APPLICATION OF ULTRA WIDEBAND WIRELESS SENSOR SYSTEM FOR LOCOMOTIVE ENGINE PARAMETERS MONITORING

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ABSTRACT

This article focuses on realization of ultra wideband wireless sensor system for locomotive engine parameters monitoring. We uses "On-Off Keying" modulation scheme, energy detection technology and asynchronous transfer mode in this system. Different thermal and pressure sensors are grouped based on their location in four data acquisition and processing units with ultra wideband transmitters. Construction of data acquisition and processing unit, ultra wideband pulse generator, analog and digital part of receiver are considered. Realized ultra wideband wireless sensor system is preliminarily tested. Signal's parameters are equal to expected ones. Further, the system is tested on working locomotive engine. Transmitters is located at a distance from 1.5 to 4.5 meters. Working of all sensors are proved to be efficient. The percentage of correctly received packets is obtained as performance indicator.

Keywords: *Data acquisition; Digital signal processing; Energy detector; Wireless sensor networks; Ultra wideband communication; UWB pulse generator*

INTRODUCTION

Modern sensor networks are actively used in various areas: environmental monitoring, medicine, industrial automation. The transition from wired systems to wireless ones leads to reduction of weight and size of system elements while maintaining reliability. Our work is devoted to one of the tasks of industrial automation: development of locomotive engine monitoring system. Application of narrowband systems (Bluetooth, ZigBee) is the classical approach of sensor networks. However, it is necessary to take into account the specifics of the system operation for installation on the engine: presence of multiple reflections and narrowband interference. Narrowband systems can't be effective in such cases. Transition to ultra wideband (UWB) signals is logic. Sensor networks are already used UWB signals [1-6]. Next parameters of sensor networks were chosen: asynchronous transfer and combination of "On-Off Keying" (OOK) modulation scheme and Energy Detection (ED) technology [1, 7-11]. Asynchronous transfer was chosen because such technology requires less resources in comparison with synchronous ones [7-9]. Note, that OOK modulation is most energy efficient scheme. We have already considered the experimental wireless ultra wideband sensor network for data collection [12].

The work objective is application of UWB sensor network on real locomotive engine. Data sources are thermal and pressure sensors installed on the engine. Data transfer frequency is equal to 5 Hz.

The structure of this study is organized as follows: Section 1 presents the introduction, Section 2 provides the method description, Section 3 describes the result and discussion, while Sections 4 presents the conclusion.

METHOD

Wireless Network Structural Design

At first step analysis of the characteristics of sensors and their locations is done. We form structure of distributed UWB wireless sensor network for locomotive engine parameters. It is logical to combine the sensors into several groups based on sensors location (Fig. 1).

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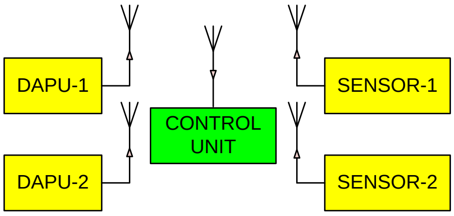

Fig. 1. *Structure of wireless sensor network*

Group №1 consists sensors: Aftercooler Temperature Sensor, Coolant Temperature Sensor, Unfiltered Fuel Pressure Sensor, Filtered Fuel Pressure Sensor, Unfiltered Engine Oil Pressure Sensor, Filtered Engine Oil Pressure Sensor. This group is processed by data acquisition and processing unit DAPU-1. Group №2 consists sensors: Left Exhaust Temperature Sensor, Right Exhaust Temperature Sensor, Left Turbocharger Compressor Inlet Pressure Sensor, Right Turbocharger Compressor Inlet Pressure Sensor. This group is processed by DAPU-2. Group №3 (Sensor-1) and №4 (Sensor-2) consist Turbocharger Compressor Outlet Pressure Sensor and Crankcase Pressure Sensor, respectively. These sensors are located relatively isolated from the others. Control unit consists receiving antenna, UWB receiver and Human Machine Interface.

