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UNIVERSAL HARDWARE AND SOFTWARE SYSTEM OF SIGNAL CONVERTING FOR INTEGRATED SENSOR DEVICES IMPLEMENTATION

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Summary. *The problem of developing a universal signal converter for the construction of integrated sensors in data fusion concept is solved. Considering the requirements of modern microcircuit technique, in particular for sensory devices of the Internet of Things, the signal path of the synthesized sensors is implemented based on PSoC of 5LP Family Cypress. The testing of the developed system was carried out in the process of realization the integrated sensors of thermal analysis, optoelectronics, magnetic tracking and impedance spectroscopy.*
Key words: *sensor, Data Fusion, signal converter, programmable system.*

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IntroductionThe development of many branches of science and technology requires constant improvement of the processes of measuring electrical and non-electrical parameters. A significant segment of modern sensor devices on the principle of «activator-sensor» is based on impedance spectroscopy methods, the informative parameters of which are the frequency dependences of the active and reactive components of electrical or electrochemical impedance [1]. Capacitive sensors of spatial approximation, control, deformation, chemical and biochemical analysis are built using electrical processes of charge accumulation. Calorimetric sensors are used to investigate thermal processes. They cover a wide range of methods of physicochemical analysis, in which the thermal power of phase transitions of chemical and biochemical reactions is measured [2]. The informative values of such sensors are the amount of heat energy of the heater and the instantaneous temperature distribution values measured by temperature sensors. Measurement of luminous flux parameters is used in optical sensors and spectroscopy [3], the basis of which is optopars mainly based on light emitting diodes and photo sensors. Magnetic field measurement is used in magnetometry, geodesy, spatial navigation, etc. [4]. Magnetic Coils are mostly used as magnetic field actuators, and Hall elements, magnetoresistors, magnetotransistors are used as magnetic sensor. The activator-sensor principle is the basis for the construction of magnetic tracking sensors for determining the spatial position in virtual and augmented reality systems.

Such sensors measure individual parameters with high accuracy. However, measurements of a single parameter in the study of new materials, during the control of technological processes in various industries and agriculture, unfortunately, cannot provide all the necessary information to understand their behaviour and properties. Therefore, it is necessary to combine different research methods or different measuring devices into a single complex. A characteristic example of functional integration is the TG/DSC synchronous thermoanalysis method combining differential scanning calorimetry and thermogravitometry [5]. In this case, the amount of energy consumed for the phase transition in the investigated sample is measured along with recording the change in the weight loss of the sample over time. Another example is the combination of

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thermal and capacitive methods of investigation [6] or thermal and optical methods [7]. The design of biparametric sensors for simultaneous measurement of temperature and magnetic field is described in [8–9].

The concept of data fusion, which reflects the process of integrating multiple data sources to obtain more consistent, accurate, and useful information than that provided by any individual data source, is discussed in [10]. However, there are objective difficulties in providing broad functionality with respect to combining different measurement conversion methods and meeting current trends in microelectronic sensor development.

The aim of the research is to develop and test a universal hardware-software signal conversion system for integrated sensors creation. The main requirements for such systems are the wide functionality and compliance with modern trends of microelectronic sensor development. Functionality means the ability to implement the measurement transformation of the signal on the basis of the «actuator-sensor» with different physical quantities such as electric current, electric capacity, heat, light, magnetic field, etc. (Fig. 1).

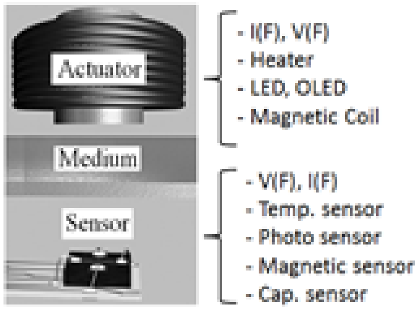

Figure 1. Generalized representation of the «actuator-sensor» system

The major requirement for modern sensor devices is the conformity of their signal converters to the concept of hardware and software implementation of Programmable System on Chip (PSoC) [11]. Such sensory signal converter, nowadays referred to as Sensor Front-End, should provide low-voltage operation, minimal power consumption, versatility, stability of functioning under external factors changing, rail-to-rail modes, etc. Besides, when it comes to current trends in development of information systems, the next generation of sensor devices must comply with the concepts of Lab-on-Chip [12] and the Internet of Things (IoT) [13].

