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Wireless Ultrawideband Communications and Sensor Networks

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Abstract—An actively advancing branch of wireless ultrawideband communications is considered. Direct chaotic transceivers of two types are described. The transceivers were developed at the Institute of Radio Engineering and Electronics, Russian Academy of Sciences. Application of these transceivers in wireless sensor networks is demonstrated.

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INTRODUCTION

Radio communications, which is based on the studies of such outstanding engineers and scientists as M. Faraday, J.C. Maxwell, A.S. Popov, G. Marconi, and N. Tesla, has been used for communications purposes for more than 100 years. Development of wireless (radio) communications called for their mass application. As a result, radio broadcasting was developed and radio-broadcasting networks were constructed in the 1920s–1930s. Telecasting systems, a new branch of radio communications, appeared from 1930 to 1940. Development of wireless telecasting networks provided access to high-quality video information for remote corners of the world and even further.

The development of radio broadcasting was fueled by joint efforts of researchers and designers in various fields of science and technology. Owing to implementation of massive projects of mass radio communications, as well as more special applications of radio, such fields of science as radiophysics and information theory have appeared and have been successively developed. As early as the 1920s, some outstanding scientists and engineers (when we talk about these people, we can hardly make a distinction between these occupations) realized the necessity of in-depth study of physical phenomena related to generation, modulation, radiation, propagation, reception, and processing of radio signals. Moreover, fundamental issues of the content of transmitted signals had to be solved. Although the development of radio communications began with systems of transmission of discrete information, radio broadcasting and telecasting, which are the most widespread systems using radio technology, were analog for a long time. In the 1930s–1940s, the basis of information theory was formed owing to the breakthrough studies of V.A. Kotel'nikov [1] and the results obtained by C. Shannon [2]. These studies were supported and mathematically substantiated by A.N. Kolmogorov, A.Ya. Khinchin, R.L. Stratonovich, A.M. Yaglom, and other Soviet scientists. As a result, information theory became a science (see [3] and the references therein).

Owing to the successful development of radiophysics, electronics (components), and information theory, it became possible to solve a number of extremely complicated problems of space communications and planetary radar in the 1950s–1960s. In respect to mass communications, the emergence and development of space communications was an important achievement of those times. For this purpose, the application of highly elliptical orbit and geostationary-orbit satellites began. It became evident that it is necessary to transmit a lot of information via satellites–retransmitters, the information originating from a variety of sources, including telephone conversations, TV programs, and digital data transmission required for information exchange between computers. Owing to the importance of this problem, complex solutions that allow transmission of miscellaneous information through the use of the same radio system were developed. These solutions are space, frequency, time, and code division of signals. Also, the idea of a complete transition to digital methods of transmission appeared. Gradually, this concept became dominant.

The application of digital methods of information transmission is closely related to the development of computers. Indeed, implementation of division of signals, data packaging, and information addressing and processing require significant computing power. Application of digital methods to personal communications systems became possible between the 1980s and 1990s, when efficient signal processors and microcontrollers were developed.

By that time, the first wireless cellular-telephone networks had appeared. Owing to the combination of mobile cellular technology with digital methods of signal processing, it became possible to use time and frequency division of signals, thus giving rise to a fantastic synergetic result: Cellular communications became very widespread. As far as 20–30 years ago, the possibility of realizing personal communications for billions of people was discussed only by the authors of science fiction.

Such development of wireless communications appeared by the beginning of the 21st century. It seems that all of the most unusual and intriguing possibilities have already been realized. However, imagination and needs do not have limits.

This study considers the new scientific and technical potential of systems and means of wireless communications that have been developed in recent years. Such systems and means will be used to face the challenges of the new century. Our consideration pertains to the example of ultrawideband radio, a potentially very important branch of radio communications.

1. ULTRAWIDEBAND SIGNALS AND NEW TYPES OF INFORMATION CARRIERS

For a long time, harmonic oscillations have been the main type of carrier in transmission of information. However, owing to the development of ultrawideband communications, this situation has changed in recent years.

A signal with center frequency F_c and bandwidth ΔF is considered an ultrawideband (UWB) signal if its fractional bandwidth is such that $D = \frac{\Delta F}{F_c} > 0.2$–$0.25$. In accordance with the regulations [4] of the US Federal Communications Commission (FCC) that were enacted in 2002 and that permitted unlicensed usage of UWB signals in wireless-communications devices, signals with the bandwidth $\Delta F > 500$ MHz in the frequency band 3.1–10.6 GHz are likewise treated as ultrawideband signals.

Initially, ultrashort pulses were considered the main type of UWB signal. The development of communications technology based on these signals resulted in an overall progress in UWB technology. Then, other UWB technologies appeared. Some of these technologies are currently regulated by communications standards.

Today, the list of UWB wireless technologies is as follows:

(i) Ultrashort pulses [5, 6]. In general, the duration of the pulses depends on the frequency band used, but, usually, it constitutes 100–2000 ps. It is typical of these signals that the relation between the pulse duration and the width of the power spectrum is rigid and the that power spectrum spreads along the frequency axis from zero to $f \approx 1/T$, where T is the length of the ultrashort pulse (Fig. 1a). The bandwidth–time product is $B \approx 1$.

(ii) Short radio pulses–oscillation trains [7]. In accordance with this approach, a signal is formed in a given frequency band. As is the case for ultrashort pulses, the relation between the duration of the pulse and the power spectrum of the signal is rigid. In order to obtain a more uniform spectral density in the frequency band, the pulse envelope is bell shaped (Fig. 1b). The bandwidth–time product is $B \approx 1$.

