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# A MEASURING SYSTEM BASED ON SENSORS OF MAGNETIC FIELD AND TEMPERATURE WITH DIGITAL SIGNAL PROCESSING

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**Abstract:** The paper deals with the investigation of electro-physical properties of $Si_{1-x}Ge_x$ whiskers; the possibility of their use as sensitive elements in magnetic field and temperature sensors is considered. The possible ways of improving the output characteristics of these sensors, particularly through the use of a measuring system with digital signal processing.

**Key words:** whisker, sensor, magnetic field, digital processing.

### 1. Introduction

As of today there are many various measuring systems based on sensors of physical values, including multifunctional ones, i.e. sensors that measure simultaneously two or more physical values, for example, strain and temperature sensors, temperature and magnetic field sensors etc. [1–4]. However these systems have a few significant drawbacks which are the following: the high cost of individual components and the system as a whole; a large number of functional units complicating measuring system operation; lack of stability and reproducibility of output characteristics [5–8]. Therefore, the main task of research is either to develop and create the new modern measuring systems without aforementioned drawbacks, or improve the work of existing ones. In terms of technology the investigation of electro-physical properties of sensor sensitive elements is a necessary condition for ensuring the optimum output signal. The aim of this work is the investigation of electro-physical properties of $Si_{1-x}Ge_x$ whiskers for making a dysfunctional sensor for measuring magnetic field and temperature quantities and the development of measuring system with improved output characteristics due to digital signal processing.

### 2. Experimental results

The investigations of electro-physical properties of $Si_{1-x}Ge_x$ whiskers with resistivity $\rho_{300K}$=0,02 Ohm×cm and diameter 200 nm at a temperature range 4,2–300 K and a magnetic field up to 14 T have shown that resistance linearly depends on temperature at range 4,2–77 K, and the relative change of transverse magnetoresistance reaches 250 % at temperature 4,2 K. This allowed for making a dysfunctional sensor for simultaneous measurement of magnetic field and temperature. Constructively such a sensor consists of two identical sensitive elements placed perpendicularly to each other. The first one detects only temperature and is not sensitive to the magnetic field, because its longitudinal magnetoresistance is equal to zero, and the second one – detects the temperature and magnetic field. The sensor sensitivity to the magnetic field is (0,1–0,2) $T^{-1}$ at temperature 4,2 K, which allows for measuring a magnetic field with an accuracy 5 mT in the range of 4,2–77 K. The calibration curves of thermoresistive and magnetic component of sensitive elements are depicted on Fig. 1.

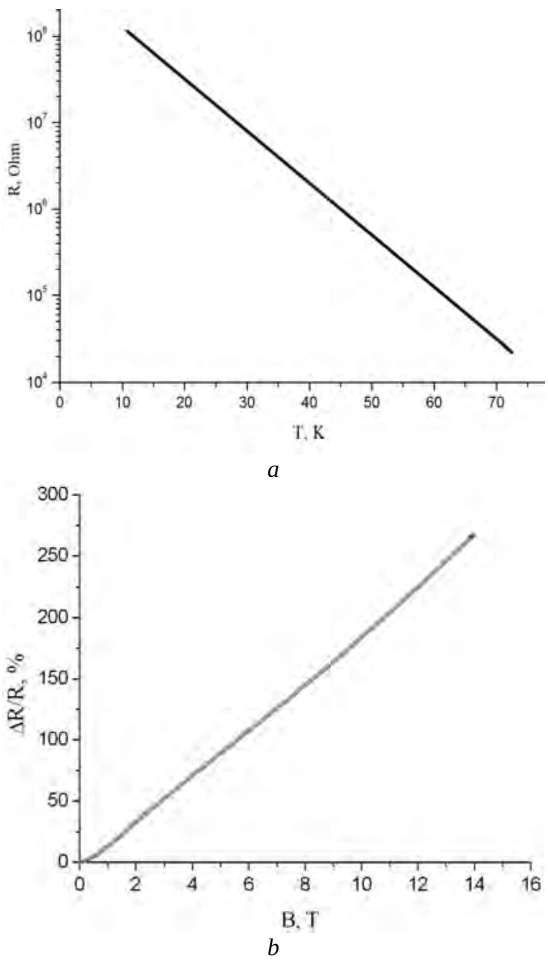


*Fig. 1. The calibration curves of a thermoresistive (a) and magnetic (b) component for sensitive elements of sensor of magnetic field and temperature on the basis of $Si_{1-x}Ge_x$ (x=0,03) whiskers.*

