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Development of a Digital Gas Sensor Module Designed for Industrial Safety Systems and Their Application

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Annotation: The article discusses the development of a wireless monitoring system for the control of toxic and combustible gases to solve the actual problem of automated control of the gaseous environment at hazardous production facilities. The architecture of the monitoring system, which consists of wireless gas analyzers with connected remote digital modules, is described . The article discusses design and circuit solutions for the development of a digital gas sensor module, which includes: a microcontroller, an RS-485 transceiver, an integrated power supply based on a pulse converter, a unit with digital gas sensors. The principle of combined protection against electrostatics and microsecond interference, as well as the concept of digital gas sensors with sensitive elements of various physical types, is considered. The developed module makes it possible to detect explosive and toxic gases in the atmosphere, and can be used in industrial accident prevention systems together with actuators.

Key words: monitoring system, industrial safety, gas sensor, intelligent digital sensor, zigbee , micro assembly, RS-485, toxic gas, explosive gas.

Introduction. The task of warning and avoiding hazardous situations associated with the presence of combustible and toxic gases in the atmosphere is relevant and timely. At present, wired automated systems for monitoring toxic and explosive gases are used at large production facilities of the chemical industry. In technological processes associated with the extraction, transportation, processing, production, storage and use of combustible and toxic gases, there is always a high probability of the formation of explosive and toxic mixtures [1,2]. A high concentration of combustible gases can lead to ignition or explosion when the gas content in the air is between the lower and upper flammable concentration limits [3,4]. A high concentration of toxic gas above the established maximum permissible concentration of P(DK) in industrial premises can cause severe poisoning of personnel. At present, the causes of explosions and poisonings in Uzbekistan are most often a gross violation of the rules for the safe operation of equipment, a lack of control over technological processes, and sometimes a low level of qualification of the working personnel[4,5].

Thus, in Uzbekistan, the task of automated control of the gaseous environment at industrial facilities is very relevant. Modern Western industrial enterprises install automated detection systems for toxic and explosive gases[6,7]. Such systems , consisting of gas analyzers, controllers, warning devices and actuators, perform the functions of early warning of the development of a dangerous situation. Thus, gas detection systems make it possible to localize the development of dangerous situations at an early stage, and also increase the period of time for taking appropriate protective measures and actions to eliminate emergency situations[8,9]. To solve it, it is necessary to constantly improve existing gas analyzers - to increase their reliability, accuracy of measuring concentrations, as well as versatility and ease of operation. As a result , an urgent task is to develop complex gas analyzers that meet modern requirements for speed and accuracy, and operate stably under conditions of disturbing environmental factors [10,11].

Wireless monitoring system

To detect leaks of toxic and combustible gases at production facilities, a special system based on wireless gas analyzers has been developed. The wireless monitoring system of the IEEE 802.15.4 standard consists of a network coordinator, a router and an end device [12,13]. In the network topology, the router and the end device are multi-channel and non-volatile gas analyzers. IEEE 802.15.4 ZigBee standard allows to provide data transmission over long distances with low power consumption of transceivers [14,15]. A feature of the IEEE 802.15.4 ZigBee standard is that devices support relay and routing functions to increase the communication range. The architecture of the monitoring system is presented.

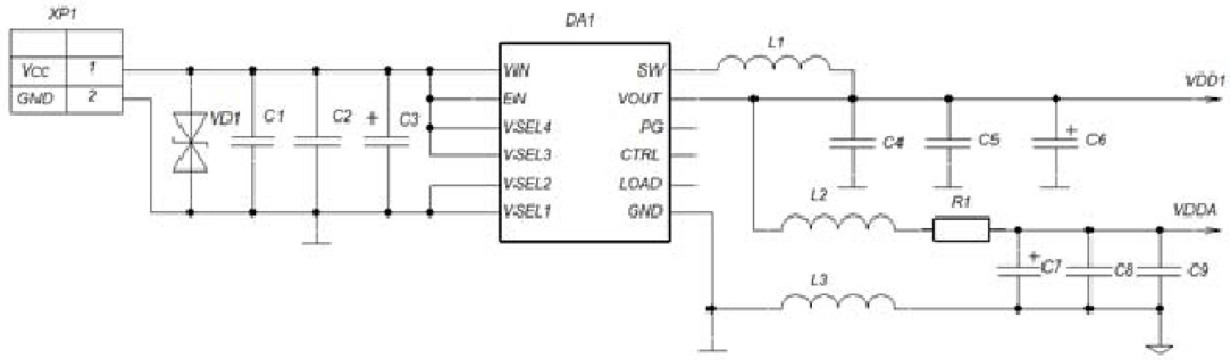
The developed monitoring system based on wireless non-volatile gas analyzers is designed to measure the concentration of toxic and combustible gases, signaling the excess of concentration levels and control the actuating elements of ventilation systems, sound and light alarms and automation[16,17]. The main components in the monitoring system are multi-channel wireless non-volatile gas analyzers, each of which consists of: a power source with batteries, a ZigBee transceiver, a control microcontroller, a micro-assembly of power switches, a galvanic isolation unit with digital interface drivers RS-485, USB. Specialized digital modules of gas sensors are connected to wireless gas analyzers. In turn , the multichannel wireless gas analyzer provides power for remote digital sensors, signal processing and indication of measured gas concentrations, data reception and transmission to the wireless network, alarm devices triggering when the threshold values of measured gas concentrations are reached, and diagnostic self-monitoring[18,19,20].

Digital gas sensor module.

