Indonesian Journal of Electrical Engineering and Computer Science
Vol. 35, No. 2, August 2024, pp. 812~822
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v35.i2.pp812-822

Assembling and testing optoelectronic system to record and process signals from fiber-optic sensors

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Article Info

Article history:

Received Jan 14, 2024
Revised Mar 24, 2024
Accepted Mar 28, 2024

Keywords:

Fiber-optic sensor
LED
Light source controller
Microcontroller
Optical power detector
Optoelectronic system
Super luminescent diode

ABSTRACT

The given research presents assembling and testing optoelectronic system to record and process signals from fiber-optic sensors. The main optoelectronic systems to record and process the signals from fiber-optic sensors are light source controller and optical power detector. There was assembled controller diagram, which apart from light source includes current source for its adequate operation, as well as the systems necessary for stabilizing its working point. The scheme was modelled for specifying nominal and maximum operation criteria. Construction has been designed in the way, that light source controller includes structures of the current regulation and stabilization super luminescent diode (SLED) and temperature stabilization. Apart from that, there was assembled the microsystem of optical power detector additionally to the light detector, which includes the microsystems of intensification and filtration of the signal measured, processing analog data into digital form, microcontroller, used for preliminary data analysis. Data of optoelectronic systems diagram to record and process the signals from fiber-optic sensors has high response speed, low noise level and sufficient progress.

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1. INTRODUCTION

Currently there is great interest to developing specific, sensitive, cheap and portable optoelectronic devices. The latest development of new sensitive and selective materials plays an important role in complex industrial samples, environmental objects. Additionally, fiber-optic technologies are widely applied to many processes of optical measurements due to their important advantages, such as noise immunity and possibility of their usage for distance and multi-positional measurements.

Rachev *et al.* [1] the authors developed the light-emitting diode topology, capacity or stress analysis and diagrams of light-emitting diodes (LED) focus, which are technologies of LED. Shur and Zukauskas [2] there were developed and studied the possibilities of using LEDs, applying solid-state technologies. Schubert and Kim [3] presents research of stability, reliability and use of digital control of LEDs. Wang *et al.* [4] there was studied the light intensity, which was controlled by means of light-emitting diode drivers to manage the light emission, as well as, light-emitting diode sources, which have fixed correlated color temperature (CCT) and color reproduction. Since over half a century the LED is an integral part of everyday life. At first, the

LEDs property was insignificant, but scientific-technical developments brought to widening their usage in many areas [5]-[11]. The authors in [12]-[14] developed LED illuminators, which have a lot of advantages comparing to conventional incandescent lamps or gas discharged light source. The advantages are the ability to synthesize the colors, wide emission angles, high contrast and light output, low voltage power source and convenient to a user method of the stream control. The works [15]-[17] study LED sources, which have peculiar shortages, such as, LED scattering, LEDs dilapidation, change of environmental temperature, connections' temperature and environment humidity. Watjanatepin [18] shows, that LEDs high performance, design advantages and ease of power supply result in their wider usage. While developing LED technologies first there was regulated the working temperature of separate LEDs and multi-spectral LED's light source, which uses a small spectrometer to control the flow in the real time system. There was offered the method of optical sensor operation micro-electro-mechanical systems (MEMS) [19] as real-time spectrometer. Subsequently there is described the implementation of the sensor control circuit, which shows the reliability of spectral measurements and, consequently, the output stream property. Additionally, there was presented customer way to connect the analog part of the flow measurement path with the analog-to-digital conversion and the control system on the base of programmable logic device (PLD). Martín *et al.* [20] there was developed optoelectronic devices for optical chemical (bio) sounding. Particular attention was devoted to chemical sensors themselves, although only a few of them covered the design process of optoelectronic devices. Study of optical devices and optical measurement technologies used in this field was also suggested to provide a thorough understanding of the application areas. The light detector (photodetector) converts the optical signal into an electrical signal. The spectral characteristics of the photodetector are adapted to the emission spectrum of the optical sensor in order to avoid loss of information at critical wavelengths. In addition, the photodetector design accordingly has high sensitivity to cover the high signal-to-noise ratio (SNR). Fang *et al.* [21] and Han *et al*. [22] photodetectors with the main components of modern multifunctional technologies capable of converting light signals into electrical ones have been developed and researched. High-performance photodetectors play an important role in many areas of everyday life, including imaging [23], environment monitoring [24] and optical connections [25]. The works [26]-[32] created photodetectors, that specifically convert light into electrical signals, photodetectors have been developed for numerous applications, including medical diagnostics, aviation, target recognition, missile warning and other areas. Zhang *et al.* [33] investigated self-contained photodetectors that can perform light setting without an external power source. Self-powered devices can operate on their own due to the photoelectric effect based on p-n or Schottky transition, upon illuminating from the light source. Long *et al.* [34] introduced self-powered photodetectors based on p-n junction, showing outstanding photovoltaic characteristics. As part of this study, the design of the new assembly was investigated and tests were carried out on an optoelectronic system for recording and processing signals for fiber optic sensors. While previous research has examined photodetectors with the core components of modern functional technology capable of converting light signals into electrical signals, photodetectors that specifically convert light into electrical signals have also been created. LED topology, capacitance or voltage studies, and LED focusing circuits have been created that are represented by LED technologies. The ability to use LEDs using semiconductor technologies was also invented and studied.

