FPAA BASED DESIGN AND IMPLEMENTATION OF SPROTT N CHAOTIC SYSTEM

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Abstract

Nowadays, chaotic systems are used in various studies of different disciplines. Today, chaotic systems are used in various studies of different disciplines. In the literature, chaotic systems with various features have been introduced up to the present. In order to use these new chaotic systems in real-world engineering applications such as encryption, secure communication and authentication, they must be realized besides numerical simulations. In the literature, analog chaotic system implementations have been realized mainly with OPAMP devices. FPGAs and microcontrollers are used mostly in digital designs of chaotic systems. In this study, FPAA (Field Programmable Analog Array) based design and realization of Sprott N chaotic system was carried out. FPAA based design and numerical simulation results confirmed each other. As a result, it has been shown that the Sprott N chaotic system can be used based on FPAA in various engineering applications.

Keywords: *Chaotic system, Sprott N chaotic system, FPAA*

1. Introduction

Chaotic systems have been used in different disciplines since they were first noticed. Chaotic systems are especially used in areas such as secure communication [1, 2], encryption [3, 4], authentication [5, 6] and optimization [7, 8]. In addition, many chaotic, hyper chaotic and multi-scroll chaotic systems have been introduced in the literature. Some of these introduced systems have only been examined numerically and have not been realized. However, these chaotic systems must be designed as analog circuits or digital circuits (embedded system) in order to be used in real engineering applications. For this purpose, different designs and approaches are available for the realization of chaotic systems. OPAMP is generally used in analog circuit designs [9-11]. In digital designs, FPGA (Field Programmable Gate Array) [12, 13] and microcontroller [14, 15] usage is more.

Digital designs can be easily redesigned and programmed according to analog designs. But in digital designs, the system needs to be digitized. FPAA (Field Programmable Analog Array) is used when analog design of chaotic systems and easy reprogramming of the system is desired. FPAA is an embedded system product based on switched-capacitor technique. FPAA includes configurable analog blocks (CABs) to perform the desired analog operations. In the design software developed by the manufacturer, configurable analog modules (CAMs) for various functions are prepared and presented to the users. [16]. The use of FPAA in the realization of dynamical systems provides more efficient and small-scale designs [17]. There are studies in the literature on FPAA based realizations of various chaotic systems [16-23].

In 1994, Sprott introduced 19 new three-dimensional algebraically simple chaotic systems [24]. These chaotic systems are named from A to S. In this study, FPAA based design of Sprott N chaotic system is examined.

In this study, firstly numerical analysis results of Sprott N chaotic system were obtained. Afterwards, FPAA based design and implementation of Sprott N chaotic system was performed. The numerical analysis results of the Sprott N chaotic system and the FPAA based realization results confirmed each other.

2. Numerical Simulation of Sprott N Chaotic System

In this section, numerical results of Sprott N chaotic system were obtained in Matlab-Simulink program. The mathematical model of Sprott N chaotic system is given in Eq. 1. The system (1) contains a total of six terms. One of these terms is a nonlinear term and one is a fixed term. The outputs of the *x*, *y* and *z* state variables obtained as a result of numerical calculation in Matlab-Simulink program are given in Figure 1. The initial conditions of the system (1) were taken as ($x_0 = 0$, $y_0 = 0$, $z_0 = 0$).

$$\begin{aligned} \dot{x} &= -2y \\ \dot{y} &= x + z^2 \\ \dot{z} &= 1 + y - 2z \end{aligned} \tag{1}$$

