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The simulation of sound signal masking with different chaotic oscillations and its circuit application

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Abstract: The chaotic masking process on sound signals using the systems of Lorenz, Rössler, Sprott, Chen, and Arneodo chaotic oscillations are simulated with MATLAB/Simulink. The PID control method providing synchronization in the system is defined and the mean square errors between the times to reach synchronization and the input-output sound signals are compared for the system performance. The Sprott chaotic system is found to be the best synchronized system. Therefore, the application circuits are designed with respect to the Sprott chaotic system and its results are investigated in this study. It is seen that the system marked with the Sprott chaotic oscillator has a shorter time with respect to the time reaching synchronization, while the Lorenz chaotic oscillator gives a smaller mean square error.

Key words: Chaotic masking, synchronization, PID, chaotic oscillator

1. Introduction

In recent years, chaos has played an important role in scientific studies [1,2]. Chaos communication systems are applied to many engineering fields such as chemical reactions, power transmissions, and biological systems [1,3,4]. Scientifically, constructing, controlling, and synchronizing chaos have mostly been studied [5,6].

The studies on chaotic systems have gained speed with the works by Edward Lorenz in modeling air flow in atmosphere and followed by new chaotic systems such as Rössler, Arneodo, Chua, Chen, and Sprott [7–11].

The synchronization of two different chaotic systems was firstly fulfilled by Pecora and Carrol [12] and then it was applied to confident communication systems. In the studies on synchronization of chaotic systems, the synchronization is demanded to be robust and the setting time to synchronization to be much shorter. Different methods such as an adaptive fuzzy-wavelet artificial neural network [13] and proportional–integral–derivative (PID) method [14,15] have been used for synchronization.

In the literature, the Lorenz, Rössler, Sprott, Chen, and Arneodo chaotic systems are introduced, and how to make chaotic masking and the PID control method used for synchronization are explained.

The aim of this paper is to compare the different chaotic systems with different performance criteria. In this study, a simulation of masking on sample sound signals using certain different chaotic oscillators is performed with MATLAB/Simulink. In the simulations, the performances of chaotic systems are compared according to the setting time to synchronization and the mean square errors between the input–output sound signals. The quality of synchronization is calculated and an application circuit with the fastest synchronization

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time is designed using the Sprott chaotic system. Finally, the results of this application circuit are compared with the simulation results.

2. Simulation of signals using chaotic systems

In this study, the masking process on sound signals using different chaotic oscillators (Lorenz, Rössler, Sprott, Chen and Arneodo [7–11]) is simulated with MATLAB/Simulink. In the simulations, the process of masking is done with five different chaotic oscillators and the same type of two different oscillators with different initial conditions and parameter values are used for removing the mask. In the meanwhile, a PID controller is used to synchronize the two chaotic oscillators. PID coefficients used in this study are defined by using the Ziegler–Nichols and response surface based optimization methods [16]. Masking of the sound signals with the chaotic oscillator and the removal of the mask are given in Figure 1.

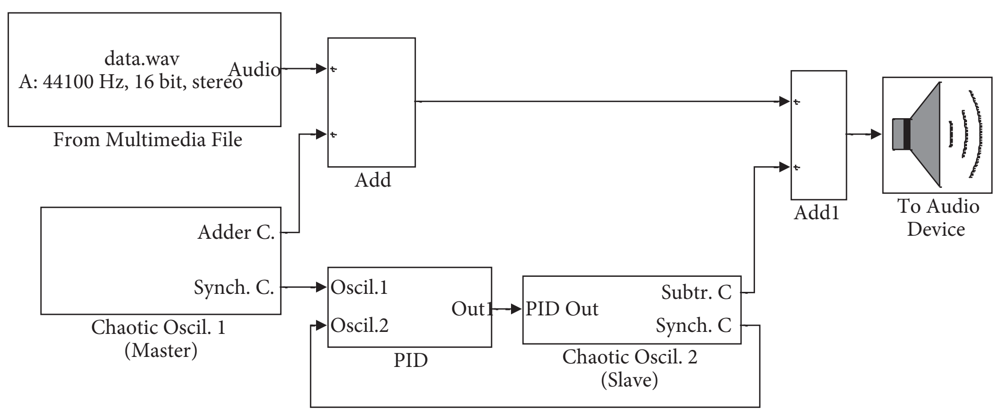

Figure 1. Masking of the sound signals with the chaotic oscillator and the removal of the mask.

