CDSK Modulator and Demodulator System Based on FPAA Technology

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***Abstract*—Experts have been concerned about the security of digital communication systems and the reduction of interception in recent years. Because of its inherent characteristics and high efficiency in encoding information, chaotic signals can play a significant role in this respect. A dynamically reconfigurable FPAA AN231E04 from Anadigm is used to implement of Correlation Delay Shift Keying (CDSK) communication system. The FPAA chip can be used in almost any electronic hardware for analog system implementations. It permits the experimental selection or amendment of the system structure to achieve its specific properties. The performance of the Rossler oscillator was evaluated via MATLAB Simulink environment. The practical implementation demonstrates and validates chaotic dynamic behavior. The effect of Additive White Gaussian Noise (AWGN) on the performance of the proposed CDSK systems was studied. Under the impact of the AWGN channel, the performance efficiency of the suggested CDSK and noncoherent differential chaos shift keying (NC-DCSK) systems were examined. The CDSK bit transfer technique is safer than the NC-DCSK bit transfer technology. The power consumption of the proposed system is (only 763±18 mW) according to performance studies.**

***Index Terms*—FPAA, rossler oscillator, CDSK system**

I. Introduction

In recent years, there has been an increased interest in chaotic digital communications since Pecora and Carroll demonstrated in 1990 that chaotic systems can be synchronized [1]. However, adaptive synchronization between two linearly coupled different chaotic systems has received less attention [2]. Chaos theory has applications in a variety of domains, including physics, biology, medicine, engineering, communications, and economics [3]. Different electrical circuits were discovered to be chaotic. In communication systems, chaotic signals could be employed as carriers. High sensitivity to initial conditions is an essential concept in chaotic systems. Another appealing property of chaos is the simplicity of chaotic signal generators, which has sparked widespread interest in using chaotic signals in signal transmission [4]. Chaos signals offer several advantageous qualities such as randomness, determinism, and great sensitivity to the initial value, making chaos secure communication systems challenging to break through [5], [6]. Chaos communication systems are nonlinear systems with nonperiodic, wide-band, unpredictable behavior, and ease of application in spread spectrum communication systems [7]. Symmetry coefficient modulation is a fundamental technique for the creating viable communication systems [8].

Modulating the symmetry parameter of a continuous chaotic system's finite-difference model yields a coherent chaotic transmission mechanism [8]. The Rössler system is a nonlinear set of equations with good chaotic behavior introduced by Rössler in 1976. It is based on the Lorenz system [9]. Rossler popularized the Rossler system as a straightforward differential equation with only one nonlinear element in one variable [10].

Chaos signals, such as chaos shift keying (CSK) and differential chaos shift keying (DCSK), can be used for digital communication [5], [11]. CSK was initially proposed by Parlitz *et al*. [11] and Dedieu *et al*. [12], [13]. Sushchik proposed correlation delay shift keying (CDSK) bandwidth efficiency [14]. Due to the vast number of intraspinal cross-terms at the correlator output, CDSK has a lower noise performance than DCSK [15]. CDSK is a noncoherent communication technique that does not require a synchronized replica of the chaotic basis functions at the receiver [16]. Because the transmitted information is correlated, the bit error rate (BER) of a CDSK-modulated system is substantially more significant than that of a coherent chaotic system [17]. The performance of the CDSK system has been researched in numerous communication scenarios during the last decade, such as the chaos multi-input multi-output (MIMO) communication system [18], DCSK, and CDSK methods combined in this system [19]. By incorporating the reference signal inside the M-ary data signal, the M-ary CDSK technique improves system integrity [20]. In this paper, a dynamic CDSK system will be built based on FPAA technology.

The rest of the paper is organized as follows. Section II covers the chaotic oscillator principle, the FPAA design, and CDSK. The security transmitter system based on the Rössler oscillator and CDSK is shown in Section III. The IV section defines the simulation and analysis of the Rossler chaotic system and hardware implementation of the proposed system. The V section ends with a summary of our contributions.