The aspect of the technological novelty of the project is the development of an innovative optoelectronic system for monitoring and diagnosing the state of building structures, based on a combination of conventional fiber Bragg gratings and the so-called inclined fiber Bragg gratings. This concept is the result of a dynamic development in measurement technology that uses passive fiber optic components of this type. The possibility of their use in explosive environments, small size, resistance to electromagnetic interference and high sensitivity to deformation make fiber Bragg gratings attractive elements for these purposes.

2. METHOD

The basic equipment of optoelectronic components connected to optical sensors is simple in principle, because it uses conventional, commercially inexpensive spectroscopic components (optical electronics), normal light sources, optical filters or monochromators, light diverters and light detectors, the characteristics and cost of which will be determined according to specific needs. The probability of a single choice of any of those parts guarantees a large number of combinations. In fact, it is possible to design according to customer's order in the way so that it has sufficient characteristics for each specific case.

The purpose of the work is to create an optoelectronic system for recording and processing signals from fiber optic sensors:

- Analysis and selection of electronic components of the light source controller.
- Analysis and selection of electronic components of the optical power detector.
- Testing of optoelectronic system for recording and signal processing.

We found that when testing the light power controller, it was found that due to the capacity of the converter, the current ripple in the heated diode circuit was minimized, it was 20 A. Changing the temperature of the selected LED dramatically affects the power supplied by optical thorium. Thus, a three-stage sequential temperature stabilization design is maintained. The method proposed in this study typically has a new topology, which is dictated by the need to keep the temperature of the light source and optical power detector in temperature range.

3. RESULTS AND DISCUSSION

3.1. Assembly of an optoelectronic system for recording and processing signals from fiber-optic sensors. Assembling the light power controller

In this part of the study, an analysis of the used light sources was carried out according to the length of the emitted wavelength, electrical power and installation feasibility. Figure 1 shows the controller diagram. In addition to the light source, the controller circuit contains a current source necessary for its correct operation, as well systems necessary to stabilize its operating point. The proposed circuit was modeled to determine the nominal and limiting operating conditions. The system is designed in such a way, that the light source controller contains superluminescent diode (SLED) current adjustment and stabilization units, as well as temperature stabilization. Actuating elements must be made using MOSFET technology (MOSFET -Metal-Oxide-Semiconductor). The diode current was regulated and stabilized using a PID controller. Adjustment and stabilization of the temperature of the diode junction is carried out using the PI controller. There are three topologies of integrated light source systems as shown in Figure 2. Due to availability and economic aspects, it was decided to set up the internal connections of the module.

