LETTER

BER Estimation of a Chaos Communication System including Modulation-Demodulation Circuits

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SUMMARY In this study, a simple chaos communication system including modulation-demodulation circuits is studied. The influence of modulation-demodulation circuits to chaos synchronization is investigated. For the estimation of communication quality, bit error rate (BER) is calculated by computer simulation when a sequential random pulse information signal is transmitted via this proposed system.
key words: *chaos, chaos synchronization, AM, communication, BER*

1. Introduction

Since a chaos synchronization phenomenon in a coupled chaotic system is reported by Pecora and Carroll [1], a variety of behavior concerned with chaos synchronization phenomena on various coupled systems has been studied. Especially chaos communication systems exploiting the feature attract many researchers' attentions as one of engineering applications. Although a variety of studies on chaos communication systems has been reported [2]–[4], we consider some problems are remained. In many chaos communication systems, chaos synchronization plays an important role [5] and the accuracy of the synchronization directly influences on communication quality. Therefore, it is important to research the effect of noise or nonlinearity of communication channel including transmission terminal. On the other hand, in order to transmit chaotic signals by radio frequency, it is necessary to modulate baseband chaotic signal to radio frequency. It is generally known that real modulation and demodulation circuits have a bad influence on the quality of communication. However, influence of modulation and demodulation circuits in communication systems using chaos synchronization has not been discussed until now.

In this study, we investigate a chaos communication system including modulation and demodulation circuits. Two chaotic systems are connected by the modulation-demodulation circuits. We use a simple chaotic masking communication system using Chua's circuits [6]. Information signals are modulated by an amplitude modulation (AM) circuit. The radio-band modulated signal is demodulated at the receiver side. We confirm that those nonlinear systems influence to the chaos synchronization by numerical simulation. In order to estimate communication quality, BER for several conditions (e.g. carrier frequency and bit rate are tuned) are obtained by computer simulation. The obtained results indicate adverse influence to the communication quality of the chaos communication system.

2. Circuit Model

In this study, we use a chaotic masking method for transmission of signals, which is the simplest chaos communication system using chaos synchronization based on Pecora-Carroll concept, and we adopt an AM system for the modulation-demodulation. Figure 1 shows a concept of a chaos communication system using a chaotic masking method. Figure 2(a) and (b) show a Chua's circuit for generating an original chaotic source, and its characterized piecewise-linear resister, respectively. We know that Chua's circuit has two types of chaotic attractors, two of them are called as single-spiral and double-scroll chaotic attractors, respectively. Hereafter the circuit parameters of Chua's circuit in numerical simulation are given as

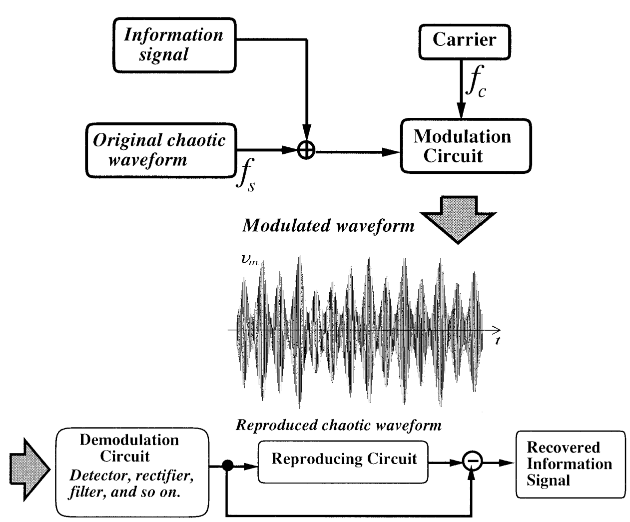

Fig. 1 Concept of a chaos communication system.

