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PARALLEL TEMPERATURE MEASUREMENT SYSTEM FOR ELECTRIC VEHICLE

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Abstract: A parallel temperature measurement system for monitoring a battery stack in an electric vehicle is presented in the paper. The proposed system utilizes parallel multi-channel temperature measurements with digital temperature sensors operating on separate serial buses. An FPGA device collects data from sensors and translates it into CAN bus frames. The CAN bus is incorporated for communication with car Battery Management System. The described system can parallel measure 8 temperatures but it can be extended in case of additional needs. The structure of the system as well as particular devices are described in the paper. Selected results of experimental investigations which show proper operation of the system are presented as well.

Keywords: Digital temperature sensor, temperature measurement, CAN bus, 1-Wire bus.

1. INTRODUCTION

Contemporary automation systems are frequently equipped with temperature measuring devices. Generally, temperature can be measured utilizing a variety of available temperature sensors. There are many different analog and digital temperature sensors on the market today. Digital sensors are convenient in use, do not need difficult or expensive calibration and are typically ready to use right out of the box. Such sensors feature a digital interface and need a micro-controller for communication. Digital communication gives higher immunity to electromagnetic interferences. Major disadvantages of digital sensors comprise higher prices and greater complexity of the system software. Analog sensors are still in use because of many reasons, one of them can be lower prices and a possibility to simultaneously measure more than one parameter (for example temperature and deflection) [1, 2]. The measurement system proposed here consists of eight digital temperature sensors that can start the measurement at the same time. Because of parallel measurements, a FPGA (Field Programmable Gate Array) device is used in the system. Its use allows for parallel temperature measurement that in many applications, including automotive electronics, may be crucial. A good example of this may be a battery stack utilized in electric vehicles (EV) or hybrid-electric vehicles (HEV). Lithium based batteries used in such systems should be monitored for temperature. Secondary batteries for EV generate a lot of heat during rapid charge and discharge cycles at current levels exceeding the batteries' rating, e.g. when the EV quickly starts consuming battery power or when recovering inertia energy during sudden stops. During these rapid charge and discharge cycles, the cell temperature may increase above allowable limits [3]. Since there are a considerable number of them in either an EV or HEV, a single temperature sensor is not enough. During an uncontrolled charging or discharging process, batteries can get hot which may be dangerous and cause fire. In such cases, the temperature measurement system should be a multi-channel one and also be able to work in parallel to detect dangerous heating processes in a particular battery. Parallel measurements make it possible to control all batteries at the same time. The opposite solution is to use multiple sensors communicating with the central processor in a strictly defined order one by one. The overall time needed to check all temperatures in such case depends on number of sensors, communication speed and temperature conversion time of one sensor. In parallel measurement the number of sensors has no impact on the overall conversion time.

2. TEMPERATURE MEASUREMENT SYSTEM

2.1. Digital temperature sensors

In an EV or HEV, the maximum allowed temperature depends on the utilized Lithium batteries. If the outer temperature of the analyzed battery exceeds 150°C, semiconductor sensors cannot be used. But there are Lithium-ion cells with cobalt cathodes that should never exceed temperature 130°C (265°F). At 150°C (302°F) the cell becomes thermally unstable. Lithium based cells may be subjected to high temperatures involving three sources: high ambient temperatures, normal or extraordinary I^2R heating from the duty cycle that is being supported and internally generated heat from a short-circuit cell failure [4]. Depending on the used materials in the cell there can be a daisy-chain effect of increasingly severe reactions, potentially leading to a fire [4].