(iii) Chaotic radio pulses [8, 9]. The envelope of the power spectrum of these signals is determined by the initial spectrum of a continuous chaotic signal and, under certain conditions, is practically independent of the pulse duration (Fig. 1c). The bandwidth–time product varies over a wide range.

(iv) Bursts of short pulses [10]. As in the case of a single short pulse, the shape of identical pulses is matched to a given frequency band (Fig. 1d). The bandwidth–time product is proportional to the number of pulses in the burst.

(v) Direct sequence of spread-spectrum signals. This solution implies breaking a sinusoidal signal into very small fragments called chips [11]. In order to transmit one bit, a series of chips is used. In the extreme case, when only one chip is used for transmission of one bit, this method is the same as the method of generation of ultrashort pulses. The bandwidth–time product is equal to the number of chips used for transmission of one bit of information.

(vi) Orthogonal frequency-division multiplexing (OFDM) signals [12]. This signal type has been successfully used in wireless communications for a long time (Fig. 1e). In the case of UWB systems, this signal has a larger spectrum bandwidth (≈500 MHz) than that of the OFDM signals that were used before.

(vii) Frequency-modulation ultrawideband (FM UWB) signals [13, 14]. These signals are formed via frequency sweeping in voltage-controlled oscillators (Fig. 1f). In the case of one frequency sweep per pulse, the bandwidth–time product of this signal is proportional to the duration of the pulse. The frequency-tuning rate determines the minimum pulse duration required for complete frequency tuning. In this case, the bandwidth–time product of a signal is $B = \Delta T \Delta F$, where ΔT is the pulse duration and ΔF is the sweeping bandwidth.

This list can be continued.

It is worth mentioning that the basic idea of mass application of UWB communications is closely related to impulse UWB technology. The idea is to create very simple and cheap wireless-communications devices. In fact, everything looks quite simple in communication systems using ultrawideband pulses: A pulse corresponds to 1, while the absence of a pulse at a certain

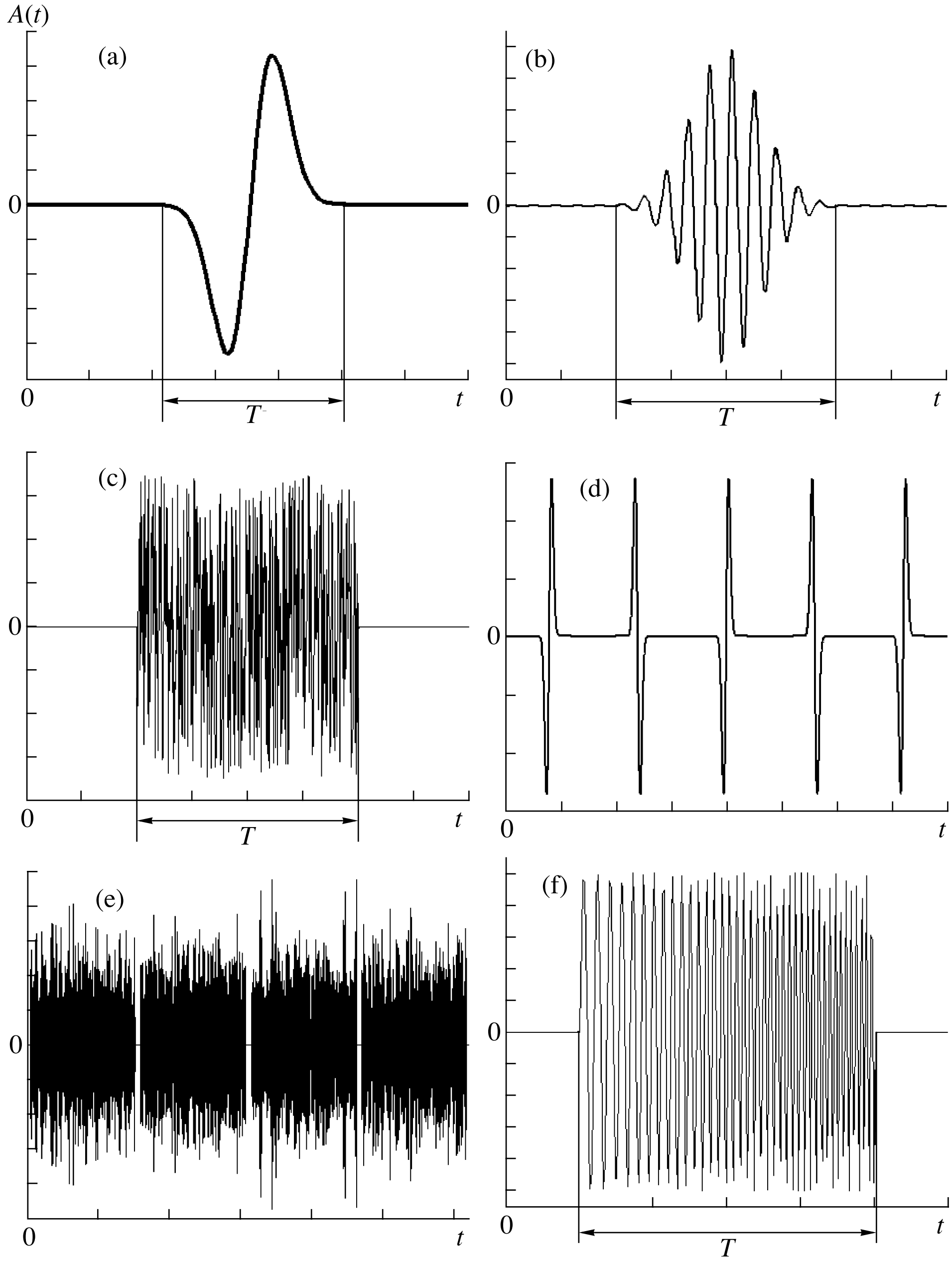

Fig. 1. The shapes of UWB signals: (a) an ultrashort pulse with duration T, (b) a short pulse formed from a fragment of a harmonic signal with duration T and a Gaussian envelope, (c) a chaotic radio pulse with duration T, (d) a burst of ultrashort pulses, (e) an orthogonal frequency division multiplexing signal, and (f) a chirp pulse with duration T.

moment corresponds to 0. Any complication of this arrangement results in increased costs of transceivers. However, there are problems even in this scheme, although it seems a simple scheme at first sight. Synchronization of a transmitter and a receiver is one of these problems. For example, for efficient coherent reception, the devices must be synchronized to no worse than 10 ps for a pulse duration of 150 ps. This task is not simple, and, in order to overcome this difficulty, technologies with high power consumption and complex circuit design are used.