Circuit and nodes of signal converter. TIn accordance with the formulated problem, the article presents the further development of hardware and software solutions for synthesized sensors based on the microelectronic components. Taking into account the requirements for modern microelectronics, in particular, for sensory devices of the Internet of Things, the signal converter of developed system is based on the PSoC 5LP Family of Cypress Semiconductor Corporation [14]. The PSoC structure includes digital and analog system nodes, microprocessor nodes, power-dependent and non-volatile memory matrices, system resources, programming power and management nodes. The basis of digital nodes is a matrix of universal digital blocks, specialized digital blocks, in particular for the implementation of interfaces, timers, pulse-width modulators, etc. PSoC analog nodes are blocks on switching capacitors and blocks with continuous signal converting, in particular, operational amplifiers, comparators, bandgap reference voltage sources, analog multiplexers, etc. The nodes are connected by a software-configured network of signal lines. The signal converter based on PSoC5 (Fig. 2) includes VDAC8 digital-to-analog converter, Wave DAC8 synthesizing generator, timer, control register, frequency divider, multifunctional mixer, operational amplifiers (Oamp), Programmable Gain Amplifier (PGA), Analog Multiplexer (AMux), analog-to-digital converters ADC based on delta-sigma modulator (DelSig) and successive approximation register (SAR).

The configuration of the signal path is shown in fig. 3, its outputs in the hull CY8C5888LTI-LP097 are presented in fig. 4. The control of the measuring circuits modes and the signal converting are performed using the universal serial UART interface. PSoC components are configured and dynamically programmed using the Application Programming Interface (API).

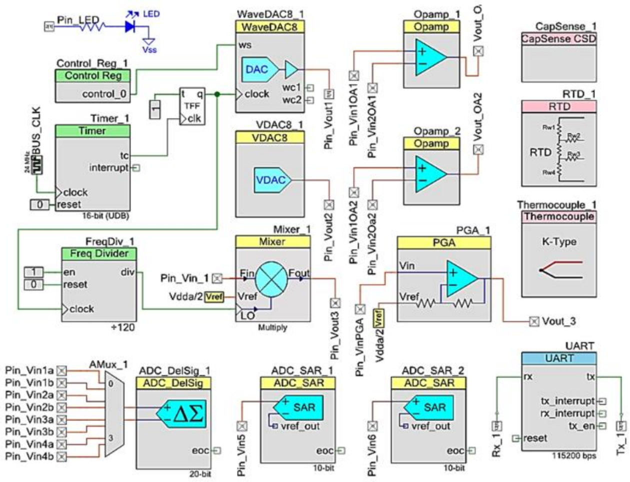

Figure 2. Internal structure of the signal converter

The photo of the model layout of the universal hardware-software signaling system for the construction of synthesized sensors is presented in Fig. 5.

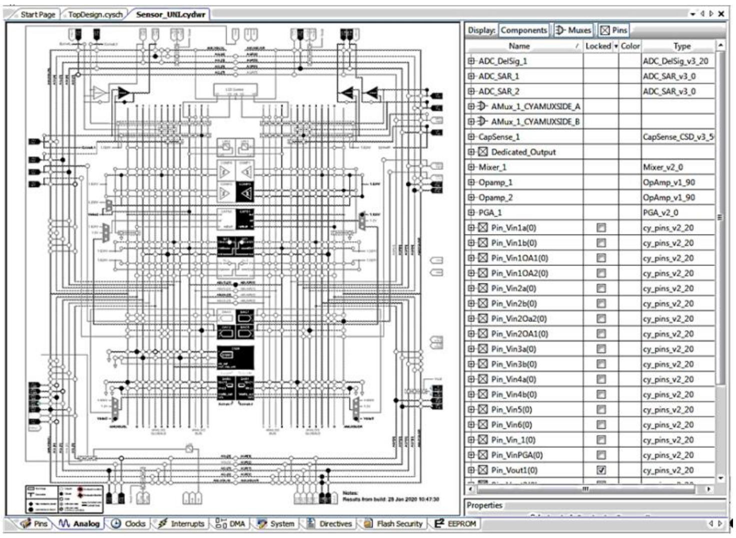

Figure 3. Signal path of the signal converter circuit

Configuring the VDAC8 digital-to-analogue converter (Fig. 6) includes the selection of output voltages in range from 0 to 1.024 V with a resolution of 4 mV/bit and from 0 to 4.080 V with a resolution of 16 mV/bit. Two operation modes are possible – energy-efficient with slow and high conversion speed. The output voltage of the VDAC8 is controlled by the values in millivolts (mV) or 8 bit Hex system.

