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Technical solutions and SPICE modelling of optical sensors

***Abstract**. Paper represents the technical and circuit solutions of optoelectronic sensors designing. The noise in information signal such as a parasitic effect of external (non-informative) optical radiation and electromagnetic interference could be decreased using hardware and software "GIRATO" package. The main results of this implementation by using SPICE simulation was carried out in our paper.*

***Streszczenie.** Artykuł przedstawia rozwiązania techniczne i układowe w zakresie projektowania czujników optoelektronicznych. Szumy w sygnale informacyjnym, takie jak pasożytniczy efekt zewnętrznego (nieinformacyjnego) promieniowania optycznego i zakłóceń elektromagnetycznych, mogą być zmniejszone za pomocą pakietu sprzętowego i programowego "GIRATO". Główne wyniki tej realizacji z wykorzystaniem symulacji SPICE zostały przedstawione w naszym artykule. (**Rozwiązania techniczne i modelowanie czujników optycznych z użyciem SPICE**).*

Keywords: impedance converters; noise immunity; parasitic signal; optoelectronic sensor; SPICE simulation
Słowa kluczowe: przetwornik impedancji; odporność na zakłócenia; sygnał pasożytniczy; czujnik optoelektroniczny; symulacja SPICE.

Introduction

The perspective direction of development of modern microelectronic sensors is optical sensor devices for the investigation of gases, liquids, biological objects.

The information signal of such sensors is formed by modulation of the spectral characteristics of a sensitive medium that interacts with the substance being studied. The spectral characteristic is measured by the optocoupler, which consists of a controlled, mainly pulsed, light source and a photo-sensing element [1]. The source of light may be a light-emitting diode, a group of LEDs with a transmitted spectral characteristic, etc., and photosensitive elements - photodiodes, a group of photodiodes, phototransistors, etc. An important component of such sensors is signal transducer [2, 3, 4].

In the paper for the experimental verification and research of the proposed structural and schematic solutions of noise-proof signal converters of optical sensory devices, the hardware-software USB-compatible "GIRATO" package was developed. The package uses a modern elemental base of signal transformation, in particular, micropower Rail-to-Rail operational amplifiers, AD8542 and ADG736 switches, ADuC431 microcontrollers, FT232R USB interfaces, etc.

The information noise problem

Providing the high noise immunity of signal transducers of optical sensor devices is based on new circuit solutions that implement on compensation as a parasitic effect of external (non-informative) optical radiation and electromagnetic interference. The intensity of radiation from third-party light sources in hundreds, even thousands of times, may exceed the useful component of the deviation of the optical signal from the active medium of sensors. The parasitic effect of electromagnetic interference is due to a significant level of radiation of the power network with a frequency of 50 Hz. This interference is most pronounced in the high-end circles of signal transducers of optoelectronic sensor devices.

Technical and circuit solution

Therefore, in accordance with the tasks solved in this paper, the main nodes of the signal conversion are impedance converters, which by implementing the reactive load of the photosensitive element, provide the selection of useful components of the signal.

The implementation of frequency selection occurs immediately in the signal circle of the photosensitive element, forming a high impedance at the frequency of the useful component of the photocurrent and low impedance at the frequencies of the parasitic components, which ensures the highest possible signal-to-noise ratio. It is fundamentally important that, under the requirements of integrated microelectronics, such a solution does not require to use the inductive elements, and the steepness of the frequency selection function is significantly higher than the inductive load and optimized following the parameters of the signal conversion.

The block diagram of the "GIRATO" package is shown in Fig. 1. The informative signal is formed by modulation of the spectral characteristics of the active medium AM (Active Medium) that interacts with the test substance material. As the LED light sources are used with offset spectral characteristics - LED1 (red, R), LED2 (green, G) and LED3 (blue, B), a photosensitive element is a PD photodiode. LED currents are set stabilizer on current operational amplifier OA1, OA2 and OA3.

