ULTRA WIDEBAND DIRECT CHAOTIC COMMUNICATIONS FOR LOW BITRATE INFORMATION TRANSMISSION

Alexander S. Dmitriev (member IEEE)*, Andrey A. Kletsov**, Alexey V. Kuznetsov*, Anton M. Laktushkin**, Andrey I. Panas (member IEEE)*

* Institute of RadioEngineering and Electronics, Russian Academy of Sciences,
Mokhovaya St. 11/7, GSP-3, 103907, Moscow, Russia,
E-mail: chaos@mail.cplire.ru

**Moscow Institute of Physics and Technology
Institutskii st. 9, 141700, Dolgoprudnyi, Moscow region, Russia
E-mail: chaos@mail.cplire.ru

Abstract – **The ultra wide band (UWB) Direct Chaotic Communication (DCC) technology is considered in application to low bit rate information transmission. Performances of low bit rate DCC are discussed. In particular we pay attention to the effect of multipath processing. The implementation and experimental verification of basic elements for low bit rates DCC are also presented.**

Index terms – **Ultra wide band, UWB, chaotic communications, DCC, chaos generator, sensor networks, location.**

I. Introduction

Ultrawideband systems are usually defined as systems with relative bandwidth satisfying the inequality

$$B_f = 2\,(f_{max} - f_{min})/(f_{max} + f_{min}) > 0.25 \qquad (1)$$

Spring 2002 the Federal Communication Commission (FCC) allowed use of ultrawideband signals for communications in the territory of USA. In the approved document the notion of ultrawideband is interpreted more loosely than condition (1). According to this decision, signals with the bandwidth exceeding 500 MHz are also called ultrawideband even if their relative bandwidth is $B_f < 0{,}25$.

At first the idea of using ultrawideband signals implied forming of ultrashort impulses like “spikes” [1]. The power spectrum of each such impulse is stretched from practically zero to $f_{max} \sim 1/T$, where T is the impulse duration. By emission, the impulse is “differentiated” and a signal whose form is close to one sine period goes to space. Its spectrum is unimodal with the center frequency equal to $f_{av} = 1/T$.

As soon as the ultrawideband signals attracted attention, especially in context of their loose interpretation, ultrashort pulses proved to no longer be a unique paradigm. In particular, direct chaotic signals [2-6], fragments of periodic oscillations [7] and signals obtained by modulation of periodic carrier by relatively wideband periodic signals (e.g., OFDM) are proposed as ultrawideband carriers [8]

Interest to ultrawideband communication systems is not limited by their capability to provide very high rates of communication. Analysis shows that there are other attractive areas of application of such systems. In particular, an opposite case is of interest, i.e., application of ultrawideband systems for transmitting information with low rates. This problem is topical in connection with extension of IEEE 802.15.4 standard. The aims of this extension are: (i) essential increasing of aggregate throughput of communication channels and (ii) solution of the problem of space location of transmitters by emitted signal.

In this problem statement, ultrawideband (UWB) signals seem interesting due to the following reasons:

– a new, capacious, unlicensed frequency band (3.1–10.6 GHz) is put into operation for purposes of wireless communications;

– UWB signals can provide higher system security and reliability, are advantageous compared to narrowband signals in questions of electromagnetic compatibility and ecological safety;

– using such signals the problem of radio source space location can be solved with several centimeter to one meter precision.

By present moment, a large set of potential applications of low-rate UWB communication systems became visible. Among them are: location of people and goods, systems for controlling the state of buildings and rooms, wireless sensor grids for industrial automation and control, “smart” office and residence.

In this report we describe capabilities of ultrawideband direct chaotic systems and compare these systems with other ultrawideband systems in connection with the problems of low-rate data transmission (up to 10 Mbps).

