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Chaotic dynamics model based on field-programmable analog array technology

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ABSTRACT

Engineering applications in secure communications and encryption based on chaotic signals have attracted a lot of attention in the past decade. This paper presents an extensive study of the chaotic dynamics model of the Van Der Pol oscillator via MATLAB/Simulink simulation and its practical implementation using field-programmable analog matrix techniques. The obtained results show the ease of changing the frequency of the oscillator signal once it is retrieved, creating the required changes, and loading it again according to the required changes. An unlimited number of signals can be generated, allowing them to be used as a chaotic signal oscillator used in many transceiver systems, which require the generation of an unlimited number of such a signal. These research results confirmed that the AN231E04 field-programmable analog array (FPAA) device could be an interesting choice for analog circuit designers, it has the advantage of the ease of use in introducing design changes and testing many critical design solutions.

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1. INTRODUCTION

The chaos-based communication systems have appealed to large interest, starting with Shannon's 1947 admission that a noise-like signal with a waveform of maximal entropy produced an optimization wireless communications channel capacity [1]. Wireless chaotic communication has many features than the blueprints dependent on a classical harmonic signal, viz, enormous safety and hide information advantages [2], weak power spectrum intensity, impervious to multipath fading, and simply implemented for broadband communication system [3]. Scientists and researchers have grown more interested in chaotic communication systems because of the wide bandwidth that they enjoy compared to traditional systems with narrow bandwidth which is loaded with a large amount of data [4]. Many applications that depend on chaotic communications become familiar [5]. There are many chaotic communication systems that were proposed at the beginning of the focus on this type of secure communication for information transmission such as including chaotic masking, the information is mixed with the carrier chaotic signal using a nonlinear mixer [5], [6]. The chaotic demeanor of effective systems can be applied in numerous realism implementations like engineering, microbiology, biology, encryption, random generation, modeling of different electrical, laser, mechanical oscillators, washer machines, physics, robotics, mathematics, economics, philosophy, meteorology, computer science, pseudorandom bit generator, Rikitake chaotic system, artificial neural networks, and civil engineering [7]–[9].

2. LITERATURE REVIEW

Nowadays, an enormous number of chaotic oscillators have appeared [10]–[12]. Ahmad *et al.* [13] presented a case of the path of exploratory naturalist philosophy in the laboratory during the twenties and thirties of the last century. He scouts electrical circuits, including vacuum tubes arrived at the information that these circuits include completely stable oscillatory conduct, called boundary cycles [13]. A traditional Van Der Pol established on forcible oscillator is utilized to paradigm the cardiac patterns to give outcomes identical to those carried out with modified relaxation oscillators. The Van Der Pol oscillator was the first one to depict the cardiac athlete pattern [14].

Studied the state of controlled synchronization between the Van Der Pol oscillator as master and the Chua's circuit as a slave system. The concurrence of the Chua circuit with another oscillator is elaborated by different researchers [9]. Hou *et al.* offered a model to evaluate the other Van Der Pol's parameter examined. In this operation, the modified voltage is combined with the oscillator bias cyclically in order to troubleshoot the operating situation. Van Der Pol's parameters can be determined by studying the mathematical analysis of the energy spectrum of the confused oscillator, which contains many data [15].

An unfamiliar analytical solution is suggested for the Van Der Pol equation considering the variation of the amplitude and frequency at the beginning of oscillation. In addendum, a novel model for pulsed oscillations is offered. Compared with numerical emulations the Van Der Pol equation displays perfect accuracy [16]. Jin and Jie proposed a novel process to suppress a nonlinear chaotic Van Der Pol oscillator with dynamic uncertainties that is sophisticated. The major concept of this research is that the doubt is conglomerate in a widespread new state where its dynamic is made from the measure of the designed uncertainty controller [17].

The structure of the passive resistance of the transistor has been adopted in the design and construction of the voltage-controlled oscillator mathematical model. Oscillations caused by this oscillator have been studied using the Van Der Pols oscillator [18]. Synchronization between Van Der Pol oscillator and DC Motor has carried out a utilized algorithm of twisting. The utilization of pursuit control of technique with chaotic signals produced benefits in plentiful fields where some mechanical shakings are wanted [19]. An adaptive radial basis function control (RBF) was used to design and simulate an online tracking control of the Van Der Pol oscillator. Neural networks are used in the design of the control and adaptation formals of the RBF controller that give approximate results. Lyapunov stability standard is used for the analysis of the designed control stability and adaptation formals are obtained. MATLAB/Simulink program is applied for the emulation of a prepared adaptive controller for the pursuit monitoring of the Van Der Pol oscillator [5].