Taking into consideration that the simulation results can show some changes depending on the initial conditions, different trails are also made, changing the initial conditions of the added and subtracted chaotic oscillations. After masking the initial conditions, the trails are made taking a reference as the signal in the transmission medium being incomprehensible.

Masking of the sound signal with the Sprott chaotic oscillator and regeneration process are shown in Figure 2.

3. Design of application circuit

The quality of synchronization is calculated and an application circuit with the fastest synchronization time is designed using the Sprott chaotic system using the selected initial conditions according to the results of simulations. The designed circuit is composed of three different circuits (transmitter, controller, and receiver circuits). In the application process, auxiliary circuits such as accumulative, subtractive, and amplifier are also designed and installed.

3.1. Transmitter circuit

The electronic application circuit chart of a set of differential equations belonging to the Sprott chaotic oscillator is given in Figure 3.

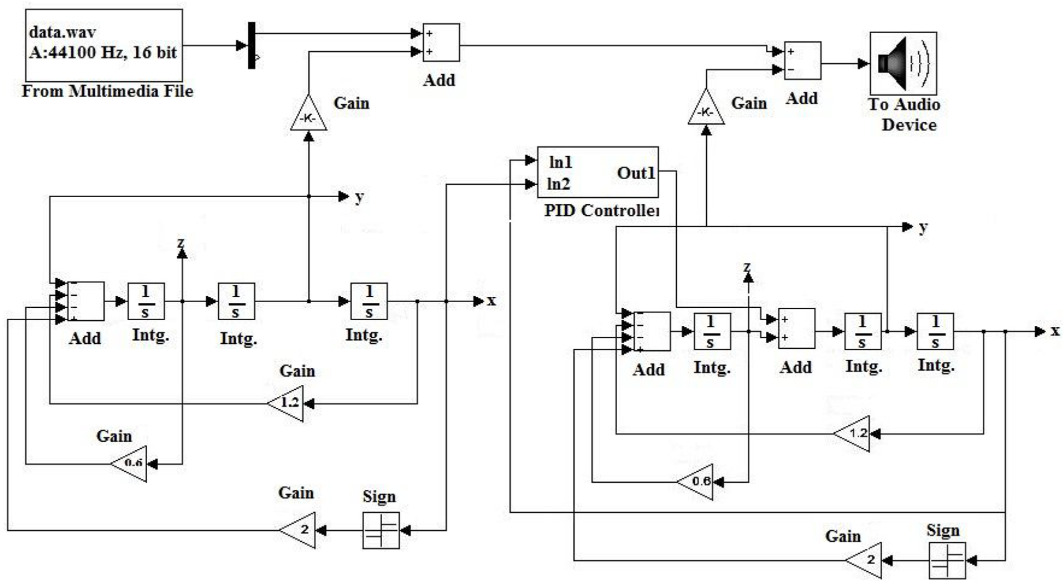

Figure 2. Masking of the sound signal with the Sprott chaotic oscillator and the regeneration process.

In the circuit given in Figure 3, chaotic signals are generated on three channels using the X, Y, and Z values of differential equations defined in the Sprott chaotic system. The integral, amplifier, accumulative, and subtractive circuits involved in equation sets are executed with TL 084 operational amplifier devices. Moreover, two diodes connected with reverse polarity to each other are used to supply the signum function.