UWB Transmitter Structural Design

The transmitter structure is shown in Fig. 2. The microcontroller performs all processing of data form sensors and formation of data link frames and physical layer packets. Formed physical layer packets are transferred to UWB pulse generator with frequency equal to 5 Hz.

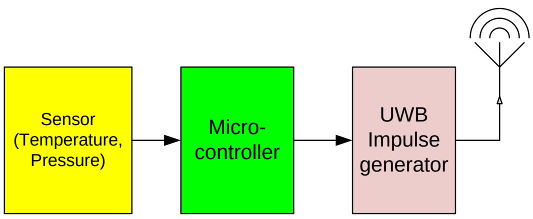

Fig. 2. *Transmitter structure*

UWB Pulse Generator Design

The UWB pulse generator uses a MAVR-044769-12790T step recovery diode (SRD). The scheme from the article [13] is used as a basis for the development of UWB pulse generator. The scheme is further refined, the main directions for increasing the efficiency of the scheme and reducing power consumption were:

- use of one +3.3 volt power supply;
- calculation of operating points of active elements;
- use of a current source to pump energy into the SRD diode;
- rejection of use a differential chain to reduce transmission line losses.

The reverse inclusion of the SRD diode has significantly reduced the power consumption of the generator circuit.

Packet Format Design

Let's determine frame and packet formats of our sensor system. Data link frame is presented on Table 1. Dimension of data from different sensors is equal to N bits. Data link frames are transferred to physical layer after completion of formation.

Table 1. *Physical layer packet and data link frame format*

Physical layer packet			
Preamble	Data link frame		
(1000 elements)	ID (4 bits)	Data (N bits)	CRC (8bits)
[1000 + (ID + N + CRC)*32] elements			

Each bit of data link frame must be spread by m-sequence. Length of this sequence is equal to 32 elements. Spread sequences are unique for different transmitters. Thus, length of physical layer packet without preamble is equal to (ID + N + CRC)*32 elements, where ID is the unique transmitter identifier of the corresponding group of sensors. Each transmitter has unique preamble on physical layer. We use m-sequence as preamble. Separation of transmitted information is done on the basis of analyze of received preamble. Note, that different transmitters of different groups of sensors (Fig. 1) have different preambles, different spread sequence and different data payload (Table 2).

Table 2. *Parameters of the fields of physical layer packet and data link frame*

	Spread Sequence	Preamble	ID	Data	CRC8	Total
DAPU-1	32 elements	1000 elements	4 bits	68 bits	8 bits	3560 elements
DAPU-2	32 elements	1000 elements	4 bits	40 bits	8 bits	2664 elements
Sensor-1	32 elements	1000 elements	4 bits	12 bits	8 bits	1768 elements
Sensor-2	32 elements	1000 elements	4 bits	10 bits	8 bits	1704 elements

Signal Processing Unit Design

Unit DAPU-1 consists 6 different sensors (Fig. 5).

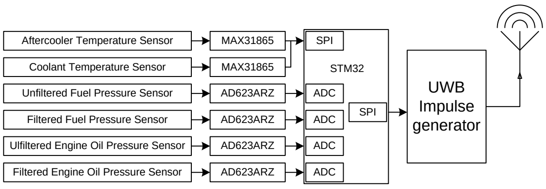

Fig.5. *Structure of unit DAPU-1*

Chip MAX31865 is used for operations with thermocouple Pt100 type. Pressure sensors have analog output and bridge connection scheme. Sensitivity of bridge connection scheme is equal to 10 mV/V. Normalized amplifier of pressure sensor amplifies the signal up to 20 times.

Unit DAPU-2 is realized by same way (Fig. 6). One of the purpose of DAPU-2 is measuring high temperatures. So we use K-type thermocouple as thermal sensor. This thermocouple provide thermal measuring in wide range from –200 °C to 1300 °C. Specialized converter MAX31855K with SPI interface is used to connect with these sensors. Pressure sensors are also connected to different ADC channels.

