Circuit Simulation of Analog Secure Communication Based on Synchronized Hyperchaotic System

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Abstract **This paper presents an efficient realization of an effective technique for the secure communication. This technique is based on the use of the 5D hyper-chaotic system as transmitter, and the nonlinear state observer as the receiver. To obtain the estimates of both the system states and the transmitted signal, the Lyapunov stability theory and sufficient synthesis conditions are given in terms of linear matrix inequalities (LMIs). An analog circuit simulation with Multisim software and Ultiboard software are provided to show the effectiveness of the proposed circuit.**

Keywords— 5D hyperchaotic system, observer based synchronization, secure communication and linear matrix inequalities, Multisim software and Ultiboard software.

I. INTRODUCTION

Since the pioneering work of Pecora and Carroll [1] in the field of chaos synchronization, it has aroused considerable interests in this research topic over the past several years for its potential usage in communications [2], biology [3], economics [4] and chemicals [5].

The idea for transmitting information via chaotic communication systems is that, the information signal is included in the transmitter system which produces a chaotic signal, and the information signal is recovered by the receiver. Many synchronization schemes had been developed such as impulsive control [6], passive control [7], backstepping control [8] and others.

In this paper, the design of circuit for the secure communication transmission using 5D hyperchaotic system and nonlinear state observer presented in [11] is proposed. The problem addressed is the design of a synchronization scheme such that the response system can synchronize the driving system globally. An effective algebraic matrix inequality approach is developed to solve the hyperchaotic synchronization problem. An analog circuit simulated with Multisim software and Ultiboard software are provided to show the effectiveness of the proposed circuit.

II. THE DESIGN OF THE SECURE COMMUNICATION SYSTEM

The block diagram of the proposed secure communication system is shown in the Fig. 1.

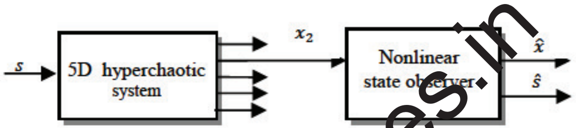


Fig. 1. Block diagram of a communication system

A. The Design of the Transmitter Circuit

Consider the hyperchaotic transmitter system described by [10]:

$$\begin{aligned}\dot{x} &= Ax + Bs + f(x,s,y)\\ y &= Cx + Ds\end{aligned} \quad (1)$$

$x \in R^n$, $y \in R^r$ and $s \in R^m$ denote the state, output and information signal respectively.

$$A = \begin{bmatrix} -a_1 & a_1 & 0 & 0 & 0 \\ a_2 & a_2 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & -a_3 & 0 \\ a_5 & 0 & 0 & a_4 & -a_4 \end{bmatrix}, \quad B = \begin{bmatrix} 0 \\ 30 \\ 0 \\ 0 \\ 0 \end{bmatrix}, \quad D = 1$$

$$C = [0\ 1\ 0\ \ 0\ 0], \text{ and } f(x,y) = \begin{bmatrix} x_2x_3x_4x_5 \\ -x_1x_3x_4x_5 \\ 0.1x_1^2 \\ x_1x_2x_3x_5 \\ x_1x_2x_3x_4 \end{bmatrix}.$$

An analog implementation of the transmitter using the Multisim is shown in Fig. 2, where an operational amplifier LMC6482 and some passive components are used. The transmitted signal *m*(*t*) is a sinusoidal signal with the frequency f = 30Hz.

As can be seen in Figure 2. the system being simulated in the Multisim generates a hyperchaotic signals, which hides very well the transmitted message s (t) through the second state of the tranmitter system.

