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Experimental implementation of differentially coherent wireless communication scheme based on chaotic radio pulses

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Received July 18, 2022
Revised July 18, 2022
Accepted July 26, 2022

The possibility of practical implementation of differentially coherent wireless communication scheme based on chaotic radio pulses has been experimentally proven. For this purpose a prototype of that communication scheme was created in the frequency range of 200−500 MHz for binary information transmission and experiments were carried out with it. The obtained results fully confirm the previously developed theoretical principles of scheme functioning and its main properties.

Keywords: dynamic chaos, ultra-wideband signals, differentially coherent information transmission, correlation reception.

DOI: 10.21883/TPL.2022.09.55082.19312

Systems with coherent demodulation, which feature copies (or have the capacity to produce such copies) of reference signals at the receiver side, are the most efficient data transmission systems. If the above is infeasible, differentially coherent data transmission systems, which transmit reference signals for comparison together with data signals, are used [1–3]. The irregularity of analog chaotic signals makes it hard to establish a system of reference signals and keep a copy of them at the receiver side. Therefore, differentially coherent transmission systems have attracted attention as soon as the first studies into chaotic signals as data carriers in communications were published. Differential chaotic shift keying (DCSK) [4] was the most widespread of the differentially coherent transmission schemes for chaotic signals proposed at the early stages of this research. It provided a significantly higher resistance to noise than the methods based on chaotic synchronization that were known at the time [5–8]. In practical terms, DCSK is specific in that it requires the introduction of a time delay in the receiver and the transmitter. Since the delay is comparable in magnitude to the duration of the bit transmission, a long delay line (tens or hundreds of meters) is needed in an analog implementation of this scheme. This is the reason why DCSK experiments were focused not on an analog implementation, but on a digital one [9,10].

A direct chaotic differentially coherent (DC^2) data transmission scheme was proposed in [11,12] as an alternative to DCSK without the long delays. In contrast to DCSK with a time delay tied to the bit duration, the delay in the receiver and the transmitter in DC^2 is defined by fall time τ of the autocorrelation function of a chaotic signal. This fall time is equal in order of magnitude to $1/\Delta F$ (ΔF is the chaotic signal band width). If, for example, the chaotic signal band width is 300 MHz, the autocorrelation time is 3 ns, and the distance travelled within this time by an electromagnetic wave in free space is 0.9 m. A delay line may then be fabricated from, e.g., a high-frequency cable less than 1 m long.

It should also be noted the DC^2 scheme relies on chaotic radio pulses with a high processing coefficient and protective interpulse intervals for data transmission. In theory, this ensures a high transmission stability in multipath channels with a significant noise level.

The aim of the present study is to fabricate a prototype DC^2 model and examine its parameters experimentally in order to verify the feasibility of the proposed transmission method and the correspondence of its characteristics to theoretical estimates and computer modeling data.

The prototype experimental implementation of the DC^2 scheme presented in Fig. 1 is characterized and examined below.

The source of chaotic radio pulses in the model is a two-transistor voltage-controlled chaos generator (board *1* in Fig. 1). It shapes chaotic radio pulses with a continuous power spectrum in the 200−500 MHz range (Fig. 2, *a*) and an autocorrelation function with fall time $\tau \approx 4-5$ ns (Fig. 2, *b*). The duration of each pulse is $T_i = 2\,\mu$s, and the duration of interpulse (protective) intervals is $T_g = 4\,\mu$s. The net duration of a pulse and a protective interval is the time of transmission of a single bit: $T_b = 6\,\mu$s. Each pulse is sent to a divider (board *2*) and enters two channels. In the first channel, it is modulated with a data signal via multiplication by ± 1 (the modulating signal is fed from board *1*); in the second channel, it is just delayed by τ. Multiplication by $+1$ and -1 corresponds to the transmission of „1“and „0,“respectively. The signals are then summed, and the resulting signal is amplified, fed to antenna *3*, and radiated. The duration of this radiated pulse is $T_r = T_i + \tau \approx 2\,\mu$s.