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II. Material and Methods

A. Rössler Chaotic Oscillator

The Rössler oscillators is a nonlinear equations system with good chaotic behavior. Creating the chaotic sequence is made more accessible by using chaotic Rössler maps, one of the most used polynomial maps. The Rössler simple state equations are as follows [21]-[24]:

$$\dot{m}_1 = -m_2 - m_2 \tag{1}$$

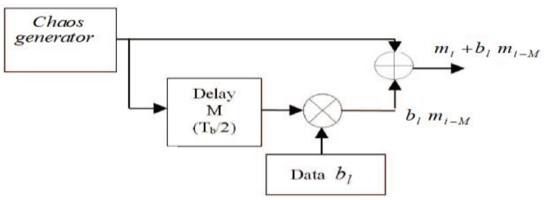
$$\dot{m}_2 = m_1 + am_2 \tag{2}$$

$$\dot{m}_3 = b + m_3(m_1 - c) \tag{3}$$

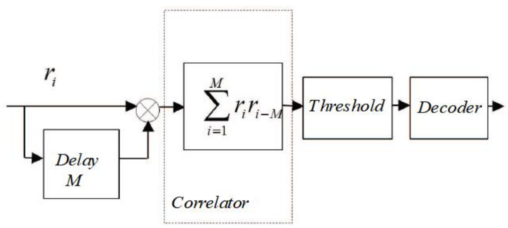
In the above equations, m_1, m_2, and m_3 are system variables, and a, b and c are the system constants. The behavior of the Rössler attractor is substantially determined by the values of its constant parameters a, b, and c. In general, varying each parameter has a comparable effect by causing the system to converge toward a periodic orbit, fixed point, or escape towards infinity; however, the specific ranges and behaviors induced vary substantially for each parameter. Periodic orbits, or “unit cycles,” of the Rössler system are defined by the number of loops around the central point before the loop series begins to repeat itself. The behavior of the Rössler attractor is examined by varying parameter c and keeping the values of a and b constant.

B. Correlation Delay Shift Keying

The vast majority of noncoherent systems use either DCSK or CDSK. The bandwidth issue is caused by the received signal's multiplication and delayed copying [19]. This paper proposes a CDSK based on the Rossler chaotic signal as a spreading signal. The CDSK system is depicted in Fig. 1, Fig. 1 (a) represents the transmitter, and Fig. 1 (b) represents the receiver [15].



(a) CDSK transmitter



(b) CDSK receiver

Fig. 1. Block diagram of CDSK system.

The transmitted signal is the product of the generated Rossler chaotic signals m_i, and the delayed Rossler chaotic signals m_{i-M} is multiplied by the lth transmitted information symbol b_i =1. The transmitted signal is equivalent to (4) [14]:

$$S_i = m_i - b_l m_{i-M} \tag{4}$$

A receiver based on the CDSK is performed to restore the symbol. Thus, in the receiver, the information can be found is multiplied by the received signal and the delayed signal as in (5):

$$Y_i = \sum_{i}^{N} R_i R_{i-M} \tag{5}$$

where R_i is the received signal carried via the channel, and N is the spreading factor. The approach makes use of the chaotic segment's shifted version's low correlation value [15].

C. FPAA Structure

FPAA comprises basic analog processing blocks organized to form a configurable analog block (CAB) connected to other CABs via a routing network [25]. Filter synthesizers, multipliers, and amplifiers are all included in the FPAA. FPAA can be used to verify dynamical systems quickly, and those blocks can be constructed by utilizing integrated circuit technology in a subsequent stage [26]. FPAAs are switched-capacitor systems that are architecturally like programmable logic devices (PLDs) but execute analog instead of digital circuitry; with only a few commercially available general-purpose arrays, physical deployment of nearly arbitrary circuits is possible [27], see Fig. 2 [28].

In the following, we will highlight the performance evaluation of the system in the presence of the proposed additive white Gaussian noise (AWGN) system, including using MATLAB software to build a chaotic Rossler oscillator for spreading signal generation.