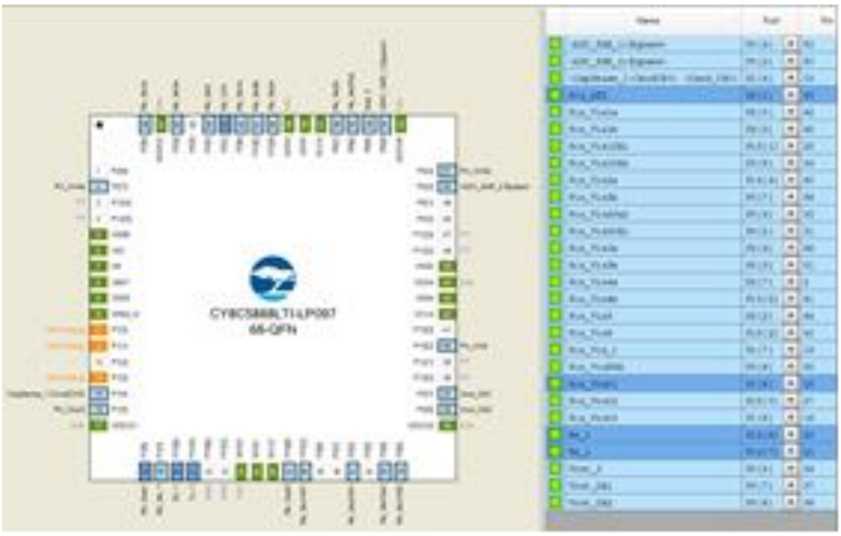

Figure 4. Outputs of signal converter based on the PSoC CY8C5888LTI-LP097

The binary control code is supplied via the DAC bus or directly from the CPU (Central Processing Unit) of the Data Bus. High management efficiency is ensured by the Direct Memory Access (DMA) mode. Strobe Modes for synchronization with external sources or internal Register Write are provided.

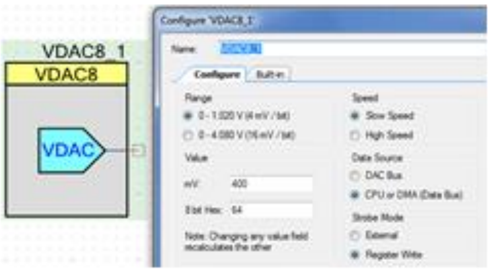

Figure 5. Photo of the signal converter based on the PSoC

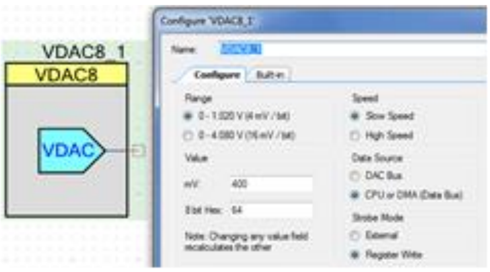

Figure 6. VDAC8 Configuration Window

The WaveDAC8 synthesizing generator is based on a buffered 8-bit digital-to-analog converter. The synthesized waveform is set by instantaneous voltage values stored in the non-volatile memory of the microcontroller. The main parameters that are set in the process of generator configuring (Fig. 7) are range of signal change (Range), type of synchronization (Internal or External clock), number of samples per second (Sample rate, kSPS), Wave type, Amplitude, Offset, Phase, and the number of samples in one period of a synthesized signal (Samples).

It is important to rapidly change the signal form (Wave type) and frequency (Sample rate, kSPS). An example of WaveDAC8 synthesized signals is shown in Fig. 8. Another example (Fig. 9) demonstrates phase-shifted harmonic signals used in impedance spectroscopy sensors. These signals are offset by $\pi/2$, which makes it possible to measure the real and the imaginary components of the impedance.