Semenov [20], presented a modern style of conjunction circuit that employs the second symmetric which is applied to employ efficient elements. A theory was developed to get substantial states for steady common-mode second harmonic coupling. These inferences are promoted by the design of a 5 GHz minimal power quadrature oscillator. The residual paper scenario will be presented: In section 2 an explanation of the mathematical model of the modified Van Der Pol Osc. will be adopted in this paper. In section 3, design, implementation, and analyses for adopted Van Der Pol Oscillator simulated circuit using the MATLAB/Simulink software. Section 4 describes the design and implementation of the Van Der Pol oscillator circuit using Field programmable analog array techniques and discusses the results obtained. Section 5 concludes with a discussion is present. Section 6 contains the conclusion.

3. MODIFIED VAN DER POL OSCILLATOR MATHEMATICAL MODEL

The Van Der Pol oscillator is explained as a private situation of Lennard's equation as a differential equation of a second-order [8], [21], [22].

$$\ddot{x} = p_1 (1 - p^2)\dot{x} - p_2 \,.\, x \quad (1)$$

Where p_1 & p_2 are scalar parameters that indicate the nonlinear and damping coefficient. The Van der Pol oscillator can be represented by an electrical equivalent circuit as shown in Figure 1. The values of the capacitor and inductor are assumed to be constant. An effective element with the voltage-controlled relation is given by (2).

$$i = \varphi_t(v) \quad (2)$$

i is used to representing the negative resistance [8]. In studying the case $p_1 \gg 1$, van der Pol discovered the importance of what has become known as relaxation oscillation. These oscillations have become the cornerstone of geometric singular perturbation theory and play a significant role in the analysis of (1) [22].

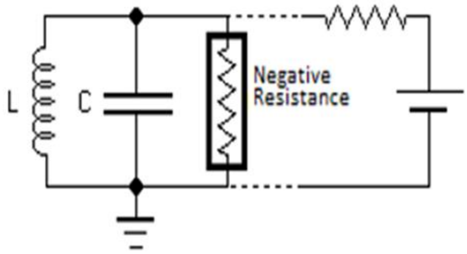


Figure 1. Electrical equivalent circuit of Van der Pol oscillator

4. SOFTWARE SIMULATION RESULTS

Figure 2 presents a simulation model for building a Van Der Pol oscillator using MATLAB/Simulink software to study and predict the behavior of this oscillator. Different blocks are used for the presentation of the equation of the oscillator mathematical model like an integrator, gain, summer, differential encoder, zero-order hold, math function, constant source, tapped delay, spectrum analyzer, auto, and cross-correlator, x-y graph, and scope. These blocks were connected to generate the Van Der Pol oscillator signal in (1). The simulation was implemented for the Van Der Pol oscillator shown in Figure 1, and some results were obtained, see Figure 3. A differential encoder block was used to convert oscillator output from analog to digital form.