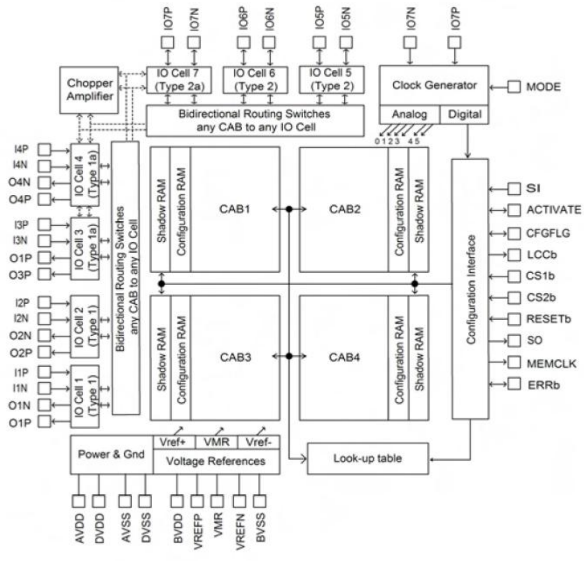


Fig. 2. Architectural overview of Anadigm FPAA AN231E04 [28].

III. Results and Performance

A. Rossler Chaotic Map

A simulation model for the Rossler chaotic oscillator system, shown in Fig. 3, was constructed using Matlab-R2018a to examine the system's chaotic behavior and randomization features. Fig. 4 depicts chaotic attractors' unusual state space, enabling them to generate secure keys for multimedia encryption and a carrier wave for secure multimedia transmission. The system is made up of three variables: m_1, m_2, and m_3, as well as three fundamental parameters: a, b, and c. Rossler chaotic oscillator designed in the MATLAB-R2018a program to provide its chaotic behavior by choosing the values of the parameters a, b, threeand c. The time series and attractors of the Rössler system describe the chaotic behavior; see Fig. 4. We discovered that the time series is periodic, and that the attractor is a limit cycle when the parameter *c* (*c* = 4) is altered while maintaining *a* and *b* constants at *a* = 0.006, *b* = 0.1, as shown in Fig. 4 (c). When the time series exhibits distinct values, the dynamics reveal chaotic behavior at *c*= 2 and *c*= 3.1, as shown in Fig. 4 (a) and Fig. 4 (b), respectively. The attractors in this diagram have an unusual shape that corresponding to well-known chaotic activity characteristics.

