SPREAD SPECTRUM COMMUNICATION VIA CHAOTIC SYNCHRONIZATIONS AND MODULATIONS

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SUMMARY

During the past, there has been tremendous interest worldwide in the possibility of exploiting chaos in wideband communication systems. Several different chaotic modulation techniques have been proposed up to date. In this paper it is demonstrated how Chua's circuits can be used to implement a secure communication systems. Finally chaotic system for use with standard spread-spectrum modulation is introduced.

Keywords: *chaos, spread spectrum, modulation*

1. INTRODUCTION

Mobile telecommunication systems, wireless local area networks and unlicensed radio applications facilitate the availability of voice and data transmission services. Conventional narrowband communication systems have serious disadvantages in these applications. Namely, narrowband signals are sensitive to selective fading caused by multipath propagation and the high-transmitted power spectral density causes high levels of interference with other users. Disadvantages of narrowband systems mentioned above could be avoided by applying spread spectrum (SS) techniques, in which the spectrum of the information signal is spread over a wide bandwidth for transmission.

An alternative approach to making a transmission wideband is to represent the transmitted signals by inherently non-periodic chaotic signals. Because chaos provides a pseudo-noise characteristic to its output patterns and can be reproduced with special synchronization, it has applicability as a spreading signal in spread spectrum communications. Chaos can be used in multiple ways in both analog and digital communications.

During the past, there has been interest in the possibility of exploiting chaos in wideband communication systems. Some of them are realized by the continuous-time dynamical system, and are using Chua's circuit as its basic circuit element. The security of the system comes from the high sensitivity of synchronization versus parameter changes.

Deterministic dynamical systems can produce a number of different steady state behaviour including DC, periodic, and chaotic solutions [1]-[4] and [6]-[11]. Chaotic systems are characterized by "sensitive dependence on initial conditions"; a small perturbation eventually causes a large change in the state of the system. Equivalently, chaotic signals decorrelate rapidly with themselves. The autocorrelation function of a chaotic signal has a large peak at zero and decays rapidly. Thus, while chaotic systems share many of the properties of stochastic processes, they also possess a deterministic structure. The code in the system is chaotic signal produced by a Chua's circuit, while the coding is accomplished for example by either multiplication in time, or division in time, with the inverse operation used to decode.

In Sec. 2 the system is described and its behaviour analysed. In Sec. 3 some simulation results by PSpice software is presented.

2. CHUA'S CIRCUIT

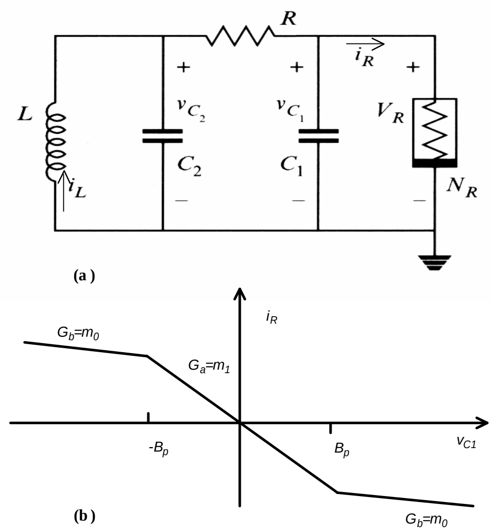

Fig.1 (a) Chua's circuit (b) V-A characteristic of the nonlinear element (Chua's Diode)

The main reason for using chaotic signals for secure communications is because they are asymptotically stable. Chua's circuit (see Fig. 1) is the simple and robust circuit, which exhibits the complex dynamics of bifurcation and chaos.

The circuit consists of linear elements (one resistor, one inductor, two capacitors) and a nonlinear element (called Chua's Diode). The Chua's diode has been fabricated as a microelectronic IC chip [2]. The state equations of Chua's circuit are given by:

$$C_1 \frac{dv_{C1}}{dt} = \frac{1}{R}(v_{C2} - v_{C1}) - i_R(v_{C1})$$

$$C_2 \frac{dv_{C2}}{dt} = \frac{1}{R}(v_{C1} - v_{C2}) + i_L \qquad (1.1)$$

$$L \frac{di_L}{dt} = -v_{C2}$$

where v_{C1}, v_{C2}, and i_L are the voltage across the capacitor C_1, the voltage across the capacitor C_2, and the current through the inductor L, respectively and $i_R(v_{C1})$ is the current versus voltage characteristic of the nonlinear element shown in Fig 1(b).