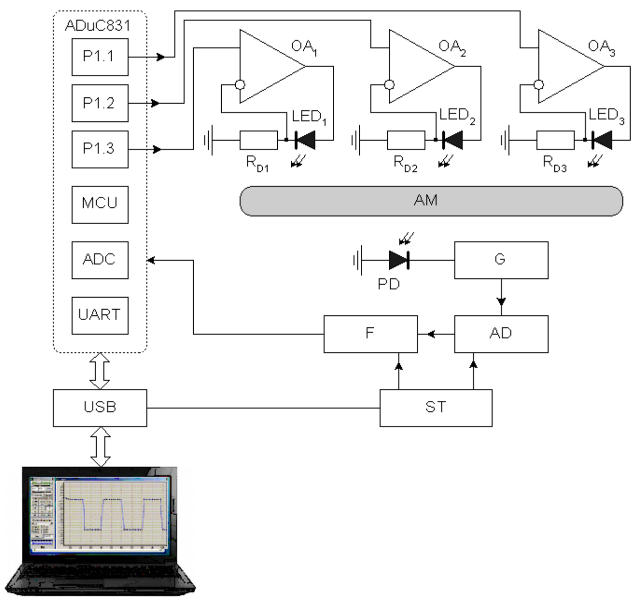

Fig. 1. Block diagram of hardware and software "GIRATO" package

The noise immunity of the signal conversion was provided by converters of impedance G, structural-circuit solutions and parameters of which were the research subject of this paper. The received signal amplified and AD detected and then filtered using F. The power supply stabilization was provided by the ST stabilizer. Analogue-digital conversion and control of the measurement process were carried out by the ADC831 microcontroller. The main components of the microcontroller used during the measurement are: P1.1, P1.3, P1.3 - LED control ports; MCU - microprocessor; ADC - analogue-digital converter; UART interface. The connection to the PC and the device's power was via a USB port. “GIRATO” software windows are shown in Fig. 2.

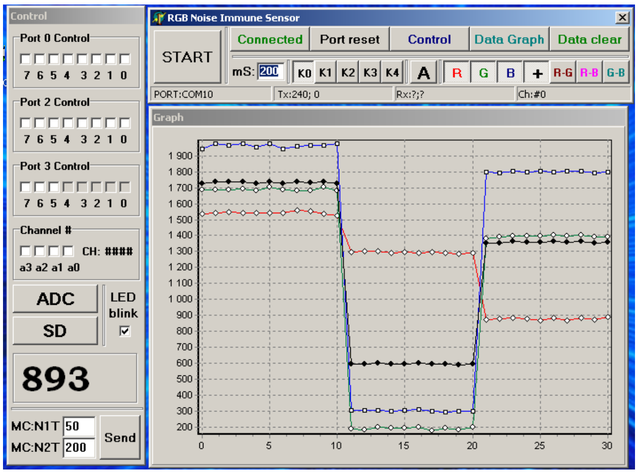

Fig. 2. “GIRATO” software windows

The main window is RGB noise immunity sensor - provides control of the measurement process as a whole. Options for selecting and installing: USB port interface parameters; time measurement parameters; gain factor; measurement modes, in particular switching between measurements of useful signal components (R) (G), (B) and noise from third-party light sources (A), measurement of the total signal strength (S+) and differential components (RG), (RB), (GB). Using these differential components that measurements of the spectral characteristics of the active optical medium of the sensor device are provided.

The visualization of the measurement results is performed in the Graph window, and control of the measurement processes and operating modes of the signal converters is in the Control window.

Numerous experimental studies of the preceding units of signal converters were carried out. The results of such studies were compared with the corresponding results of model research. Based on the results of such comparisons, the SPICE correction of the signal converter circuit patterns was performed [5, 6].

As a result of the research and parametric optimization, a prototype signal converter was developed and manufactured and it combines high immunity to external (parasitic) light sources and electromagnetic interference of the 50 Hz power network. In addition, such a signal converter meets the requirements of modern electronics in terms of minimum power consumption, the ability to operate with unipolar low-voltage light sources, high stability of operation, etc.

The noise immune signal converter (conventional name - GX) is shown in Fig. 3. Its basis is second-order impedance converter. As already noted, the novelty of the circuit decision of the impedance converter of the second order is the use of the operational amplifier to form comprehensive feedback.

Several types of operational amplifiers were investigated and optimization of operating modes was performed. Consider the typical example and the result of such work.