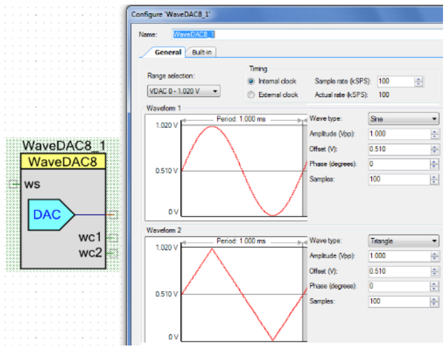

Figure 7. Wave DAC8 Configuration Window

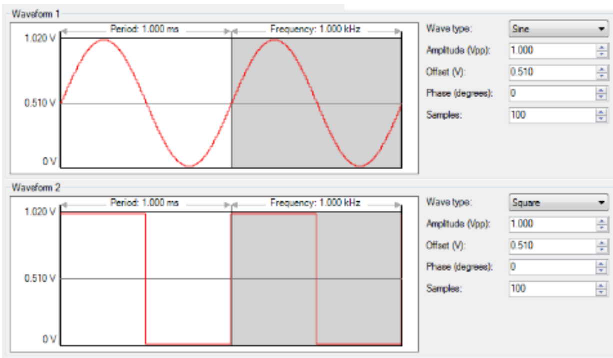

Figure 8. Setting (upper) and synchronizing (lower) signals of the WaveDAC8 generator

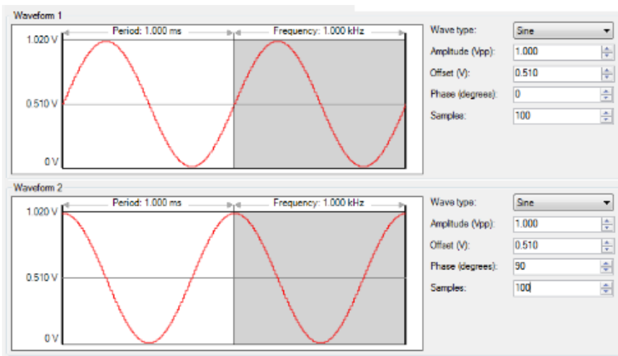

Figure 9. WaveDAC8 generator signals for impedance type sensors

Multifunction mixer implements signal modulation in one of two modes. Up mixer is continuous-time balance mixer, which performs the function of signals switching multiplier and Down mixer is discrete-time mixer, that performs the function of sample-and-hold of the signal. In the mixer configuration window (Fig. 10), the operation mode and a number of other parameters are selected, including the level of the supply current, the use of an internal or external Local Oscillator, (LO), the oscillator frequency (LO Frequency). It also displays the input and output signals as well as the results of Fast Fourier Transform (FFT) of these signals.

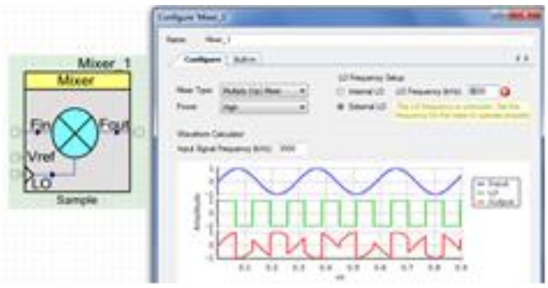

Figure 10. Mixer configuration window

The PGA programmable amplifier is implemented on the basis of a universal SC/CT unit, which can function in both the Switched Capacitor and Continuous Time Feedback modes. The programmed gain is determined by a set of discrete values – 1 (0 dB), 2, 4, 8, 16, 24, 32, 48 or 50 (34 dB). It is possible to select the power level (High, Medium and Low). In turn, these power levels of the amplifier determine its bandwidth and the rate of the output signal increase. The amplitude-frequency response of the amplifier for the selected power supply level is displayed in the configuration window (Fig. 11).