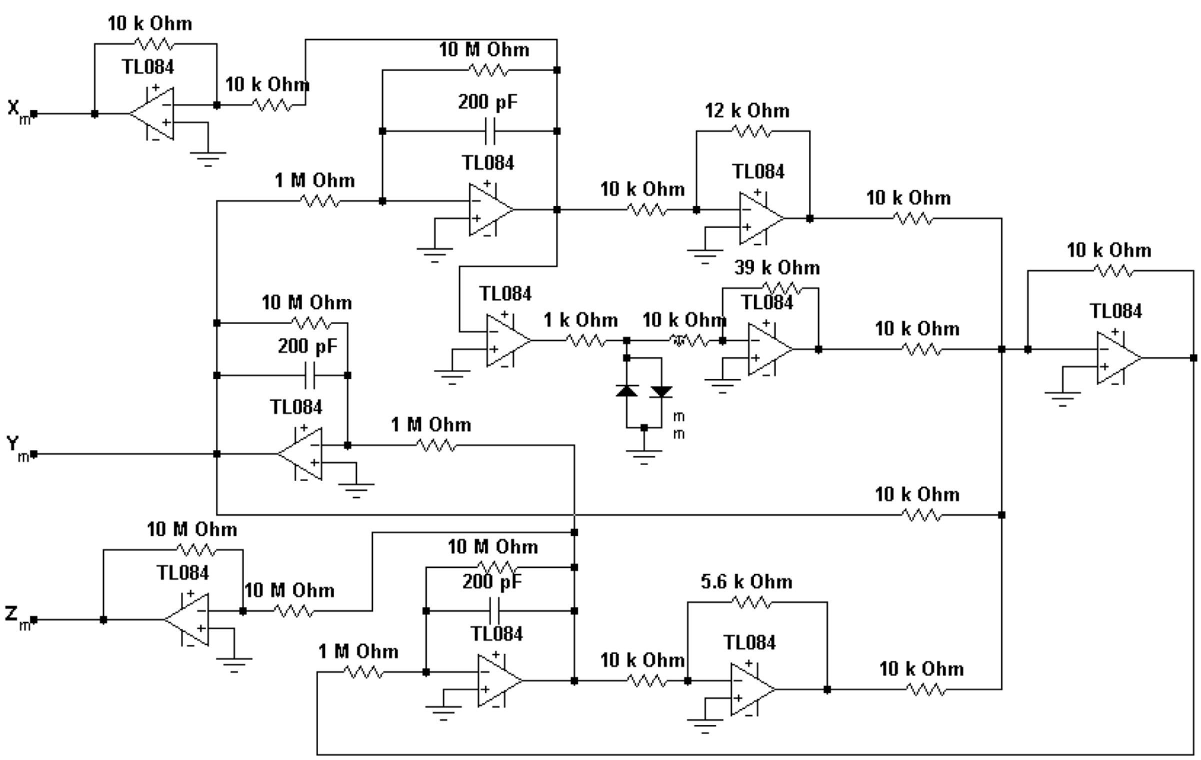

Figure 3. Electronic circuit design according to the Sprott chaotic oscillator.

The resolution of the sound signal in transmission medium is prevented by adding the X channel generated by the oscillator in circuits installed to the sound signals. The circuit chart for adding a chaotic sign to the sound signal is given in Figure 4.

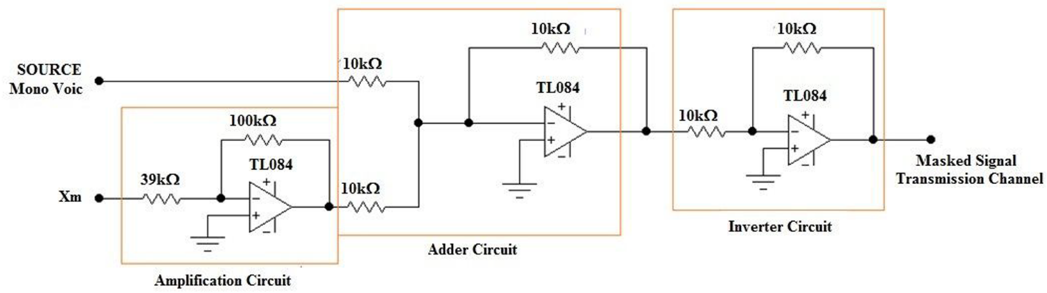

Figure 4. The circuit chart for adding a chaotic sign to the sound signal.