B. The Design of the Receiver Circuit

We introduce the following notations for more simplicity of the presentation:

$$E = [I_n \quad 0] = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}, H = [C \quad D] = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

$$M = [A \;\; B] = \begin{bmatrix} -39 & 39 & 0 & 0 & 0 & 0 \\ 13.5 & 13.5 & 0 & 0 & 0 & 30 \\ 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -10.5 & 0 & 0 \\ 1.5 & 0 & 0 & 15 & -15 & 0 \end{bmatrix}, \text{ and } \varphi = \begin{pmatrix} x \\ s \end{pmatrix}$$

(2)

The hyperchaotic receiver system proposed is in the form [10]:

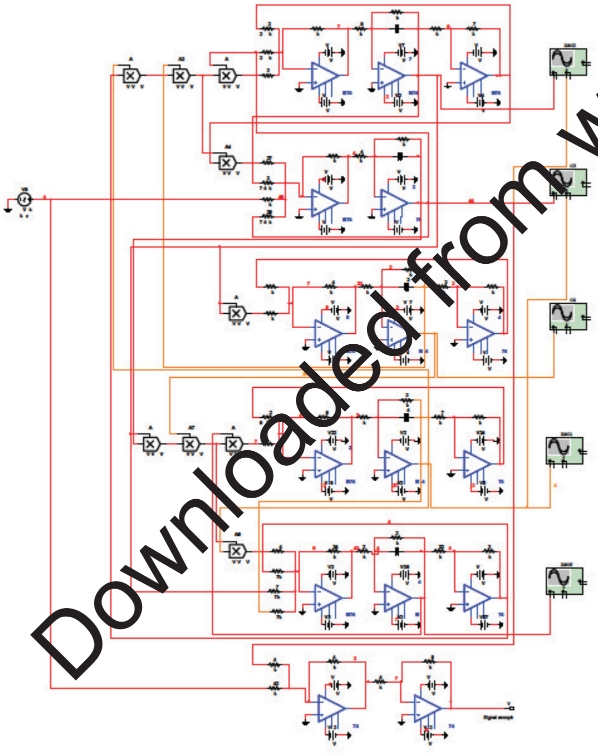
$$\begin{aligned} \dot{z} &= Nz + Ly + g(z, y) \\ \hat{\varphi} &= z + Qy \end{aligned} \qquad (3)$$

Where $\hat{\varphi}$ denotes the state estimation vector of φ. Q is a real matrix that verified $PE + QH = I_{n+m}$ with P is a real matrix. Matrices N, L and the nonlinear vector field $g(z, y)$ should be determined such that $\hat{\varphi}$ converges asymptotically to φ.
Consider the error vector

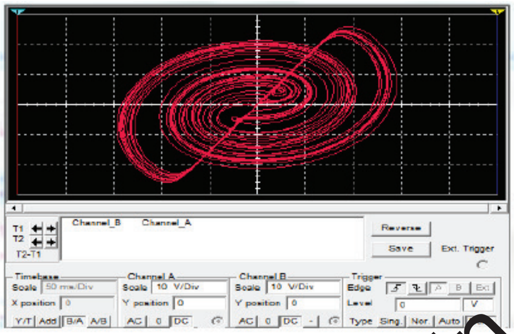
$$e = \hat{\varphi} - \varphi \qquad (4)$$

Substituting (3) and (1) into (4) we obtain:

$$e = z - PE\varphi \qquad (5)$$

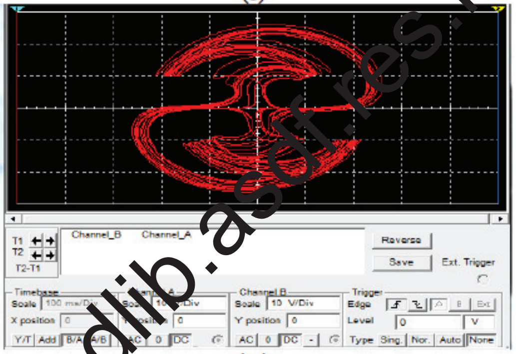


(a)



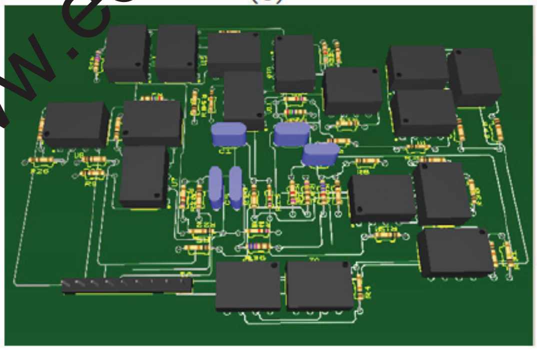
Timebase Scale 50 ms/Div
X position 0
Channel A Scale 10 V/Div
Y position 0
Channel B Scale 10 V/Div
Y position 0
Trigger Edge
Level 0 V
Type

(b)



Timebase Scale 100 ms/Div
X position 0
Channel A Scale 10 V/Div
Y position 0
Channel B Scale 10 V/Div
Y position 0
Trigger Edge
Level 0 V
Type

(c)



(d)

Fig. 2. Transmitter circuit realization. (a) transmitter circuit, (b) $x_1 - x_2$ plane projection, (c) $x_2 - x_4$ plane projection (d) general view of the circuit.