There are two types of analog-to-digital converters. The first of them is ADC based on the Delta Sigma modulator DelSig with high resolution and the second one is based on the SAR sequential register with high conversion rate. Configuring ADC DelSig (Fig. 12) involves the choice of Selectable resolutions (from 8 to 20 bits); input voltage range (7 ranges); Analog-to-digital conversion rates (from 8 SPS (Sample per second) to 384000 SPS); Operational modes (Single sample, Multi-sample, Continuous mode, Multi-sample Turbo). The ADC DelSig component has a built-in high-ohm buffer with programmable gain KV = 1, 2, 4, 8. The signal conversion occurs in the full range of supply voltages (Rail-to-Rail) or with offset beyond the supply voltage (Left Shift). A significant advantage of this component is the ability to save multiple user-configured configurations (Config) and to switch between these configurations programmatically. Configuring the ADC SAR (Fig. 13) involves selecting of Selectable resolutions (8, 10 or 12 bit); input voltage range (7 ranges); speeds of analog-to-digital conversion (up to 106 SPS); Sample modes (Free running, Software trigger or Hardware trigger).

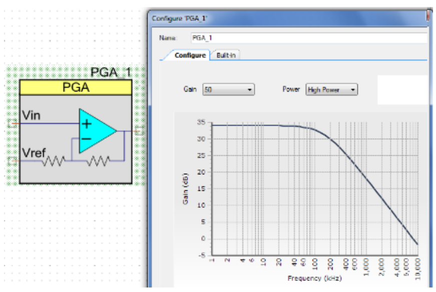

Figure 11. PGA Configuration Window

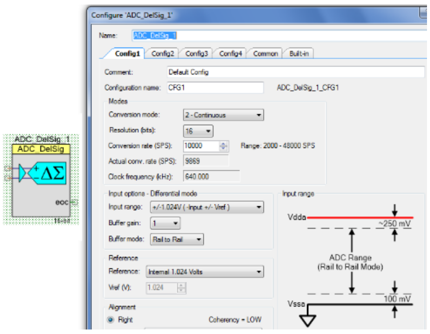

Figure 12. ADC DelSig Configuration Window

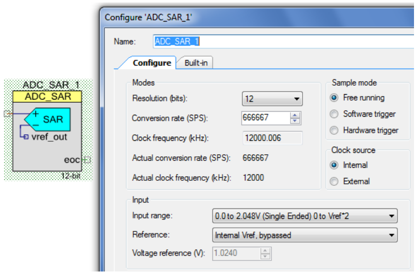

Figure 13. ADC SAR Configuration Window

An important component of the analog path is the AMux multiplexer (Fig. 14), whose configuration allows to select the number of Channels, Mode and Mux Type, in particular, by switching Single or Differential circuits.

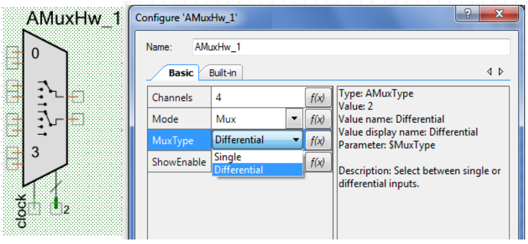

Figure 14. AMux Multiplexer Configuration Window

The CapSense CSD component is provided for the implementation of capacitive sensor devices in PSoC5 systems. Configuring this component (Fig. 15) involves selecting the type of capacitive sensors, naming and setting them. There are 7 types of sensors: Buttons, Linear Slider, Radial Slider, Matrix Buttons, Touch Pads, Proximity Sensors, and Generics. The programmable parameters of signal converters of capacitive sensors are Finger Threshold – detection threshold; Noise Threshold – noise threshold; Hysteresis; Debounce – the amplitude of oscillations of transients; Scan Resolution – the resolution of a measuring transducer. The measurement accuracy is improved by a set of hardware and software solutions, including signal averaging, tracking off-set instability, forming a hysteresis switching function, etc. A significant advantage of the CapSense CSD component is the ability to debug a designed capacitive sensor, taking into account signal instability and the spurious effects of third-party objects (Fig. 16).