II. Direct chaotic communication systems

The main idea of direct chaotic communications (DCC) is generation of chaotic carrier and its modulation by information signal directly in microwave band. As a method for inputting information, one can use generation of a sequence of chaotic radio pulses which position in time domain (presence or absence) encodes the transmitted information [2-6, 14]. In the simplest case, the present of pulse on a prescribed time position corresponds to “1”, and its absence on the same position to “0”. As another method for inputting information pulse position modulation (PPM) can be used.

Let the chaotic signal be generated in the frequency band $\Delta F = f_{max} - f_{\min}$. If the duration of chaotic radio pulse is $\tau > 1/(2\Delta F)$, then the power spectrum of the sequence of chaotic radio pulses is practically indistinguishable of the spectrum of the chaotic signal itself. Since the value $B = 2\tau\Delta F$ is the base (processing gain) of the signal, extension of the length of the chaotic radio pulse increases the signal base.

In order to understand the main features of chaotic radio pulses as information carrier, let us compare it with two other kinds of carriers: harmonic signals and ultrashort ultrawideband video pulses.

Judging from the value of base B, elementary signals with $B \sim 1$ and complex signals with $B >> 1$ are distinguished.

Elementary signals are, e.g., radio pulses obtained by multiplication of harmonic signal with frequency f_0 and video pulses of duration τ. Despite the ultrawideband frequency bandwidth, ultrashort pulses of simple form are also elementary, because the product of their duration by frequency bandwidth is also ~ 1.

In contemporary communication systems, especially those operating under complicated conditions of signal propagation (cellular networks, local wireless communications, etc.), large-base signals are preferably used. Operation with signals based on harmonic carrier involves techniques of spectrum spreading (direct spread sequences), with which the signal base is increased in proportion to the spectrum spreading. To obtain large-base signals based on ultrashort pulses, energy of several pulses is accumulated. Obviously, this solution leads to a complicated communication system.

In DCC the bandwidth of chaotic signal is fixed and the signal base is defined by the duration of chaotic radio pulse. No supplementary operations are necessary to change the processing gain. Moreover, the receiver input circuitry remains the same at different rates and processing gains.

Note also that direct chaotic signals can be produced in any necessary frequency range (which is difficult, e.g., in UWB-technology with ultrashort pulses).

The structure of direct chaotic communication scheme in the case of low transmission rate is depicted in Fig. 1.

The transmitter is composed of a chaotic oscillator that generates the signal directly in the frequency range of information transmission, i.e. in the range from hundreds MHz to several GHz; a baseband processor; a switch (SW) and a transmitting antenna.

The baseband processor forms pulses of chaotic signal and intervals between them. The pulses are formed either externally, or by means of modulating the inherent dynamics of chaotic oscillator.

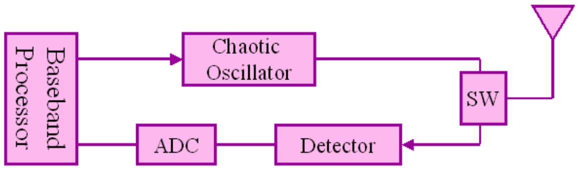

Fig. 1. The structure of WB and UWB Direct Chaotic Commbnications for low bit rate.

To transmit an information bit in a direct chaotic communication system, one might use single pulses as well as pulse sequences. In either case a stream of chaotic radio pulses is formed in time domain.

The duration of chaotic radio pulse and the mean duty cycle may be varied. This allows one to flexibly control the rate of information transmission by means of varying the pulse repetition rate and the mean power of the transmitted signal. For low transmission rates chaotic radio pulses with duration from 10 to 1000 ns seem reasonable.

The formed signal is emitted to space with a ultra-broadband antenna.

The receiver part of the receiver additionally includes detector and analog-digital converter (ADC). The signal from output of detector is processed in baseband processor.

III. Performance in Gaussian-noise channel

Use of chaotic radio pulses as information carriers allows compilation of various systems of signals for coherent and noncoherent receivers. In low-rate systems noncoherent reception is more reasonable due to strict requirements on cost, size and energy consumption.