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The analysis of output characteristics of the designed sensor showed:

- using compensation methods through digital signal processing, it is possible to extend the operating range due to installation of software approximation algorithm;
- while carrying out the temperature compensation of output signals it could be possible to reduce the error of measuring a magnetic field by introducing the correction coefficients.

To solve these tasks a measuring system has been developed which performs the following functions:

- signal transmission from the sensor to user (amplification, analog-to-digital conversion, filtering etc.);
- temperature correction, linearization and other output signal conversions.

The structure and principles of operation of secondary transducer are described in detail below.

### 3. Circuitry solution of digital signal processing

A new generation of microcontrollers – PSoC (PSoC3 CY8C3866-AXI040, ES3), so-called programmable system-on-chip [9], was used as the main functional center of the system. PSoC is the family of integrated circuits by Cypress Semiconductor Corporation [10].

The selection of this microcontroller as a basic element of the system was caused primarily by integrating configurable analog and digital peripheral functions, memory and a microcontroller in a single chip. This allows operating mixed signals by using the array of configurable digital and analog blocks. The integration of the entire system on a single chip significant reduces energy consumption (this is important for applications that need low energy consumption, i.e. miniaturization of devices, power supply from independent energy sources etc.), reduces the cost of the system and, most importantly, improves the reliability of the circuit compared with a set of separate blocks for circuits with the same functionality. Also, the presence of fewer components simplifies the device configuration and installation.

To configure the hardware resources of the system-on-chip (PSoC) we developed a software with the addition of applied program interfaces (API), since the role of a software component is as important for the proper functioning of the system as that of the hardware.

Fig. 2 shows the block diagram of an information system.

The output signal of the sensor is input to the expansion board, where the signal is primary amplified and filtered. The appearance of designed and developed amplifier module is shown in Fig. 3.