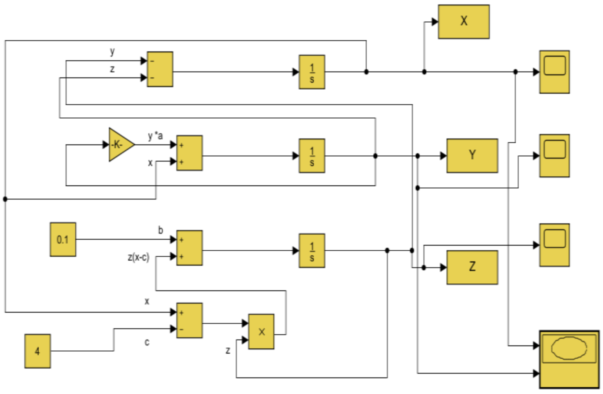
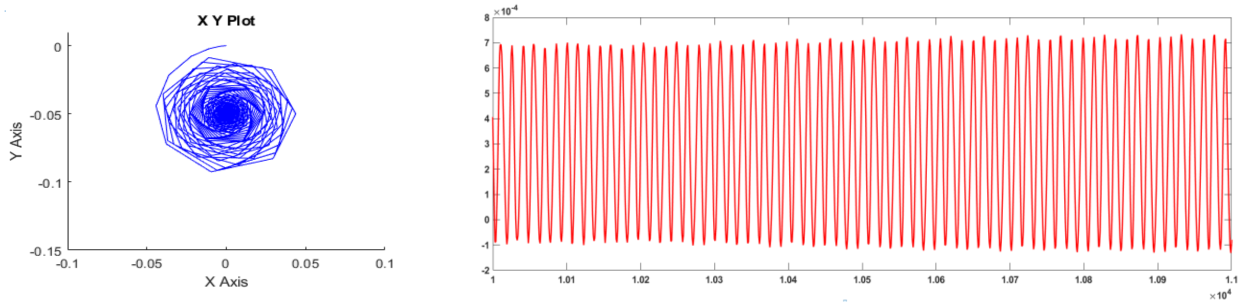
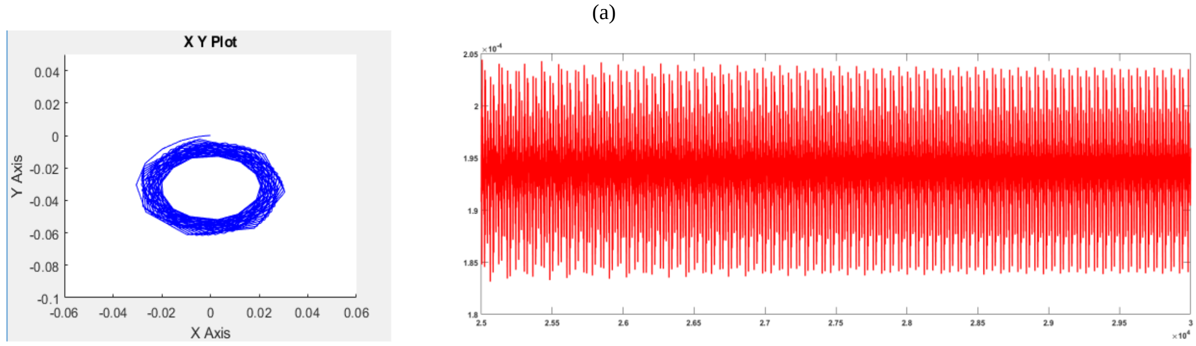


Fig. 3. Simulink model of the Rossler chaotic oscillator



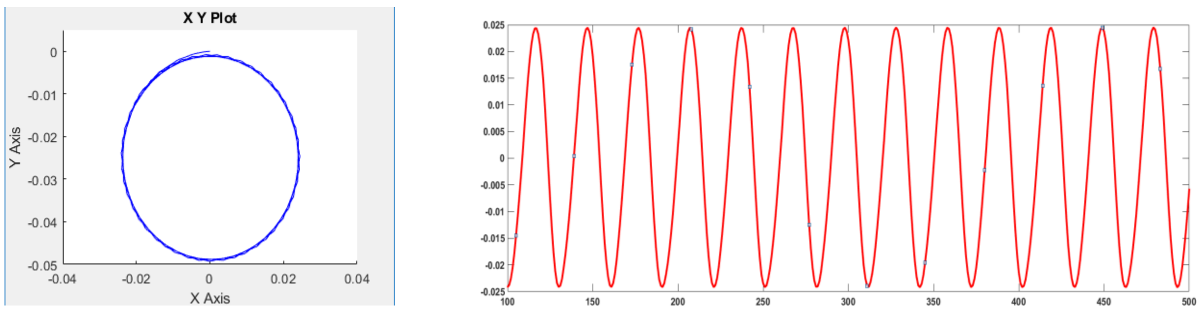
a = 0.006, *b* = 0.1, *c* = 2

(a)



a = 0.006, *b* = 0.1, *c* = 3.1

(b)



a = 0.006, *b* = 0.1, *c* = 4

(c)