2. REGULATORY REQUIREMENTS

Since 2002, when the above-mentioned FCC regulations were adopted, analogous work aimed at freeing frequency bands for unlicensed UWB communications has been conducted in a number of countries. Taking into consideration local conditions, each of the countries (or groups of countries, like the EU) formed its own admissible power spectral-density mask of electromagnetic signals in the frequency band 3.1–10.6 GHz. Some of these countries have completed their work and

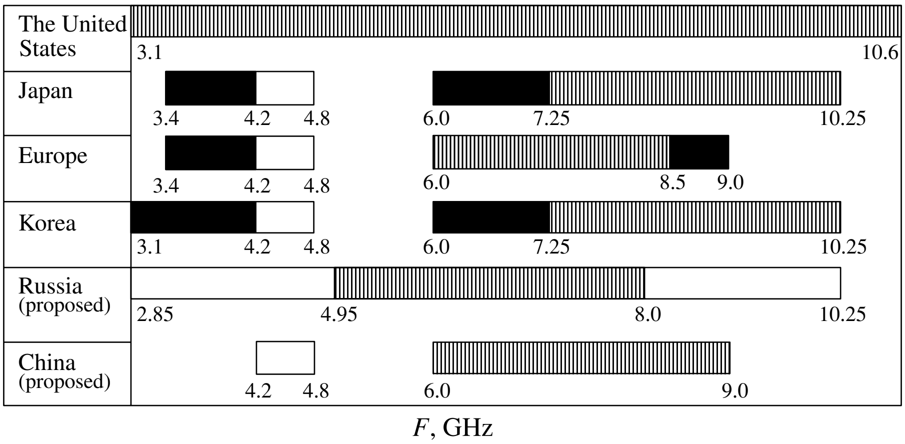

Fig. 2. Frequency maps for UWB devices (approved or pending) in different countries of the world. The hatching means that the band is open for free usage, the black filling means that the question of usage of the band is discussed, and the white filling means that the limitations on radiation of UWB devices are discussed.

have adopted the decisions on the spectral mask (Singapore, Japan, Korea, and the EU). Some other countries are scheduled to complete their work in 2008 (Russia and China). The frequencies allocated for unlicensed UWN communications in different countries are presented in Fig. 2.

In accordance with current trends and limitations on spectral density, above all, UWB signals will be used in personal and sensor area networks. In this case, the operating range of a separate device will be several meters to dozens of meters.

The throughput of a communication channel is an important characteristic of UWB devices. An advantage of UWB systems over narrowband systems is that the transmission rate of an individual device or the total transmission rate of a group of devices located at one place is potentially high. In accordance with this criterion, UWB communication systems can be divided into the following three categories: high-speed (from 50 to 500 Mbit/s), medium-speed (from 1 to 50 Mbit/s), and low-speed (lower than 1 Mbit/s) systems.

The development of the first standards for high-speed and medium-speed systems began in 2002 and 2004, respectively.

In 2002, the Institute of Electrical and Electronics Engineers (IEEE) 802.15 Working Group, which develops standards for wireless-communications systems intended for personal-computer networks, started collecting proposals for the standard of a new (alternative) physical layer for wireless personal area networks (WPANs) and wireless local area networks (WLANs). The communications ought to be based on UWB technology with high throughput provided at comparatively small distances (about 5–10 m).

The proposals were considered in accordance with the following basic criteria:

(i) The transmission has a rate of up to 500 Mbit/s at one connection, has a high throughput (up to 1.5 Gbit/s per node), and features a large number of termination devices.

(ii) The average effective isotropic-radiated power is in accordance with the FCC mask.

(iii) The data transmission is secure.

(iv) A network cell (piconetwork) is electromagnetically compatible with at least three other cells.

(v) There is a low delay level, which is needed to provide real-time transmission of multimedia information and compliance with the quality-of-service (QoS) requirements.

(vi) There is electromagnetic compatibility with WPAN and WLAN systems and other telecommunications systems.

(vii) Multipath (indoor) propagation is stable.

Moreover, a special group developed possible sample applications and models of channels for various physical implementations of UWB networks. Practically all leading international communications companies contributed to this process. The players actually participating in the process of the standard development fell on two sides, each of them defending its own principles of arranging the physical level of the standard.

Correspondingly, the work on creating the new technology was conducted in accordance with the following two parallel guidelines:

(i) The first group of companies, named the Multi-Band OFDM Alliance UWB (MBOA–UWB), proposed to divide the allocated frequency band into subbands with a width of 528 MHz and to use OFDM modulation. This approach provides an operating distance of up to 10 m. The system throughput is 480 Mbit/s at a distance of 3 m and 110 Mbit/s at a distance of 10 m.