In noncoherent scheme the pair of orthogonal signals can be represented by the presence of chaotic radio pulse on prescribed position («1») or its absence «0».

Expected error probability for this method of modulation approximately corresponds to standard characteristics of the systems of orthogonal signals.

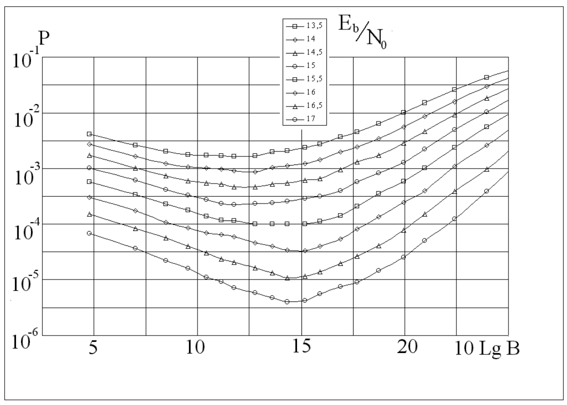

Fig. 2. Error probability P of noncoherent receiver as a function of processing gain B for different ratios E_b/N_0.

However, these expected characteristics need to be corrected by means of direct numerical simulation because the signal energy varies from pulse to pulse due to its chaotic nature. Besides, by noncoherent reception certain loss of efficiency can be expected at high processing values. Simulation results are presented in Figs. 2 and 3. By simulation the chaotic signal was assumed to have uniform distribution over [–1, 1] interval.

Error probabilities *P* of noncoherent receiver as functions of processing gain for different values of SNR are given in Fig. 3. As can be seen, in particular, stable reception is possible even when the noise level is higher than the signal level.

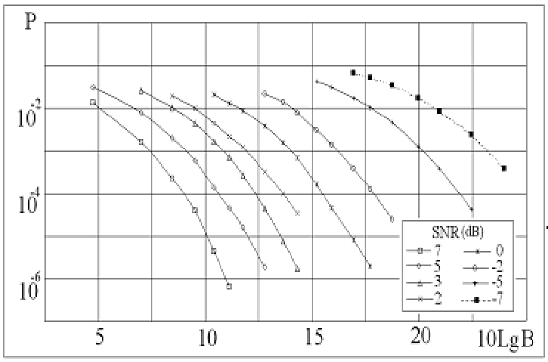

Fig. 3. Error probabilities *P* of noncoherent receiver as functions of processing gain at different SNR.

IV. Multipath immunity

Multipath propagation of small-base signals leads to two effects: (i) signal fading in certain space regions due to interference of two or more beams; (i) inter-symbol interference (ISI), when information symbols overlap in the reception point.

In UWB DCC there is no fading because of large signal base.

Elimination of inter-symbol interference at low rate can be provided by guard intervals of ~ 100 ns duration.

Besides, in the case of large pulse duration and the presence of guard intervals the multipath propagation can produce a considerable effect as compared to single-beam propagation. This effect — ***multipath processing*** — is noncoherent summation of power of many beams in the receiver. This summation is natural and it needs no special actions. The more beams, the better. For example, with 10 approximately equal-power beams the effective energy potential increases by 10 dB.

V. Experiments

Here we present the results of experimental investigation of low-rate UWB DCC. Results for high-rate UWB DCC were published earlier [9-15].

The aim of this investigation was to demonstrate possibility of construction of small-size direct chaotic transceivers providing transmission rates from 1 kbps to 10 Mbps.

In Fig. 4 a testbed of a transmitter is shown, composed of a chaos generator, an amplifier, a modulator, and a ultrawideband microstrip antenna. The testbed is made on a single plate with dimensions 50×35×3 mm^3.