Fig. 4. Simulation results using MATLAB Simulink

B. FPAA Implementation of CDSK System

The Anadigm Designer software application was used to create and build the CDSK system's transmitter and receiver representations. The proposed transmitter system is separated into two parts, the first of which is the implementation of the CDSK transmitter and the second of which is the implementation of the CDSK receiver. The mathematical system of the Rossler chaotic was designed and implemented using the Anadigm Designer software tool. According to the Simulink model presented in Fig. 3, Rossler chaotic system is built by using configurable analog modules (CAMs) in Anadigm Designer2, as shown in Fig. 5 (FPAA1 & FPAA2) and downloaded to the development boards. Due to the limited capacity of FPAA board, two-series connected AN231K04 FPAA evaluation boards from Anadigm Inc. were utilized to build the circuit. The configuration allows the programming of both AN231E04 FPAA chips via the personal computer's serial port. The Rossler oscillator is implemented using four sum/difference stages with LPF blocks as a summing stage. Three integrators with 4 μsec integrating constants are used. The Multiplier1 block fulfills the multiplication of the integrator 1&3 output signals. The Hold blocks are used to ensure that the signals at the outputs of the various functional blocks look the same. The circuit's output is linked to the controller's upper input FPAA3.

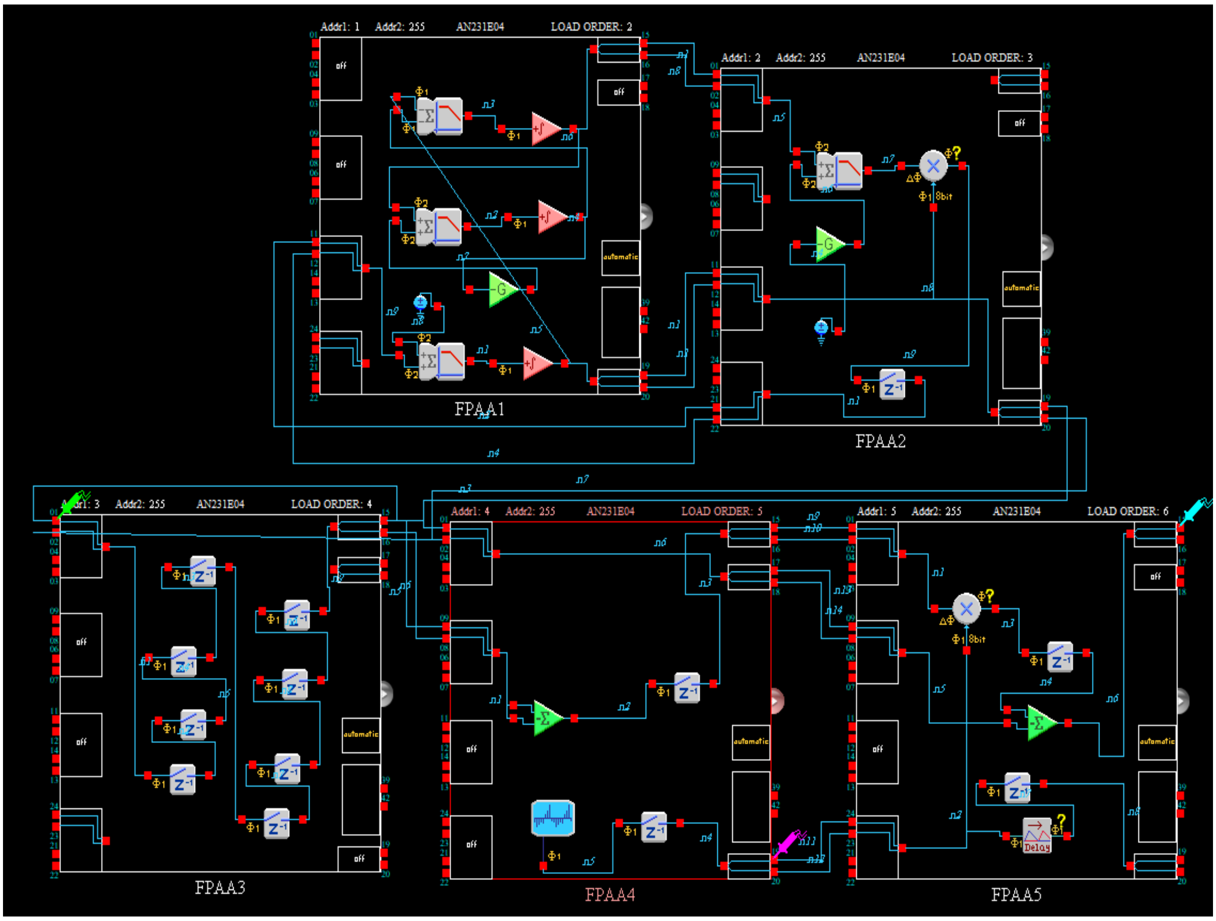


Fig. 5. CDSK Transmitter.

