Wireless communication system for temperature monitoring

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***Abstract* — In today's world we are facing with many different types of emergencies which are caused increasing temperature. Response to such emergencies is critical in order to protect resources including human life and also we can save property from damage. In order to prevent disasters caused by structural failure due increasing temperatures, temperature sensors are needed.**

In this paper is shown design of temperature sensor, fabricated in thick film technology, and realized wireless communication between sensor node (sensor board) and PC node for collecting data (data board). Temperature sensor (thermistor) is made in thick film technology using NTC paste and PdAg electrodes applied on alumina substrate. A wireless communication is realized using developed peripheral node, router node and receiver nodes based on 8-bit microcontrollers and RF Transmitter/Receiver modules.

An intention is that temperature monitoring of depth sensors will be applied to measure temperature in some of the applications which requires for this kind of monitoring, as asphalt of burdened high way, or some walls of hazardous rooms.

***Index Terms* — NTC Thermistor; Temperature sensor; Thick film; Wireless sensor; Wireless Sensor Networks**

I. INTRODUCTION

Temperature sensors capable of monitoring temperature changes in asphalt or hazardous walls are needed in order to monitoring traffic, changes in structures of asphalt and wall, and prevent possible disasters, caused by structural or system functional failures due to increasing temperatures.

Response to such emergencies is critical in order to protect resources including human life and also we can save property from damage.

In this paper developing temperature depth sensor in thick film technology (thermistor) is presented, which is a part of sensor node. Temperature sensor (thermistor) is made in thick film technology using NTC paste and PdAg electrodes applied on alumina substrate [1]. Another part of sensor node is sensor board, data board which is communicating using wireless communication with master board [2], or monitoring node which is working on data processing. Data board and master board are realized on printed circuit boards using Reduced Instruction Set Commands (RISC) 8-bit Microcontroller Atmega48.

Using wireless sensor it is possible to inform appropriate user in timely manner, and in this way to save life of people, or avoid damage of property.

II. REALIZATION OF TEMPERATURE DEPTH SENSOR IN THICK-FILM TECHNOLOGY

In recent years thick film temperature sensors (thermistors) have been used in a variety of microelectronic applications. They are often utilized as the temperature detectors or temperature compensating elements.

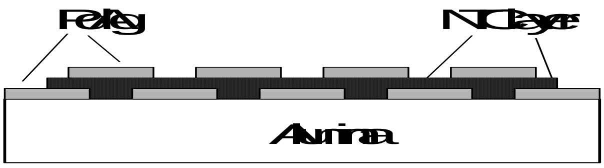

Figure 1. Realized NTC thermistor.

Thick film thermistors offer advantages in package size and ease of integration in the ceramic circuits, as well as generally lower unit cost. The growth in their utilization has been stymied, however, mostly because of lower temperature sensitivity than their monolithic counterparts.

NTC thermistors are ideally used for temperature sensing applications over range of -80o C to – 250o C. NTC thermistor (Fig.1.) was printed and sintered on alumina base, using NTC paste. On the upper layer were placed four PdAg electrodes, and on the lower layer were placed five PdAg electrodes, in zigzag order. A thermistor can actually be seen as a serial connection of five thermistors. The contacts with the electrodes are realized by two-component conductive epoxy adhesive, because of the sensitivity to higher temperatures of soldering.

The realization of temperature depth sensor is made by connecting of three NTC thermistors (Fig 2.) This is actually a serial connection of three thermistors, with 8 realized contacts. As you can see, three thermistors (Fig 1.) are mounted on the drilled pertinax board. Dimensions of the prototype are 150x28mm. In order to easy access, the contacts were conducted to the 2x4 header. In this way of the connecting, 7 thermistors actually were realized, giving the opportunity for more precisely sensing temperature by depth.

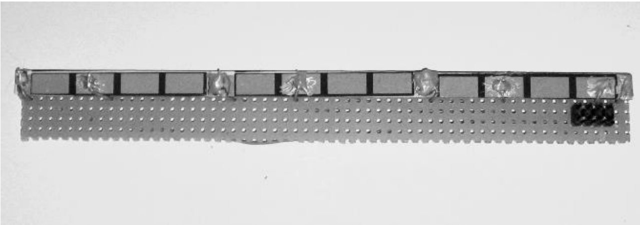

Figure 2. Prototype of temperature depth sensor.