The proposed measuring system makes use of semiconductor digital sensors DS18B20 working with 1-Wire communication bus. The DS18B20 digital thermometer provides 9-bit to 12-bit temperature measurements and has an alarm function with nonvolatile user-programmable upper and lower trigger points [5]. The sensor is able to measure temperatures from -55°C to +125°C (±0.5°C accuracy from -10 °C to +85 °C) which is not enough for all kinds of battery cells on the market but is suitable for measuring temperatures of popular Lithium-ion cells based on cobalt cathodes. Such a semiconductor digital temperature sensor should be utilized in systems with batteries that must not be heated over 125 Celsius degrees. It communicates over a 1-Wire bus that by definition requires only one data line (and ground connection) for communication with a central microprocessor or microcontroller. In addition, the DS18B20 can derive power directly from the data line (parasite power), eliminating the need for an external power supply [5]. However in the presented project, ”parasite power” capability is not used. During laboratory tests it was revealed that normal supply with an additional wire gives a more robust solution in an electromagnetic interference environment. Each sensor is connected to the digital controller by individual 1-Wire bus. As there are no such microcontrollers, with enough number of hardware 1-Wire interfaces, available on the market, all interfaces as well as a soft NIOS II microcontroller have been implemented in one FPGA chip. That is very important in the presented system because all temperature sensors can be triggered at the very same moment and temperature conversion results are obtained at the same time from all used sensors. The data transfer is accomplished on the automotive CAN (Controller Area Network) bus in periods between temperature sampling. A single conversion with 12-bit resolution takes 750 ms and that is why sequential measurement with all sensors one by one will give results shifted in time. The more sensors are used (in operation on just one 1-Wire bus) the more shifted the results are. In the presented solution this is not the case. The 1-Wire bus frame consists of special time slots representing logical low and high levels. Any communication starts from the RESET pulse, after which responding device sends the PRESENCE pulse. It is depicted in Fig. 1. All data and commands are transmitted least significant bit first over the 1-Wire bus. It can be seen in Fig. 1.

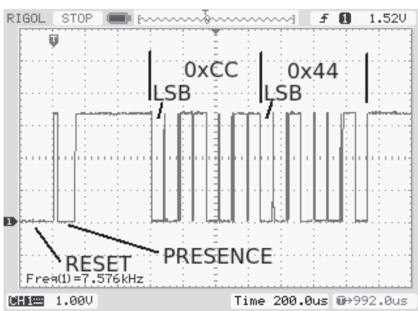

Fig. 1. The 1-Wire frame carrying Skip ROM 0xCC and Convert T 0x44 commands

The whole frame carrying Skip ROM command 0xCC and Read ROM command 0x33 and sensor response (64 bit serial code stored in ROM) is presented in Fig. 2. The presented oscillograms were saved using RIGOL DS1052E oscilloscope. A detailed description of all available commands and configurations is presented in [5].

2.2. FPGA implementation

Due to a relatively high number of 1-Wire sensors that should be connected by individual 1-Wire buses and controlled simultaneously, a FPGA based solution is proposed. Owing to the fact that there are tasks in the proposed system that should be accomplished in a sequential way, a soft-core microcontroller has been implemented as well. The operational algorithm involves a few steps. First, all sensors initiate the process of temperature conversion at the same time (in the moments of the system temperature sampling). Next, (between temperature samples) conversion results are collected by the main processor and are transmitted according to a predefined schedule (TTCAN - Time Triggered CAN) or on demand after receiving data remote request frame from the vehicle CAN bus.

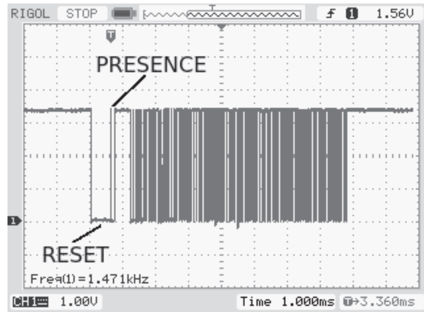

Fig. 2. The 1-Wire frame carrying Skip ROM 0xCC, Read ROM 0x33 and sensor response

The NIOS processor communicates with the CAN bus through an additional CAN controller MCP2515. The communication between NIOS and MCP2515 goes through the SPI (Serial Peripheral Interface) bus. A special library of functions related with MCP2515 has been written for that purpose. The CAN controller is connected with a CAN transceiver required to connect the system to the vehicle’s CAN bus. The block diagram of the solution is presented in Fig. 3. A chosen part of the FPGA implementation is presented in Fig. 5.