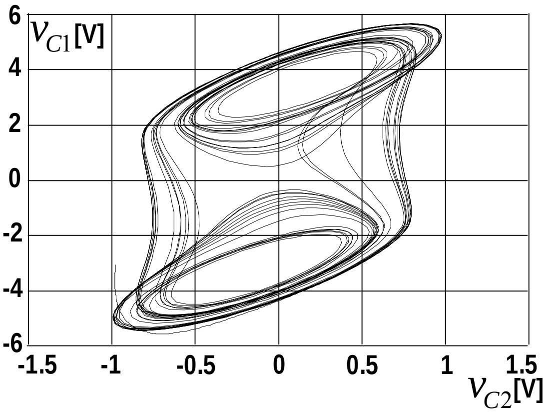

Fig. 2 Typical trajectories for a double scroll attractor

Fig. 2 shows the trajectories around two attractors over a period of time. By taking the state equations of the Chua's circuit and implementing them in a digital microprocessor, the chaotic behavior seen in the figure can be used in the communication systems.

3. SPREAD SPECTRUM COMMUNICATION THROUGH MODULATION OF CHAOS IN CHUA'S CIRCUIT

The system used for the secure communication is shown in Fig. 3. A Chua's circuit is used for each the transmitter and the receiver. A signal $i_i(t)$ is given as input to the Chua's circuit in the transmitter. The voltage signal v_1 (t) is the output of the transmitter, which is then used by the receiver to get $i_d(t)$.

The current signal $i_i(t)$ contains the information signal $v_s(t)$ that we want to transmit. In the receiver $i_d(t)$ is obtained, which varies in proportion to the information signal $v_s(t)$. That is, the informational signal can be recovered by using the current detectors in Fig. 3 (integrated circuit *IO1A* and resistor R_4).

The nonlinear resistors *G1* and *Gc1* Fig. 3 have the following three-segment piecewise-linear *v-i* characteristics, respectively [12]

$$i_R = f(v_R) = G_b v_R + \frac{1}{2}(G_a - G_b) \cdot \{|v_R + B_P| - |v_R - B_P|\} \qquad (1.2)$$

$$i'_R = f'(v'_R) = G'_b v'_R + \frac{1}{2}(G'_a - G'_b) \cdot \{|v'_R + B'_P| - |v'_R - B'_P|\} \qquad (1.3)$$