New amplifier circuits executed by operational amplifiers amplifying the sign on the X channel are installed to attenuate the dominance from the amplitude of the sound signal. In the application circuit the chaotic sign added is increased approximately 2.5 times.

3.2. PID controller circuit

The signal generated by the PID circuit, using Y or Z channels, is applied to the second channel of the master circuit. The difference between the channels driven to the PID is decreasingly applied to the second channel of the master circuit at each time. After a while, the difference converges to zero and the two oscillators start to generate the same chaotic signals. The PID circuit chart and application circuit are given in Figures 5 and 6, respectively.

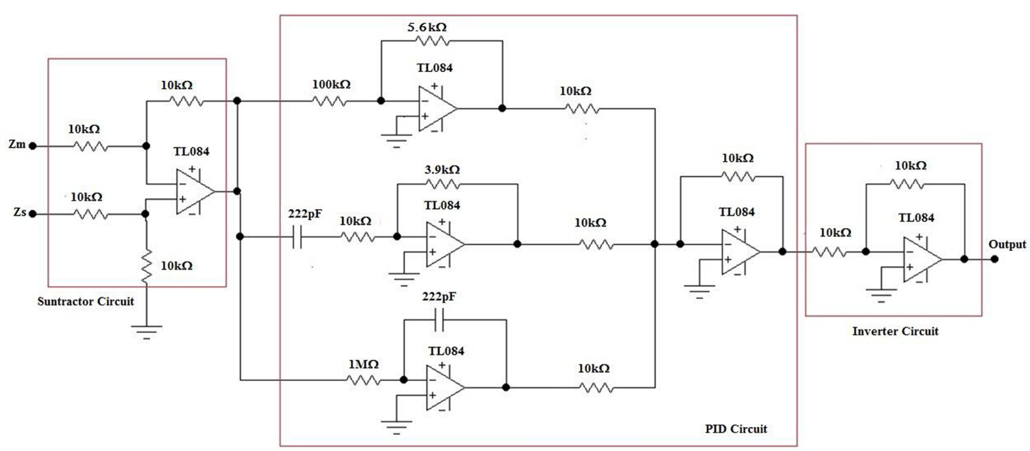

Figure 5. PID circuit chart.

3.3. Receiver circuit

The receiver circuit regenerates the chaotic signals in transmission medium and the masked sound signal. This regeneration process is fulfilled by subtracting the sign on the transmission channel from the chaotic sign generated by the master chaotic oscillator. Therefore, a second chaotic circuit called a slave chaotic oscillator circuit has to be installed and it is necessary to subtract the same channel added to the sound signal on the side of the receiver from the sign on the transmission channel. Even though the same materials are used, there are many factors affecting the features of chaotic circuits. The effects of these factors together with the same channels of master and slave chaotic circuits will never generate signals with the same characteristics. In application, generating the same signals with the master and slave chaotic circuits can be synchronized with the aid of controllers. The set of differential equations belonging to the slave circuit is given as follows:

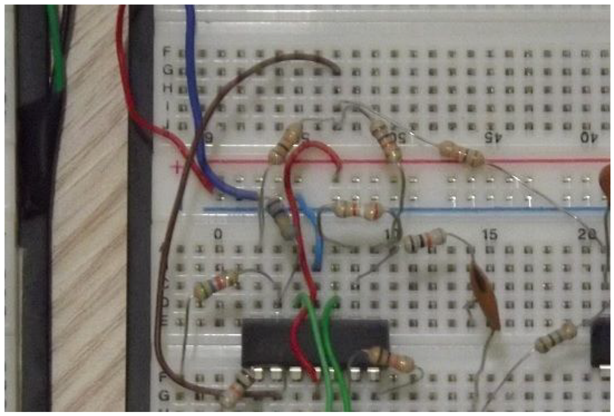

Figure 6. PID application circuit.