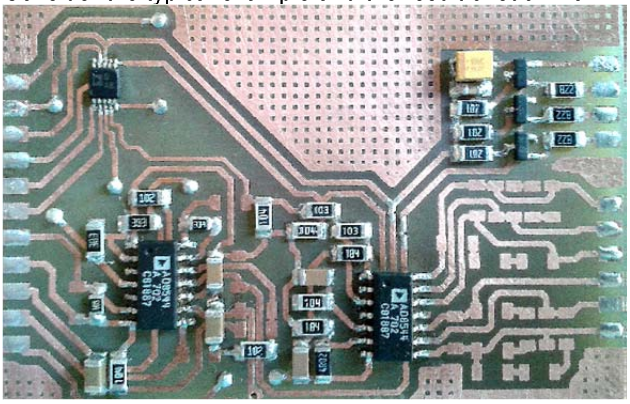

Fig. 3. The GX noise immune signal converter

Figure 4 shows the results of model investigation of the GX noise immune signal converter on the microscopic Rail-to-Rail AD8542 operational amplifiers (GBW = 0.98, SRP = SRN = 0.7V/s). The comparison of the frequency dependence of the impedance of the converter of the first one (the informative parameter of the impedance - V (10) / I (Gin1)), and the second (the informative parameter of the impedance - V (4) / I (Gin1)) orders. It is seen that in contrast to the well-known scheme of the first order, the scheme of the impedance converter of the second-order proposed is characterized by a substantially higher steepness of the frequency characteristic.

So, the steepness of the converter of the first order is 20dB per decade, which is typical for such circuits. Instead, the function of frequency dependence of the impedance of the second-order converter has two extremes, the first of which is the rectification of the network power supply with 50 Hz frequency value, and in the second - a selective allocation of an informative signal with a frequency of 700Hz. The ratio of the impedance values at the frequency of the informative signal Z (F = 700Hz) and the frequency of interference Z (F = 50Hz) exceeds the value of 104, which corresponds to 80 dB.

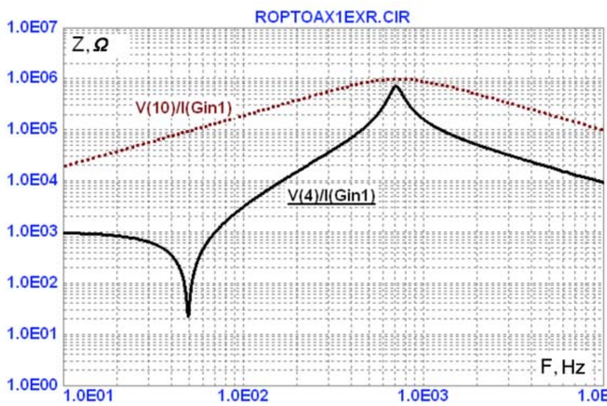

Fig. 4. The result of model investigations of the characteristics of signal transducers on first and second order impedance converters

The result of experimental studies of the frequency characteristic of the prototype of the GX noise-proof signal converter on the second-order impedance converter is shown in Figure 5.

The high conformity of the results of experimental and model researches, which testifies to the high quality of

SPICE models and approaches to model research proposed in the paper, is evident [7-9]. In addition, on the inset of Figure 5 a section of the characteristic in the bandwidth of a useful signal is shown.

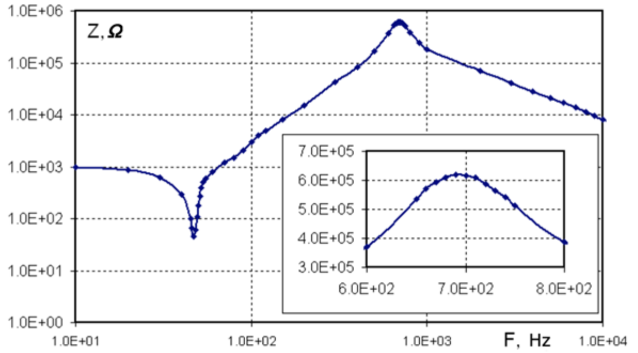

Fig. 5. The result of an experimental study of the characteristics of the signal converter on the second-order impedance converter

An example of the measurement results of signals obtained with the help of the developed hardware and "GIRATO" software package is shown on the inset of Fig. 6.