The divider on board *2* in the transmitter has an operating band width of 1 GHz. The same device with inverse

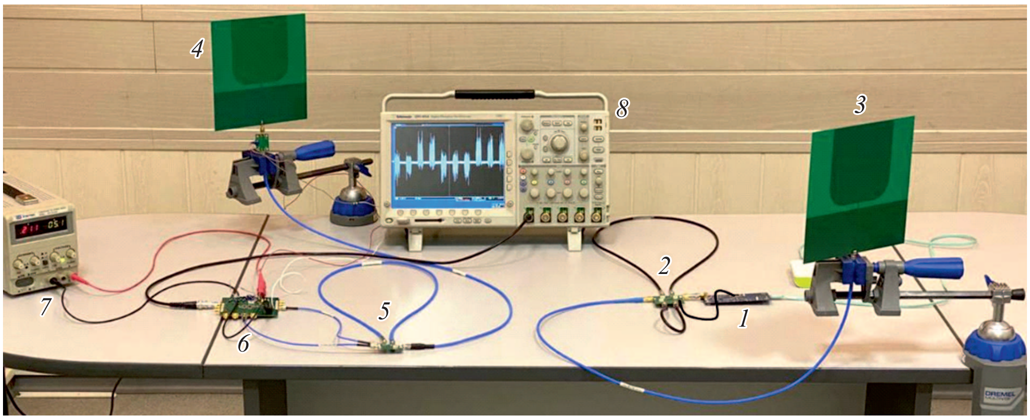

Figure 1. Prototype model of the transmitting-and-receiving system. *1* — board with a source of chaotic radio pulses and a microcontroller that shapes the data sequence; *2* — board with a two-channel divider, a modulator, a delay line for one of the channels, and an adder; *3* — transmitting antenna; *4* — receiving antenna with an LNA at the output; *5* — board with a two-channel divider, a delay line for one of the channels, and two outputs; *6* — multiplier board; *7* — power supply; *8* — oscilloscope.