Correct placement of gas sensors of various physical types is the key to the effective operation of the monitoring system[21,22]. At present, multi-channel digital modules with RS-485 interface, which are connected to stationary or mobile devices, have proven themselves the most well. On fig. 1. The appearance of the developed digital module of gas sensors for wireless gas analyzers and for industrial stationary systems of the existing type is presented[23,24,25].

Rice. 1. - External view of the digital gas module with 4 sensors.

Remote gas modules are installed near the zone of possible gas release and connected to a wireless gas analyzer. The installation height of the remote module completely depends on the physical properties of the controlled gases[26,27]. Since gases heavier than air (carbon dioxide, propane , chlorine, etc.) will accumulate in the lower part of the room, the sensitive elements are installed at a height of no more than 1 meter from the floor. Lighter gases will rise to the top of the room and the sensors should be placed near the ceiling. For gases having a density close to air, the location can be any[28,29]. For toxic gases, sensors are located at the level of human breathing. When receiving information and interpreting it from a remote gas module, it is required to be guided by the general sanitary and hygienic requirements for the air of the working area GOST 12.1-005-88. The digital gas sensor module may only be connected in a non-explosive atmosphere[30,31]. On a real object, the number of sensor units and their location is determined by the project and regulatory documents. Each remote digital module of gas sensors is connected to an autonomous main gas analyzer using a twisted pair cable, through which power is supplied and service information is transmitted according to the RS-485 standard. The use of the RS-485 standard for data communication between a wireless non-volatile gas analyzer and a remote sensor enables low-cost and reliable data communication in environments with high levels of noise and adverse conditions, such as rooms with a large number of industrial installations. Reducing the susceptibility to external interference on the RS-485 bus is achieved due to the differential signal transmission method[32,33]. The digital module includes : a microcontroller, an RS-485 transceiver, an integrated power supply, a block with digital gas sensors. Currently, when developing a digital gas module, it is required to strictly take into account the power consumption of all its components in order to increase the battery life of the system. Almost all electronic components that were created more than 5 years ago are not suitable for use in stand-alone devices due to the high level of power consumption. On fig. Figure 2 shows the electrical circuit of the integrated power supply implemented in the developed module.



Rice. 2. - Part of the circuit of the electrical circuit of the power source.

The integrated power supply of the digital module receives external power via a twisted pair cable no longer than 10 meters from a wireless gas analyzer and generates a constant analog and digital 3V power supply for the control microcontroller, gas sensors, and an RS-485 driver chip[34,35]. On the side of the wireless gas analyzer, to which digital remote modules are connected, a galvanic isolation unit is installed to protect the main product. Capacitors and a specialized suppressor (VD1) are installed at the power supply input to suppress impulse noise. The developed power supply uses a switching voltage regulator (DA1 in the circuit) TPS62740. The miniature switching regulator has its own current consumption of only 360nA, its conversion efficiency reaches 95% at a rated load of up to 100mA [36,37]. Such indicators are achieved through the use of the DCS- Control control architecture , which combines the advantages of hysteresis control and voltage control mode [38]. The output voltage of the switching voltage regulator is set by a four-bit combination. Noise filtering is carried out both on the power supply (L2) and on the common wire (L3). Anti-ringing resistor R1 serves as a fuse, and capacitors of various capacities (C4-C9) suppress high-frequency and low-frequency noise on the digital and analog power lines. The use of just such a regulator makes it possible to reduce the power consumption of the module by several times, since digital gas sensors have a pulsed mode of operation. In the pulsed mode of operation , digital gas sensors are in “sleep mode” for a greater amount of time, and only wake up according to the timer every 15-30 seconds to measure the concentration of toxic and explosive gases[39].

Power consumption of the digital gas sensor module.

The general trend in the development of instrumentation is towards miniaturization and reduction of energy consumption. Modern monitoring systems use battery-powered wireless systems. Because of this, the issue of reducing the energy consumption of the components of the product and thereby increasing the operating time of the product is acute. In gas analytical devices that control combustible gases with semiconductor and thermocatalytic sensing elements, the most energy-intensive object is the sensing element, which must be heated to an operating temperature reaching 400-500 °C. In gas analytical instruments , which control toxic gases, the most energy-intensive component is already the control microcontroller and the RS-485 driver chip[40].

The power consumption of the developed digital module can be divided into 2 parts - active mode and sleep mode. In active mode, the STM32L011 microcontroller, operating from an internal clock source, consumes only 76 μA / 1 MHz clock frequency, in sleep mode, only 0.29 μA with the options for waking up from an external interrupt and UART receiving a package from the RS-485 driver chip. The RS485 driver chip in active mode consumes at least 1.1 mA, in sleep mode only from 10nA to 5uA. Unfortunately , the RS-485 driver chip cannot be disabled, since at any time a package with important data may arrive from the master device. In sleep mode, digital gas sensors draw less than 0.1 mA[41].

Conclusion. On the basis of a modern ECB, a low-power digital module of gas sensors has been developed for the industrial safety and environmental monitoring system. Structural and circuit solutions allow the developed module of gas sensors to function in an unfavorable electromagnetic environment at real industrial facilities. Using the concept of digital intelligent gas sensors can greatly simplify the maintenance of the finished monitoring system. The developed module makes it possible to detect explosive and toxic gases in the atmosphere and can be used in industrial accident prevention systems together with actuators. Monitoring systems based on the developed module make it possible to localize the development of dangerous situations at an early stage, and also increase the time period for taking appropriate protective measures and actions to eliminate emergency situations. The results of the work can be used in various industries, at enterprises: gas and oil industries, oil refining and chemical industries, energy, mining and coal industries, metallurgy , food industry.

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