The use of an NTC thermistor device as a temperature sensor allows resolutions of ± 0.1 to ± 0.2 to be easily achieved [3]. The high sensitivity of NTC thermistor sensors, combined with the availability of tight resistance tolerances, makes them the ideal choice when designing temperature control systems.

A thermistor is a type of electronic component whose principle characteristic is that its electrical resistance changes in response to the changes in temperature. The relationship between the resistance and temperature is non-linear. Although there are mathematical models available for establishing the non-linear relationship.. All segments, between two outputs, were tested using impedance analyzer HP 4914 was used for the measurements, in impedance mode CpRp. The temperature sensor is heated by pistol with hot air, and a temperature of thermistor was measured by a thermal camera of manufacturer Ulirvision.

The investigations were performed at 25^{o}C, 50^{o}C and at 80^{o}C, in the range of 100 Hz to 40 MHz, in order to test a behavior of the temperature sensor at higher frequencies, and to obtain information about an influence of parasitic elements. For each segment, particular thermistor, is obtained graphic dependence of the resistance, frequency at temperatures 25^{o}C, 50^{o}C and 80^{o}C. All measurements were performed at room temperature and humidity. One of obtained graphics of temperature dependence is shown in Fig. 3, from where is possible to notice Negative Temperature Coefficient dependence.

The obtained graphics are showing that an impedance of each segment depends by temperature, and in a same way by the parasitic capacitance between the PdAg electrodes of an NTC thermistor.

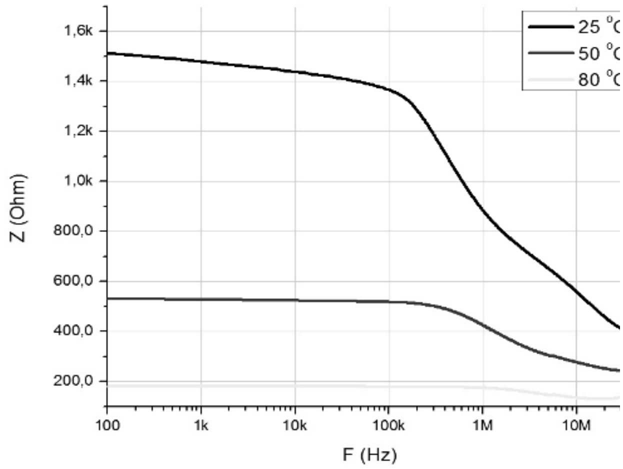

Figure 3. Tested segment of temperature depth sensor.

III. DESIGN OF WIRELESS COMMUNICATION FOR TEMPERATURE MONITORING

Digital processing capability is available in many electronic systems at reasonable cost. The basic principle of such systems is the Micro-Converter, (µC) IC concept. Such devices have an Analog to Digital Converter (ADC), microprocessor and output stages integrated in a single module or chip. They have the capability to be programmed by the user to perform various mathematical functions. In systems based on such devices, the NTC thermistor can typically be interfaced to the ADC stage in a potential divider configuration.

Other configurations may also be suggested in the application notes supplied with the ADC or µC. The choice of resistance value of the series resistor is determined by considerations such as the current levels in the thermistor and power consumption in the circuit. Limiting the current in the thermistor is advisable to minimize power dissipation in the thermistor, which can cause undesirable self-heating effects. Typically the power dissipation in the thermistor should be lower than 100 µW.

The proposed time-driven Wireless Sensor Network [4] consists of peripheral nodes, router module and receiver module connected with personal computer. Router is connected with peripheral nodes through wireless RF interface, in a star topology. The task of router is to interact with peripheral nodes and to collect periodically a measured temperature. The received data are stored in the SD Card memory of router, and when it is necessary, it is sent to receiver module and to personal computer.

The peripheral modules of the system are designed to interact with analog and digital interface sensors for data collection. The sensor nodes perform analog to digital data converting, sending packets of information to the router module, data board, when it is required.

The peripheral node is composed of several modules: microcontroller, transmitter/receiver module, analog part, analog interface and digital interface temperature sensors, battery and power management module. In Fig. 4 is shown a structural scheme of the peripheral module.