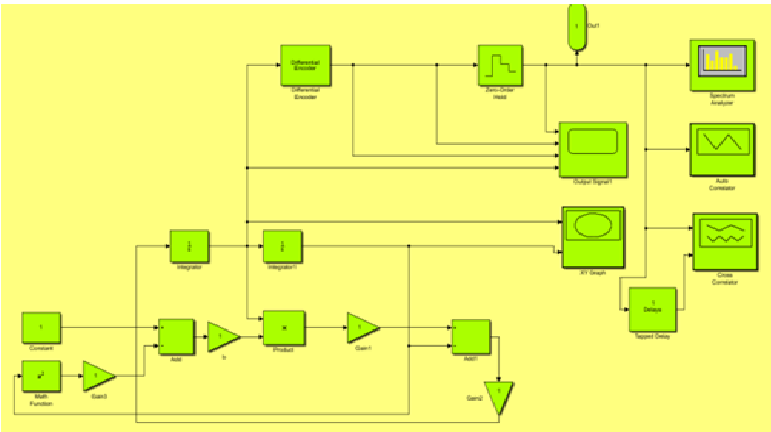


Figure 2. MATLAB Simulating model of Van Der Pol oscillator

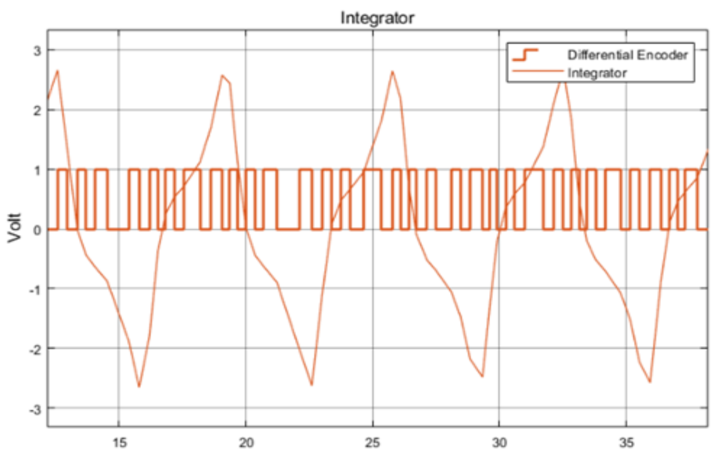
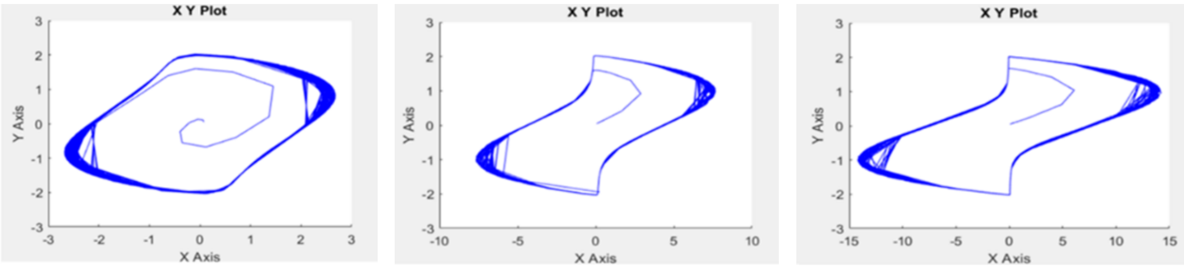


Figure 3. Van Der Pol oscillator output signals

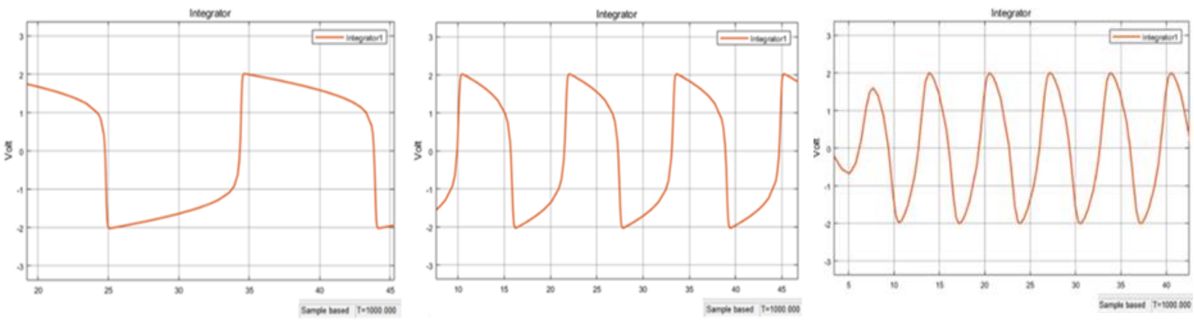
4.1. Analysis of initial value sensitivity

Van Der Pol signal has chaotic behavior represented by a group of continuous curves with a recurring geometric pattern and there is no specific way to characterize this model because it represents a two-dimensional shape and not a flat shape. There are two important parameters in determining the chaotic signal specifications, which are the initial conditions, whose values are chosen so that the conditional factors of the Lyapunov function will be achieved, and thus will we guarantee that the initial values of the chaotic convergence signal will diverge quickly and Bifurcation parameter. Figure 4 presents the Van Der Pol oscillator attractor for different initial condition values of the integrator block. It can say that the Van Der Pol oscillator is easy to build, in addition to the possibility of obtaining an infinite number of the output signal by changing the most crucial parameter $p1$ which affects not only the amplitude but also the frequency and shape of the output of the system see Figure 5.



Initial condition = 0.5 Initial condition = 1 Initial condition = 2

Figure 4. Van Der Pol oscillator attractor



p_1= 0.5 p_1= 1 p_1= 1.5

Figure 5. Van Der Pol oscillator output signal with fixed initial condition = 0.5 and different values of p_1

4.2. Analysis of balance property

This characteristic represents a measure of the probability of a 0 or 1 bit in the oscillator output signal which has an ideal value equal to 0.5. The results presented in Figure 6 show the probability that this ratio will be equal to the value of 0.5 with the increase in the length of the sequence of this signal.