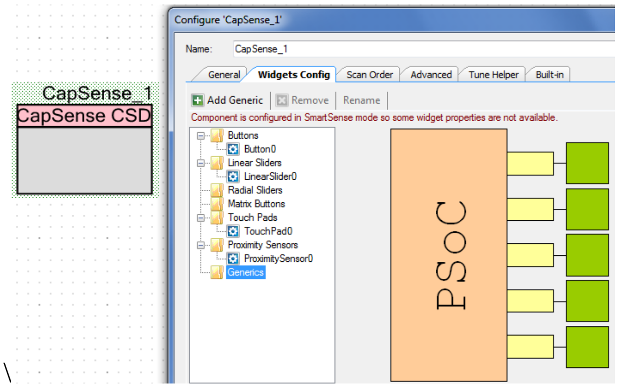

Figure 15. CapSense configuration window

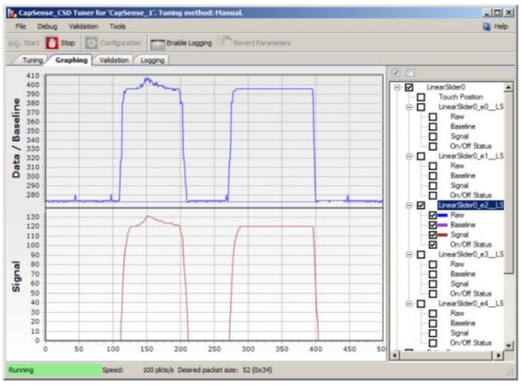

Figure 16. CapSense Capacitor Sensor Debug Window

In order to increase the efficiency of the development of high-precision temperature sensors [15], the components of the measuring transformation on the Resistance Temperature Detectors (RTDs) (Fig. 17) and Thermocouples (Fig. 18) are provided in the PSoC5 system. Polynomial approximation of the transformation function is used to improve the measurement accuracy. The configuration windows of these components show the calculation of the temperature measurement error depending on the measurement range and the approximation parameters. The result of temperature measurement is obtained using API functions and transformations, in particular rtdRes = GetRTDRes(vRef); rtdTemp = RTD_GetTemperature (rtdRes); decTemp = rtdTemp/100; fracTemp = rtdTemp – (decTemp * 100).

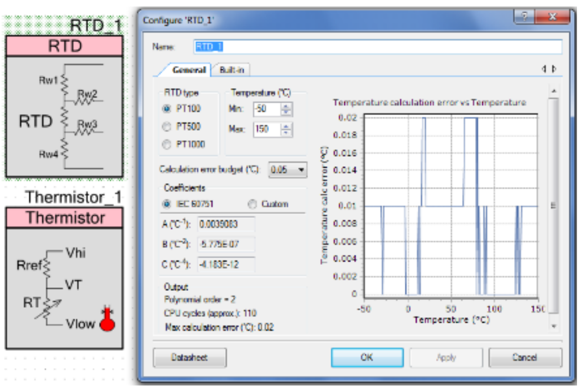

Figure 17. The RTD component configuration window

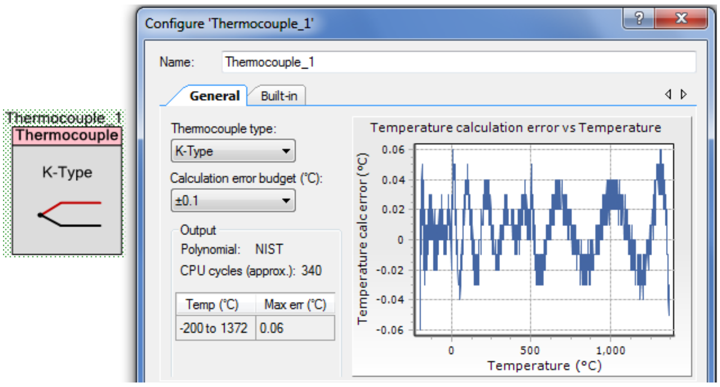

Figure 18. Thermocouple component configuration window

Experimental research and examples of implementation. PSoC Multi Sensor software has been developed to configure the elaborated hardware-software system of signal converting and to implement integrated sensors based on it. Using this software, it is possible to dynamically reconfigure the system and specification of its components, set measurement modes and graphically display the results.

The testing of this system was carried out in the process of realization of various integrated sensors, in particular, sensors of thermal analysis on the principle of Differential Scanning Calorimetry, sensors of the spatial position on the principle of Magnetic Tracking, sensors of optoelectronics LED (OLED) and Impedance Spectroscopy.

Examples of the use the signal converting system in the case of calorimetric sensors are presented in Fig. 19, and in the case of magnetic tracking sensors – in Fig. 20.