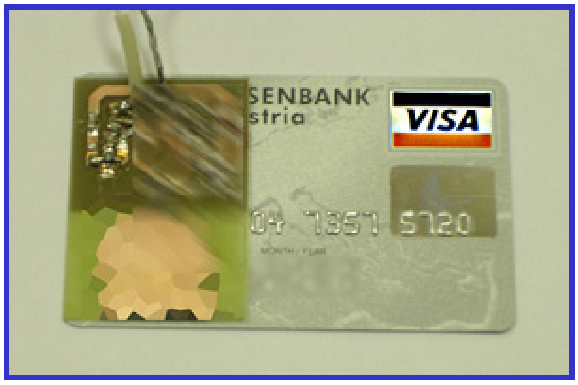

Fig. 4. Testbed of a small-size transmitter against a credit card

The transmitter operation band is 2–4 GHz. Output power is 3–4 mW. It is implemented with the help of typical electronic components from market. The emitted signal spectrum is shown in Fig. 5.

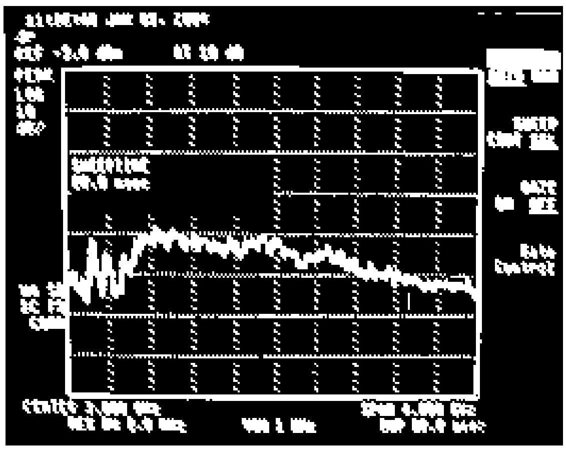

Fig. 5. Power spectrum of ultrawideband chaotic oscillations

Formation of chaotic radio pulses is illustrated in Fig. 6. Each pulse is 100 ns long. In the upper area of the screen a sequence of chaotic radio pulse is shown. Horizontal sweep is 2 µs. In the lower part of the screen a zoomed fragment of the sequence is shown, corresponding to bit sequence 0 1 1 0 1 0 0 1 0 0. This sequence gives information rate 10 Mbps. Lower transmission rate can be provided by means of decreasing duty cycle (increasing gap between information intervals) (in Fig. 6 duty cycle is 1). For example, to have the rate of 1 kbps the duty cycle is approximately 10^{-4}. Another way of low-rate operation is transmission of portions of information with subsequent pauses. For example, the same average rate of 1 kbps can be realized according to the scheme: 1000 bits with 1/2 duty cycle at the beginning of one-second interval ($2{\cdot}10^{-4}$ s) plus $1–2{\cdot}10^{-4}$ s pause. Then the cycle is repeated.

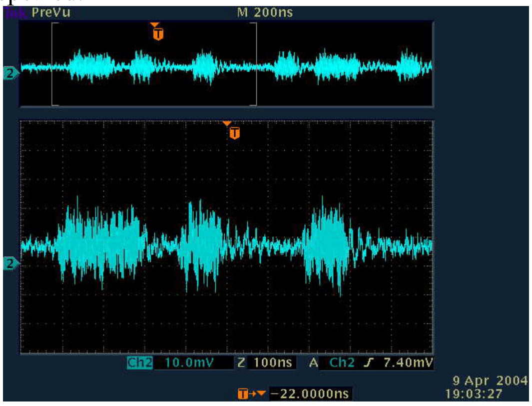

Fig. 6. Chaotic radio pulse sequence (upper plot) and its zoom fragment (lower plot).

VI. Conclusions

Ultrawideband Direct Chaotic Communications provide both high and low rates of information transmission under difficult (multipath) propagation conditions. They can be accomplished as very simple, from technological viewpoint, devices and may be used in many wireless applications.

Acknowledgments

This report is supported in part by grants from Russian Foundation for Fundamental Research (No. 02-02-16802, 03-02-16747).