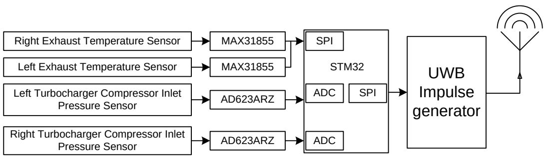

Fig. 6. *Structure of unit DAPU-2*

Units Sensor-1 and Sensor-2 (Fig. 8) are identical. Sensor-1 works with Turbocharger Compressor Outlet Pressure Sensor, Sensor-2 works with Crankcase Pressure Sensor.

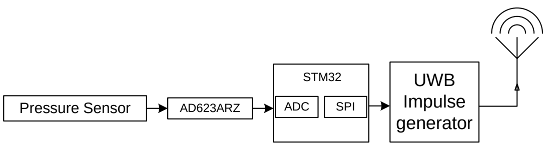

Fig. 7. *Structure of unit SENSOR-1 and 2*

Receiver Design

Receiver structure is shown on Fig. 8. Receiver consists of low-noise amplifier (LNA), energy detector (ED) block, D-trigger and FPGA [13]. Received signals after amplifier are compared with a reference level using a high-speed analog comparator in block "ED". D-trigger provide forming of rectangular pulses for FPGA.

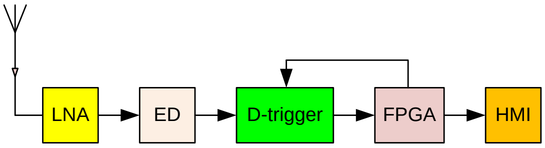

Fig. 8. *Structure of Receiver*

Receiver and receiving antenna have usually large dimensions in comparison with transmitter and transmitting antenna. Note, that large dimensions allows to realize significantly higher gain and broadband coefficients. Developed compact universal receiver's antenna (Fig. 9) is well coordinated with 50-Ohm cable (SWR ≤ 2) for frequency bandwidth 1.5–10 GHz. Antenna gain smoothly increase from 2 dBi to 12 dBi.

Fig. 9. *Receiver's antenna*

Analog-Digital Part of the Reciever

Low noise amplifier ERA-5SM amplifies received signals from antenna by 15-20 dB. After that signal are transmitted to comparator ADCMP582 and DAC AD5643R. Last step is output signal forming. Scheme for output signal forming is realized by D-trigger

SY10EP51V. Reset signal for trigger is produced by FPGA. Forming digital signals are transmitted to FPGA to further processing, circuit board of analog-digital part of the receiver is fabricated on microwave material Rogers RO4350B.

Digital Part of the Reciever

Structure of the digital part of the receiver is presented on Fig. 10. It consists of next blocks: Timing synchronization, Preamble Search, Spread sequence demodulator, Checksum verification, UART transmitter.

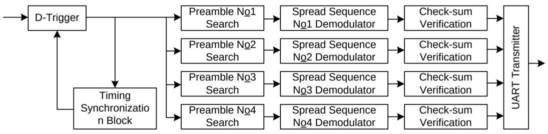

Fig. 10. *Structure of the digital part of the UWB reciever*

The block "Timing Synchronization" is designed for signal reading from output of analog part of receiver and reset signal forming for this analog part. The symbol rate in system is equal to 1 MSymbol/sec. FPGA produce reset signal for analog part with a periodicity equal to 1 microsecond. Moreover, FPGA must read signal form analog part before reset signal production.

The block "Preamble Search" solves the problems of correlational detection of the preamble of the packet and must produce trigger signal for the blocks "Spread Sequence Demodulator" and "Checksum Verification".

The block "Spread Sequence Demodulator" performs the conversion form channel bits to information ones. This process is counting the number of matched channel bits and corresponding symbols of the m-sequence for the duration of one information bit. The decision on information bits is made according to majority rule after the counting completion. The length of used m-sequence is equal to 32 elements.

8-bit checksum CRC–8 Dallas/Maxim with forming polynomial $x^8+x^5+x^4+1$ is used to check the integrity of the payload. Block "Checksum Verification" starts by block "Preamble Search" and received information bits from output of block "Spread Sequence Demodulator". The calculation is performed bitwise. Initial value of the checksum register is equal to «11111111».