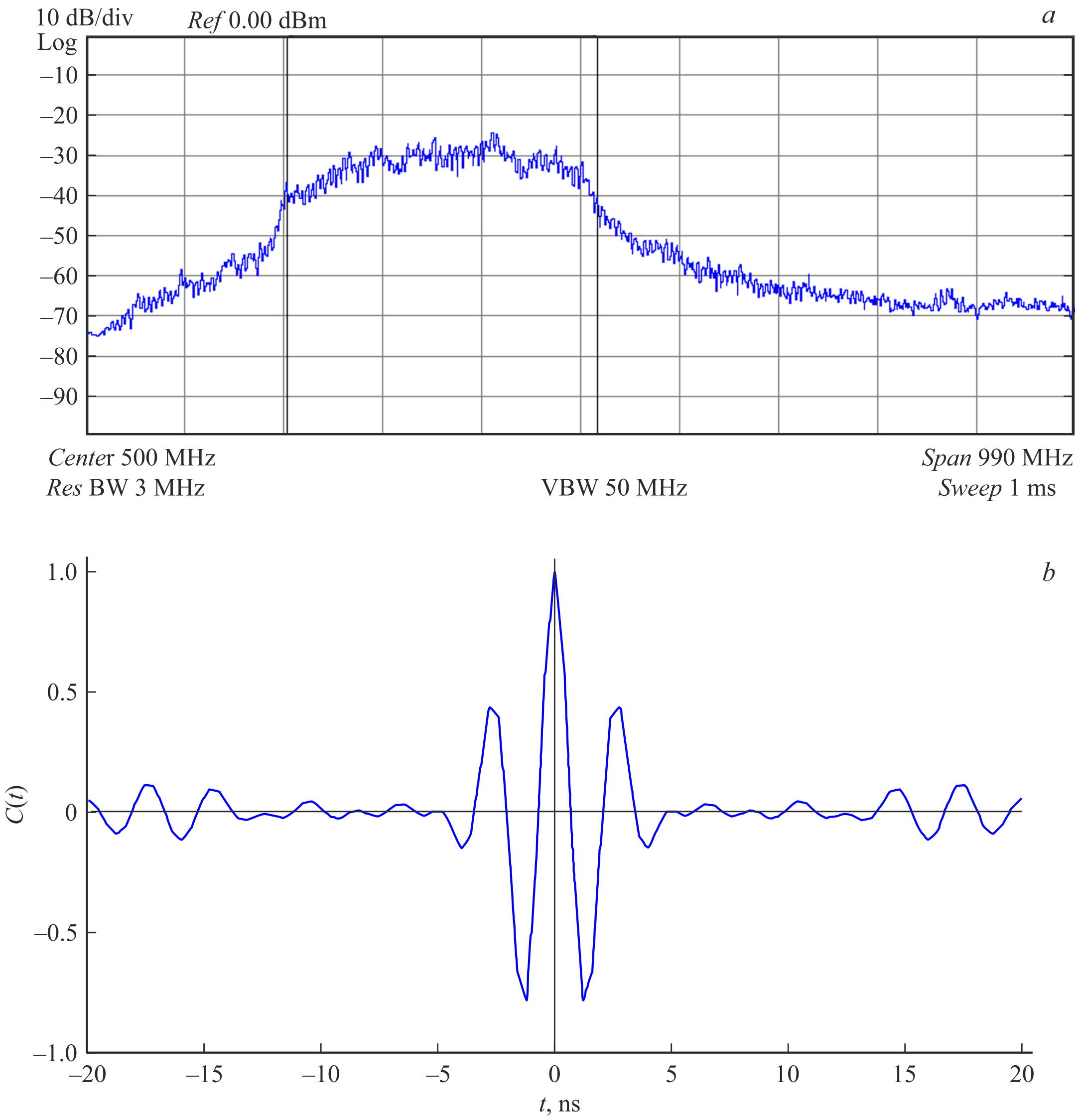

Figure 2. Characteristics of chaotic radio pulses. *a* — Power spectrum, *b* — autocorrelation function.