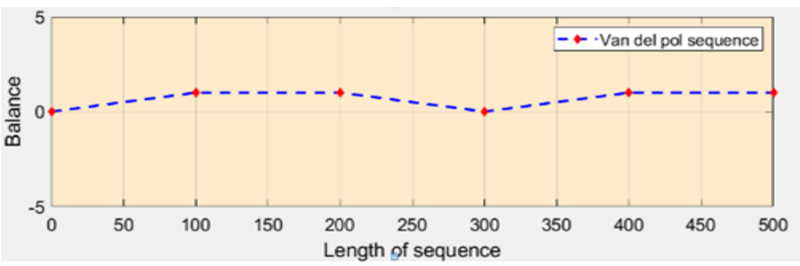


Figure 6. Balance property

4.3. Auto and cross-correlation properties

The sample and hold units are utilized to face the loss of compatibility between the different units which is the most important problem facing the implementation of the proposed system. The auto-correlation analysis is used to find the Van Der Pol oscillator signal properties, which require a long period of analysis to obtain accurate results. Through Figure 7 we can observe that the value of the signal length does not fade to zero value and has a fixed amplitude while the amplitude of the signal changes suddenly and its length reaches a very small value, but it does not reach zero value in cross-correlation analysis, as shown in Figure 8.

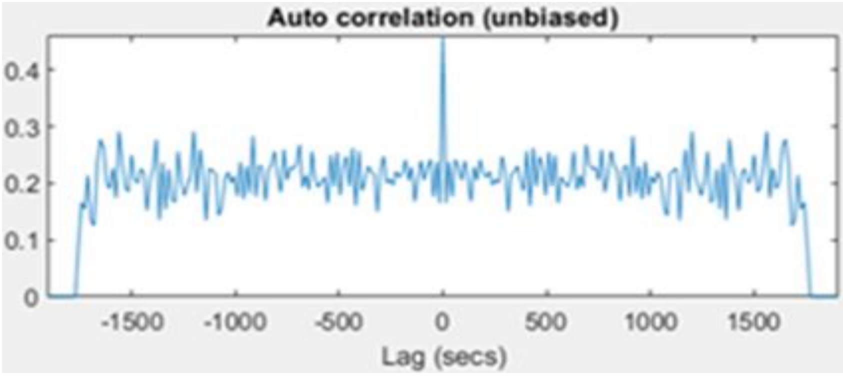


Figure 7. Auto-correlation properties

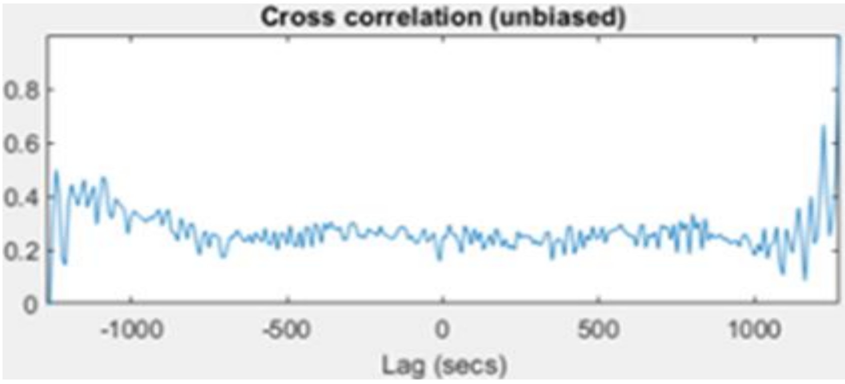


Figure 8. Cross-correlation properties

5. IMPLEMENTATION OF VAN DER POL OSCILLATOR USING FIELD-PROGRAMMABLE ANALOG ARRAY TECHNOLOGY

Reconfigurable computing has contributed many solutions to countless engineering cases. Field-programmable analog array (FPAA) technologies are the ideal solution for countless analog signal processing implementations. This technology contains many components for each chip, such as integrators, multipliers, summing, gain, filters, and other blocks. It provides high accuracy, electronic efficiency, and ease of implementation compared to DSP processors. FPAAs' provides the ability to change specifications designed in real-time to meet requirements with the variable demand of the system.

