A CHAOTIC COMMUNICATION SYSTEM USING THE ELECTRONIC BOUNCING BALL CIRCUIT

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Abstract: There has been significant interest in exploiting chaotic dynamics in communication systems. Because chaotic signals are broadband, they can be used in various communication applications. In this work, the chaotic behaviour of the electronic bouncing ball circuit is applied in a secure communication system. The synchronization process between the transmitter and receiver is achieved when two identical nonlinear are coupled. In this paper, the electronic bouncing ball circuit is proposed to implement a secure communication system based on the self-synchronization reported by Pecora and Carroll [24,25]. The error feedback synchronization [19] between two coupled chaotic systems (transmitter and receiver) is used to implement a secure communication system. The scheme proposed was simulated and the results were discussed.

Keywords: Synchronization, Chaotic Dynamics, Communication with Chaos.

1. INTRODUCTION

There has been significant interest in exploiting chaotic dynamics in communications [1-7]. Chaotic systems provide a rich mechanism for random signal generation, with potential applications to communications and signal processing. Because chaotic signals are broadband, they can be used in various communication applications [3,8-18].

In the literature there are several electronic circuits which can be used to generate chaotic signals to applications in communication systems. Some examples are the Chua’s circuit [3,19,20], the Lorenz-based chaotic circuit [8], the chaotic Rössler circuits [21] and the particle in a box electronic circuit [22]. In this work, the electronic bouncing ball circuit [23] is applied in a communication system. In this study, it was proposed an electronic bouncing ball circuit to generate the chaotic behaviour. This circuit simulates the mechanical behaviour of a bouncing ball on a vibrating surface but it has not been used in communication systems yet.

In recent years, there has been some interest in use the Pecora-Carroll synchronization and error-feedback synchronization in chaotic communication systems [19]. The use of a chaotic transmitter in a communication channel is intended for security reasons. The synchronization between the transmitter and receiver is achieved when two identical nonlinear are coupled. In this study, the electronic bouncing ball circuit is proposed to implement a secure communication system based on the self-synchronization property reported by Pecora and Carroll [24,25]. The error feedback synchronization [19] between two coupled chaotic systems (transmitter and receiver) is used to implement a secure communication system. The scheme proposed was simulated and the results were discussed.

2. THE ELECTRONIC BOUNCING BALL CIRCUIT

The scheme proposed is based in the chaotic behaviour of the electronic bouncing ball circuit of Figure 1. This circuit was proposed by Zimmerman et al. [23] and it simulates the mechanical behaviour of a bouncing ball on a vibrating surface. The key devices of the bouncing ball electronic circuit are the diode D1 and the resistor R. They electronically implement the nonlinearity of this circuit in a simple way. This circuit has as input a sinusoidal signal \( V_{TD} = A \sin(\omega t) \), and the contribution of the currents in the point S, shown in Figure 2, results in the differential equation (1).

\[
CR_2 C_2 \frac{d^2 V_{BD}}{dt^2} - I_D (-V_{BD} - V_{TD}) = \frac{V_{id}}{R_i}
\]

In (1), the signal \( V_{BD} \) corresponds to the position of the ball of the mechanical system, and the signal \( dV_{BD}/dt \) corresponds to the velocity of the ball. The component values are resistors (\( R = R_2 = 10k\Omega \), \( R_L = 510\Omega \) and \( R_i = 1M\Omega \)); capacitors (\( C = C_2 = 0.047uF \)); diode (\( D_1 \): 2N4148); operational amplifiers (741 or equivalents); \( V_{id} \) is a source DC voltage of 1.5V. The current \( I_D \) depends on signals \( V_{BD} \) and \( V_{TD} \).
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![Electronic Bouncing Ball Circuit Diagram]

**Fig. 1.** The electronic bouncing ball circuit. AO are operational amplifiers of kind 741. D1 is a diode 2N4148. Resistors (R= R2=10kΩ, R6=510Ω and R1=1MΩ). Capacitors (C=C2=0.047uF). \( V_{in} \) is a source DC voltage with 1.5V.