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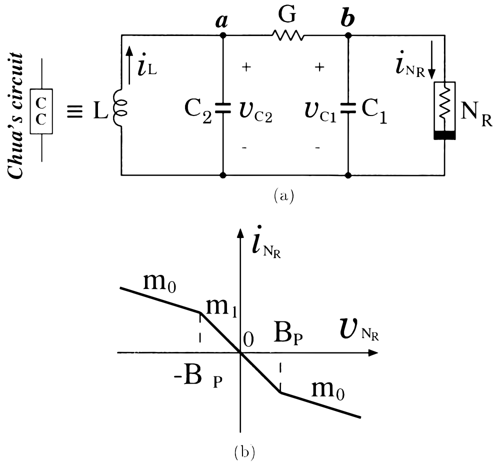

Fig. 2 (a) Chua's circuit and (b) characterized Chua's diode.

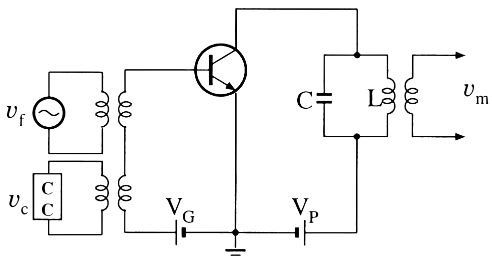

Fig. 3 AM modulation system.

- **Setting of Chua's circuit for single-spiral chaotic attractor**

C_1 = 5.56[nF], C_2 = 50[nF], L = 7.14[mH], G = 1/R = 0.7[mS], m_0 = 0.241[mS], m_1 = 0.807[mS], and B_p = 1.0[V].

- **Setting of Chua's circuit for double-scroll chaotic attractor**

C_1 = 5.0[nF], C_2 = 50[nF], L = 7.14[mH], G = 1/R = 0.75[mS], m_0 = 0.241[mS], m_1 = 0.807[mS], and B_p = 1.0[V].

We can also calculate the natural frequency of the circuit as around 8.4[kHz] from the value of C_2 and L in Chua's circuit.

The modulation circuit is shown in Fig. 3. It is a typical amplitude modulation system which consists of a transistor and some circuit elements. We model the transistor by the Ebers-Moll model for numerical simulation. In this study, we use a chaotic signal obtained from the terminal of **b** in Fig. 2(a) for obtaining the attainment of chaos synchronization easily. The demodulation circuit is constructed by a rectifier, an RC filter and several circuits as shown in Fig. 4. Further, two subsystems based on Chua's circuit are interconnected by voltage buffers to reproduce the original chaotic signal as shown in Fig. 5.

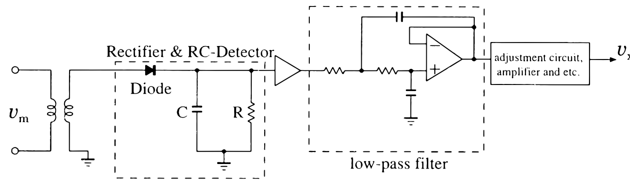

Fig. 4 Demodulation system.

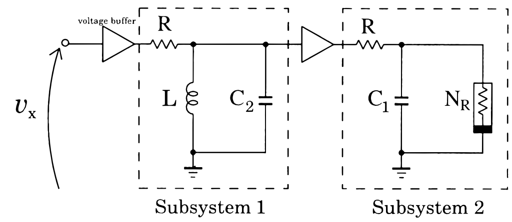

Fig. 5 Reproducing circuit based on Chua's circuit.

3. Influence to Chaos Synchronization

At first, we consider the case that the only chaotic signal obtained from Chua's circuit is modulated. Please notice that the transmitted signal does not include general information signals. Only chaotic signal is modulated by the amplitude modulation circuit in Fig. 3, then the modulated signal is transmitted to the receiver side. We compare the transmitted chaotic signal with the reproduced chaotic signal. Figures 6 and 7 are computer simulated results in the cases of single-spiral and double-scroll chaotic attractors, respectively. (a-1) shows an original chaotic attractor obtained from Chua's circuit of the transmitter side, (a-2) synchronization state between a demodulated chaotic signal and a reproduced chaotic signal, (a-3) the reproduced chaotic attractor at the receiver side, (b) the original chaotic waveform, (c) the modulated chaotic waveform, (d) the demodulated chaotic waveform, and (e) the reproduced chaotic waveform at the receiver side. We can see that the recver cannot reproduce the original chaotic signal completely, especially for the case of double-scroll attractor. Because it was known that Chua's circuit can achieve chaos synchronization completely without any noise, the synchronization error is due to the modulation-demodulation circuits. Chaos synchronization of Chua's circuit is described in [7].