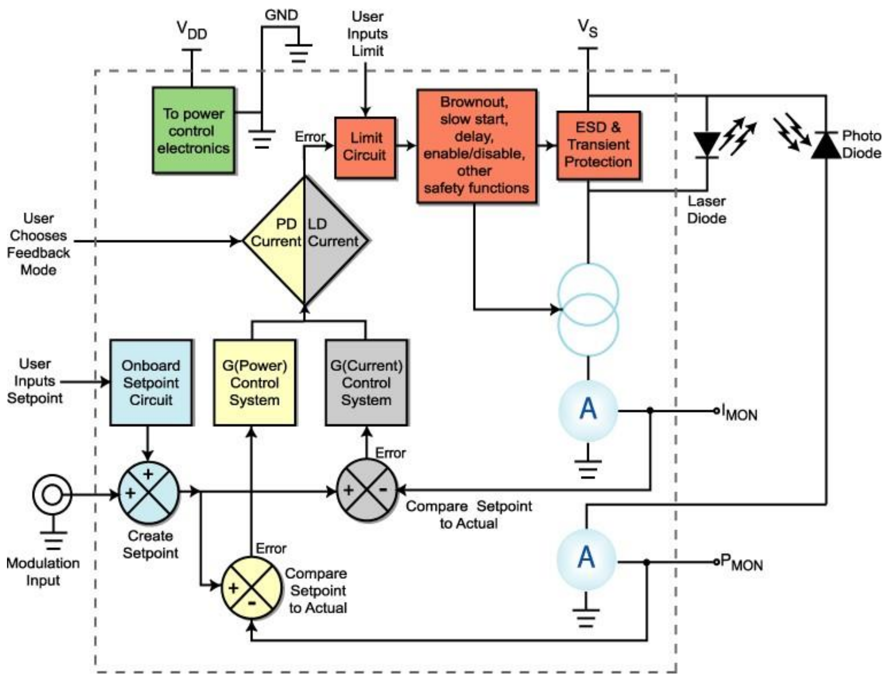

Figure 1. Control unit diagram

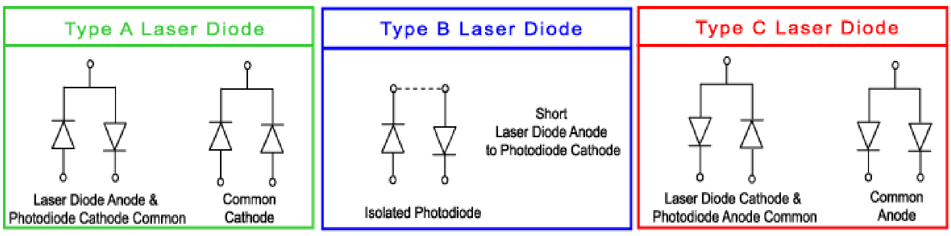

Figure 2. Possible internal configurations of the built-in SLED

Among the components available on the market, an integrated diode from Thorlabs was chosen. SLD1550S-A2 with the following options:
- Light wavelength δ_c: minimum 1520 nm, maximum 1580 nm (preferred 1550 nm);
- IOP diode current: 600mA maximum;
- PASE optical power: 2.5mW maximum;
- 3dB bandwidth: 90nm maximum (preferred 85nm);
- Effective value of ripple δ_G: preferred maximum 0.25 dB;
- Forward voltage VF: 1.6V maximum;
- TEC maximum ITEC current: 1.5 A;
- TEC allowable voltage VTEC: 3.5 V;
- Temperature sensor resistance RTH: 10 kOhm. The characteristics of the selected SLED are shown in Figure 3.