$$\begin{aligned} \frac{dX_s}{dt} &= Y_s \\ \frac{dY_s}{dt} &= Z_s + y\,(t) \\ \frac{dZ_s}{dt} &= -1,2X_s - Y_s - 0,6Z_s + 2sign\,(X_s) \end{aligned} \tag{1}$$

The mathematical expression of the slave chaotic oscillator shows great similarity with that of the master circuit. The only difference between the two expressions is the y(t) parameter added to the Y channel. This parameter is a signal on the output of the PID and has a tendency to decrease in the time domain until the two oscillators reach synchronization and then goes down to a level accepted as zero. The mathematical expression of the PID can be written as follows:

$$\begin{aligned} y(t) \quad = \quad & K_p\,[Z_m\,(t) - Z_m\,(t)] + K_i \int [Z_m\,(t) - Z_m\,(t)]\,dt \\ & + K_d \frac{d\,[Z_m\,(t) - Z_m\,(t)]}{dt} \end{aligned} \tag{2}$$

The mathematical expression of the slave circuit is then determined by substituting Eq. (2) into Eq. (1).

The slave chaotic oscillator chart and slave chaotic oscillator circuit used in the application are given in Figures 7 and 8.

4. Results and discussion

4.1. Simulation of chaotic system

The simulation for masking of the sound signal with the chaotic oscillator and removing of the mask are shown in Figure 1. The performances of the systems simulated are analyzed and the performances of the chaotic systems are investigated by looking at the duration for reaching synchronization and the mean square error (MSE). In this study, the real data are the sound signal applied to the input, while the predicted data are the signal obtained at the output. The formula for MSE is given as follows [17]:

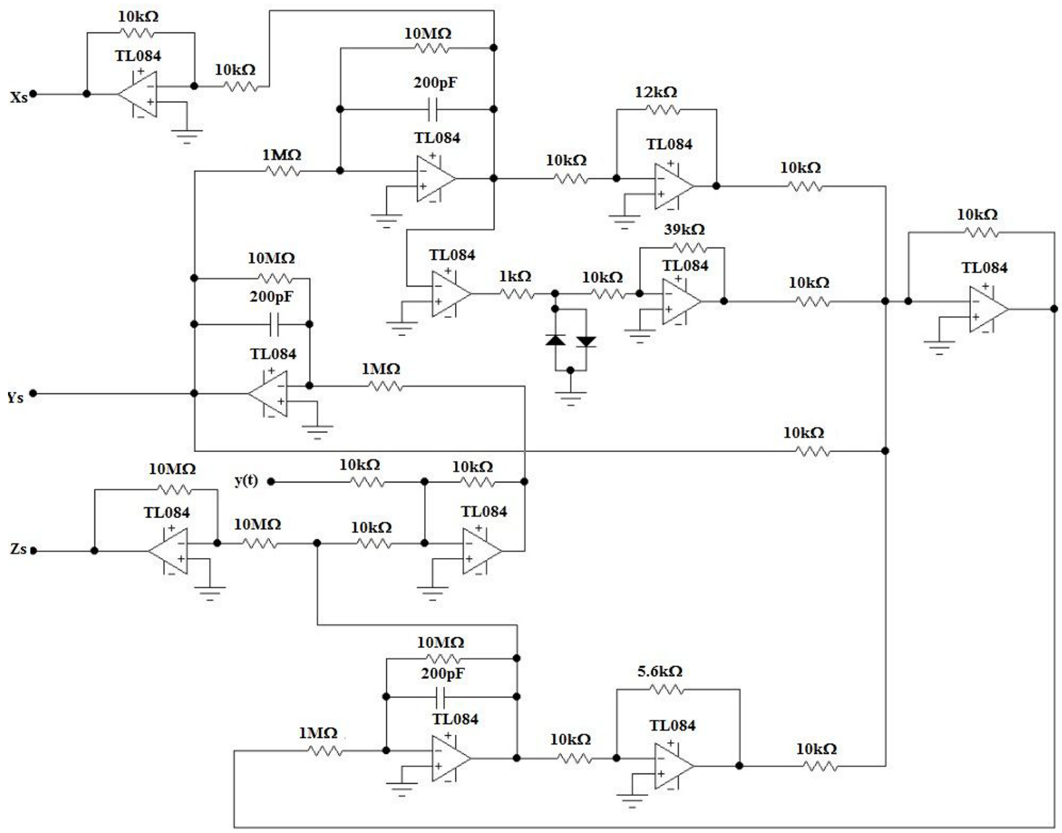

Figure 7. Slave chaotic oscillator chart.