4. Estimation of Communication Quality

4.1 Simulation on Transmission of Information

Hereafter, we consider the case of transmission of modulated chaotic signals including information. We use a sequential square random pulse for the information signal. Here we carry out the simulation of data transmission on numerical calculation. The computer simulated results for both single-spiral and double-scroll chaotic

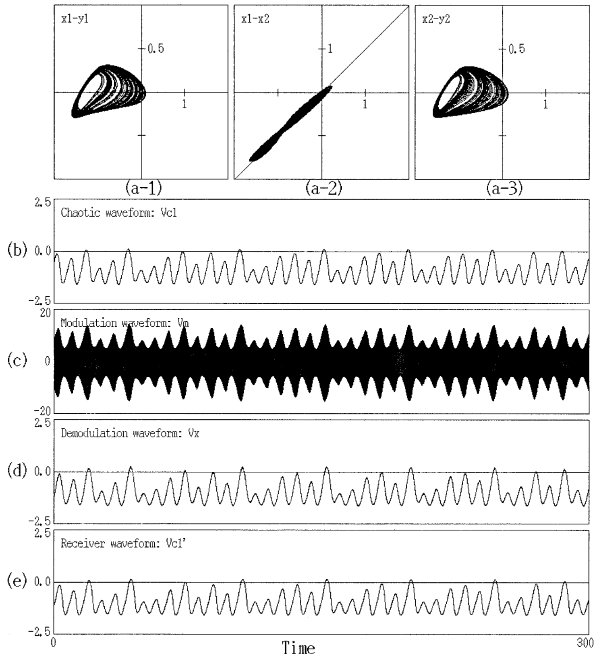

Fig. 6 Transmission of a chaotic signal (single-spiral chaotic attractor) for $f_c \simeq 130$[kHz]. Horizontal axis of (b)∼(e) is time ($\tau \times \sqrt{LC_2}$[sec]).

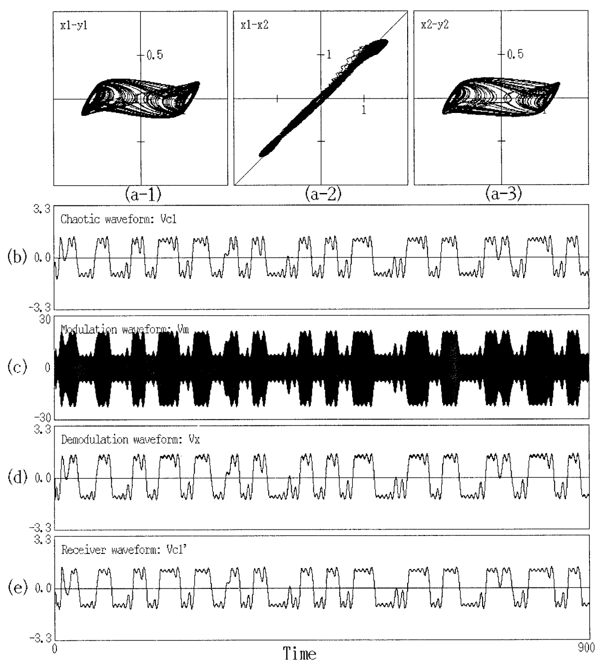

Fig. 7 Transmission of a chaotic signal (double-scroll chaotic attractor) for $f_c \simeq 130$[kHz]. Horizontal axis of (b)∼(e) is time ($\tau \times \sqrt{LC_2}$[sec]).