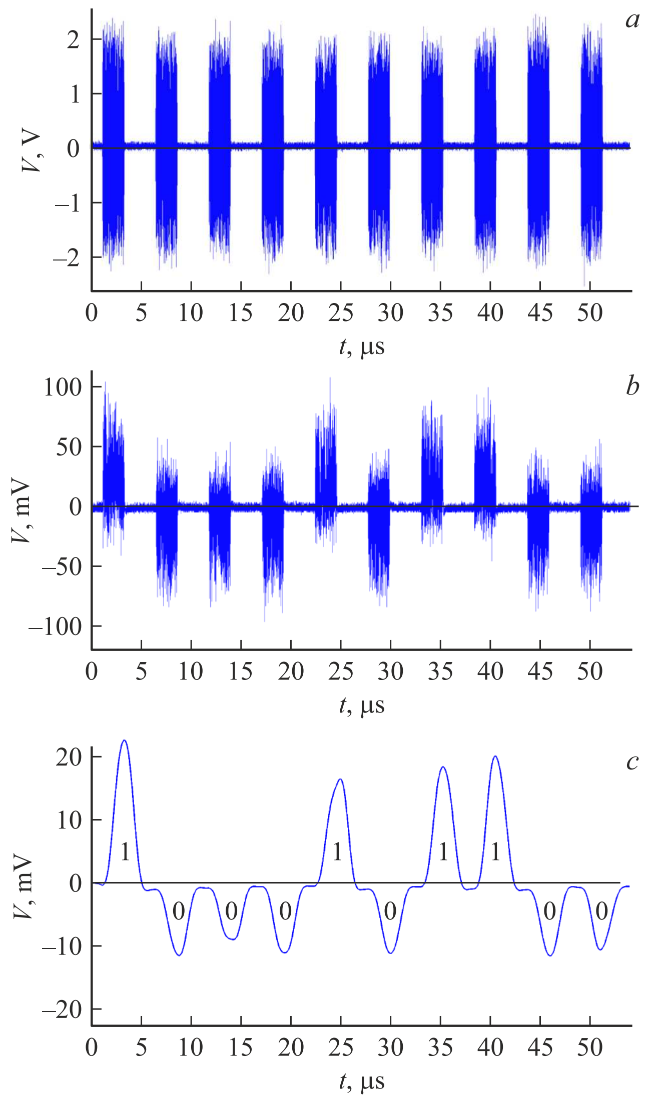

Figure 3. Waveforms of signals being transformed in the receiver. *a* — Stream of pulses at the transmitter adder output, *b* — signal at the multiplier output, *c* — signal at the low-pass filter output.

connection is used as an adder at the output of board *2*. Identical time delays being equal to (or greater than) the autocorrelation time of pulses shaped by the source of chaotic radio pulses need to be set in the transmitter and the receiver.

An ultrahigh-frequency coaxial cable 1 m in length was used to form τ time delays.

The next component of the transmitter circuit is the modulator. As was already noted, the modulator is meant to control the signal sign: like-sign signals are needed at the modulator input and output if „1" is to be transmitted, while the output signal for „0"should be inverted relative to the input one. A cable section providing a delay of approximately 1 ns, which corresponds to the fall time of the autocorrelation function of a chaotic signal to the first minimum (Fig. 2, *b*), was used as the inverting element. The sign of the autocorrelation function at this minimum is negative. A chaotic pulse with its values being inverted in sign relative to those of the input pulse is thus formed at the inverter output (i.e., the initial pulse is multiplied by -1). The length of the cable section introducing a delay of 1 ns is 0.23 m. A cable section of this exact length served as the signal inverter in our model.

The signal received by antenna *4* in the receiver of the transmission system model (Fig. 1) is amplified by a low-noise amplifier (LNA), fed to a divider on board *5*, and split into two components. The first one is sent directly to a multiplier (board *6*), while the other component is delayed first. The multiplier is constructed based on a broadband microcircuit for multiplication of analog signals with an operating frequency band of 0–2 GHz. The signal at the multiplier output was processed in two stages. At the first stage, an oscilloscope was used to exclude signal components above 500 MHz, digitize the signal, and create CSV files to be sent to an external signal processor (personal computer). At the second stage, a digital low-pass filter was applied in Matlab to isolate the low-frequency data component of the signal.

The constructed model was tested in experiments on wireless data transmission. The system operated in a continuous mode at a transmission rate of 167 kbit/s. Figure 3 presents a fragment of the signal at different nodes of the system transmitting a binary sequence (1000101100). Pulses at the output of the transmitter adder are shown in Fig. 3, *a*. The signal level is slightly above 2 V. The wireless channel in our experiments was formed by transmitting and receiving antennas with an air gap ~ 1 m in size between them. Small-sized (20×20 cm) antennas matched within the entire chaotic signal range were used. Each of them had an attenuation coefficient of approximately 7 dB. If ideal omnidirectional antennas are used, the coefficient of signal attenuation within a distance of 1 m due to wave scattering in space at the frequencies tested in our experiment is 22 dB. Therefore, the total losses are on the order of 36 dB. In accordance with the schematic diagram of the transmission system, an LNA with $K = 20$ dB is installed at the receiver input (the output of antenna *4*) to offset these losses. With this amplification taken into account, the expected signal levels at the receiver input are sufficient for reliable reception and demodulation. This assumption was verified experimentally. Figure 3, *b* shows a fragment of the pulse stream at the multiplier output. The pulse stream envelope (Fig. 3, *c*) at the low-pass filter output corresponds to the binary sequence of the data signal at the input of the experimental transmission system model.

Thus, a transmitting-and-receiving model system for differentially coherent ultrawideband direct chaotic communication was designed and constructed. The first successful experiments on wireless digital data transmission within this model were carried out, and the feasibility and efficiency of the DC^2 scheme proposed in [11,12] were verified.

Conflict of interest

The authors declare that they have no conflict of interest.

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