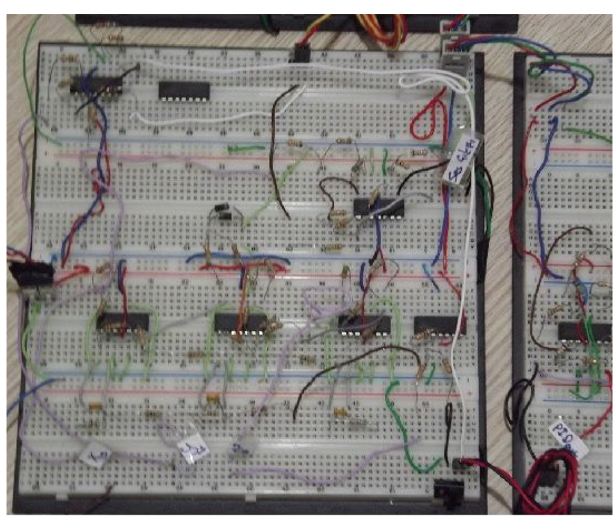

Figure 8. Slave chaotic oscillator circuit application.

$$MSE = = \frac{1}{N} \sum_{i=1}^{N} \left(S(t_i) - \hat{S}(t_i)\right)^2, \tag{3}$$

where $S(t_i)$ and $\hat{S}\,(t_i)$ are the input and regenerate output sound signals, whereas N is the sample number.

Masking of sound signals of the chaotic oscillators and the durations to reach synchronization for regenerating them are given in Figure 9. As seen in Figure 9, according to the simulation results, the system masked with the Sprott chaotic oscillator reaches synchronization at the shortest time of 0.5 s.

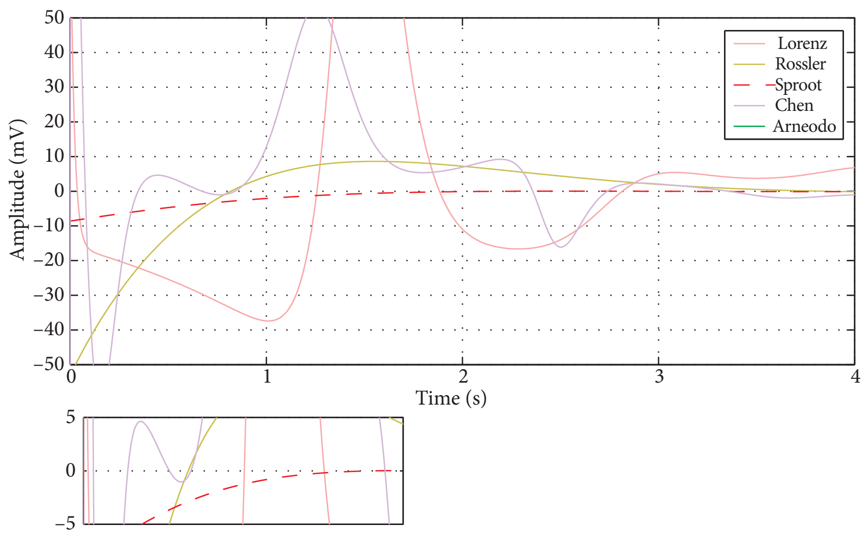

Figure 9. The durations to reach synchronization.

The second performance criterion, which is the MSE between the input and regenerate output signal of the chaotic systems, is calculated using Eq. (3) and the results are shown in the Table. According to the results, the lowest error is found in the Lorenz system.