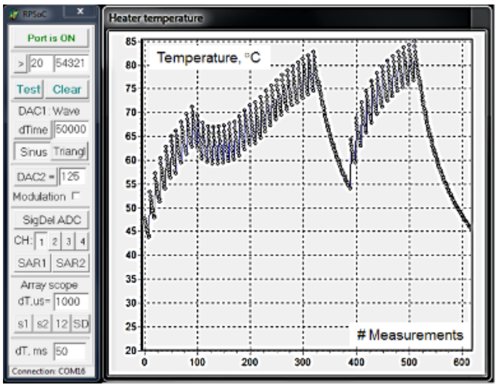

Figure 19. PSoC MS control window and calorimetric sensor signal

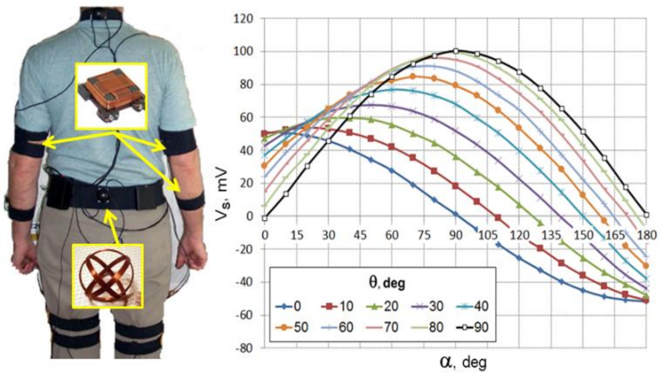

Figure 20. Sensors and angular dependencies of the signal in the magnetic tracking system

The measuring transducers of signal converting system for impedance spectroscopy are mainly based on two methods – galvanostatic and potentiostatic. In the galvanostatic method, the informative value of the measuring impedance is the time dependence of the instantaneous voltage value VZ(t) on the investigated bipolar system at a predetermined modulation of the current. Instead, the informative value of the potentiostatic method is the time dependence of the instantaneous current value I (t) at a given voltage modulation. In both methods, two components of the impedance of the investigated object, its active Re (resistance) and its reactive Im (impedance) parts, are obtained based on the results of the measurement transformation. After this, an impedance hodograph on a complex plane, also called the Nyquist diagram, is constructed using these impedance components. The form of Nyquist diagram allows to determine the structure and parameters of the investigated medium.

Measurement transformations in impedance spectroscopy are performed by synchronous quadrature detection and integration of the output voltages of the signal converter.

Fig. 19 presents the results of measuring the forms of the activation signal (upper dependence) and the signal at the output of the synchronous detector (lower dependence) which are used to calculate the real and the imaginary components of the impedance. In order to form a Nyquist diagram, measurements of the real and the imaginary components of the impedance are performed with a certain step in a given frequency range. An example of the generated Nyquist diagram based on the above measurements is presented in Fig. 22.