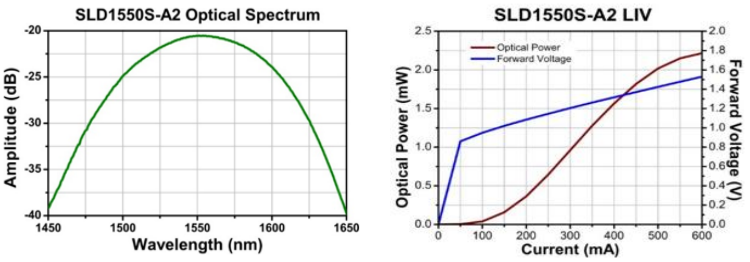

Figure 3. Characteristics of selected source of SLED

The case and conclusions of the proposed solution are shown in Figure 4. Figure 4 shows the characteristics of the selected SLED source. As can be seen from this figure, the dependence of wavelength on amplitude increases to a critical point, but decreases over time. This indicates that the SLED 1550S reaches an optimal level in terms of its technical characteristics. Characterization of the light source to determine the appropriate parameters for the PI (temperature) and PID (current) controllers was performed using a prototype with digital-analog transformer. The scheme of this circuit is shown in Figure 5.

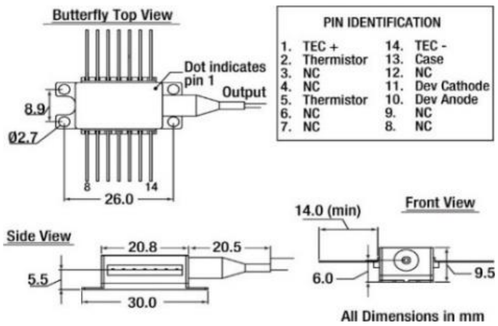

Figure 4. Selected light source – case and pinouts

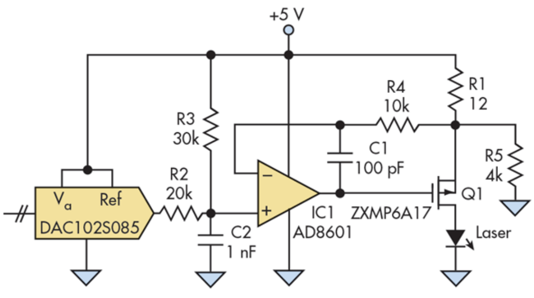

Figure 5. Preliminary circuit diagram of SLED current-carrying diode

3.2. Assembly of light power detectors

In this study, an analysis was made of the used detectors of light optical power due to the emitted wavelength, efficiency and feasibility of installation. Figure 6 shows the optical power detector chip. The optical power detector microcircuit, in addition to the light detector, includes microcircuits for amplifying and filtering the measured signal, a microcircuit for processing analog data into digital form, and a microcontroller used for preliminary data analysis. The proposed scheme was modeled to determine the nominal and limiting operating conditions. The optical power detector chip is an optoelectronic integrated circuit containing a photodiode and a transimpedance amplifier, constructed using two operational amplifiers in a single dielectrically isolated silicon structure. A visual diagram of the proposed solution is shown in Figure 6.

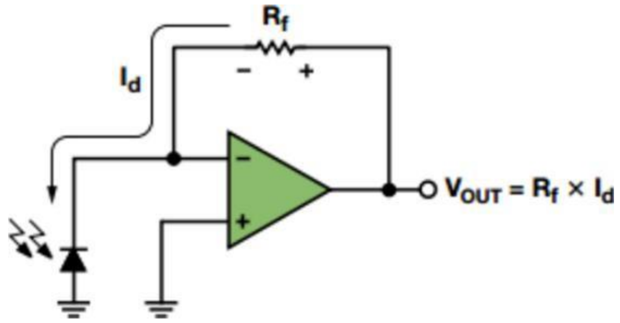

Figure 6. Suggested transimpedance amplifier configuration

The first stage of the transimpedance amplifier is implemented on an operational amplifier with a high-precision field-effect transistor and a built-in resistor with a metal layer. The second stage of the amplifier is divided by a voltage divider, where the output voltage range of the entire detector power system will be regulated.