Table. The mean square error (MSE) between the input and output signal of chaotic systems.

Chaotic Systems	MSE
Lorenz Systemic	7.0037e-006
Rössler Systemic	2.0231e-004
Sprott Systemic	4.2513e-005
Chen Systemic	1.0869e-005

For the Sprott system, the simulation is executed and physical circuit is installed and then the data obtained are analyzed. In the first step, the master and slave circuits are run independently without synchronizing. In the simulation, when the master and slave chaotic oscillators are run without synchronizing, the signals (Xm and Xs) on the X channel added to the sound signal are shown in Figure 10.

In the second step of the simulations and applications, running of the master and slave circuits is supplied in a synchronized way and it is observed visually and auditorily.

For the system simulated, activating the PID controller and reaching synchronization of the master and slave circuits are shown in Figure 11.

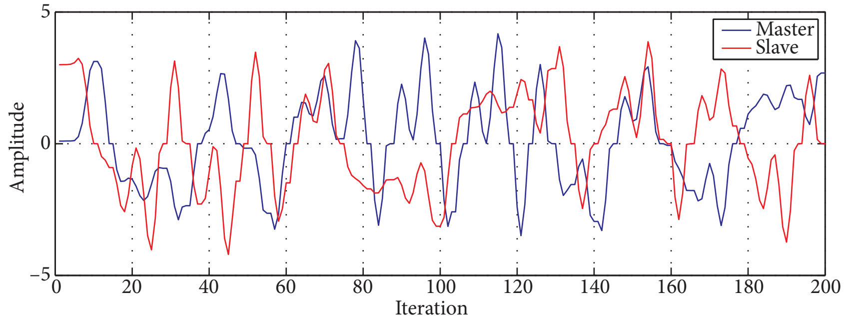

Figure 10. The simulation results before synchronization.

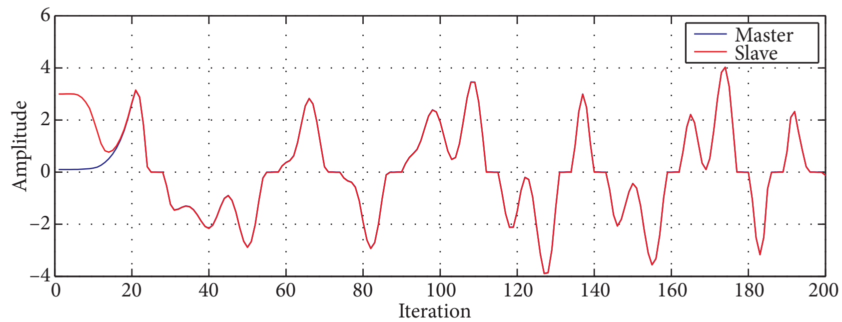

Figure 11. The simulation results after synchronization.

4.2. Result of application circuit

Both in the simulation and physical application circuit, synchronization of the transmitter and receiver circuits is successfully fulfilled and the operating status of the system is found to be successful.

The signals (Xm and Xs) on the X channel added to the sound signals in the application circuit are shown in Figure 12 when the master and slave chaotic oscillators for the application circuits are run without synchronizing. The oscilloscope outputs of the signals of two chaotic circuits after activating the PID are shown in Figure 13.

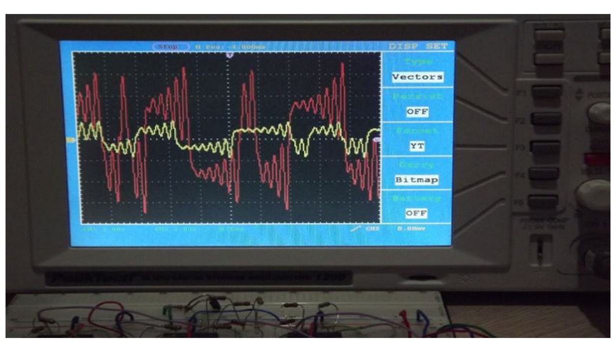

Figure 12. The application results for physical circuit before synchronization.