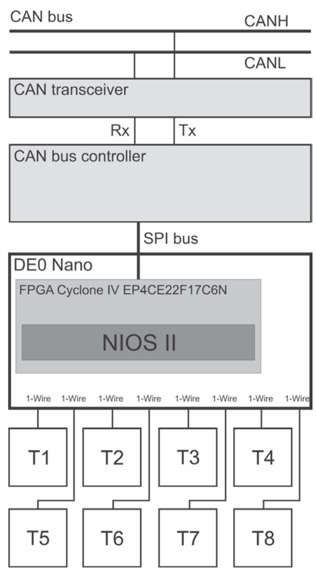

Fig. 3. The block diagram of the proposed system

The system from the vehicle side is visible as a CAN bus node and can send data frames with identifiers from 0x454 to 0x457. The identifiers can be changed if needed. The DS18B20 provides 12-bit temperature measurements. Each CAN frame can carry up to 8 data bytes. Four of them are used for time stamps transfer. The time stamps are 32 bit values from the NIOS based 32 bit seconds timer. The 32-bit resolution of the seconds timer ensures that seconds count overflows every 133 years, so in practice it will not happen. Additional four data bytes in the CAN frame are used for transferring temperature measurements from two sensors (2 x 2 bytes). The format of the transferred data is presented in Table 1. As can be seen from Table 1, there are 8 16 bit long temperature values named from T1H, T1L to T8H, T8L.

T1H for example represents a higher byte of temperature from sensor 1. TC3 to TC0 represents the 32 bit time stamps of temperature sample carried by the CAN data frame.

Table 1. Data allocation in CAN frames

Id.	D0	D1	D2	D3	D4	D5	D6	D7
0x0 454	T1H	T1L	T2H	T2L	TC3	TC2	TC1	TC0
0x0 455	T3H	T3L	T4H	T4L	TC3	TC2	TC1	TC0
0x0 456	T5H	T5L	T6H	T6L	TC3	TC2	TC1	TC0
0x0 457	T7H	T7L	T8H	T8L	TC3	TC2	TC1	TC0

The temperature sensors communicate with the NIOS processor implemented in Cyclone IV family FPGA. It is important that in the proposed solution each sensor has its own independent 1-Wire bus for parallel communication. It gives overall better control of the supervised vehicle battery stack. The NIOS II processor has been specially configured for the project using QSYS System Integration Tool in Quartus II Web Edition. This configuration in a graphical form is presented in Fig. 4.

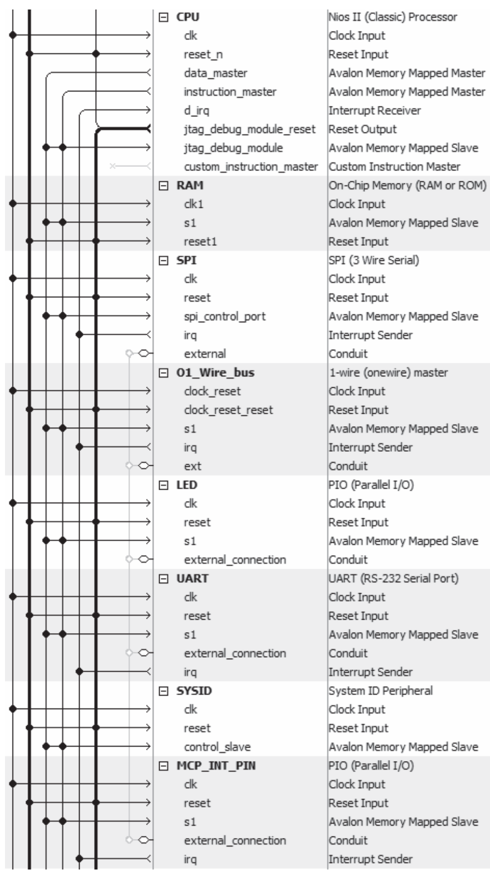

Fig. 4. Part of NIOS II processor configuration in QSYS System Integration

The NIOS processor is equipped with Universal Asynchronous Receiver and Transmitter (UART) for an easier debugging purpose. As the debugging platform a PC running Ubuntu Linux and CuteCom serial port terminal was used.