Then, the error dynamics is

$$\dot{e} = \dot{z} - PE\dot{\varphi} \qquad (6)$$

From (1)-(3) and by making use of (6), we obtain

$$\dot{e} = Ne + (N + FH - PM)\varphi + g(z, y) - Pf(\varphi, y) \qquad (7)$$

With : $F = L - NQ$

If we take:

$$\begin{cases} N = PM - FH \\ g(z, y) = Pf(\hat{\varphi}, y) = Pf(z + Qy, y) \end{cases} \qquad (8)$$

The error dynamics then becomes

$$\dot{e} = Ne + Pf(\hat{\varphi}, y) - Pf(\varphi, y) \qquad (9)$$

In order to recover the message z and s, the theorem in [9] must be verified.

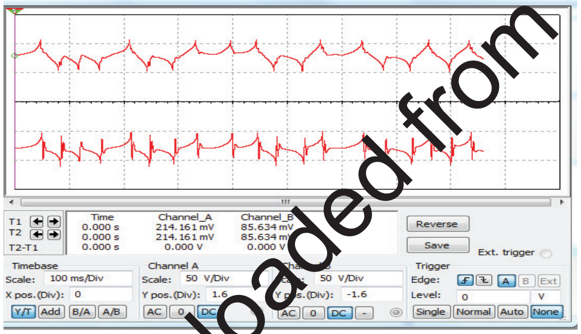
Using the LMI toolbox of Matlab 7.8, we get:

$$R = \begin{bmatrix} 0.9702 & -0.5259 & 0 & 0.0097 & -0.0356 & 0.20594 \\ -0.5259 & 0.7207 & 0 & -0.0171 & -0.0230 & 0.2683 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0.0097 & -0.0171 & 0 & 1.5076 & -0.0639 & -0.0216 \\ -0.0356 & -0.0230 & 0 & -0.0639 & 1.1754 & 0.0599 \\ 0.2594 & 0.2683 & 0 & -0.0216 & 0.0599 & 1.2457 \end{bmatrix}$$

$$F = \begin{bmatrix} 31.7937 \\ 38.2917 \\ 0 \\ 0.0860 \\ 3.1570 \\ -19.1172 \end{bmatrix}, \quad L = \begin{bmatrix} 0 \\ 30 \\ 0 \\ 0 \\ 0 \\ -30 \end{bmatrix} \text{ and}$$

$$N = \begin{bmatrix} -39.0000 & 7.2063 & 0 & 0 & 0 & -31.7937 \\ 13.5000 & -24.7917 & 0 & 0 & 0 & -8.2917 \\ 0 & 0 & -1.0000 & 0 & 0 & 0 \\ 0 & -0.0860 & 0 & -10.5000 & 0 & -0.0860 \\ 1.5000 & -3.1570 & 0 & 15.0000 & -15.0000 & -3.1570 \\ -13.5000 & 5.6172 & 0 & 0 & 0 & -10.8828 \end{bmatrix}$$

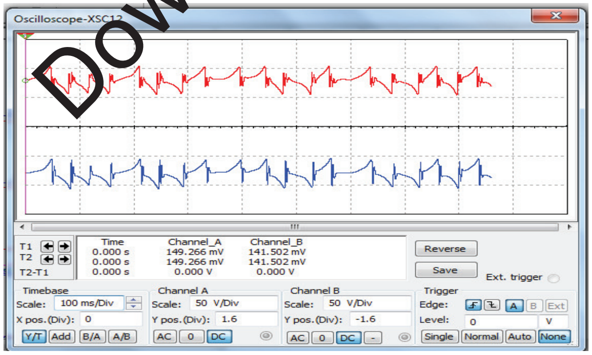
The simulation results are shown in Figures 3-8. As can be seen, the proposed observer recovers not only the five states of the system, but also, the transmitted message. Figure 9 shows the receiver circuit simulated with Ultiborad circuit.



```
Time      Channel_A   Channel_B
0.000 s   214.161 mV  85.634 mV
0.000 s   214.161 mV  85.634 mV
0.000 s   0.000 V     0.000 V
```