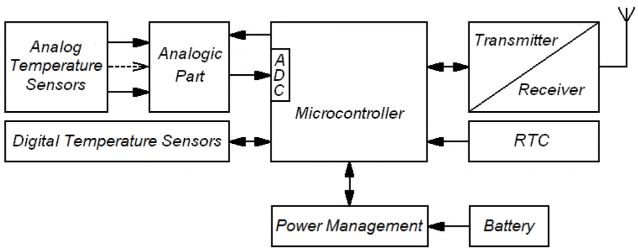

Figure 4. Structural scheme of the peripheral module.

The functionality of the peripheral node is based on Reduced Instruction Set Commands (RISC) 8-bit Microcontroller Atmega48. The MCU has the following functions:

- Interaction with transmitter/receiver module to receive commands and transmit temperature data to the main device;
- Interaction with the analog part of the module into a digital signal conversion, changing the

operational amplifier gain of the final cascade to achieve an optimal level of input signal at the input of analog to digital converter, digital signal processing of the data from the sensors;

- Collect data from digital interface sensors;
- Convert analog data to digital using internal Analog to Digital Converter (ADC);
- Packaging the measured data from sensors and sending to the router;
- Power management.

To convert the variations of resistance into the variations of electrical signal at thermistor output, it is used resistance's Wheatstone Bridge, where one of the resistors is our temperature sensor.

The temperature sensor and one fixed resistor make a voltage divider. Output voltage is dependent of temperature sensor's resistance and is applied at one input of the differential amplifier based on operational amplifier.

Another two resistors from the Wheatstone Bridge form another voltage divider. The output voltage will be reference voltage, and will be applied at another input of amplifier.

The signal obtained from Wheatstone Bridge is too small in order to convert it into a digital signal. The microcontroller has 8 inputs, 10-bit resolution ADC that means 2^{10} = 1024 values from 0 volts to Reference Voltage (in our case 3.3 Volts). Therefore, the minimum measurable value of input signal of ADC is 3.22 mV. In order to obtain desired level of the signal from the sensor, a signal has to be firstly amplified.

The analog part of the device consists of 8 identical channels with Wheatstone Bridges and differential amplifiers in order to use 8 thermistor outputs.

The peripheral node has possibility to measure temperature from the digital sensors also, using One-Wire Interface. The power supply of the digital sensors is realized through microcontroller pins, to reduce as well power supply.

In order to provide stable voltage for power supply in a wide range of input voltage from battery, peripheral node uses the DC/DC converter, based on buck-boost converter small size, which demands just one inductor as external component. The transmitter/receiver module has a large power consumption current in an active transmitter mode as well as in an active receiver mode. To reduce the power consumption the microcontroller provides transceiver's sleep mode.

The amplifiers and digital interface sensors are supplied likewise by microcontroller, for a short period when, it is necessary to measure the temperature. For the same reason, to have less consumption and longer battery life, the microcontroller can also be transferred into a sleep mode [5]. After fixed period of time (6 hours) the microcontroller can wake up by using an internal timer and all needed measurements could be performed. All data can be packed in a current time from Real Time Clock module, in data packet, and to be sent to router module. After receiving acknowledge from a router, peripheral node can go back to sleep mode, waiting the next measurement operations.

The router task is to collect data from all peripheral nodes, and to store collected data in the internal memory. It must be near peripheral nodes, less than 20 meters, and router must have low power transmitter/receiver modules in order to be able to collect data from them. The transceiver module of router node has larger power. In this way, it is possible to have communication with receiver module, connected to personal computer, which can be at long distance from the router, up to 1 km open air.

The router module consists of several modules: microcontroller, transmitter/receiver module, Real Time Clock module, SD Card memory, battery and power management module. The structural scheme of the router module is presented in Fig. 5.

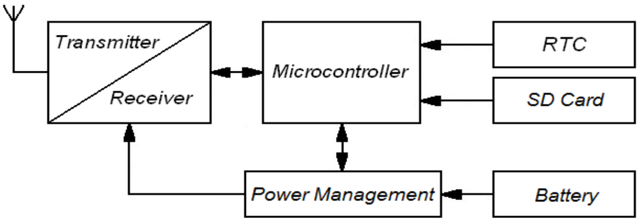

Figure 5. Structural scheme of the router module.

SD Card memory which is being used in this module represents a highly cost-efficient small package with a large volume memory. The interface between the microcontroller and memory is SPI (Serial Peripheral Interface) which works at speed of 10 MHz. This frequency allows the big quantity storage of received data until they have to be sent to receiver module.