2.3. CAN bus implementation

The CAN bus is a serial, asynchronous bus designed primarily for automotive use. The undeniable advantages of CAN bus caused wide use also in other industries. The main advantage which was considered in choosing of a proper interface for this project was high level of security and compatibility with automotive systems. Its performance, and upgradeability provide for good flexibility in system design. Additional bus nodes can be easily added later to the already working system. In this case the system can be easy extended to include an additional bunch of temperature sensors. The robustness of a CAN bus may be attributed to its numerous error-checking procedures and differential signaling. It is really important in the EMI (Electromagnetic Interference) polluted environment. The CAN protocol incorporates five methods of error checking, and some of them are really difficult to deceive. Each bus node receives message that is broadcasted on the bus and if the message fails any one of these error detection methods, it is not accepted and an error frame is generated from the receiving node. This mechanism forces the transmitting node to resend the message until it is received correctly. The CAN protocol supports two message frame formats, the only essential difference being in the length of the identifier. The CAN standard frame, also known as CAN 2.0 A, supports a length of 11 bits for the identifier, and the CAN extended frame, also known as CAN 2.0 B, supports a length of 29 bits for the identifier.

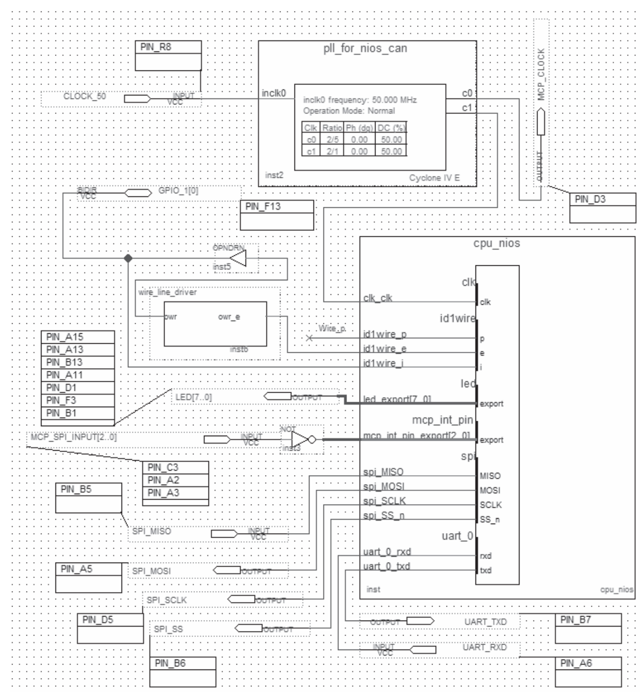

Fig. 5. The block diagram of FPGA implementation (fragment)

In this solution we have used the CAN standard frame format. To allow transmission of measured temperatures from all eight implemented temperature sensors, special data format has to be chosen. A standard CAN bus frame is depicted in Fig. 6. Using the following abbreviations: RTR - Remote Transmission Request, IDE - Identifier Extension, DLC - Data Length Code, CRC - Cyclic Redundancy Check, del.-delimiter, ACK – acknowledge from the responding device. For the purpose of the project, the transmitted data is located at specific locations in CAN frames with specific identifiers. Data allocation is presented in Table 1. A chosen part of the CAN frame transmitted in the system recorded using a Rigol DS1052E oscilloscope is presented in Fig. 7 and Fig. 8.