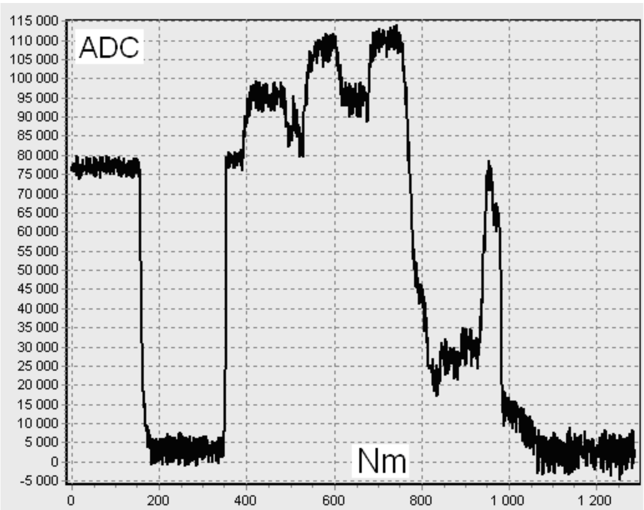

Fig.6. An example of a measurement result of a parasitic signal from third-party light sources (when changing the level of room lighting)

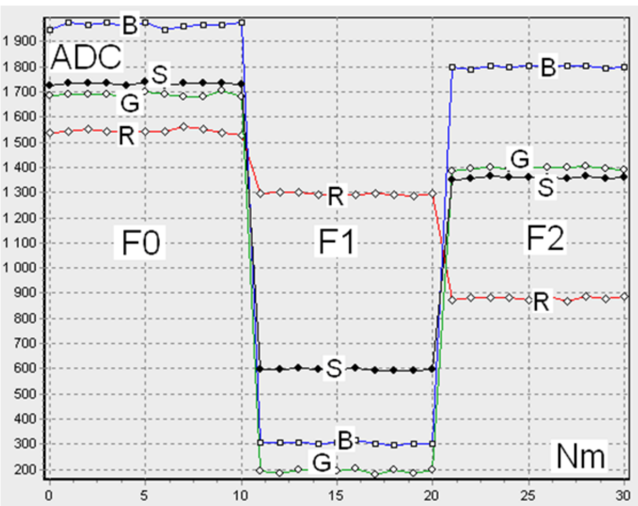

Fig.7. An example of a measurement result of useful signals (ADC - signal in the binary code of the analogue-to-digital converter, No - measurement number)

The ADC denomination (in units of equivalents) corresponds to the binary code of the analogue-to-digital converter, and Nm is the serial number of the measurements sequence. Plot F0 corresponds to the initial conditions of measurement, and the sites F1 and F2 depend on the corresponding changing in the spectral characteristics of the active media of the optical sensor, where: R, G, B are the components of the useful signal corresponding to red, green and blue LEDs, S is the total level of the useful signal.

It is seen that the level of a parasitic signal from foreign sources of light (Fig. 6, mode of measurement - A) exceeds A10 5 and obviously depends on the change in the level of illumination of the active media of the optical sensor device. At the same time, there is considerable noise (the distribution of measurement results in a fixed illumination), the level of which, as already noted, is caused by the electromagnetic interference of the 50Hz power network. The level of such noise in the conditions of the experiments conducted (located next to power units, computers, light sources, etc.) is approximately Ns 5 103.

Instead, using of interference-free measurement modes (Fig. 7, modes - R, G, B, S) provides the ability to measure the level of the useful signal (spectral characteristics of the optical environment of the sensor device) in the range up to M 2 103, the value of which is commensurate with the aforementioned noise level Ns and two orders of magnitude less than the level of noise from third-party light sources. The resolution at the level of residual noise is approximately 10 corresponding to 1% of the range of measurement of the useful signal and 0.01% of the level of interference.

A nanostructure based on porous Al_2O_3 with pore diameter 20nm doped with CLC EE1 with 0.3% of Fe3O4 magnetite was used As an active medium AM. In the range of sensitivity of such a nanostructure is approximately 140nm (maximum displacement of the spectral characteristic), the spectral sensitivity coefficient is 1.4nm/mg/m^3, which corresponds to the resolution 1% [11-15]. Thus, the parameters of the developed signal converter GX correspond to the task of realizing the optical sensor on the above-mentioned nanostructure.

Conclusions

Thus, the obtained results confirm the high efficiency of using the impedance signal transducers of optical sensors developed and the high correspondence of the real parameters of these converters with the results of SPICE model research.

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