RESULTS AND DISCUSSION

Experimental Setup

Transmitter units DAPU-1,2, Sensor-1,2, and receiver unit are located directly on the engine surface. We used DIN-rails with magnets for installation units on the engine. Example of working transmitter units installed on engine are shown on Fig. 12.

Fig. 12. *Example of working transmitters units installed on engine*

Three types of sensors are used as data sources:

1) Thermocouple type RTD Pt100, range of measured values –40 to +120 °C (Aftercooler Temperature, Coolant Temperature);

2) Thermocouple type K, range of measured values +49 to +850 °C (Left and Right Exhaust Temperature);

3) Pressure sensor type PDCR5020-TB-A1-CA-H0, range of measured values 0 to 200 psi (Unfiltered Fuel Pressure, Filtered Fuel Pressure, Unfiltered Engine Oil Pressure, Filtered Engine Oil Pressure, Left Turbocharger Compressor Inlet Pressure, Right Turbocharger Compressor Inlet Pressure, Turbocharger Compressor Outlet Pressure, Crankcase Pressure).

Results and Discussion

We performed some preliminary experiments in laboratory with Agilent Technologies DSO9104A oscilloscope for transmitter testing. First of all we recorded shape of single received UWB pulse (Fig. 13).

Distance between transmitter and received antenna was equal to 5 meters. Record rate of oscilloscope is equal to 1 Gs/s. As we can see duration of UWB pulses is less than 10 ns.

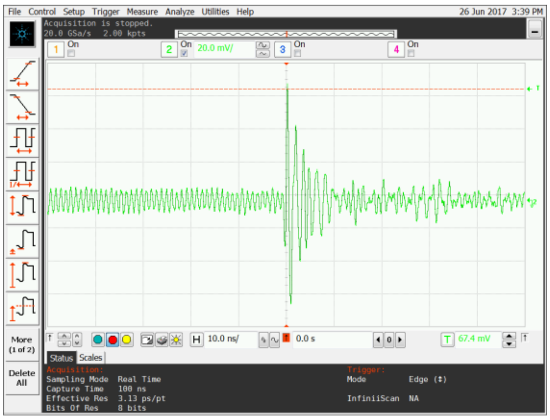

Fig. 13. *Received UWB pulse*

Then we checked duration of one physical payer packet of DAPU-1 (Fig. 14).

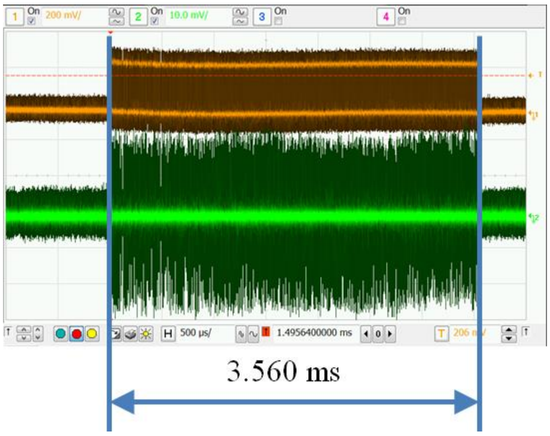

Fig. 14. *Physical layer packet of DAPU-1*

Signals from antenna are shown on the bottom; signals from D-trigger (input signals to FPGA) are shown on the top. Duration of one physical layer packet from this unit is equal to 3.560 ms. This values is consistent to total number of elements in physical layer packets (Table 2) for UWB pulse period equal to 1 μs.

At final stage of laboratory tests we checked physical layer packet's frequency (Fig. 15). Signals from antenna are also shown on the bottom; signals from d-trigger (input signals to FPGA) are shown on the top As we can see period between different physical layer packets is equal to 200 ms, that corresponds to 5 Hz.