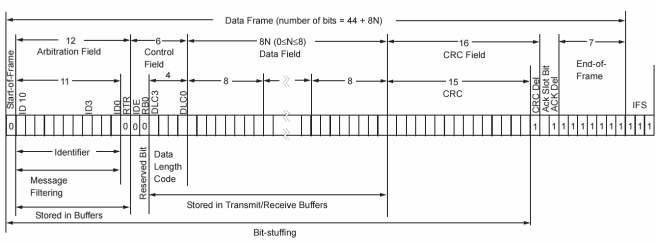

Fig. 6. CAN bus standard data frame [6]

Fig. 7 presents CANH and Tx line signaling at the input of the CAN transceiver. Additional stuffed bits are visible after each 5 consecutive bits of the same polarity (in this case 00000). The bit stuffing algorithm is explained in [6]. Figs 7 and 8 show also the effect of long cable used between the CAN nodes during laboratory investigations. CAN bus frame with visible identifier 0x0454 is presented in Fig. 8.

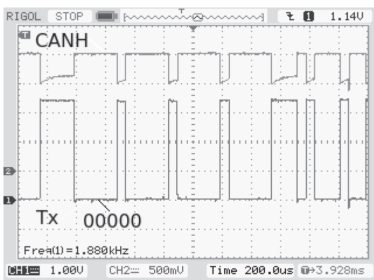

Fig. 7. CANH and Tx line signaling at the input of the CAN transceiver

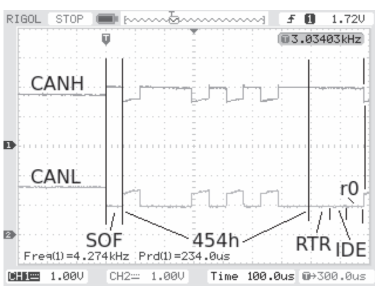

Fig. 8. A fragment of CAN bus frame transmitted in the system, id=0x0454

4. SUMMARY

A multi-channel temperature measurement system for monitoring of an automotive battery stack is presented. Lithium based batteries used in either EV or HEV systems should be monitored for temperature. However, a single temperature sensor is not enough as there are typically a great number of batteries in an EV. During uncontrolled charging or discharging process, batteries can get hot which may be dangerous and cause fire. The presented system incorporates digital temperature sensors communicating through 1-Wire buses, individual 1-Wire bus for each sensor for parallel computing (parallel measurements instead of sequential), FPGA device which collects data from sensors and translates it for the vehicle's CAN bus. The laboratory results show proper operation of the system. The CAN bus is incorporated for communication with car Battery Management System. The structure of the system as well as particular devices are shortly described in the paper.

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5. REFERENCES

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RÓWNOLEGŁY POMIAR TEMPERATURY AKUMULATORÓW W POJAZDACH ELEKTRYCZNYCH

W artykule przedstawiono system równoległego pomiaru temperatury zestawu akumulatorów stosowanego w pojazdach elektrycznych EV lub hybrydowych HEV. Podczas ładowania lub rozładowywania akumulatorów Li-ion, może dochodzić do nadmiernego nagrzewania a nawet do pożaru. Aby tego uniknąć stosuje się układy nadzorowania akumulatorów pełniące także funkcje balansowania ładunku. Takie układy potrzebują do działania informacji o temperaturze zewnętrznej poszczególnych akumulatorów. Cyfrowe czujniki temperatury wyposażone w interfejs szeregowy komunikują się z procesorem nadzorującym w sposób sekwencyjny. Przy większej liczbie czujników czas odczytu wszystkich wartości jest nadmiernie wydłużony. W prezentowanym rozwiązaniu zastosowano oddzielne magistrale szeregowe dla każdego czujnika. W związku z tym czas pełnego odczytu nie zależy od liczby czujników. Aby to było możliwe, wykorzystano układ FPGA z zaimplementowanymi interfejsami 1-Wire. Całość jest kontrolowana przez procesor programowy NIOS, który dodatkowo zapewnia komunikację z systemami pojazdu przez magistralę CAN. W artykule przedstawiono strukturę proponowanego systemu oraz zostały przedstawione wybrane wyniki badań laboratoryjnych.

Słowa kluczowe: cyfrowy czujnik temperatury, pomiary temperatury, CAN, 1-Wire.