From the elements available on the market, a Thorlabs photodiode with the Thorlabs FGA01FC symbol and parameters was selected:

- Light wavelength range λ: minimum 800 nm, maximum 1700 nm;
- Preferred light wavelength λ_P: 1550 nm;
- Photosensitive element diameter: 0,12 mm preferred;
- Ascent/descent time: (for R_L=50 Ω, 5 V) maximum 0,30 ns,
- Current dark I_d: (for 5 V): Preferred maximum 2,0 pF;
- Connector capacity Cj (for 5 V): Preferred maximum 2,0 pF;
- Maximum optical power: minimum 18 mW;
- Case: preferred- TO-46 (FC/PC);
- Semiconductor detector material: Preferred InGaAs.

The spectral characteristics of the selected photodiode are shown in Figure 7, and case form output is in Figure 8.

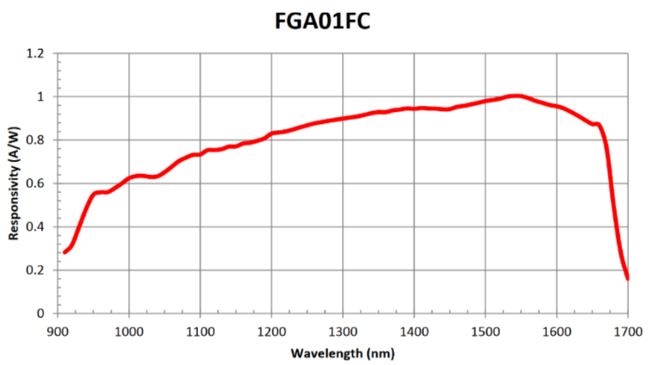

Figure 7. Spectral characteristics of the selected photodiode

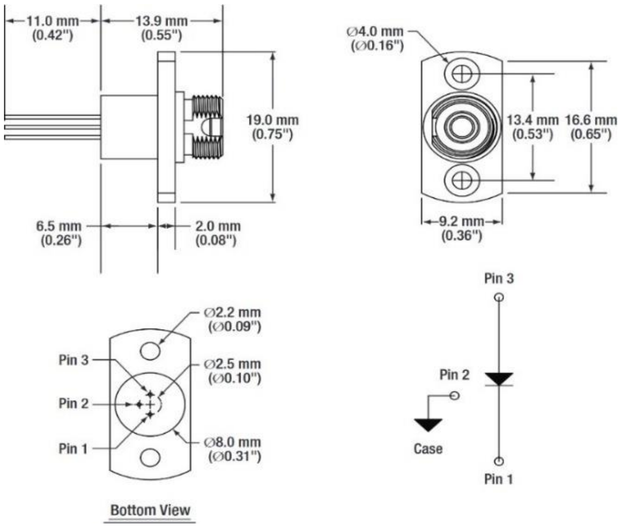

Figure 8. Housing and pin assignment of the selected

The proposed design of the measuring system ensures the voltage polarization of the receiving diode with almost zero bias current (bias). This solution will significantly improve the processing characteristics of the proposed system, improving its linearity, and will also allow operation at very low values of the dark current of the photodiode. Reducing these settings will greatly reduce the problems, associated with leakage current error, increased noise, and gain peaks caused by random capacitance. An additional advantage of the proposed circuit is a low supply current of about 400 µA. For testing, a prototype power detector system was developed and manufactured, including a measuring amplifier, a test power supply system with a reduced ripple factor, as well as, additional measuring systems, i.e. measuring the temperature and current consumed by the proposed solution as shown in Figure 9. For testing, a prototype power detector system was developed and manufactured, including a measuring amplifier, a test power supply system with a reduced ripple factor, as well as, additional measuring systems, i.e. measuring the temperature and current consumed by the proposed solution as shown in Figure 9. Figure 10 shows the circuit board of the prototype optical power detector and Figure 11 shows the maximum ripple of the SLED current (1 MA/1 V).