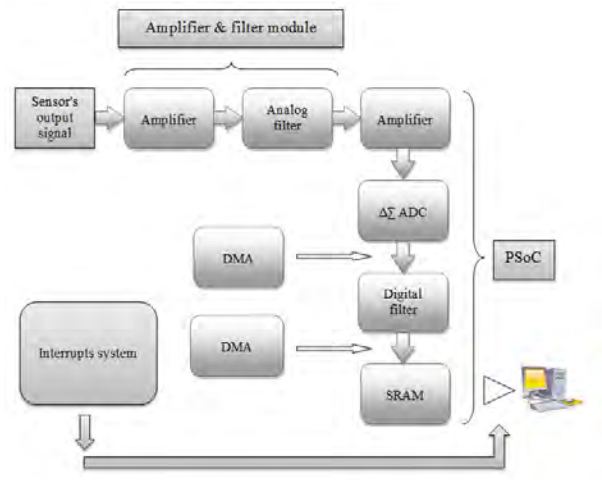


*Fig. 2. Functional diagram of an information system.*

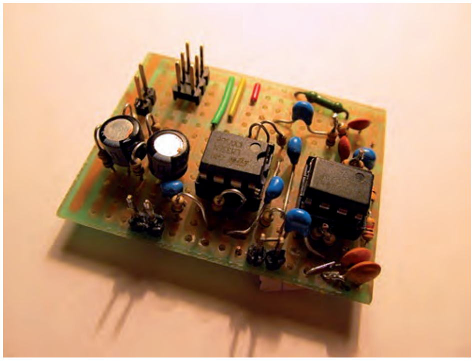

*Fig. 3. Expansion module.*

Then the filtered output signal is input to PGA module (programmable gain amplifier), whose gain is set programmatically by analyzing the difference signal at the output of the digital filter. The analog signal from the output of the amplifier is converted into a digital stream using delta sigma analog-to-digital converter DelSigADC. Further, this information (packets of 40 bytes) is transferred from ADC_DelSig to the inputs of a digital bandpass filter FilterA&B and from its outputs to memory cells (SRAM) using direct access channels DMA, thus preserving the processor resources for digital signal processing of information stream. Additionally, the bytes of information stream are transmited through these direct access channels to memory for digital-to-analog converters for visualizing digital stream with an oscilloscope.

When the data packet is ready, the system generates an interrupt signal which starts the procedure of processing. The temperature correction of the sensor output signal is as follows: CPU selects the required value of the magnetic field from memory according to the magnitude of a change in magnetoresistance required for a measurement range, corrects and records the value

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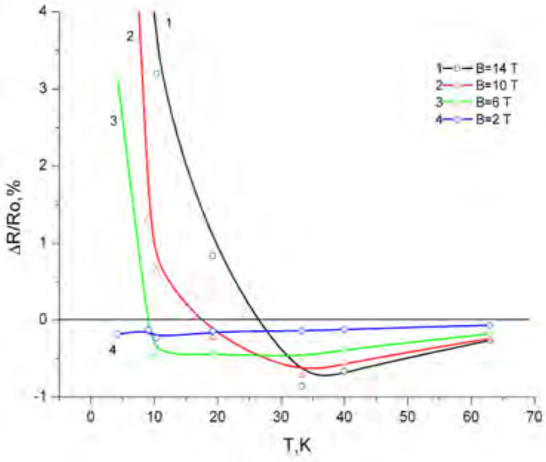
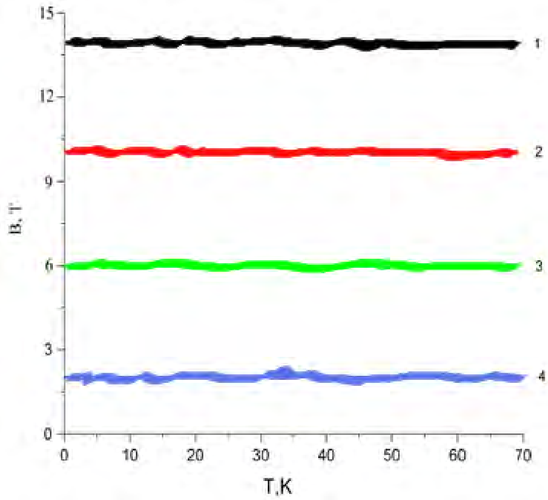
in memory which then will be displayed on the LCD or transmitted through the port to a personal computer.




*a*




*b*

*Fig. 4. Output characteristics of the sensor:*
*(a) – before temperature correction; (b) – after temperature correction.*

Figure 4 (a) shows the temperature dependent relative changes of magnetoresistance. Evidently, the temperature is a destabilizing factor in the measurement of a magnetic field leading to the presence of the measurement error, which is about 5 %. As a result of using the developed output signal processing circuit, the secondary transducer is able to reduce the error to zero, avoiding the influence of the temperature (see Fig. 4, b). The software developed has made it possible to obtain adjustable sensors that can be used both in research and industry.

**4. Conclusions**

As a result of studying electro-physical properties of $Si_{1-x}Ge_x$ whiskers, the possibility of creating sensors based on this phenomenon for detecting simultaneously the magnetic field and temperature has been presented. The measuring system based on the sensor of a magnetic field and temperature with improved characteristics due to the temperature correction of the output signal has been designed. The latter has been provided by the secondary transducer with developed signal processing software.