Simulink software is recognized worldwide as a standard simulation tool. In this paper, simulation software is designed and built using MATLAB Simulink. The results obtained are used based on the validity of the FPAA circuit. Specialized development software Anadigm Designer2 is used to design a Van Der Pol oscillator system described by the mathematical relationship clarifies by (1) in addition to the MATLAB/Simulink design offered in Figure 2. The circuit consists of two integrators, a summing amplifier, multiplier, DC power supply, and gain units. Figure 9 shows the implementation of the Van Der Pol oscillator using two Anadigm AN231E04 FPAA chips. An infinite number of an output signals can be obtained by changing the initial condition (S) of the integral units. The Van Der Pol oscillator in Figure 9 is tested to determine step response. The result of the simulation for the S = 0.02, and S = 0.07 is shown in Figures 10 and 11 respectively.

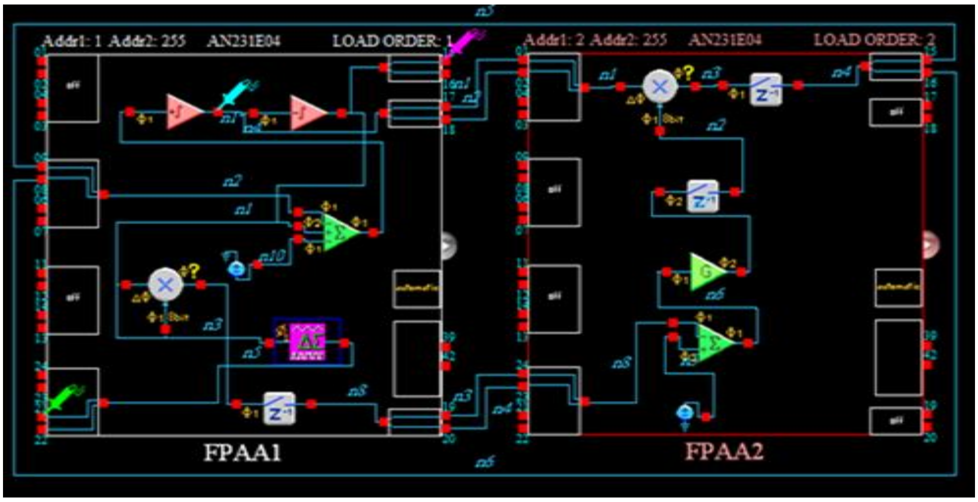


Figure 9. Van Der Pol oscillator using FPAA AN231E04 device

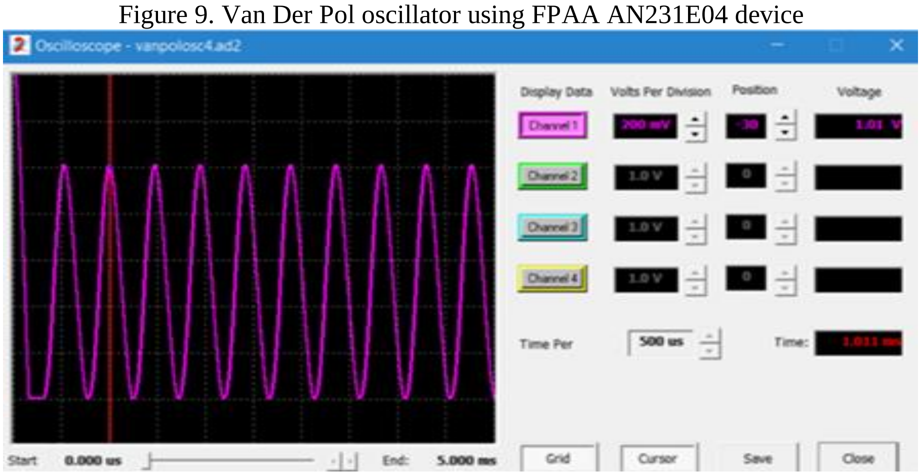


Figure 10. The Van Der Pol oscillator output for S = 0.07

Figure 11. The Van Der Pol oscillator output for S = 0.02

An infinite number of Van Der Pol output signals of different frequencies can be obtained by varying the value of the damping coefficient parameter (p_1) as shown in Figures 12 and 13. The sample and hold unit is utilized to face the loss of compatibility between the different units which is the most important problem facing the implementation of the proposed system. This trouble causes fading and distortion in the form of the Van Der Pol output signal. ΣΔ analog to digital converter (ADC) is used to perform Van Der Pol oscillator output signal to digital form as shown in Figure 14.