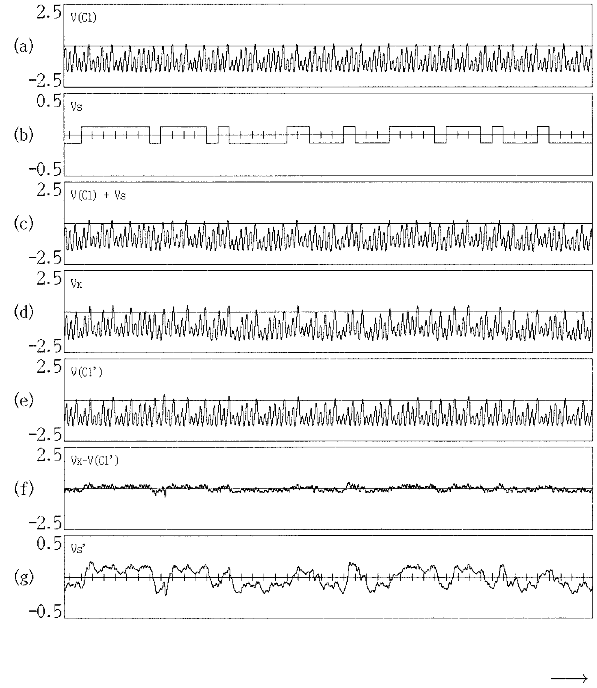

Fig. 8 Transmission of chaotic signal (single-spiral chaotic attractor) including digital information signal for $f_c \simeq 130$[kHz] and bit rate 2.65×10^3[bps].

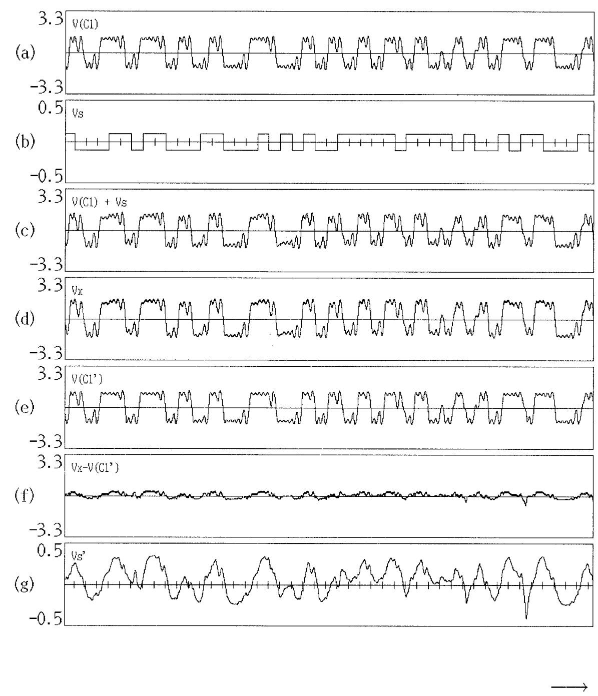

Fig. 9 Transmission of chaotic signal (double-scroll chaotic attractor) including digital information signal for $f_c \simeq 130$[kHz] and bit rate 2.65×10^3[bps].

attractors are shown in Figs. 8 and 9, respectively. (a) is an original chaotic waveform $v(C1)$, (b) is a digital information signal v_s, (c) is the sum of the original chaotic waveform and the digital information signal $v(C1)+v_s$, (d) is a demodulated waveform v_x, (e) is a reproduced chaotic waveform $v(C1')$, (f) $v_x - v(C1')$, and (g) low-pass filtered signal of $v_x - v(C1')$. We choose suitable circuit parameters for generating best performance. Bit

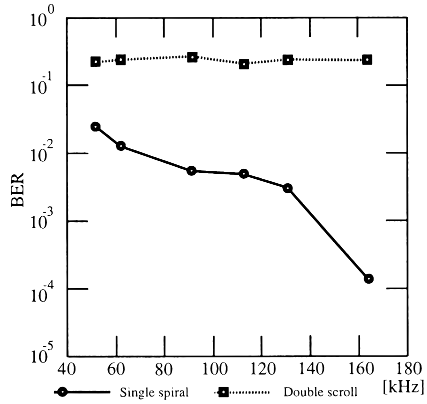

Fig. 10 BER vs. carrier frequency f_c[kHz] for E = 0.10[V] and bit rate 2.65×10^3[bps]. Each BER is simulated by 100000 points of data.