Regeneration of the sample masked sound signal in the transmission environment using the Sprott chaotic oscillator is shown in Figure 14.

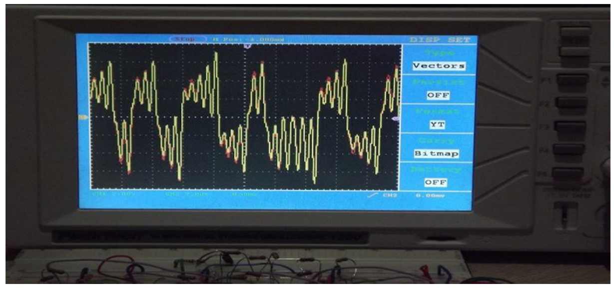

Figure 13. The application results for physical circuit after synchronization.

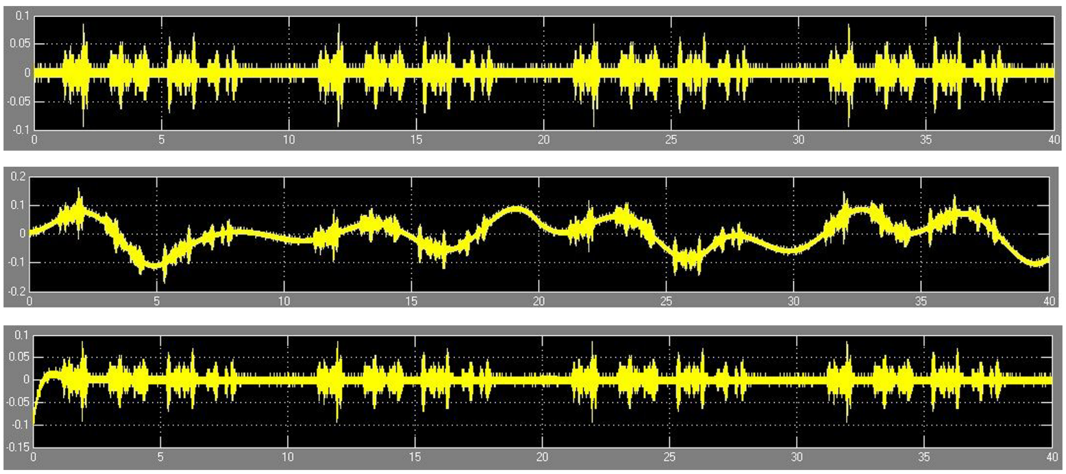

Figure 14. Regeneration of a sample masked sound signal using Sprott chaotic system; A sound signal as a sample input (a), masked signal in the transmission environment (b), and regenerated signal after removing of the mask (c).

5. Conclusion

The sound signals in the simulation and application have been affected by many factors from the selected chaotic system used in transmitting them to the control method.

The performances of the systems simulated are analyzed and the performances of the chaotic systems are investigated by looking at the duration for reaching synchronization and the MSE between the input and output signals. According to the simulation results, the system masked with the Sprott chaotic oscillator reaches synchronization at the shortest time of 0.5 s. According to the second performance criterion, which is the MSE between the input and output signal of chaotic systems, the lowest error is found in the Lorenz system.

The X channel of the physical master and slave Sprott chaotic oscillator circuits are synchronized as determined in the simulation time just after being used by the controller unit. Therefore, the original sound signal, masked signal and the output signal of the system in the application circuit are synchronized at the same synchronization time determined in the simulations. In the application of the chaotic system, a signal similar to the original signal is determined after synchronization.

The simulations and applications for masking of sound signal with the Sprott chaotic oscillator have demonstrated highly successful results in terms of the time of reaching synchronization and also supplying communication with higher performance.

The determination of dynamics of chaotic systems, optimization of control methods used giving faster synchronization, or developing new control methods can be some future works on masking of chaotic systems. Additionally, reduction of losses in the transmission of data is another important subject in this area.

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