefficient as less than 10 % of their operating range is used. The most convenient in this case is implementation of a so-called “electronic potentiometer”. This potentiometer is included into the circuit of a resistive divider that allows to accurately set the upper and lower limits of adjustment, thus ensuring almost 100 % utilization of the working range of adjustment.

Compensation of the nonuniformity of sensitivity requires a software adjustment of gain. Application of standard components, for example programmable gain amplifiers (PGA), does not solve this problem. In these amplifiers the adjustment is made by doubling the gain at each step, meantime in our case an exact change of gain in the range of 20 % is required. The best possible solution will be an amplifier with a digital potentiometer in the feedback circuit (figure 4).

As in the case of compensation of a dark signal, an electronic potentiometer is included into the circuit with additional resistors that allow to accurately set the boundaries of the gain control. Compensation signal is also connected to the divider for the subtraction of a DC component.

**Figure 4.** Gain adjustment for the uniform illumination.

Signal registration algorithm for one pixel includes the following steps:

- adjustment of the offset for the current pixel in two channels;
- adjustment of the gain for the current pixel in two channels;
- waiting for the sync pulse for the current pixel;
- acquiring data from ADC (analog-to-digital converter) via two channels;
- saving the data in the internal RAM (random-access memory) of the microcontroller.

For the correct operation for this circuit a precalibration is carried out. It consists of several stages:

- darkening of a photodetector and acquisition of an output signal;
- calculation of the correction values of the bias level for each pixel and filling of the appropriate data array in the microcontroller memory;
- application of the offset correction for obtaining of the near zero values of a dark signal;
- registration of a signal under the uniform illumination of a photodetector;
- calculation of the correction values of gain for each pixel and filling of the appropriate data array in the microcontroller memory;
- application of the gain correction for obtaining of similar values of the output signal under the uniform illumination of a photodetector.
Results of the signal detection using the proposed registration system with the correction of both offset and gain are shown in figure 5.

**Figure 5.** Signal of a multielement IR photodetector with correction of both offset and gain.

3. Conclusions
During the research was developed an amplifier design for a multielement IR photodetector with an individual correction of gain and offset of a dark signal for each pixel. Amplifier, having a minimum cost, significantly enhances the dynamic range and presents an ability to effectively detect weak signals, which is especially important in areas such as Raman spectroscopy. As a practical result of the work it can be mentioned that the use of this sensor and registration system allowed by increasing the spectral resolution in the IR range to improve the reliability of recognition of wood species using a Raman spectroscopy device [5].

References
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