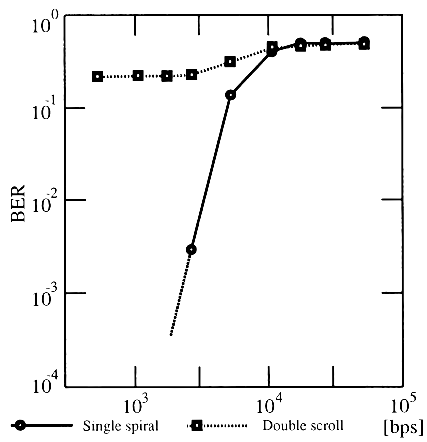

Fig. 11 BER vs. bit rate[bps] for $f_c \simeq 130$[kHz] and E = 0.10[V]. Each BER is simulated by 100000 points of data.

rate is chosen as 2.65×10^3 [bps], namely the bit width is about 3.78×10^{-4}[sec]. In Figure 8, we can almost reproduce original information signals obtained from the receiver circuits by inputting v'_s to the several circuits. In Figure 9, some bit error was confirmed.

4.2 BER Estimation

We calculate BER for estimation of communication quality including the modulation-demodulation circuits. Simulated results of BER are shown in Figs. 10 and 11. Figure 10 shows BER while carrier frequency f_c is changing, amplitude E of the information signal v_s is fixed as 0.10[V], and bit rate of digital information is fixed as 2.65×10^3[bps]. In the case of single-spiral chaotic attractor, we can confirm that the BER performance is going better as f_c increases. Meanwhile the double-scroll chaotic case, it has only a little transition for contradistinction to the case of single-spiral chaotic attractor. Figure 11 shows BER while bit rate is changing. The single-spiral case BER tends to be violently reduced as bit rate decreases, the other way, the double-scroll case BER tends to be slightly reduced.

We can conclude that high voltage E or lower frequency f_c cannot produce a good performance and that especially the double-scroll chaotic case is strongly influenced by the modulation-demodulation circuits.

5. Conclusions

In this study, we have investigated a simple chaos communication system including modulation-demodulation circuits. BER performance of the chaos communication system has been also estimated. We confirmed that nonlinearity of the modulation-demodulation circuits influenced to chaos synchronization and also communication quality. Although we have treated only AM chaotic masking communication system, the similar results could be obtained from another chaos communication systems based on Pecora-Carroll chaos synchronization.

Acknowledgment

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References

[1] L.M. Pecora and T.L. Carroll, "Synchronization in chaotic system," Phys. Rev. Lett., vol.64, no.4, pp.821–824, 1990.
[2] "Special session on applications of chaos in communications," Proc. ISCAS'97, vol.2, pp.1037–1076, June 1997.
[3] "Special session on spread spectrum communications and chaos," Proc. ECCTD'97, vol.1, pp.272–341, Aug. 1997.
[4] "Special session on communication with chaos I, II and III," Proc. ISCAS'98, vol.4, pp.457–488, 510–525, 554–582, May 1998.
[5] M.P. Kennedy and G. Kolumbán, "Chaos communications: from theory to implementation," Proc. ECCTD'97, vol.1, pp.272–277, Aug. 1997.
[6] L. Kocarev, K.S. Halle, K. Eckert, and L.O. Chua, "Experimental demonstration of secure communication via chaotic synchronization," Int. J. Bifurcation Chaos, vol.2, pp.709–713, 1992.
[7] L.O. Chua, M. Itoh, L. Kocarev, and K. Eckert, "Chaotic synchronization in Chua's circuit," J. Cir., Sys., and Comp., vol.3, no.1, pp.93–108, 1993.