Timebase Scale: 100 ms/Div
X pos.(Div): 0
Channel A Scale: 50 V/Div
Y pos.(Div): 1.6
Channel B Scale: 50 V/Div
Y pos.(Div): -1.6
Trigger Level: 0 V

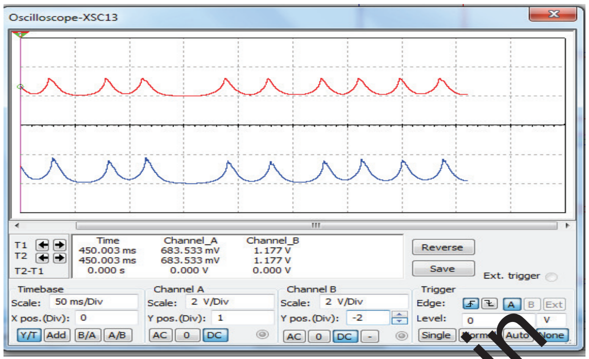
Fig. 3. x_1 and $\hat{x}_1$ simulation results with the Multisim software



```
Time      Channel_A   Channel_B
0.000 s   149.266 mV  141.502 mV
0.000 s   149.266 mV  141.502 mV
0.000 s   0.000 V     0.000 V
```

Timebase Scale: 100 ms/Div
X pos.(Div): 0
Channel A Scale: 50 V/Div
Y pos.(Div): 1.6
Channel B Scale: 50 V/Div
Y pos.(Div): -1.6
Trigger Level: 0 V

Fig. 4. x_2 and $\hat{x}_2$ simulation results with the Multisim software



```
Time        Channel_A   Channel_B
450.003 ms  683.533 mV  1.177 V
450.003 ms  683.533 mV  1.177 V
0.000 s     0.000 V     0.000 V
```

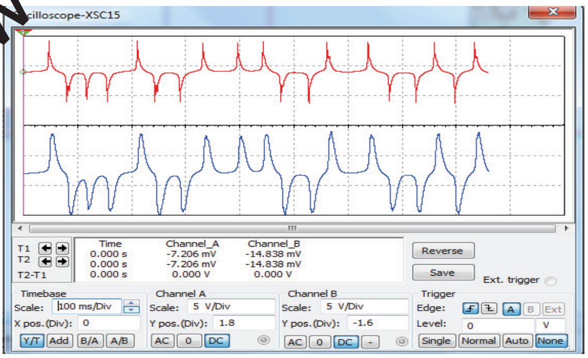
Timebase Scale: 50 ms/Div
X pos.(Div): 0
Channel A Scale: 2 V/Div
Y pos.(Div): 1
Channel B Scale: 2 V/Div
Y pos.(Div): -2
Trigger Level: 0 V

Fig. 5. x_3 and $\hat{x}_3$ simulation results with the Multisim software

```
Time        Channel_A   Channel_B
450.003 ms  1.080 V     12.405 V
450.003 ms  1.080 V     12.405 V
0.000 s     0.000 V     0.000 V
```

Timebase Scale: 50 ms/Div
Channel A Scale: 20 V/Div
Y pos.(Div): 1.6
Channel B Scale: 20 V/Div
Y pos.(Div): -1.6
Trigger Level: 0 V