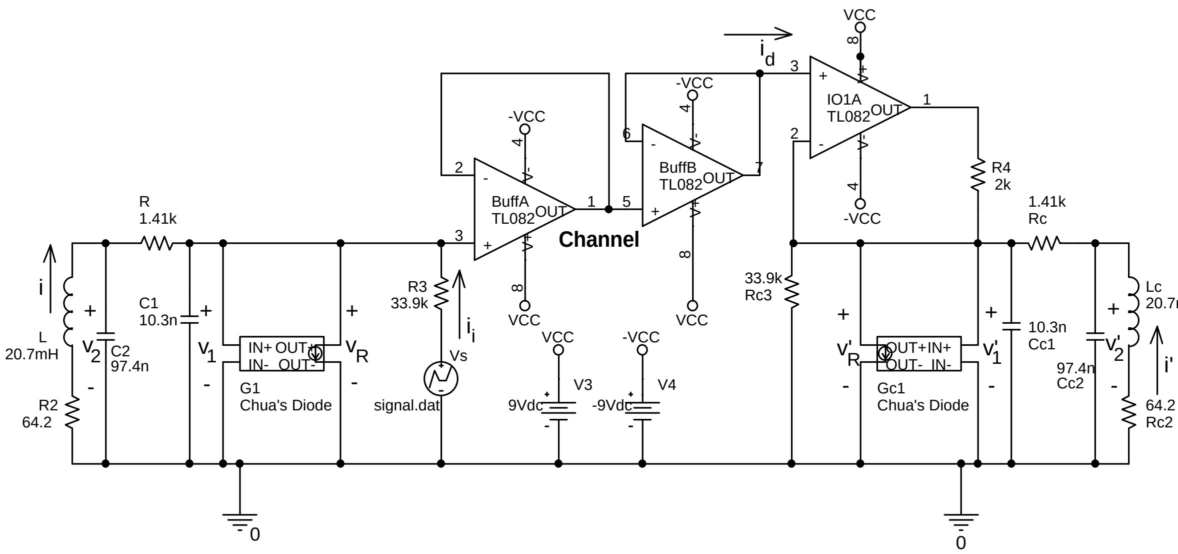

Fig. 3 Schematic diagram of the basic communication system

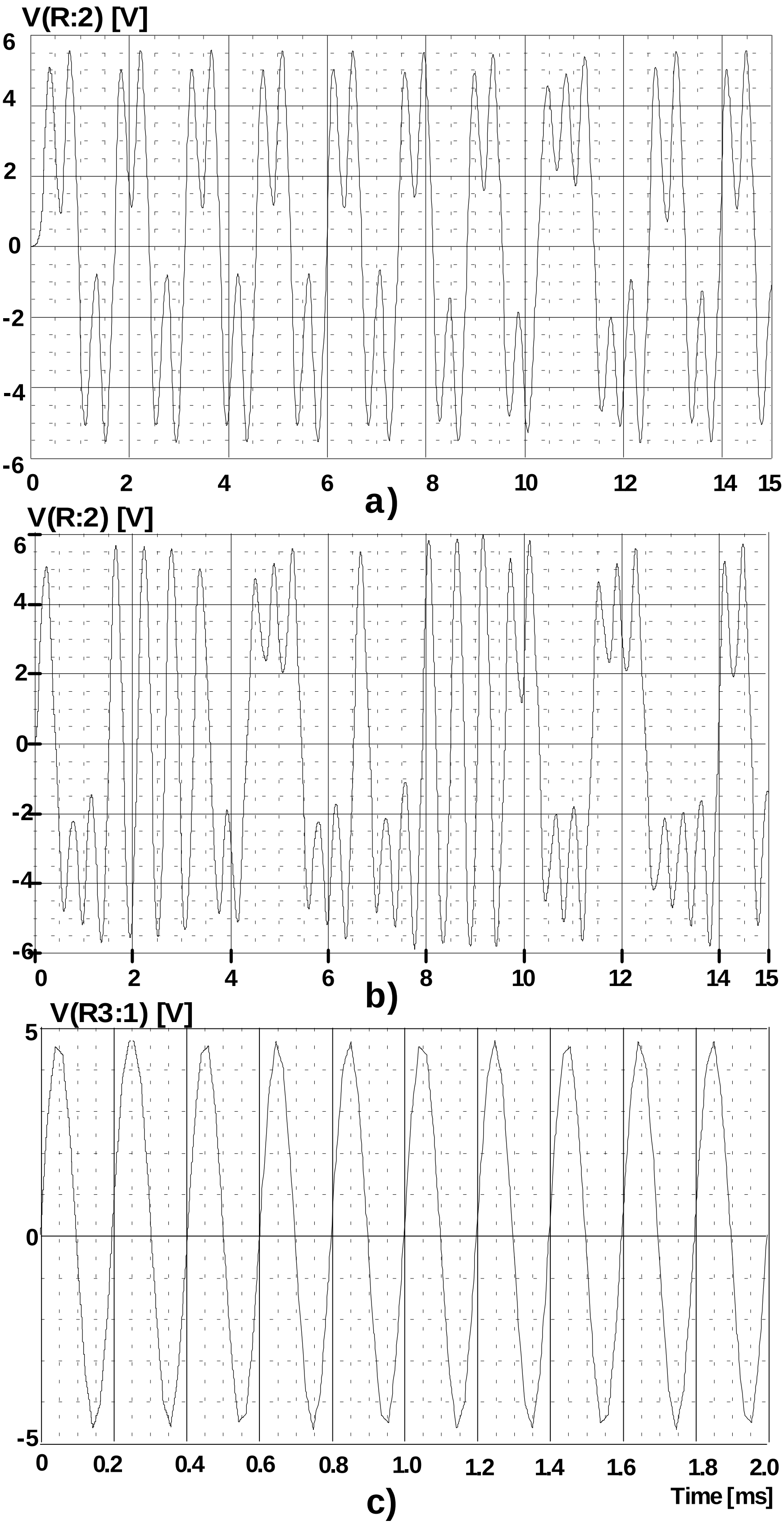

Fig. 4 Time waveforms of the transmitted chaotic signals and the input signal a) Transmitted chaotic signal with no input b) Transmitted chaotic signal with an input c) Input signal of frequency 5kHz and amplitude 4,7V