(ii) The second group of companies, named the Direct Sequence Ultra-Wideband Forum (DS UWB Forum), proposed to make use of a pulse solution (the pulse shape is in accordance with the frequency band). Two frequency bands are to be used: the lower basic band of 3.1–4.9 GHz and the upper optional band of 6.2–9.7 GHz. Each of these bands has a fractional bandwidth of ≈50%. A symbol is represented by a sequence containing 1 to 24 pulses. The pulse repetition rate is 1320 MHz. The proposed approach provides transmission rates of 660 and 110 Mbit/s at distances of 3 and 18 m, respectively.

After three years of discussions, neither of the variants proposed to the IEEE working group was approved as a standard (none of the variants gained the majority in the result of the voting) and the working group disbanded itself. The legal position of this technology was not determined. However, despite this outcome, UWB technology proliferated. The technology of MBOA–UWB which, by that time, had become the basis of the so-called Wireless USB technology and, then, of Certified WUSB, started worldwide expansion, while the DS–UWB technology found use only in some applications of automotive electronics.

In 2004, the IEEE 802.15 Working Group announced a competition seeking proposals for a new (alternative) physical layer for wireless personal networks based on UWB technology. The throughput of each individual device was supposed to be low, and the operating-distance requirement increased to 30 m.

The proposals were considered in accordance with the following basic criteria:

(i) The transmission rate at one connection is up to 1 Mbit/s, the total throughput in a network is up to 10 Mbit/s per node, and the number of terminal devices is up to 10.

(ii) The average effective isotropic-radiated power is in accordance with the FCC mask.

(iii) Data transmission is secure.

(iv) A network cell (piconetwork) is electromagnetically compatible with at least three other cells.

(v) There is electromagnetic compatibility with WPAN and WLAN systems and other telecommunications systems.

(vi) Multipath (indoor) propagation is stable.

In January 2005, companies and organizations submitted more than 25 proposals for the development of the standard, including the joint proposal of the Institute of Radio Engineering and Electronics of the Russian Academy of Sciences (IREE RAS) and the Samsung Advanced Institute of Technology, in which chaotic radio pulses were proposed for use as information carriers.

The standard was enacted in summer 2007 [15]. It stipulates the usage of pulse sequences related to a bandwidth of about 500 MHz as the main UWB solution. Chaotic radio pulses and chirp UWB pulses are considered optional solutions.

Ultrawideband wireless communications with average transmission rates in the range 10–50 Mbit/s are not regulated by any standards that are being developed. At the same time, this branch is very promising because of the possibilities of applying this technology in small personal mobile devices, gadgets (wireless audio players, wireless video glasses, etc.). Implementation of wireless communications in these devices requires high transmission rates together with high mobility and low power consumption.

3. ULTRAWIDEBAND DIRECT CHAOTIC TRANSCEIVERS

Theoretical analysis boosted by results of special investigations shows that direct chaotic communications systems have good characteristics, above all, in the case of low-speed and medium-speed UWB communications systems.

Two types of devices of this class that were created at the IREE RAS are considered below.

The principle of operation, structure, and characteristics of direct chaotic transceivers are described in [8, 9, 16–20]. At present, several types of UWB direct chaotic transceivers have been developed. Two of them will be considered further.

The PPS-40 UWB transceiver is intended for use as a means of communication between sensors as well as between sensors and a computer. The device is equipped with a UART serial interface allowing fast connection to different external devices (sensors, audio and video signal sources) and creation of experimental sensor networks.

The physical layer of the device using chaotic pulses for transmission of information over the air meets the IEEE 802.15.4a requirements.

The device is characterized by the parameters presented in Table 1.

The structure of the transceiver is shown in Fig. 3. The microwave part of the transmitter is a transistor chaos generator. In order to generate chaotic radio pulses, the internal modulation of the generator signal is used, the modulation being implemented on the basis of the idea proposed and studied in [21–25].

A highly efficient omnidirectional microstrip antenna, which was manufactured on the same board as the rest of the device, was designed especially for the transceiver. In addition to high electrodynamic characteristics, advantages of the antenna lie in that it can be produced in the process of board etching and does not require tuning.

The envelope receiver is built on the basis of a logarithmic detector designed for operation in a frequency band 1 MHz–10 GHz. The receiver design is original in that it does not contain a separate circuit for automatic gain control of the received signal. Amplification of the input signal is controlled by a logarithmic detector with a dynamic range of 50 dB (from –50 to 0 dBm).

The minimum pulse duration detectable by the receiver is 20 ns.

The exterior of the PPS-40 transceiver is presented in Fig. 4.

The PPS-50 UWB transceiver is designed for use in wireless sensor networks. A pair of such transceivers, one of which is connected to a sensor through the UART interface, while the other is used as either a terminal device or a retransmitter, forms a radio bridge. This device can operate at a larger distances than the PPS-40 transceiver. This increase is attained owing to an increased power of radiation of the transmitter, a higher sensitivity of the receiver, and a more directed microstrip antenna with two arms (Fig. 5).

Moreover, in order to ensure successful operation of a sensor network, it is necessary that the UWB transceivers can operate for a long time without replacement of batteries. Therefore, in development of the PPS-50 transceiver, a lot of attention was focused on the

Table 1. Performance data of a PPS-40 UWB direct chaotic transceiver

Bandwidth of the output signal	3.1…5.1 GHz
Average power of a radiated signal at a rate of 2.5 Mbit/s	–16 dBm
Average power of a radiated signal at a rate of 0.1 Mbit/s	–27 dBm
Operating range	5…7 m
Maximum physical rate of data transmission/reception	2.5/2.5 Mbit/s
Interface	UART
Supply voltage	4.5 V

energy-saving properties of the device, including sleep modes.

In order to attain the maximum energy conservation, the developed transceiver can operate in the following modes, depending on the stage of the problem being solved:

(i) a deep-sleep mode,

(ii) a sleep mode,

(iii) a mode of information reception from an external data source and signal radiation into ambient space, and

4) a mode of reception of a signal from ambient space and transmission of the information to an external device receiving the data.