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**ВИМІРЮВАЛЬНА СИСТЕМА НА ОСНОВІ СЕНСОРІВ МАГНІТНОГО ПОЛЯ І ТЕМПЕРАТУРИ З ЦИФРОВИМ ОПРАЦЮВАННЯМ СИГНАЛІВ**

Анатолій. Дружинін, Степан Нічкало, Євген Бережанський

У роботі наведено результати досліджень електрофізичних властивостей ниткоподібних кристалів $Si_{1-x}Ge_x$ та показано можливість їх використання як чутливих елементів сенсорів магнітного поля і температури. Запропоновано шляхи покращення вихідних характеристик сенсорів, зокрема за рахунок використання вимірювальної системи з цифровим опрацюванням сигналів.

**Anatoliy Druzhynin –** Ph.D., D.Sc., Professor, Head of the Department of Semiconductor Electronics at the Institute of Telecommunications, Radio-electronics and Electronic Engineering, Lviv Polytechnic National University, Ukraine.

Prof. A. Druzhynin is a leading expert in the field of sensor electronics. He began his career at Lviv Polytechnic National University, Ukraine, in 1980, continued it as Professor of the Department of Semiconductor Electronics from 1994 to 2005 and from 2005 as a Head of the Department of Semiconductor Electronics of the aforesaid university.

The main scientific activities of prof. A. Druzhynin include: theoretical and experimental study of strain-induced effects in silicon, germanium and their solid solutions whiskers; developing of technological foundations of laser recrystallization of polysilicon layers on insulator and preparation of doped with different impurities silicon, germanium and their solid solutions micro- and nanowires by chemical transport reaction method; developing sensors of mechanical values for various purposes including multifunctional ones and sensors based on SOI-structures operating in a wide temperature range; study thermoelectric properties of semiconductor micro- and nanowires for thermal sensors.

Prof. Druzhynin is the Director of the "Crystal" Scientific Research Center at the Department of Semiconductor Electronics and the supervisor of Sensor Electronics Research Laboratory; its research projects are being supported by international and state scientific and technical programs.

Prof. Druzhynin has authored more than 450 scientific papers including more than 40 inventor's certificates and patents. He regularly participates in international and national scientific conferences and symposia; has published three monographs in the field of sensor electronics. For a textbook called "Solid-state electronics: physical principles and properties of semiconductor devices" in 2011 prof. Druzhinin was awarded the Diploma of the Second Degree in the nomination "The best textbook of Lviv Polytechnic National University".

For his significant role in teaching and scientific work he was awarded the Diploma of the Ministry of Education and Science of Ukraine (1994), "Excellence in Education of Ukraine" Honor Pin (2004), Appreciation of the Prime Minister of Ukraine (2009). The work "Microelectronic sensors for next generation information systems" was awarded with the Diploma of "Colorful Ukraine" State Exhibition (2010, 2011). Prof. A. Druzhynin has been included to the National Public Program named "Leaders of the XXI Century" and "New Names of Lviv and its people". In 2006 he was elected the Academician of the Academy of Ukraine, since 2007 he has been a corresponding member of the International Academy of Thermoelectricity.

He is also the winner of Ukrainian State Prize in Science and Technology (2011).

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From 2003 to 2008 he studied at the Department of Semiconductor Electronics, Institute of Telecommunications, Radio-electronics and Electronic Engineering of Lviv Polytechnic National University and received Master's degree with honor in "Microelectronics and Semiconductor Devices". From 2008 to 2011 he studied at the graduate school of the same Department and in 2012 defended his Ph.D thesis entitled "Preparation and characteristics of Si and $Si_{1-x}Ge_x$ solid solution micro- and nanowires for device applications". Since 2011 he works as a junior research fellow at "Crystal" Sensor Electronics Research Laboratory. Research interests include the physical and technological aspects of micro- and nanostructures for semiconductor device integration and sensor electronics. He is the author of over 40 scientific papers, including 2 patents issued in Ukraine.

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Area of interest: digital signal processing.

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# COMPUTER-AIDED DESIGN SYSTEM FOR TECHNICAL AND ECONOMICAL COMPARISON OF CRANE ELECTRICAL DRIVES

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**Abstract:** Computer-aided design system for technical and economic comparison of crane electrical drives, considering the ratio of static and dynamic modes, load and moment inertia, relative running time with reduced speed, is designed. The computer-aided design system provides an opportunity to make a better informed decision about the choice or upgrading of electrical drives.