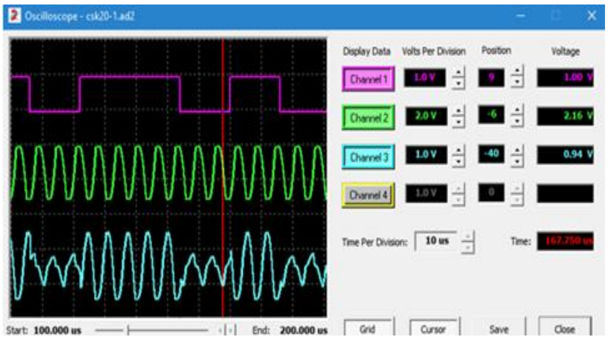


Fig. 6. Transmitter input and out signals.

To implement the delayed chaotic signal in Fig. 1 (a), several samples and hold Configurable Analog Modules (CAM) are inserted see FPAA3. The output of the circuit is connected to the second input of the FPAA4. The results obtained from programmed hardware are then compared with simulation results. Modulating the system model using Anadigm Designer2 between hardware and software results is discarded if there is a difference between hardware and software results. The implementation is completed when all the differences are discarded. The multiplication of the input signals (information and spreading signals) is fulfilled by the multiplier and inverting sum stage blocks (FPAA5). An arbitrary periodic waveform generator block is used to generate the information bits b_i, where b_i = (1, +1). (See Fig. 6)

The transmitted signal will have the information signal and reference chaotic signal. Therefore, the transmitted signal is the same as (4). The pink simulator probe marks the information signal; the green simulator probe clarifies Rossler's chaotic signal, while the blue simulator examination references a modulated output signal.

Fig. 7 shows the CDSK receiver configuration for FPAA-AN231E04 (FPAA6-8). FPAA successfully built the circuit to restore the information. Thus, to recover the information signal, only 3 pieces of FPAA are needed. 10 samples and hold, sum/difference integrator, LPF, multiplier, peak detector, and comparators are used to implement the circuit and take less power (only 334±18mW). From Fig. 7, it does not require regenerating the chaotic reference signal at the receiver. To reproduce the identical data symbol, at the receiver, the delayed signal r_{i-M} will be used as the reference component and multiplied by the received signal r_i.

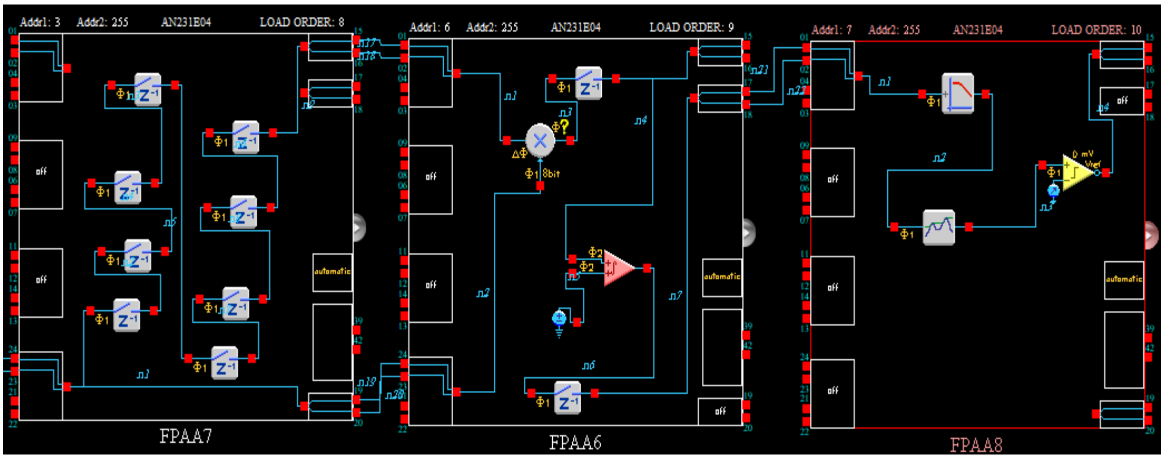


Fig. 7. CDSK receiver structure.