When in the deep sleep mode, the transceiver periodically receives signals from ambient space, while try-

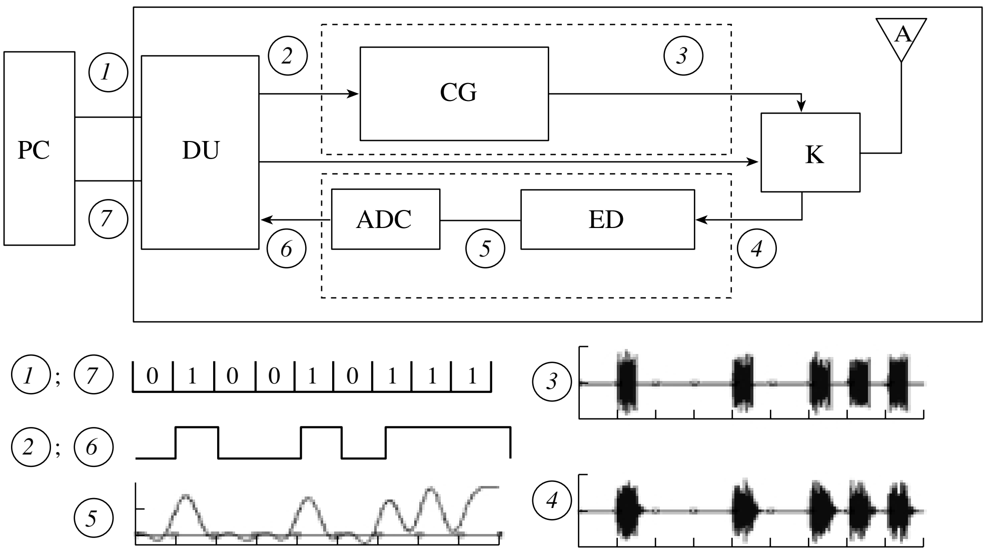

Fig. 3. The structure of a direct chaotic transceiver (TC) and fragments of the signals at different points of the system: (*1*, *7*) at the output of the TC digital board connected to a PC, (*2*, *6*) at the output and input of the digital unit (DU) controlled by the chaos generator (CG) and the key (K) and receiving the signal from the ADC, (*3*) the signal radiated into space (a sequence of chaotic radio pulses) via the antenna (A), (*4*) the received sequence of chaotic radio pulses, and (*5*) the envelope of a sequence of chaotic radio pulses at the output of the envelope detector (ED).

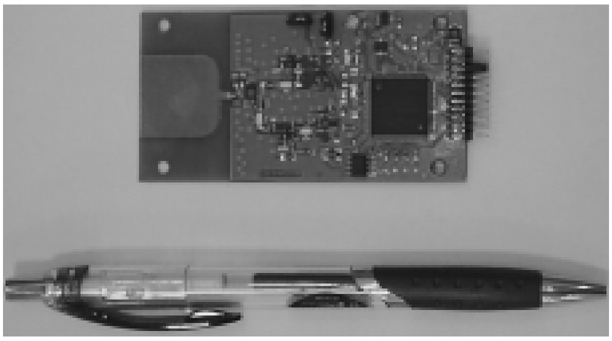

Fig. 4. Exterior of a PPS-40 UWB direct chaotic transceiver.

ing not to miss a command to switch into another operation mode. The periodicity of the receiving sessions is once per 100 s. With a set of four AA batteries, the transceiver can operate in this mode for up to three years.

In the sleep mode, the periodicity of the receiving sessions is once per 1 s. As a result, it is possible to efficiently control the transceiver's operation mode during its active usage.

In the mode of reception of information from an external data source, the transceiver continuously converts the obtained information into a sequence of chaotic radio pulses and radiates them into ambient space. In this mode, the transceiver periodically switches to the listen mode in order to check if a command to switch to another operation mode has arrived.

In the mode of signal reception from the ambient space, the transceiver continuously listens for arrival of data or control commands. If needed, the received data are continuously transmitted to an external data receiver.

Table 2. Performance data of a PPS-40 UWB direct chaotic transceiver

Frequency band of radiated signal at a level of –10 dB of the maximum of spectral density	3.1…5.1 GHz
Output power in the continuous mode	4.7 dBm
Average power of radiated signal at a rate of 2.5 Mbit/s	–8.3 dBm
Average power of radiated signal at a rate of 0.1 Mbit/s	–22.3 dBm
Operating range	40…60 m
Maximum physical rate of data transmission/reception	2.5/2.5 Mbit/s
Interface	UART
Supply voltage	6 V

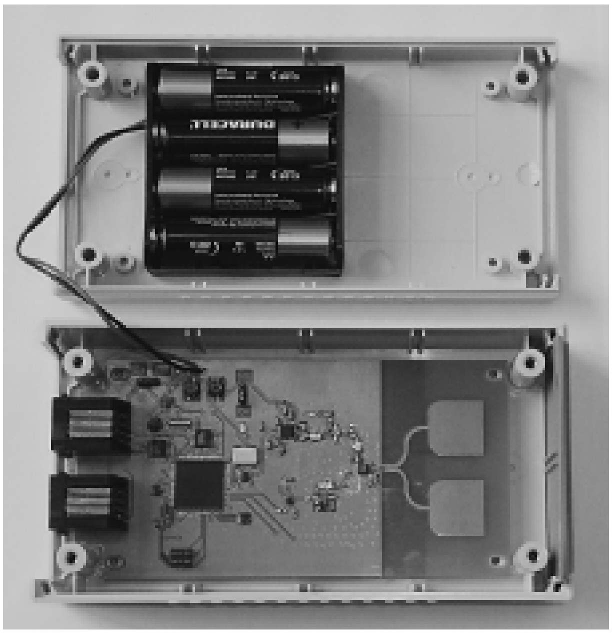

Fig. 5. Exterior of a PPS-50 UWB direct chaotic transceiver.