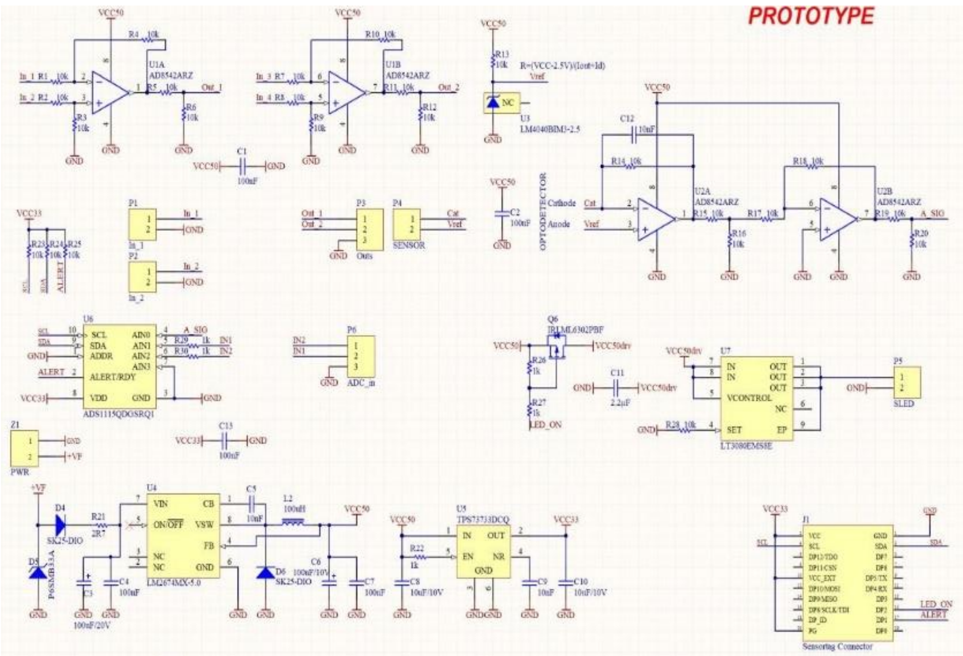

Figure 9. Electronic circuit of the optical power detector prototype

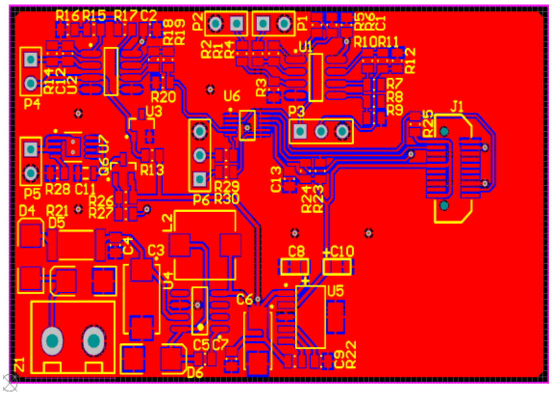

Figure 10. PCB diagram of optical power detector prototype

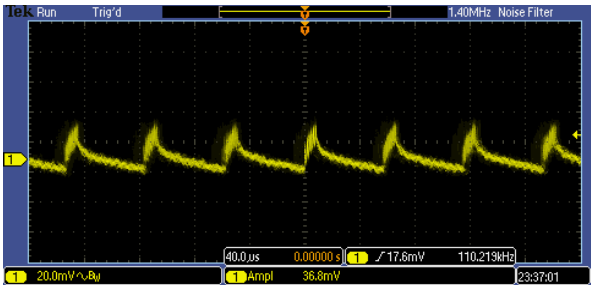

Figure 11. Maximum current ripple of SLED (1MA/1V)

The measurement results of the temperature characteristics of the light source are shown in Figure 12. Figure 12 shows the results of measurements of the temperature characteristics of the light source. As can be seen from this dependence of wavelength on dielectric constant at different temperatures, the maximum optical power transmitted by thorium at a wavelength from 1560 to 1590 has a critical maximum.