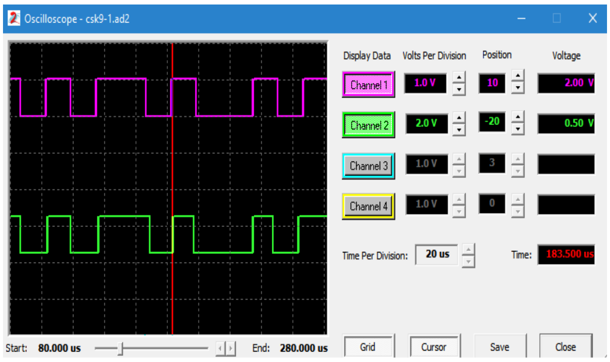
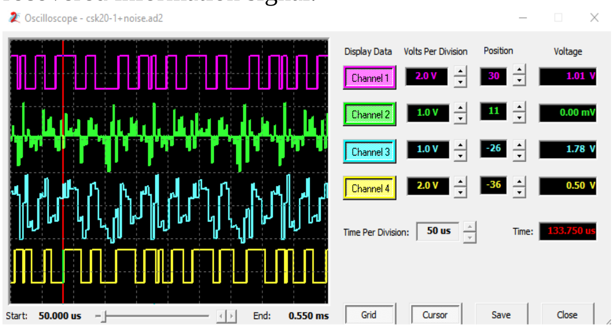


Fig. 8. Input & output signals.

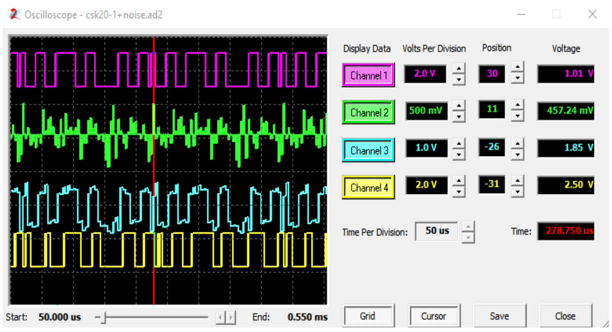
Fig. 8 presents the results from the receiver output. The forms and characteristics of theoretical results agree perfectly with practical examinations.

IV. Experimental Results

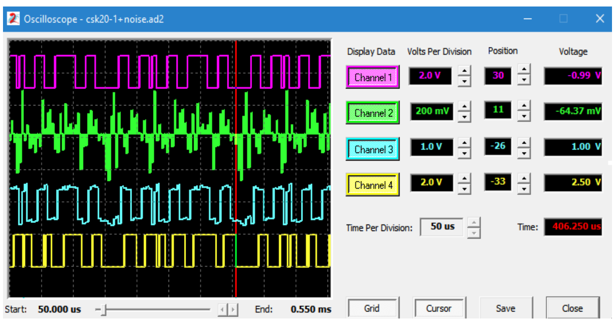
Gaussian noise is significant in the analysis of communication system performance. This section performs a performance analysis of the CDSK system over the AWGN channel. The AWGN is assumed to have a constant power spectral density (PSD) over the channel and a Gaussian amplitude probability density function. The AWGN is set up for transmitting a signal using an arbitrary waveform generator and hold CAM, which functions as an additive component. The receiver part will receive the transmitted signal plus the noise from the AWGN channel. To evaluate a specific signal-to-noise ratio (SNR) point in performance simulations, the modulated signal from the transmitter needs to be added with random noise of particular strength. The strength of the generated noise depends on the desired SNR level. The simulated performance of CDSK with AWGN is shown in Fig. 9, the simulator pink probe marks the information signal, and the simulator green probe clarifies the AWGN signal, while the simulator blue probe references a modulated output signal corrupted with noise and the simulator yellow probe presents the recovered information signal.