The characteristics of the transceiver are presented in Table 2.

4. SENSOR NETWORKS

Let us consider two examples of construction of sensor networks based on the above-described UWB transceivers.

Laboratory Sensor Network

A wireless UWB sensor network (a data-acquisition system) consists of 10 direct chaotic transceivers and a control panel based on a computer with the necessary software. The panel controls the state of a receiver of chaotic radio pulses, monitors the receiver's current state, receives and processes the data from a network of transmitters, automatically checks for the presence of each transmitter, and saves or implements additional processing of the information from the transmitters.

Six of the ten mentioned devices are equipped with various sensors that collect information (sensors of temperature, luminance, and alcohol), three transceivers are used in the radio relay mode only, and the remaining terminal device is connected to the serial port of the computer.

The operating distance of the transceivers ranges from 12 to 15 m in free space. The transmitters use the asynchronous packet data-transmission protocol. The packet structure is presented in Fig. 6. It consists of the following fields: the pilot synchronization byte, the byte field that determines the type of the system trans-

P	T	S	DA	OA	CN	PN	D	CS

Fig. 6. Structure of the information packet used in PPS-40 and PPS-50: pilot synchronization byte P, field T that determines the type of the system transmitting the packet, size S of a packet in bytes, destination device address DA, origination device address OA, command number CN, number PN of the transmitted packet for continuity control, transmitted data D, and packet checksum CS.

Fig. 7. The Krylatskoe skating rink.

mitting the packet, the byte field determining the size of the packet in bytes, the byte field with the address of the destination device, the byte field with the address of the origination device, a byte field with the number of a command, a byte field with the number of the transmitted packet for continuity control, the *N*-byte field containing transmitted data, and the two-byte field with a packet checksum. The total length of a packet is $9 + N$ bytes. The physical data-transmission rate is 2.5 Mbit/s. This is the rate for transmission of information contained in a packet. There are gaps between packets. These gaps determine the real data transmission rate, which is about 100 Kbit/s for the considered application.

The network is installed and tuned in the following manner.

First, transceivers with sensors are installed. Before the installation, corresponding addresses are entered in the transceiver microcontrollers. The connection between the transceiver of the control panel and each of the sensor transceivers may be established either directly or through a retransmitter. Corresponding routes are stored in the memory of the retransmitter's controller.

The information from the sensors arrives to the control panel with a time interval of ≈1 s. Each sensor transmits information to the control panel independently so that the transmission time intervals do not coincide with those of other devices. Since a transmission cycle is less than 1 ms, the probability of packet collision is small. Therefore, packet collisions are disregarded.

Wireless Ultrawideband Data-Acquisition System

The purpose of this development was to create a wireless UWB communication means for a system monitoring the technical state of the indoor skating rink situated in the Krylatskoe area of Moscow.

The ice surface of the skating rink is shown in Fig. 7. The wireless monitoring system must determine the state of the building's structures, including a semicir-

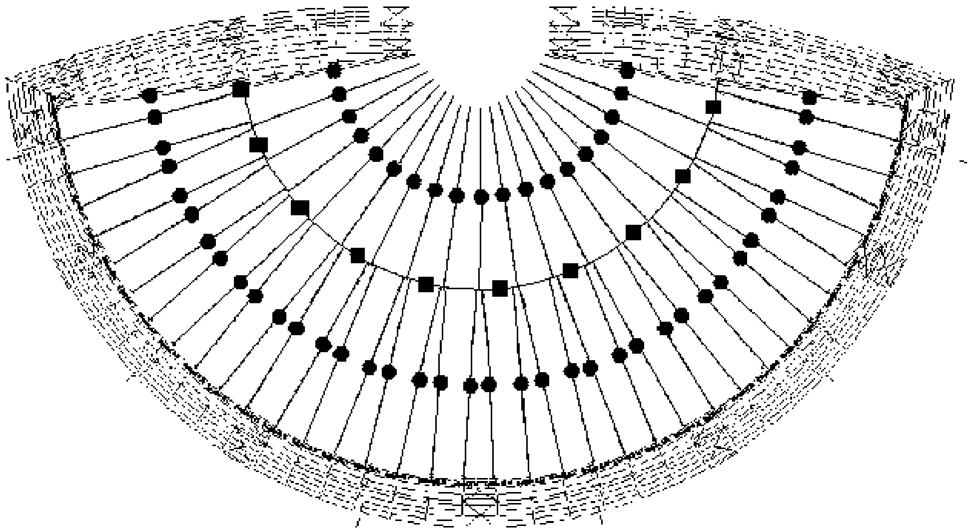

Fig. 8. Drawing of the Krylatskoe skating rink with positions of UWB direct chaotic transceivers. Positions of the frame transceivers connected to monitoring stations (seismographs) are marked with circles, while positions of the transceivers of the semicircle beam, which are connected to the network control station, are marked with squares.