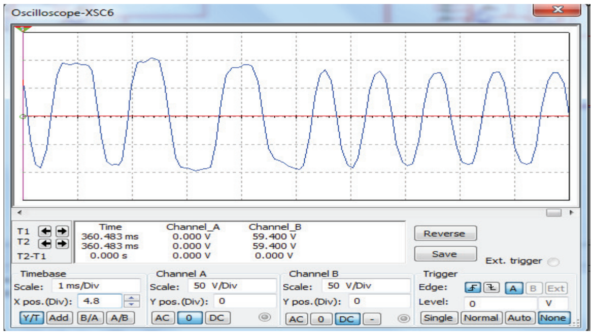
Fig. 6. x_4 and $\hat{x}_4$ simulation results with the Multisim software



```
Time      Channel_A   Channel_B
0.000 s   -7.206 mV   -14.838 mV
0.000 s   -7.206 mV   -14.838 mV
0.000 s   0.000 V     0.000 V
```

Timebase Scale: 100 ms/Div
X pos.(Div): 0
Channel A Scale: 5 V/Div
Y pos.(Div): 1.8
Channel B Scale: 5 V/Div
Y pos.(Div): -1.6
Trigger Level: 0 V

Fig. 7. x_5 and $\hat{x}_5$simulation results with the Multisim software



```
Time        Channel_A   Channel_B
360.483 ms  0.000 V     59.400 V
360.483 ms  0.000 V     59.400 V
0.000 s     0.000 V     0.000 V
```

Timebase Scale: 1 ms/Div
X pos.(Div): 4.8
Channel A Scale: 50 V/Div
Y pos.(Div): 0
Channel B Scale: 50 V/Div
Y pos.(Div): 0
Trigger Level: 0 V

Fig. 8. $\hat{S}$ simulation result with the Multisim software

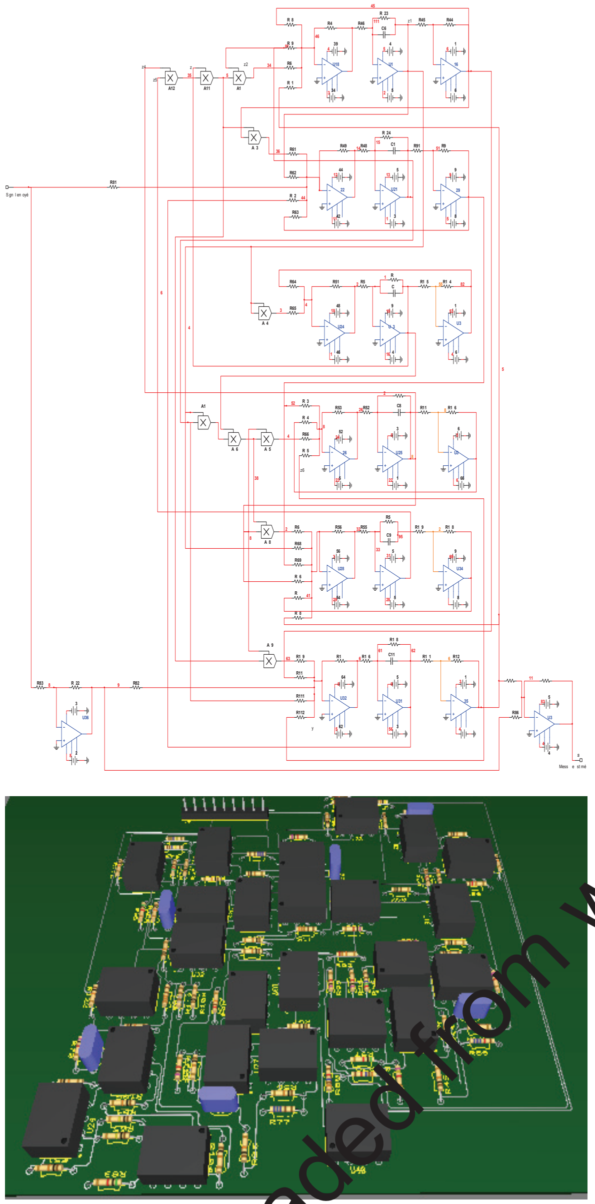


Fig. 9. Receiver circuit realization

III. CONCLUSION

In this paper, the synchronization of the 5D hyperchaotic system via the nonlinear observer and the application in secure communication are addressed. The analog circuit simulated with the Multisim software and the Ultiboard software provided has shown the effectiveness of the proposed circuit.

ACKNOWLEDGMENT

This research was supported by Algerian Scientific and Technical Information Research Center (CERIST) under the number (PNR - 12/u18/944).

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