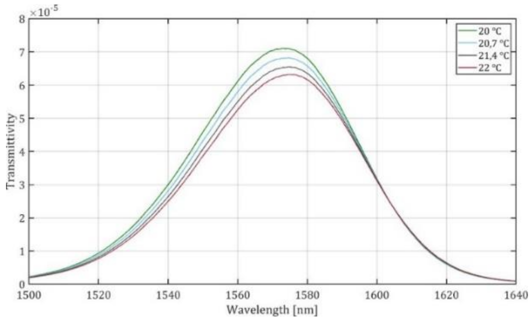

Figure 12. Temperature dependence of maximum power and radiated wavelength as a function of temperature

As can be seen from Figure 12, changing the temperature of the selected SLED significantly affects the power transmitted by optical thorium. Thus, a three-stage cascade temperature stabilization system is provided. Such a topology is dictated by the need to maintain the temperature of the light source and the optical power detector in the temperature regime of +/- 1 micron. A separate temperature stabilization is subject to a light source with a built-in Peltier module and an optical power detector mounted on its own Peltier module. The third element is the system for stabilizing the temperature of the device body.

The operation and design of all channels are identical, so the control schemes will be discussed using the example of Channel One. To turn on the Peltier module, it is necessary to force the stream of current through its structure. At rest, the output of each channel (SP1_OUT for Channel One) is held logically low by resistor R82. One can determine the high state at the SP1_OUT output by opening the channel of the transistor Q1. This channel is normally closed due to the action of the corresponding potential on the gate through the resistor R81. One channel has two control inputs: SP1_OUT1 and SP2_OUT1. The appearance of a logically low state on any of those inputs will change the gate potential of transistor Q1 and opening its channel.

Figure 13 shows the control system for Peltier modules (channels 1-3). The use of a specialized protective diode D11, which begins to conduct quickly electric current when the voltage at the output exceeds a threshold value, leads to the fact, that the energy of overvoltage coming from outside the system is converted through it into heat and does not enter the rest of the electronic system. In addition, if a voltage higher than 5 V appeared from the outside of the system, the diode D10 will be polarized beyond the limit and will not allow electric current to flow in the wrong direction. In addition, as shown in the diagrams below, the control systems are powered by a separate power region. Figure 14 shows an example of transimpedance amplifier signals in combination with a test photodiode for various LED current duty cycles. As can be seen from this figure, for various duty cycles of the LED current, the signals of the amplifier in combination with the photodiode have a stepped (square) signal, which indicates, that the amplifier with the photodiode is operating in normal mode.

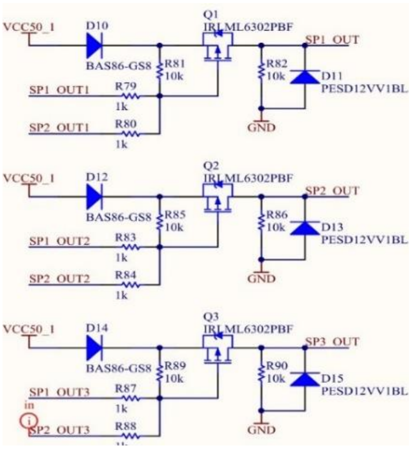

Figure 13. Peltier modules control systems (channels 1-3)