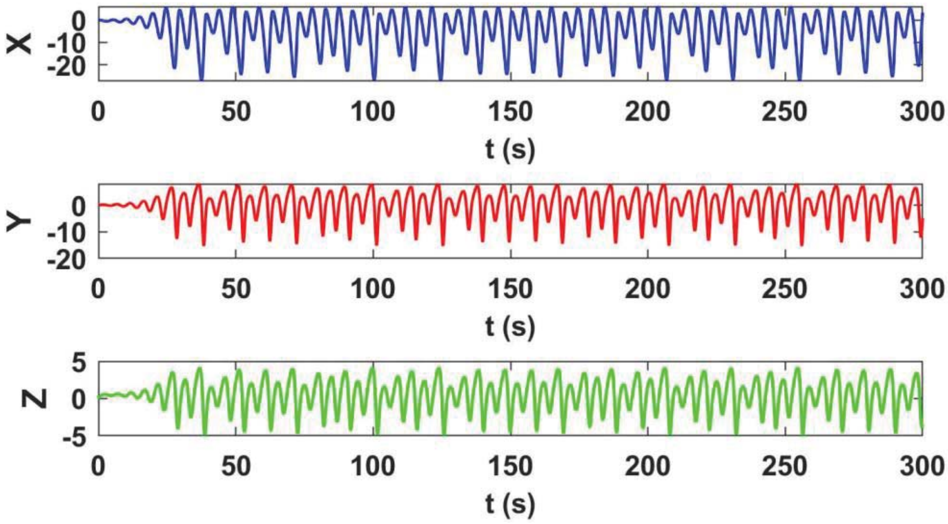


Figure 1: Numerical calculation results of state variables of Sprott N chaotic system (1) in Matlab-Simulink program

3. Scaling of Sprott N chaotic system

The operating voltage of the input/output pins of the FPAA is maximum ±3V. However, as shown in Figure 1, the state variable outputs of the system (1) are above ±3V. Therefore, the system must be scaled according to the FPAA input/output voltage values. Scale ratios are given in Eq. 2. In the scaled system, the new state variables names are given as *u*, *v* and *w*. Mathematical model of the scaled system obtained as a result of scale operation is given in Eq. 3.

$$u = \frac{x}{12}, \quad v = \frac{y}{9}, \quad w = \frac{z}{3} \tag{2}$$

$$\begin{aligned} \dot{u} &= -1.5v \\ \dot{v} &= 1.33u + w^2 \\ \dot{w} &= 0.33 + 3v - 2w \end{aligned} \tag{3}$$

The outputs of the *u*, *v* and *w* state variables obtained as a result of numerical calculation in Matlab-Simulink program are given in Figure 2. As can be seen from the Figure 2, the outputs of the state variables of the scaled Sprott N chaotic system (3) has reached the voltage limits required for the FPAA device. The phase portraits of the scaled Sprott N chaotic system (3) are given in Figure 3.