The router module has also possibility of sleep mode, in order to save the energy, but when it must to receive data from the peripheral modules, it must wait and looking for data packages from peripheral nodes and to send back confirmations.

If a router is placed at too large distance from the main receiver module, it can include a GSM module [6]. The router module can also be supplied by the power of AC adapter to work continually.

The receiver module (Fig 6.), main board, has task to collect data from the router and send it to personal computer, through serial to USB interface. It has also large power transceiver module, in order to communicate with router, to receive collected and stored data.

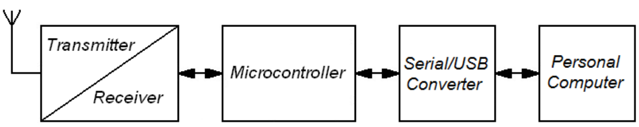

Figure 6. Structural scheme of the receiver module.

The receiver module, based on 8-bit microcontroller, transceiver module and serial/USB converter, provides the communication between microcontroller and personal computer. This module can be supplied by the USB bus and doesn't need additional batteries. The task of this module is to receive all data collected from peripheral nodes through router modules.

The receive module can be connected to laptop and can be portable, if the distance between receiver module and the router is too long, for handling device.

IV. HARDWARE REALIZATION OF WIRELESS COMMUNICATION FOR TEMPERATURE MONITORING

Using software Proteus Design Suite of producer Labcenter Electronics LTD, Printed Circuit Board, in two layers, for the Peripheral Node was designed.

The Top layer includes 8 connectors for Analog Temperature Sensors (thermistors), 4 analog channels are implemented in realization of Wheatstone Bridges and amplifiers for the measurement of temperature, the connector and RF Transceiver module, 4 connectors for Digital Temperature Sensors and one connector for power supplying and a Light Emission Diode (LED) for indicating operation of the module.

The Bottom layer of PCB includes another 4 analog channels for measurement and analog processing of signal from the thermistors (Wheatstone Bridges and amplifiers), microcontroller and Buck-Bust converter for providing stable power supply for the board.

In Fig.7 Peripheral Module with the Transceiver module realized on PCB is presented.

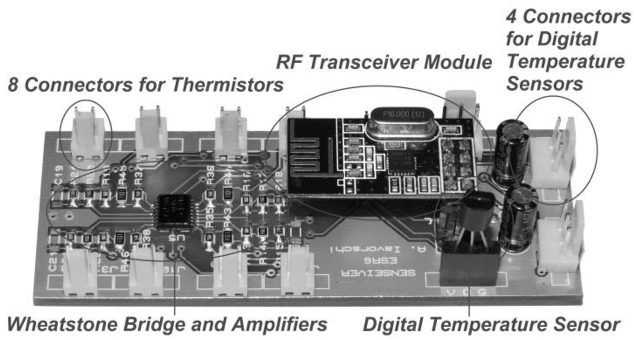

Figure 7. Realized peripheral sensor node.

The peripheral node is designed to be implemented in environments where is exist a demand for the monitoring of temperature. Its dimensions are small – 32 mm x 84 mm. Due to the buck-bust converter the input voltage of the power supply can be in a wide range – from 1.8 to 5.5 volts. For big autonomy of operation the peripheral node can be supplied from 2 or 3 batteries size AAA or a Lithium Ion Battery from cellular phones.

The receiver module was realized on the prototyping board, and it includes next components: RF Transceiver module, microcontroller and UART to USB converter.

The personal computer is using the virtual serial port to communicate with the receiver module.

V. CONCLUSION

In the second chapter of this work is shown realization of temperature depth sensor, in thick film technology, made by segments of NTC thermistors. Obtained results during tests on outputs of realized temperature sensor are satisfied, and they are giving Negative Temperature Coefficient dependence. Design of wireless communication system and realized hardware for monitoring of temperature sensors (peripheral nodes) showed in 3rd and 4th chapter are giving the satisfied results in a Real Time, collecting data in router on 10 MHz. Amplified analog signals from temperature depth sensor are successfully digitalized, processed in realized communication, and collected on PC using realized receiver module.

In future investigations, the intent is to conduct the testing of temperature depth sensor built-in the asphalt and wall of hazardous room. This data will be used for optimization and calibration of signal levels on the output of thermistors. Therefore, the possible improvements will be done on user friendly software and database for collecting data from receiver module.

ACKNOWLEDGMENTS

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