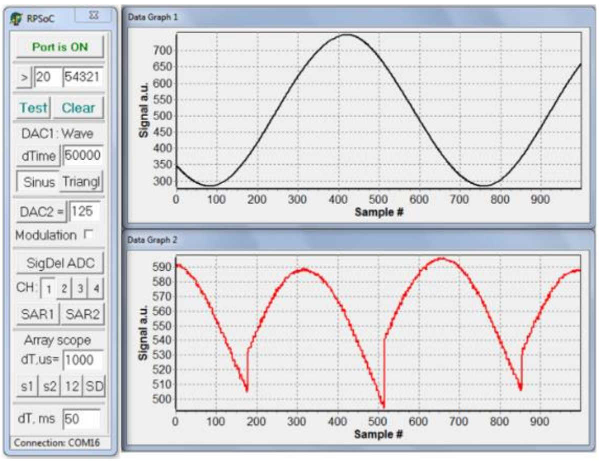

Figure 21. Result of impedance sensor signal measurement

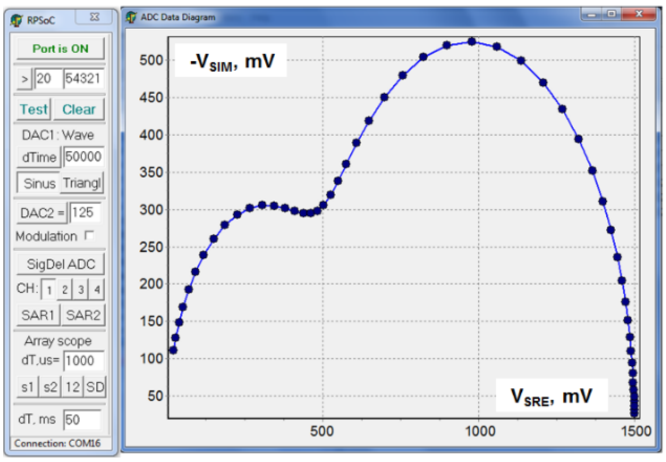

Figure 22. The result of the Nyquist diagram measurement

Conclusions. 1. The results of development of a universal hardware and software systems of signal converting for the construction of integrated sensors based on the «actuator-sensor» with different physical quantities – electric current, electric capacity, heat, light, magnetic field, etc. are presented. The measurement process is carried out by acting on the investigated objects or medium of controlled perturbations causing the activation of the corresponding physical processes. Considering the requirements of modern microcircuit technique, in particular for sensory devices of the Internet of Things, the signal path of the synthesized sensors is implemented on the basis of PSoC of 5LP Family Cypress. 2. The main components of the PSoC5 system, on the basis of which the signal converter is actualized, are digital-to-analog converter, synthesizing generator, timer, control register, frequency divider, multifunctional mixer, operational amplifiers, programmable gain amplifier, analog multiplexer, analog-to-digital converters ADC based on the delta-sigma modulator and the successive approximation register. 3. The CapSense CSD component was used for the implementation of capacitive sensors. The components of the measurement transformation based on the RTDs and Thermocouple were used for the implementation temperature sensors. The testing of the developed system is carried out in the process of implementation of integrated sensors of thermal analysis, magnetic tracking, optoelectronics and impedance spectroscopy.

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УДК 534.134

УНІВЕРСАЛЬНА АПАРАТНО-ПРОГРАМНА СИСТЕМА СИГНАЛЬНОГО ПЕРЕТВОРЕННЯ ДЛЯ ПОБУДОВИ ІНТЕГРОВАНИХ СЕНСОРІВ

Григорій Барило; Оксана Бойко; Ігор Гельжинський; Роман Голяка; Тетяна Марусенкова

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Резюме. *Роботу присвячено питанням реалізації сигнальних перетворювачів інтегрованих сенсорів у концепції синтезу даних (Data Fusion), основу якої складає процес інтеграції кількох джерел даних для отримання послідовнішої, точної та корисної інформації, ніж та, що надається будь-яким окремим джерелом даних.*

В сенсорній техніці концепція злиття даних передбачає злиття даних інтегрованих гетерогенних сенсорів), тобто різних за суттю вимірювального перетворення джерел інформації. Вирішено завдання розроблення універсальної апаратно-програмної системи сигнального перетворення для побудови інтегрованих сенсорів. Основними вимогами до такої системи є широка функціональність щодо поєднання різних методів вимірювального перетворення та відповідність сучасним тенденціям розвитку мікроелектронної сенсорики. Функціональність системи забезпечується можливістю реалізовувати вимірювальне перетворення сигналу за принципом «актюатор-сенсор» з різними фізичними величинами – електричним струмом, електричною ємністю, теплом, світлом, магнітним полем. Враховуючи вимоги до сучасної мікросхемотехніки, зокрема до сенсорних пристроїв Інтернету Речей, сигнальний тракт синтезованих сенсорів реалізовано на основі PSoC, сімейства 5LP Family Cypress. Розроблено структуру сигнального перетворювача на основі вбудованих елементів PSoC до якої входять вузли цифрових та аналогових систем, вузли мікропроцесора, матриці енергозалежної та енергонезалежної пам'яті, системні ресурси, а також вузли програмування та керування енергоспоживанням. Для наладження розробленої апаратно-програмної системи сигнального перетворення та реалізації на ній інтегрованих сенсорів розроблено програмне забезпечення, з допомогою якого можна проводити динамічне реконфігурування системи, специфікацію її компонентів, встановлювати режими вимірювання та графічно відображати отримані результати. Апробацію цієї системи була здійснена в процесі реалізації інтегрованих сенсорів термічного аналізу, оптоелектроніки, магнітного трекінгу та імпедансної спектроскопії.

Ключові слова: *сенсор, злиття даних, сигнальний перетворювач, програмована система*.

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