The periodic or chaotic behaviour can be obtained by the variation of the bifurcation parameter of the circuit of Figure 1, which controls the dynamic of the system. The parameters \( \omega \) or A of the input sinusoidal \( V_{TD} \) can be used as the bifurcation parameters. The parameter A was chosen as the parameter of bifurcation. The variation of A can cause a periodic oscillation with period T, passing by a period-doubling bifurcation, respectively with period 2T and 4T, until a nonperiodic chaotic oscillation occurs. A case of the chaotic oscillation is shown in the phase diagram (\( V_{CD} \times V_{BD} \)) of Figure 2.

![Phase Diagram]

**Fig. 2.** Phase diagram of the electronic bouncing ball circuit for the oscillating frequency \( \omega = 200 \text{ rad/s} \) and amplitude A=80mV.

3. THE CHAOTIC COMMUNICATION SYSTEM

The scheme proposed is illustrated on Figure 3. The transmitter (drive system) is implemented by the circuit of Figure 1. In this block the signal \( m(t) \) corresponds the input information signal and it is represented by \( V_{in} \) in Figure 1. The receiver is composed by the response system, the circuit of Figure 4, and a processing block which could be implemented with electronic components.

![Chaotic Communication System Diagram]

**Fig. 3.** The chaotic communication system proposed.

![Response System Circuit Diagram]

**Fig. 4.** Response system circuit of the receiver. The component values are resistors (R= R2=10kΩ, R6=4.5kΩ, R5=510Ω and R1=1MΩ); capacitors (C=C2=0.047uF); diode (D1: 2N4148); operational amplifiers (741 or equivalents); \( V_{in} \) is a source DC voltage of 1.5V. The current \( I_D \) depends on signals \( V_{BD} \) and \( V_{TD} \).

The input information \( m(t) \) is a data stream. The signal \( V_{CD} \) of the transmitter system is sent to the receiver system. The transmission channel is ideal. The signals \( V_{TD} \) and \( V_{TR} \) are not in phase because the drive and response systems are not coupled. The error feedback synchronization technique [19] is applied to get the generalized synchronization between the transmitter (drive) and receiver (response) systems. The signals \( V_{BR} \) and \( V_{CR} \) are estimated in the receiver and they are used by a processing block to recover the information \( \hat{m}(t) \). The processing block is described by equation (2) and it can be implemented by operational
amplifiers using the signal $V_{BR}$ estimated in the response system.

$$\hat{m}(t) = R_iC_RC_i\frac{d^2V_{BR}}{dt^2} - R_iI_D(-V_{BR} - V_{TR}) \tag{2}$$

4. SIMULATION RESULTS ABOUT THE CHAOTIC COMMUNICATION SYSTEM

The system of Figure 2 was simulated using a computational Euler numerical method with trapezoidal rule. The information signal $m(t)$ was chosen like a digital data stream with three discrete levels. The signal $V_{CD}$ of the transmitter was sent to the receiver. After the chaotic synchronization between drive and response systems, the signals $V_{BR}$ and $V_{CR}$ are estimated in the receiver. These signals were used to recover the input information $\hat{m}(t)$.

The signals generated in computational simulations are illustrated on Figure 5.

The synchronization between transmitter and receiver systems occur when the resistor $R_A$ has a specific value ($R_A = 4.5k\Omega$). In this situation the drive and the response systems are coupled as illustrated on figure 5. The signals of the response system ($V_{CR}$ and $V_{BR}$) are synchronized with the signals of the drive system ($V_{CD}$ and $V_{BD}$). The recovered signal $\hat{m}(t)$ looks like with the input information $m(t)$. The quality of the signal $\hat{m}(t)$ can be better with a filtering process.

5. CONCLUSION

In this work, it is proposed the application of the electronic bouncing ball circuit in a communication system. The signal sent through the transmission channel is a chaotic signal. It is a broadband signal without correlation with the input information signal. The transmitter and the receiver systems were coupled in the communication process using the error feedback synchronization. According to simulations the scheme proposed could be used in security communication systems.

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REFERENCES