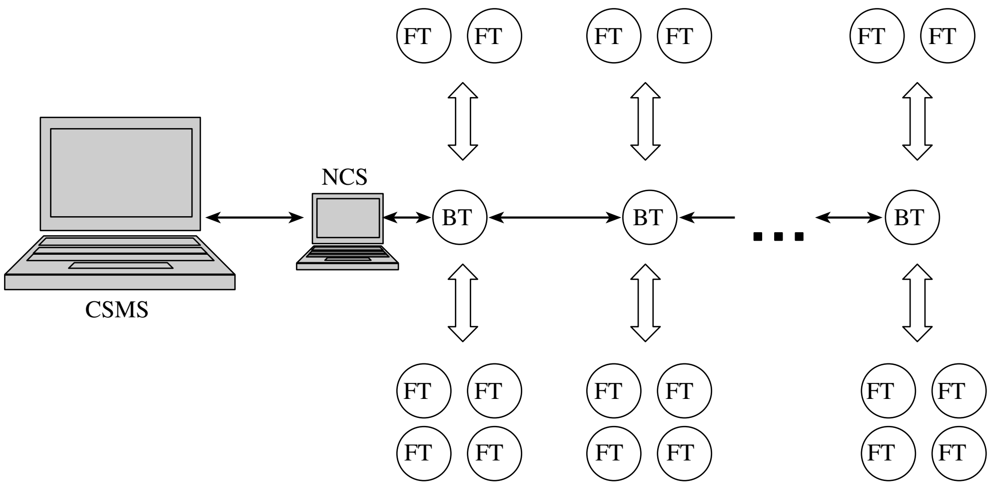

Fig. 9. Functional scheme of the wireless data-acquisition network installed at the skating rink: (FT) frame transceivers and (BT) beam transceivers, which are connected via a cable to the network control station (NCS) and, further, to the control station of the monitoring system (CSMS).

cle-shaped reinforced-concrete beam and structural frames supporting the roof.

The ultrawideband wireless communication system contains 57 transceivers positioned on the frames of the building together with monitoring stations and 10 transceivers positioned on the semicircle beam (Fig. 8).

The transceivers situated on the frames are used for reception of commands from the central control station to turn the active mode of the transceivers themselves on/off and to turn the monitoring stations on, for the reception of data from these stations, for the transmission of the data to the central control station, and for turning the monitoring stations off.

The transceivers of the semicircle beam are used as retransmitters for channeling commands from the central control station to monitoring stations situated at the frames and transmission of data from monitoring stations to the central control station. The transceivers of the beam are connected through a cable to a computer controlling the wireless network. In turn, this computer is connected to a computer controlling the entire monitoring system (Fig. 9).

Each of the transceivers on the beam is a retransmitter for a certain group of transceivers situated on the frames. All transceivers of the system have built-in power supplies ensuring long autonomous operation of the devices.

CONCLUSIONS

Above all, ultrawideband communications systems are considered short-distance communications systems. In contrast to mobile cellular phones with a radiation power of 100–300 mW, Wi-Fi systems with a power of 100 mW, and Bluetooth-like systems radiating from 1 to 10 mW, the radiation power of UWB devices is < 100 μW. This circumstance means that, in order to transmit one bit of information, a mobile phone, a Wi-Fi transmitter, a Bluetooth transmitter, and a UWB transmitter radiate 10^{-7}–3×10^{-7} J, 10^{-8} J, 10^{-9}–10^{-8} J, and 10^{-12}–10^{-10} J, respectively. Thus, the energy radiated by a UWB system per one bit of transmitted information is less than 1 nJ. At the same time, in other modern communications systems, this power is greater than 1 nJ.

It is appropriate to name the radio technologies using this extremely low level of radiated power per bit of transmitted information *subnanoradio technologies* or *nanoradio technologies*. In order to develop nanoradio technologies, it is necessary to solve a number of new radiophysical problems related to the generation of low-power signals, their radiation through the use of compact antennas, propagation of these signals in specific media over short distances, and efficient reception with low energy loss.

The other group of problems related to UWB wireless devices and sensor networks concerns electromagnetic compatibility.

In the case of mass usage of wireless communications, the problem of mutual interferences generated by radio devices appears. In order to provide the successful operation of all mobile cellular phones and computers with wireless Internet connections so that they do not interfere with each other, the entire radio band should be used. Moreover, these electronic devices should be able to analyze the situation and choose the most appropriate method and protocol of communications. Such smart radio systems that are characterized by the ability to extract and analyze the information on the ambient radio space from radio signals, that predict changes in the communications channel, and that adapt their own state parameters in response to changes of the radio medium were named by J. Mitola as *cognitive radio* [26].

The most efficient usage of available radio resources is one of the basic goals of a designer of cognitive radio. In the case of UWB communications systems, this goal can be attained via selection of one of a series of frequency bands that is based on preliminary analysis of the radio environment in these bands (Fig. 2).

Let us consider the role that will supposedly be played by wireless sensor networks in the near future.

What is a computer from the point of view of natural philosophy? This is a device that processes the information supplied in it and that outputs a result. When a computer is equipped with special software, advanced tools for inputting the information, and interfaces for interaction with people, the interaction of the external environment represented by a person and this computer is well supported. There are variants of paralleling the obtained and processed information. In special cases, various sensors, execution units, and other devices may play the role of the external environment, with which the interaction takes place: for example, the case when a computer is used to control a robot.

In accordance with this interpretation of a computer, a sensor network is a group of computers (microcontrollers) where each of the devices is connected to the external environment via a sensor (and, possibly, an additional device), which provides information. Each of the computers performs preprocessing of incoming information and transmits it through a communication network to a central station, where information from all sensors is analyzed and processed as a whole.

Thus, a sensor network (especially in a wireless variant) is a distributed system of interaction of a smart system with an external environment. This is a fundamentally new type of system as compared to usual computers. Moreover, such a system is a basis for a promising branch of technology that will have a revolutionary influence on all fields of our life, similarly to the effect of the usage of computers in the last few decades. The influence is realized through the mass application of wireless sensor technology with a small operating distance in both private life and industry. Similarly to the development of computers, software and hardware will be very important for the development of sensor technology, the software being either in traditional form or in forms that will replace the traditional form, namely, adaptive, remote, and self-programming software.