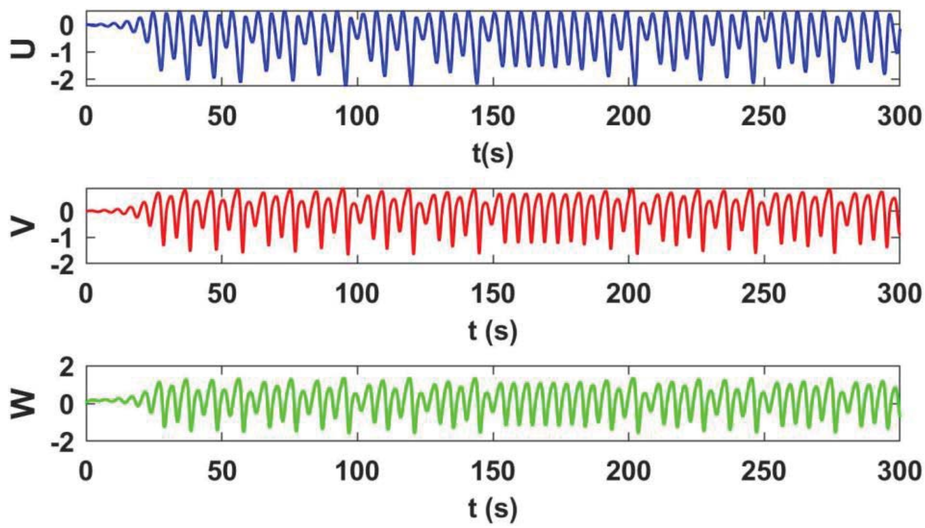
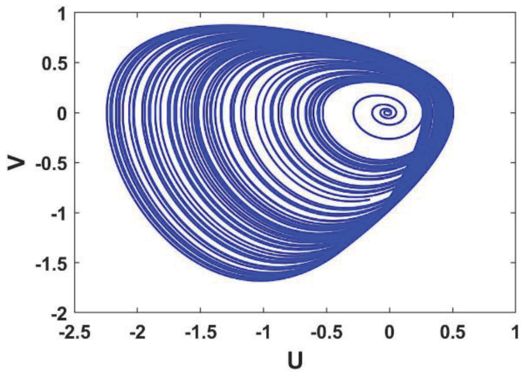
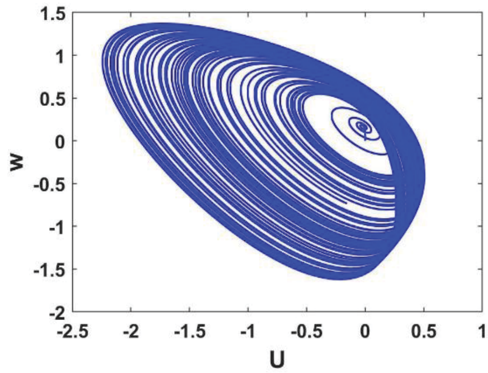
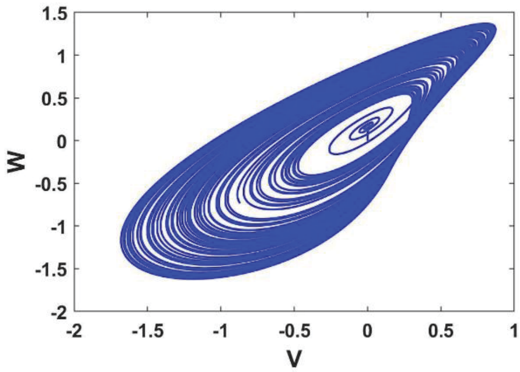


Figure 2: Numerical calculation results of state variables of scaled Sprott N chaotic system (3) in Matlab-Simulink program





(a) (b)



(c)

Figure 3: Phase portraits of scaled Sprott N chaotic system (3) in Matlab-Simulink program (a) *u-v* (b) *u-w* (c) *v-w*

4. FPAA Based Design and Implementation of Sprott N Chaotic System

In this part of the study, FPAA based design and implementation of the scaled Sprott N chaotic system (3) is performed. In the design, the Quad Apex v2.0 FPAA development board of Anadigm was used. AnadigmDesigner2 program developed by Anadigm was used for FPAA design. Figure 4 shows the circuit of FPAA based design of the system (3). The parameter values of the CAMs used in the design are given in Figure 5.

