Secure optoelectronic communication using laser diode driving by chaotic Rössler oscillators

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Abstract: Secure optical communication has been realized with two semiconductor lasers driven by two chaotic Rössler oscillators. The communication system contains two channels: optical and electronic; the information is transmitted through an optical fiber, while the Rössler oscillators are synchronized via electronic channel. One of the outputs of the Rössler oscillators serves for modulating the laser pump current, and another for coupling the oscillators. The results of numerical simulations are in good agreement with experiments which demonstrate that the system is viable.

1. Introduction

The secure transmission of information is an important matter for institutions that hide confidential information, such as banks and the government. For this reason they require communications systems which allow them to transmit information at high speeds in a secure matter. With optical communications system based on chaotic carriers, this necessity can be solved by taking advantage of the existing fiber optics technology. Today the potential of chaos theory is recognized in the worldwide with research groups actively working on this topic [1].

The chaos communication fundament is the synchronization of two chaotic systems under suitable conditions if one of the circuits is driven by another in this case the first. Since Pecora and Carrol discover that chaotic systems can be synchronized, the synchronization topic of the couple chaotic circuits and systems has been investigate intensively and some interesting application such as broadband communications systems have come out of these researches [2,3].

In this work we describe a scheme for secure communication based on two semiconductor lasers driven by two chaotic Rössler oscillators. To avoid the increase of error synchronization when the message is added, a two channel communication system is used, optical and electronic. This system consists in a transmitter and a receiver, each one containing a master and a slave Rössler oscillators.
and laser. We present experimental and numerical results for two schemes of communication system; chaotic masking and shift keying.

This paper is organized as follows. In Sec. 2 experimental setup, we describe a novel scheme for chaos secure communication that contains two channels: optical and electronic; the information is transmitted through an optical fiber, while the Rössler oscillators are synchronized via electronic channel. To encrypt information we use two schemes, chaotic masking and chaos shift keying. In Sec. 3 we show the mathematical model. In Sec. 4 we demonstrate the numerical and experimental results. Finally, the main conclusions are given in Sec. 5.

2. Experimental setup

Our scheme includes a transmitter and a receiver, where each one of them contains a Rössler oscillator electronic circuit, shown in figure 1, and a diode laser [4]. Our method consists of two channels, one to synchronize the Rössler circuits and the other one to transmit the information via the laser diode [5]. Through the first channel, the “y” component of the Rössler in the transmitter is send to the Rössler electronic circuit of the receiver, this way we can have synchronization between the two circuits. Once the two Rösslers are synchronized, the “x” components of the Rösslers are added to the pump current of the laser diodes. Since the Oscillation frequency of the Rössler system (1.3 kHz) is much smaller than the relaxation frequency of the laser (in the order of GHz), the output laser intensity will follow the same behaviour of the “x” output of the Rössler circuit. Then through the second channel, the laser output of the transmitter is sent to the receiver.

To send information we use two schemes, chaotic masking and shift keying. Through chaotic masking, the message is added to the output of the laser in the transmitter, as shown in figure 2 (a). On the other hand the shift keying method consists in adding the message to the pump current of laser diode in the transmitter, as shown in figure 2 (b).
3. Mathematical model

The Rössler electronic circuit are describe by the following dimensionless equations [6]:

\[
\begin{align*}
\dot{x}_t &= -\lambda x_t - \beta y_t - z_t \\
\dot{y}_t &= x_t + \gamma y_t \\
\dot{z}_t &= g(x_t) - z_t \\
\dot{x}_r &= -\lambda x_r - \beta[ y_r + \varepsilon(y_t - y_r)] - z_r \\
\dot{y}_r &= x_r + \gamma[ y_r + \varepsilon(y_t - y_r)] \\
\dot{z}_r &= g(x_r) - z_r \\
g(x_t, x_r) &= \begin{cases} 
0, & x_t, x_r \leq 3 \\
\mu(x_t, x_r - 3), & x_t, x_r > 3
\end{cases}
\end{align*}
\]

where \( t, r \) stand for transmitter and receiver, the parameter of Rössler equations are \( \tau = t \times 10^4 \text{ s} \) (\( t \) being the real time), \( \lambda = 0.05 \), \( \beta = 0.5 \), \( \mu = 15 \), \( \gamma = \frac{R_3 - R_0}{R + R_3} = 0.02 \), where \( R_0 = R_3 = 10 \text{ K\Omega} \) and \( R = 50 \text{ K\Omega} \), and \( \varepsilon = 1 \) is the coupling strength between the circuits. Figure 3 shows the experimental and theoretical Rössler chaotic.
To model the semiconductor lasers we use the following equations [7, 8]:

\[
\frac{dE_{t,r}(t)}{dt} = \left(1 + i\alpha \right) \left(\frac{g(N_{t,r}(t) - N_0)}{1 + s|E_{t,r}(t)|^2} - \frac{1}{\tau_p} \right) \frac{E_{t,r}(t)}{2} + \sqrt{2\chi N_{t,r}(t)} \xi(t)
\]

\[
\frac{dN_{t,r}(t)}{dt} = \frac{I_{t,r}}{e} - \frac{1}{\tau_n} N_{t,r}(t) - \left(\frac{g(N_{t,r}(t) - N_0)}{1 + s|E_{t,r}(t)|^2} \right) |E_{t,r}(t)|^2
\]

where \(E_{t,r}(t)\) is the complex amplitude of the electric field and \(|E_{t,r}(t)|^2\) is the laser intensity, \(N_{t,r}(t)\) is the average number of carriers, \(\xi(t)\) being a Gaussian noise of zero mean and unity intensity is used to model the spontaneous emission process. Typical values used for the parameters of these two equations are shown in table 1.

### Table 1. Parameter values for rate equation

| Parameter | Value | Means |
|-----------|-------|-------|
| \(g\)     | 1.5*10^8 ps\(^{-1}\) | laser gain |
| \(N_0\)   | 1.5 * 10^8 | carrier number at transparency |
| \(\tau_p\) | 2 ps | photon lifetime |
| \(\tau_n\) | 2 ns | carrier lifetime |
| \(I_{t,r}\) | 35 + \(x_{t,r}(t)\) mA | pumping term |
| \(\alpha\) | 3 | linewidth |
| \(\chi = \frac{1}{\alpha} \frac{\sigma^2}{2\tau_n}\) | 1.1 x 10^6 ns\(^{-1}\) | spontaneous emission rate |

In the case of chaotic masking, the message is transmitted as \(|E_{t,r}(t)|^2 + m(t)\) and for shift keying \(I_{t,r} = 35 + x_{t,r}(t) + m(t)\) mA.
4. Results

In the figure 4 show experimental and numerical results for the chaotic masking scheme, where the bottom time series is for the laser in the receiver, the middle time series is for the laser in the transmitter and the top trace is the recovered message. On the other hand figure 5 show experimental and numerical results for the shift keying method. The order of the time series are the same as in figures 4. In this case we are transmitting at 2.6 kB/s. A way to measure the difference between both messages, or, in other word, the synchronization error, is through the Hamming Distance defined as [9]:

$$\rho(x, y) = \frac{1}{n} \sum_{i=1}^{n} (x_i \oplus y_i)$$

where $x$ and $y$ are the two sequences to be compared, $n$ the number of bits in both sequences, and $\oplus$ is the XOR binary bitwise operator. This measure is used to assess the sensitivity of the communication channel and the bits lose. Experimental recovery of the transmitted message for chaotic masking and shift keying using the hamming distance are showed in the figure 6.

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**Figure 4.** Message recovery for chaotic masking (a) Experimental (b) Numerical
Figure 5. Message recovery for shift keying. (a) Experimental. (b) Numerical.

Figure 6. Experimental recovery of the transmitted message using the hamming distance. (a) Chaotic masking. (b) Shift keying.

5. Conclusions

We have showed a new scheme of two channel communications where the first channel uses electronic circuits to synchronize the transmitter with the receiver, and the second channel is optical which is used to send the information. Both, the experimental and theoretical results show a good agreement.

We believe quite feasible the implementation of these encryption schemes, because these results are obtained using an experimental model, which is uncontrolled environment, ie temperature and electromagnetic radiation are some of the variables that directly affect electronic assembly, in addition to that, we use electronic components with a tolerance of 10%, taking into account the above considerations is notable achieve a 5% loss of the message conveyed, should be mentioned that to retrieve the message does not use any special technique for the reconstruction of message, only filter out the noise inherent in the system, and the answers differ χ₂ and χ₃ of the transmitter and receiver respectively.
Finally we demonstrate the difference between the two encryption methods, resulting in the
best encryption technique is shift keying, because it needs an amplitude modulation of 20% to recover
the message, while that chaotic masking modulation must be greater than 50%.

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