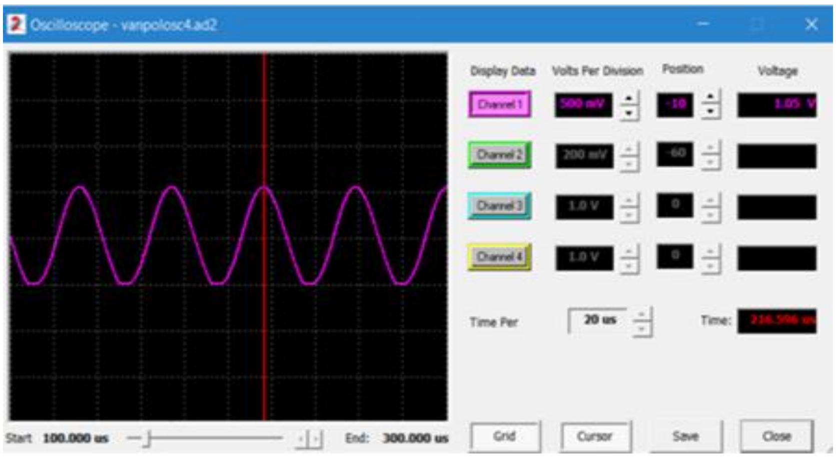


Figure 12. Van Der Pol output signals with $p_1 = 1.5$

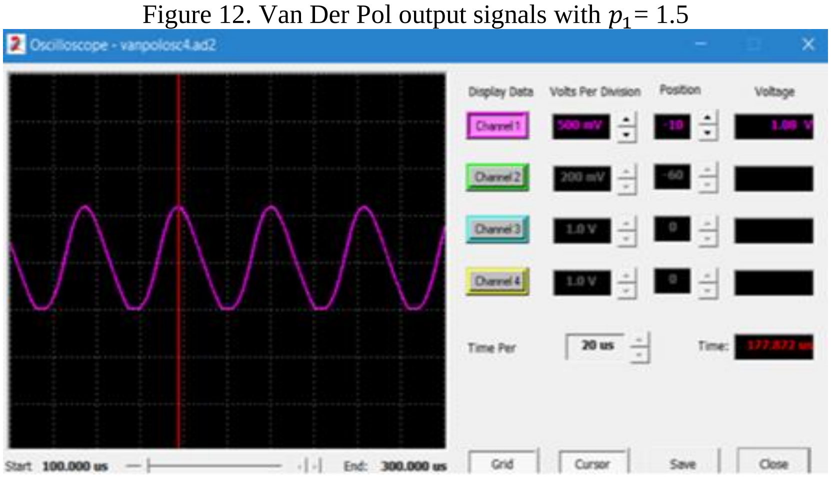


Figure 13. Van Der Pol output signals with $p_1 = 0.5$

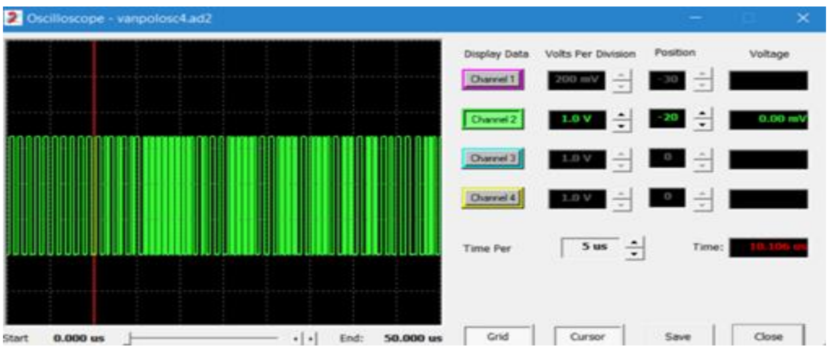


Figure 14. Van Der Pol oscillator digital output signal

6. CONCLUSION

A prototype for the Van Der Pol oscillator using FPAAs of Anadigm was presented in this paper. The Anadigm Designer2 software and the Simulink show partly identical results. The output form for both methods is extremely similar. There is some variance to be seen. The response obtained from Anadigm Designer2 has a prolonged ascent time compared to the response from Simulink. The variance can be derived from many reasons e.g., computation method and conclude the process. A novel solution for the implementation of the Van der Pol oscillator based on FPAA technology is present. This model allows varying oscillator parameters to produce an infinite number of chaotic signals.

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