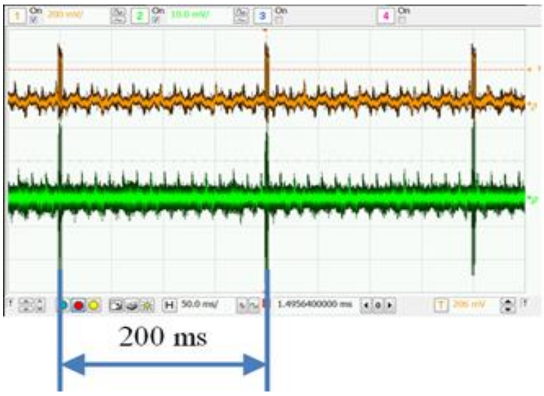

Fig. 15. *Physical layer packet`s frequency*

Human Machine Interface (HMI) for UWB wireless sensor system for locomotive engine parameters is presented on Fig. 16.

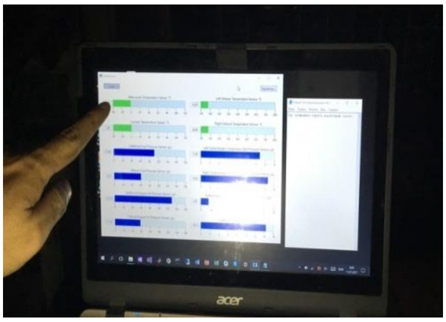

Fig. 16. *HMI for UWB wireless sensor system*

CONCLUSION

This is the first step of application the UWB wireless sensor system for locomotive engine parameters monitoring in Vietnam. We have a lot of problems to solve in order to improve this system. The first problem, threshold on analog part of the receiver still must be tuned by the most remote transmitters. The second, transmitters must be located in optimal places. Correction of these disadvantages can provide sufficient improvement of performance. Directions of future works are related with:

- Development of signal distribution model in complex environment (for example, locomotive engine): This model allows detecting of optimal sensor locations and optimal antenna orientation.

- Adaptive threshold of analog part of the receiver: This threshold can be variated by FPGA in real time to improve performance in conditions with variated noise level.

- Improvement of FPGA performance: Block "Timing synchronization" must be divided on all channels independently. It provide avoid cases of data losses in the case of packet overlapping.

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TÓM TẮT

ỨNG DỤNG HỆ THỐNG CẢM BIẾN KHÔNG DÂY BĂNG THÔNG SIÊU RỘNG TRONG GIÁM SÁT CÁC THÔNG SỐ ĐỘNG CƠ ĐẦU MÁY

Nguyễn Thế Truyện[1], Nguyễn Thế Vinh[1,*], Lê Mạnh Hùng[1], Nguyễn Lê Thùy Dương[1], Nguyễn Xuân Đồng[1], Đinh Đức Tùng[1], Nguyễn Phan Quyền[1], Sergey V. Volvenko[2], Sergey V. Zavjalov[2], Alexander S. Gruzdev[2], Andrey V. Rashich[2]

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Bài báo trình bày ứng dụng hệ thống cảm biến không dây băng thông siêu rộng để giám sát các thông số động cơ đầu máy. Trong hệ thống này chúng tôi sử dụng công nghệ điều chế "On-Off Keying", công nghệ dò năng lượng và chế độ truyền không đồng bộ. Các cảm biến nhiệt độ và áp suất khác nhau được nhóm lại, dựa trên vị trí của chúng, trong bốn bộ xử lý dữ liệu và phát xung băng thông siêu rộng. Bài báo cũng trình bày các kỹ thuật định dạng gói và xây dựng lớp liên kết vật lý một cách bài bản cho truyền thông băng thông siêu rộng. Hệ thống được thử nghiệm trên động cơ đầu máy, các bộ phát được lắp đặt tại khoảng cách từ 1,5 đến 4,5 m so với bộ thu, trong quá trình thử nghiệm hệ thống làm việc ổn định.

Keywords: *Thu thập số liệu; Xử lý tín hiệu số; Bộ dò năng lượng; Mạng cảm biến không dây; Truyền thông băng thông siêu rộng; Bộ phát xung UWB*

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