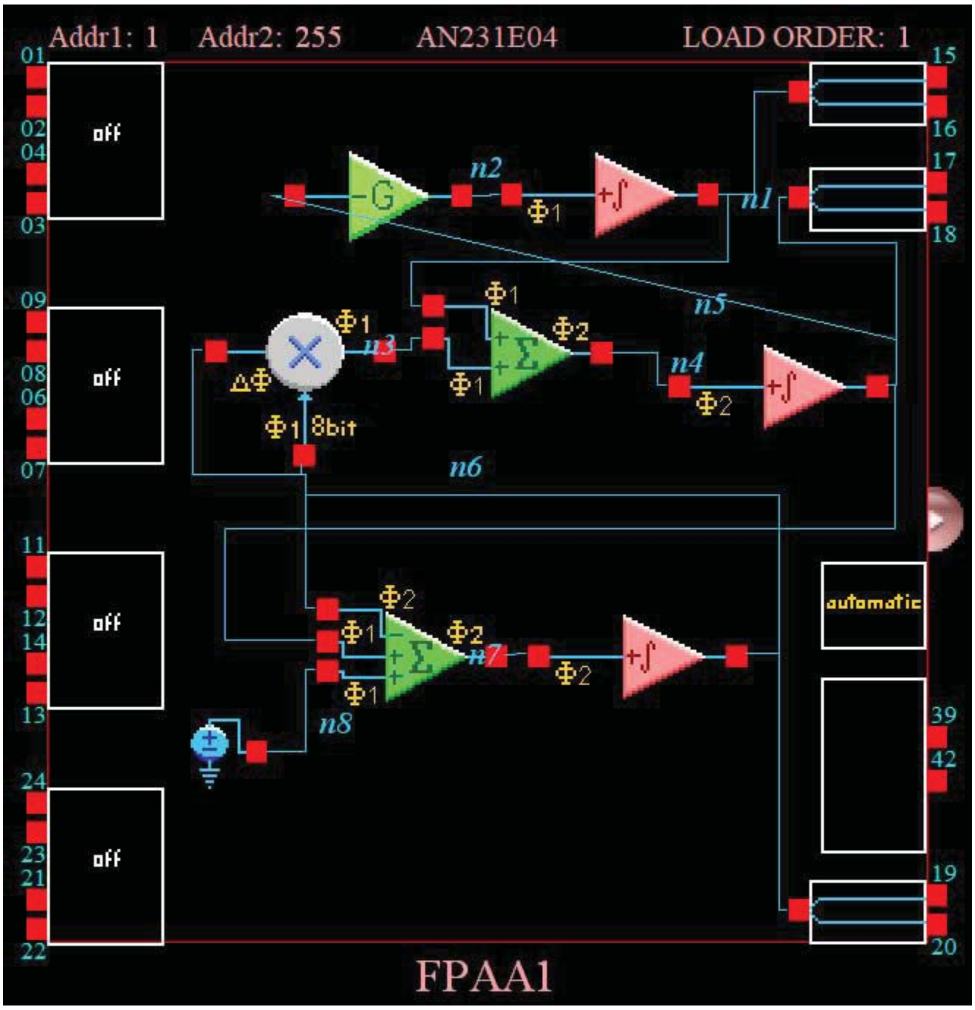


Figure 4: FPAA design circuit of the system (3)