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REFERENCES

1. V. A. Kotel'nikov, *Theory of Potential Noise Immunity* (Gosenergoizdat, Moscow, 1956) [in Russian].
2. C. Shannon, *Works on Information Theory and Cybernetics* (Inostrannaya Literatura, Moscow, 1963) [in Russian];

C. E. Shannon, *Claude Elwood Shannon: Collected Papers,* Ed. by N. J. A. Sloane and A. D. Wyner (IEEE, New York, 1993).

3. M. A. Bykhovskii, *Pioneers of Information Century: History of Communication Theory* (Tekhnosfera, Moscow, 2006) [in Russian].
4. *Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems, First Report*

and Order, ET Docket 98–153, FCC 02-48, April 22, 2002 (Federal Communications Commission (FCC), Wash., 2002); http://hraunfoss.fcc.gov/edocs-public/attachmatch/FCC-02-48A1.pdf.

5. M. Z. Win and R. A. Scholtz, IEEE Commun. Lett. **2** (2), 36 (1998).
6. J. Kelly, *Time Domain's Proposal for UWB Multi-Band Alternate PHY Layer for 802.15.3a* (IEEE, New York, 2003).
7. *A Tutorial on Ultra Wideband Technology, IEEE 802.15 Working Group Submission, Mar. 2000* (IEEE, New York, 2000).
8. A. S. Dmitriev, B. E. Kyarginskii, N. A. Maksimov, et al., Radiotekhnika, No. 3, 9 (2000).
9. A. S. Dmitriev, A. I. Panas, S. O. Starkov, et al., Radiotekh. Elektron. (Moscow) **46**, 224 (2001) [J. Commun. Technol. Electron. **46**, 207 (2001)].
10. *TG4a Proposal for Low Rate DS-UWB (DS-UWB-LR)* (IEEE, New York, 2005); http://grouper.ieee.org/groups/802/15/pub/2005/15-05-0021-00-004a-low-rate-ds-uwb-tg4a.ppt
11. J. McCorkle, *DS-CDMA: The Technology of Choice for UWB* (IEEE, New York, 2003); http://grouper.ieee.org/groups/802/15/pub/2003/Jul03/03277r0P802-15_TG3a-OFDM-vs-CDMA.pdf.
12. *Multi-band OFDM Physical Layer Proposal, IEEE 802.15.3a Working Group Submission, July 2003* (IEEE, New York, 2003); http://www.ieee802.org/15/pub/2003/Jul03/03268r2P802-15_TG3a-Multi-band-CFP-Document.pdf.
13. J. Lampe, *Introduction to Chirp Spread Spectrum (CSS) Technology, July, 2004* (IEEE, New York, 2004); http://grouper.ieee.org/groups/802/15/pub/2004/15-04-0353-00-004a-chirp-spread-spectrum-technology.ppt.
14. J. Gerrits, M. H. L. Kouwenhoven, P. R. Van der Meer, et al., European Association for Signal Processing (EURASIP) J. Advances in Signal Processing, No. 3, 382 (2005).
15. *802.15.4a-2007. IEEE Standard for Information Technology - Telecommunications and Information Exchange between Systems - Local and Metropolitan Area Networks - Specific Requirement. Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs)* (IEEE, New York, 2007); http://ieeexplore.ieee.org/servlet/opac&punumber=4299494.
16. A. S. Dmitriev, B. E. Kyarginskii, A. I. Panas, et al., Radiotekh. Elektron. (Moscow) **47**, 1219 (2002) [J. Commun. Technol. Electron. **47**, 1112 (2002)].
17. A. S. Dmitriev, B. Ye. Kyarginsky, A. I. Panas, et al., Int. J. Bifurcation and Chaos **13**, 1495 (2003).
18. A. S. Dmitriev, A. V. Kletsov, A. M. Laktyushkin, et al., Radiotekh. Elektron. (Moscow) **51**, 1193 (2006) [J. Commun. Technol. Electron. **51**, 1126 (2006)].
19. A. S. Dmitriev, A. V. Kletsov, A. M. Laktyushkin, et al., Usp. Sovrem. Radioelektron., No. 1, 4 (2008).
20. A. S. Dmitriev, A. V. Kletsov, A. M. Laktyushkin, et al., Usp. Sovrem. Radioelektron., No. 1, 77 (2008).
21. A. S. Dmitriev, E. V. Efremova, and L. V. Kuz'min, Pis'ma Zh. Tekh. Fiz. **31** (22), 29 (2005) [Tech. Phys. Lett. **31**, 961 (2005)].
22. E. V. Efremova, N. V. Atanov, and Yu. A. Dmitriev, Izv. Vyssh. Uchebn. Zaved., Prikl. Nelin. Din. **15** (1), 23 (2007).
23. N. V. Atanov, A. S. Dmitriev, E. V. Efremova, and N. A. Maksimov, Pis'ma Zh. Tekh. Fiz. **32** (15), 1 (2006) [Tech. Phys. Lett. **32**, 645 (2006)].
24. A. S. Dmitriev, E. V. Efremova, N. A. Maksimov, and E. V. Grigor'ev, Radiotekh. Elektron. (Moscow) **52**, 1232 (2007) [J. Commun. Technol. Electron. **52**, 1137 (2007)].
25. A. Dmitriev, E. Efremova, L. Kuzmin, and N. Atanov, Int. J. Bifurcation and Chaos **17** (10), 1 (2007).
26. J. Mitola III, Doctor of Technology Dissertation (Royal Institute of Technology, Kista, 2000); http://www.it.kth.se/~maguire/jmitola/Mitola_Dissertation8_Integrated.pdf

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