**Keywords:** CAD, induction motor electrodrive, technical and economical comparison.

## 1. Introduction

Induction motors with different control systems are used in mechanisms of many cranes.

Electrical drives with resistance (Rvar) and voltage (Uvar) regulation are the most common for induction motors with phase-wound rotor and frequency converters (FC) with recuperation unit and without it – for a squirrel cage motor. For choosing electric drives a feasibility analysis of the expediency of its use must be performed, taking into account the costs and possible recuperation, the cost of electric motors and components [1, 2].

The aim of this investigation is to develop CAD-system for technical and economical comparison of crane electrical drives.

## 2. Theoretical and programming basis

The most difficult task in the development of the program is to unify approaches to the analysis of operation modes of crane mechanisms and electric drive systems.

Fig. 1 illustrates static mechanical properties and operating conditions (working points) of the majority of crane mechanisms:

1, 2 - lifting / lowering a nominal load with a nominal speed in hoist mechanisms;

3, 4 - horizontal movement (rotation) or lifting / lowering of an empty hook with a nominal speed;

1', 2', 3', 4' - the same modes with reduced speed.

A typical cycle of the mechanism includes all or part of the listed modes. And work with low speed usually is $t'_{cycle} / t_{cycle} = 5$ ... 20% of the running time at nominal speed.

The power consumption in each mode is determined by the type of electric drive and can be distributed according to the technical data of engines as follows [3].

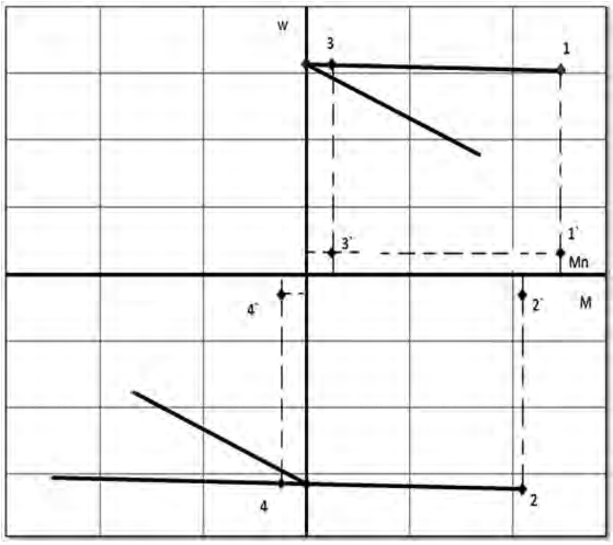


*Fig. 1. Mechanical characteristics and operating modes of crane mechanisms.*

Nominal losses when using induction motor with a rated speed can be determined as:

$$\Delta P_n = 3U_{1n} I_{1n} \cos\varphi_n - P_n, \quad (1)$$

where $P_n, U_{1n}, I_{1n}, \cos\varphi_n, \Delta P_n$ – nominal power, phase voltage and current, the cosine of the angle delay current, nominal power losses.

Mechanical losses are

$$\Delta P_{mech\ n} = 0,05 \Delta P_n, \quad (2)$$

losses from idle current $I_0$

$$\Delta P_{0n} = 3 I_0^2 R_1, \quad (3)$$

variable losses of operating current

$$\Delta P_{Mn} = M_n \omega_0 s_n \left(1 + \frac{R_1}{R_2'}\right), \quad (4)$$

iron losses

$$\Delta P_{Sn} = \Delta P_n - \Delta P_{Mn} - \Delta P_{0n} - \Delta P_{mech\ n}, \quad (5)$$

where $I_0, M_n, s_n, \omega_0, R_1, R_2'$ – idle current, nominal moment and slip, base speed, stator and rotor active resistance restricted to the stator.

Mechanical losses and losses in the steel are amended with speed control, voltage and speed fields in various electric drives as follows:

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