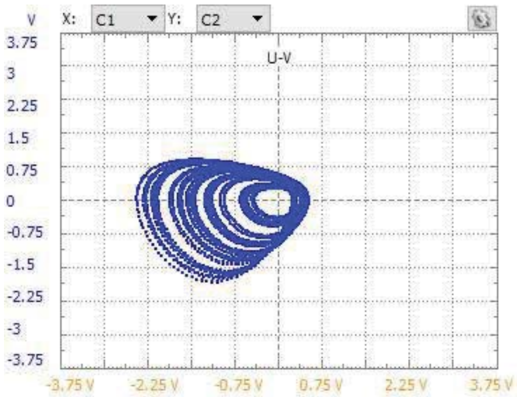
Sprott_N.ad2 - AnadigmDesigner2

Configurable Analog Modules: FPAA1

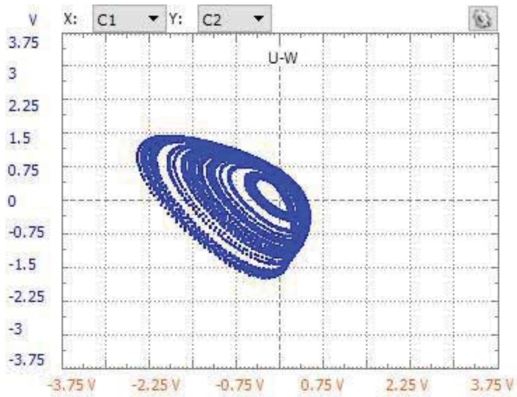
Name	Options	Parameters	Clocks
Integrator1 **(Integrator v1.1.1)** *Anadigm (Approved)*	**Polarity** *Non-inverting* **Input Sampling Phase** *Phase 1* **Compare Control To** *No Reset*	**Integration Const. [1/us]** *0.00250*	**ClockA** *250 kHz (Chip Clock 3)*
GainInv1 **(GainInv v1.0.1)** *Anadigm (Approved)*		**Gain** *1.50*	**ClockA** *250 kHz (Chip Clock 3)*
SumDiff1 **(SumDiff v1.0.1)** *Anadigm (Approved)*	**Output Phase** *Phase 2* **Input 1** *Non-inverting* **Input 2** *Non-inverting* **Input 3** *Off* **Input 4** *Off*	**Gain 1 (UpperInput)** *1.33* **Gain 2 (LowerInput)** *1.00*	**ClockA** *250 kHz (Chip Clock 3)*
Multiplier1 **(Multiplier v1.0.2)** *Anadigm (Approved)*	**Sample and Hold** *Off*	**Multiplication Factor** *1.00*	**ClockA** *250 kHz (Chip Clock 3)* **ClockB** *4 MHz (Chip Clock 0)*
Integrator2 **(Integrator v1.1.1)** *Anadigm (Approved)*	**Polarity** *Non-inverting* **Input Sampling Phase** *Phase 2* **Compare Control To** *No Reset*	**Integration Const. [1/us]** *0.00250*	**ClockA** *250 kHz (Chip Clock 3)*
SumDiff2 **(SumDiff v1.0.1)** *Anadigm (Approved)*	**Output Phase** *Phase 2* **Input 1** *Inverting* **Input 2** *Non-inverting* **Input 3** *Non-inverting* **Input 4** *Off*	**Gain 1 (UpperInput)** *2.00* **Gain 2 (MiddleInput)** *3.00* **Gain 3 (LowerInput)** *0.165*	**ClockA** *250 kHz (Chip Clock 3)*
Integrator3 **(Integrator v1.1.1)** *Anadigm (Approved)*	**Polarity** *Non-inverting* **Input Sampling Phase** *Phase 2* **Compare Control To** *No Reset*	**Integration Const. [1/us]** *0.00250*	**ClockA** *250 kHz (Chip Clock 3)*
Voltage1 **(Voltage v1.0.1)** *Anadigm (Approved)*	**Polarity** *Positive (+2V)*		

Figure 5: The parameter values of the CAMs used in the FPAA design

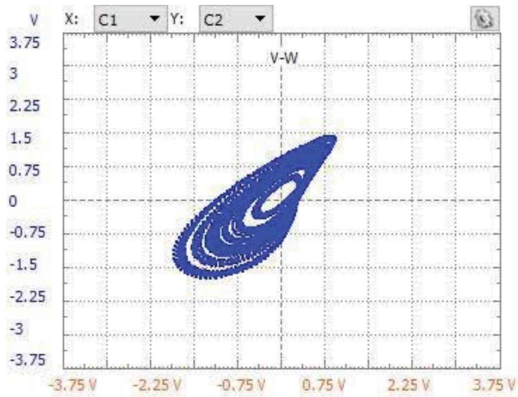
FPAA outputs were examined by PC based oscilloscope. The oscilloscope outputs of the implemented FPAA based system (Figure 4) are given in Figure 6. When the numerical simulation results (Figure 3) and FPAA output results (Figure 6) are examined, it is seen that the phase portraits obtained are the same.



(a)



(b)



(c)

Figure 6: The oscilloscope outputs of the implemented FPAA based system (a) *u-v* (b) *u-w* (c) *v-w*

5. Results

In this study, FPAA based design and implementation of Sprott N chaotic system was performed. Since the output values of the state variables of the Sprott N chaotic system are outside the FPAA operating voltage range (±3V), the system (1) was first scaled. With scaling operation, the outputs of the system (3) were matched to the FPAA operating voltage range (± 3V). When the numerical simulation results (Figure-3) in Matlab program and FPAA based implementation results (Figure-6) were examined, it was seen that they confirmed each other. As a result, it has been shown that the design of the Sprott N chaotic system with FPAA can be used in various engineering applications. In addition, the FPAA can be easily redesigned so that the design can be updated more easily than designs using analogue elements such as OPAMP, multiplication IC, capacitor, resistor.

6. References

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