References

[1] M.S. Win and R.A. Scholtz. “Impulse Radio: How it works”. *IEEE Comm. Lett.*, vol. 2, No. 1, pp. 10–12. 1998.

[2] A. S. Dmitriev, B. Ye. Kyarginsky, N. A. Maximov, A. I. Panas, and S. O. Starkov, “Prospects of Direct Chaotic Communication Systems in RF and microwave bands,” *Radiotekhnika* , vol. 42, No. 3, p. 9–20, 2000, (in Russian).

[3] A. S. Dmitriev, B. Ye. Kyarginsky, N. A. Maximov, A. I. Panas, and S. O. Starkov, “Direct chaotic information transmission in microwave band, ”*Preprint IRE RAS*, No. 1 (625), 2000, (In Russian).

[4] A. S. Dmitriev, A. I. Panas, and S. O. Starkov, Direct Chaotic Communication in Microwave Band”, *Nonlinear Sciences*. *Preprint, nlin. CD/0110047*). 2000.

[5] A. S. Dmitriev, B. Ye. Kyarginsky, A. I. Panas and S. O. Starkov, “Direct Chaotic Communications Schemes in Microwave Band,” *Radiotekhnika i elektronika*, vol. 46, pp. 224–233, 2001.

[6] A. Dmitriev, B. Kyarginsky, A. Panas, and S. Starkov, "Direct chaotic communication system. Experiments", *Proc. 9th Workshop on Nonlinear Dynamics of Electronic Systems (NDES'2001)*, Delft, Netherlands, June 21–23, 2001, pp. 185–188.

[7] R. Aiello/ Discrete Time PHY Proposal for TG3a/ Doc.: IEEE 802.15-03/099r1. March 2003.

[8] A. Botna, J. Balakrishnan, et al. TI PHY Layer Proposal: Time – Frequency Interleaved OFDM. Doc.: IEEE 802.15-03/141r1. March 2003.

[9] A. Dmitriev, B. Kyarginsky, A. Panas, D. Puzikov, and S. Starkov, “Experiments on ultra wideband direct chaotic information transmission in microwave band”, *Proc. 10th Int. Workshop Nonlinear Dynamics of Electronic Systems (NDES-2002)*, June 21–23, 2002, Izmir, Turkey, p. 5-1.

[10] A.S. Dmitriev, A.I. Panas, D.Yu. Puzikov, and S.O. Starkov, “Wideband and Ultra Wideband Direct Chaotic Communication”, *Proc. 1st IEEE Int. Conf. Circuits and Systems for Communications (Circuits and Systems in Broadband Communication Technologies)*, St.Petersburg, Russia, June 26–28, 2002, pp. 291–295.

[11] A.S. Dmitriev, B.Ye. Kyarginsky, A.I. Panas, D.Yu. Puzikov, S.O. Starkov, "Experiments on ultrawideband direct chaotic information transmission in microwave band", *Radiotekhnika i elektronika*, 2002, vol. 47, No. 10, pp. 1219–1228 (in Russian).

[12] A.S. Dmitriev, B.Ye. Kyarginsky, A.I. Panas and S.O. Starkov. “Experiments on ultra wideband direct chaotic information transmission in microwave band”, *Int. J. Bifurcation & Chaos*, 2003, vol. 13, No. 6, pp. 1495–1507.

[13] A.S. Dmitriev, B.Ye. Kyarginsky, A.I. Panas, D. Yu. Pusikov and S.O. Starkov "Ultrawideband direct chaotic communications in microwave band", *Pis’ma v GTF*, 2003, v. 29. No. 2, pp. 70-76.

[14] A.S. Dmitriev, A.I. Panas. *"Dynamical Chaos: new type of information carrier for communication sistems"*. M.: Fizmatlit, 2002, 252 p.

[15] A.S. Dmitriev, L.V. Kuzmin, A.I. Panas and D.Yu. Puzikov. “Direct Chaotic Communications”. *Uspehi sovremennoi radioelektroniki*. 2003. No 9, pp. 40-56.