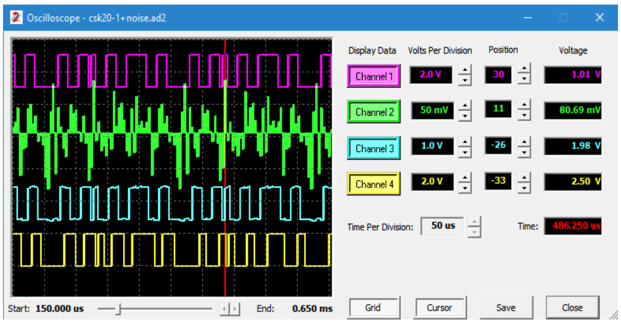
SNR = 0 dB



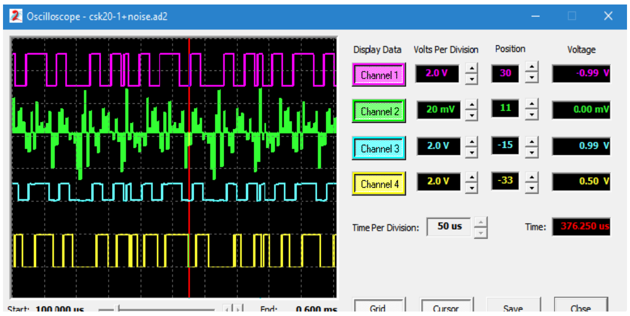
SNR = 3.4 dB



SNR = 5.7 dB



SNR = 11.345 dB



SNR = 15.745

Fig. 9. Influence AWGN on the received signal.

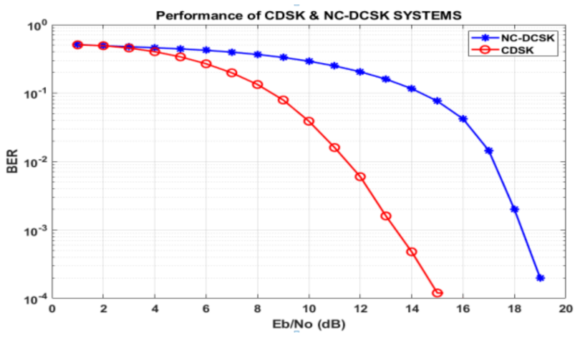


Fig. 10. BER performance of CDSK and NC-DCSK systems

The XOR gate is built by using FPAA techniques to count the number of incorrect bits. The BER performance of CDSK chaos-based systems was examined under the influence of AWGN to assess the performance effectiveness of the proposed system. CDSK systems simulated BER as compared to NC-DCSK-based systems. CDSK beats DN-DCSK, as seen in Fig. 10 [29]. Based on the applied chaos generator, the BER results for the CDSK communication system demonstrate that the system is only operable at the system's power efficiency (E_b/N_o) levels over 8 dB. The bit error rate surpasses 0.1 when Eb/No is less than 8 dB, and enough bits are erroneously recognized. Despite this, the CDSK technique provides a more secure bit transfer due to bit encoding than the NC-DCSK scheme.

V. Conclusion

CDSK wireless communication system based on Rossler chaotic and FPAA technology has been proposed. The effect of the AWGN channel on the performance of the proposed system was studied. The results were obtained by averaging the SNR. Besides the experiments, simulations of Rossler's chaotic oscillator were performed to confirm the observed results. The implementation of a CDSK system based on FPAA programmable hardware is very convenient for security systems. The simulation results of the system match very to the programmable hardware results. The simulated BER of CDSK systems was compared to NC-DCSK-based systems. The BER statistics for the ECSK communication system show that the system is only functional at E_b/N_o levels exceeding 8 dB, based on the chaos generator used.

Conflict of Interest

The author declares no conflict of interest.

Author Contributions

Thair A. Salih conducted the research, analyzed the data, and wrote the paper.

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