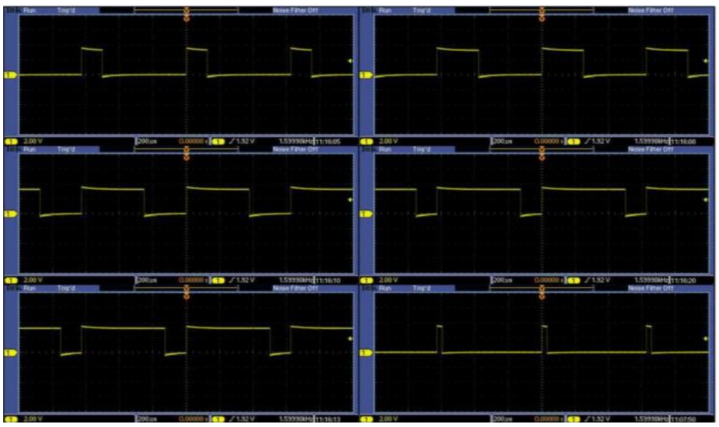

Figure 14. Example of output signals of a transimpedance amplifier in combination with a test photodiode for various fill factors of the LED current

Our research involves the use of a special safety diode D11, which initiates the rapid conduction of electric current when the output voltage exceeds the liminal value, causing the overvoltage power coming from outside the system to be reorganized through it into heat and not entering the rest of the electronic system. In addition, when a voltage of more than 5 V appears externally, the diode D10 will be polarized beyond the limit and will not allow the galvanic current to flow in the wrong direction. The proposed method can benefit from, without negatively affecting, control systems that are saturated from a separate power section. Transimpedance amplifier signals in combination with a test photodiode are driven for a variety of LED current duty cycles. With all possible changes in LED current, the signals from the amplifier in combination with the photodiode produce a consistent signal, indicating that the amplifier with the photodiode is functioning normally. This study examined the comprehensive collection and testing of an optoelectronic system for recording and processing signals from fiber-optic sensors; further and in-depth studies may be required to confirm its readiness for industrial use and commercialization, especially in relation to other fiber-optic pressure, temperature sensors.

4. CONCLUSION

In the work herein, there was shown assembling and testing optoelectronic system for recording and processing signals from fiber optic sensors. When testing the light power controller, it was found, that due to the bit resolution of the converter, the current ripple in the glowing diode circuit is minimized, it amounted to 20 A. Changing the temperature of the selected SLED significantly affects the power, transmitted by optical thorium. Thus, a three-stage cascade temperature stabilization system is provided. When testing a light power detector, the output signals of a transimpedance amplifier in combination with a test photodiode were investigated for various LED current fill factors. Changing the temperature of the selected SLED significantly affects the power, transmitted by the optical thorium. Thus, a three-stage sequential temperature stabilization system is provided. Such a topology is dictated by the need to keep the temperature of the light source and the optical power detector in the temperature regime of +/-1 mK. A separate temperature stabilization is subject to a light source with a built-in Peltier module and an optical power detector fixed on its own Peltier module. The third element is the system for stabilizing the temperature of the body of the device.

Recent observations suggest that the assembly and testing of next-generation optoelectronic devices are yielding high research results for fiber optic sensors, where sensors are concentrated for precise monitoring. Our results provide strong evidence that a new controller was designed to stabilize its operating point. The system operates from a light source controller using a superluminescent diode, as well as temperature stabilization, and not due to an increase in the number of electronic elements in the device and other electrical parts of the sensor. Our research demonstrates that this method of assembling and testing an optical-electronic system for recording and processing signals from fiber optic sensors is more stable than similar sensors. Future research could explore new designs of next-generation LEDs and transistors to improve the quality of recording and processing signals from sensors used for engineering and civil structures with possible ways to obtain new topologies and demonstrate new designs of smart sensors embedded in composite materials.

ACKNOWLEDGEMENTS

This work is supported by grant from the Ministry of Science and Higher Education of the Republic of Kazakhstan within the framework of the Project (Grant No. AP09259547 and AP19679153), Institute of Information and Computational Technologies CS MES RK. Experimental research was carried out in the laboratories of optoelectronics at the electrical engineering and computer sciences faculty of Lublin Technical University.

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