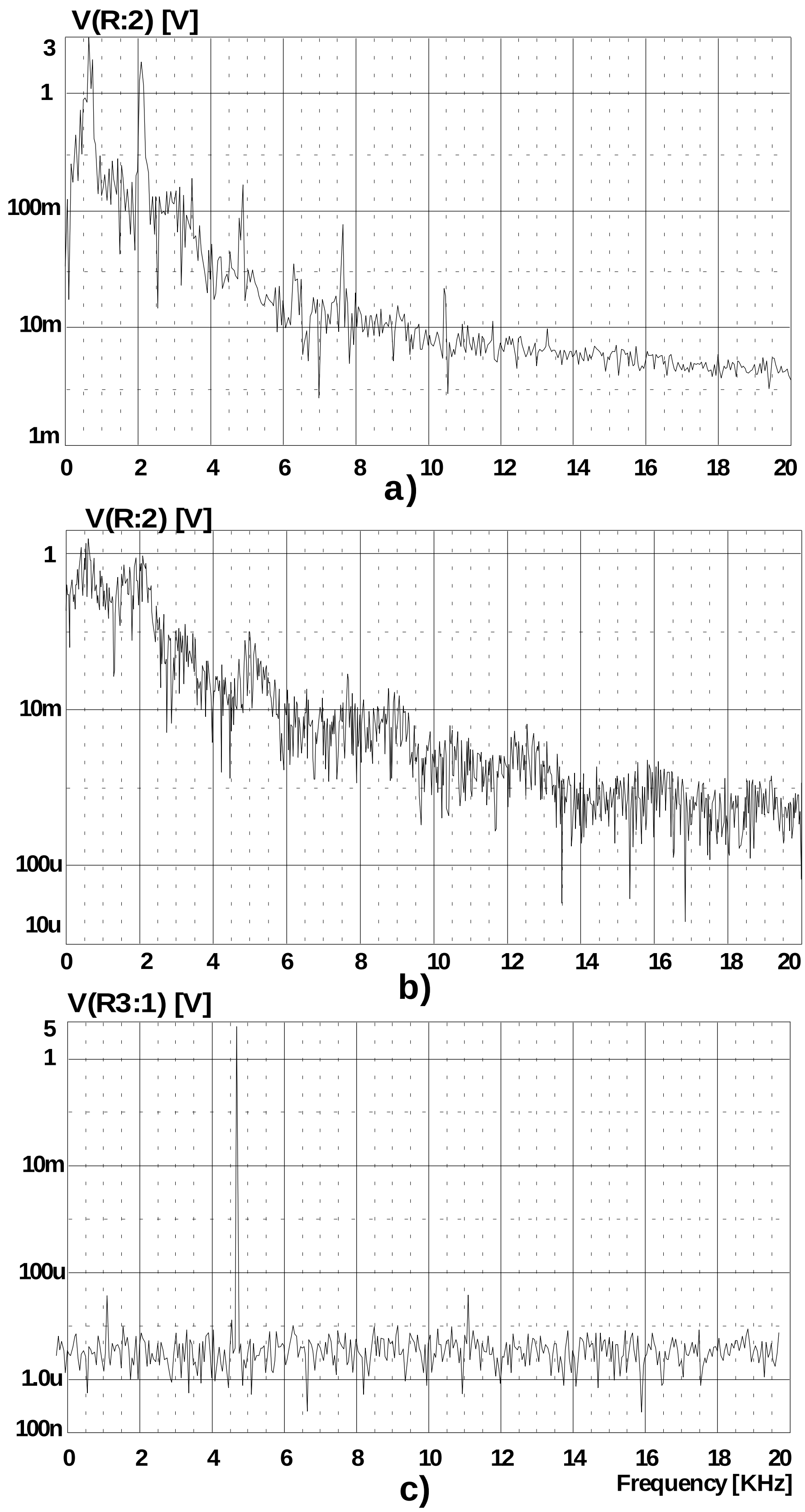

Fig. 5 Spectra of the transmitted chaotic signals and the input signal a) Spectrum of the transmitted chaotic signal with no input b) Spectrum of the transmitted chaotic signal with an input c) Spectrum of the input signal with frequency 5kHz and amplitude 4,7V

The state equations for transmitter are as follows:

$$C_1 \frac{dv_1}{dt} = \frac{1}{R}(v_2 - v_1) - f(v_1) + \frac{v_s - v_1}{R_3} \quad (1.4)$$

$$C_2 \frac{dv_2}{dt} = \frac{1}{R}(v_1 - v_2) + i \quad (1.5)$$

$$L \frac{di}{dt} = -v_2 - R_2 i \quad (1.6)$$

The circuit equations for receiving system are given by:

$$C_{C1} \frac{dv'_1}{dt} = \frac{1}{R_C}(v'_2 - v'_1) - f'(v'_1) - \frac{v'_1}{R_{C3}} \quad (1.7)$$

$$C_{C2} \frac{dv'_2}{dt} = \frac{1}{R_C}(v'_1 - v'_2) + i' \quad (1.8)$$

$$L_C \frac{di'}{dt} = -v'_2 - R_{C2} i' \quad (1.9)$$

For proper operation of the system then both the transmitter and the receiver should be exactly matched i.e. $R_C=R$, $C_{C1}=C_1$, $C_{C2}=C_2$, $L_C=L$ and $G_{C1}=G_1$. Due to the voltage buffer, we have $v'_1 = v_1$.

In summary, the operation of this system is as follows: the voltage across the capacitor C_1 is affected by $i_i(t)$. This transmitted voltage $v_1(t)$ then affects the voltage across C_{C1} in the receiver. Since both the transmitter and the receiver are matched then the current flowing into the second Chua's circuit must match the current injected into the first Chua's circuit. Since $i_i(t)$ determines the voltage $v_1(t)$ which in turn determines the current through C_{C1} and G_{C1}, then the current in the receiver must be equal to $i_i(t)$.

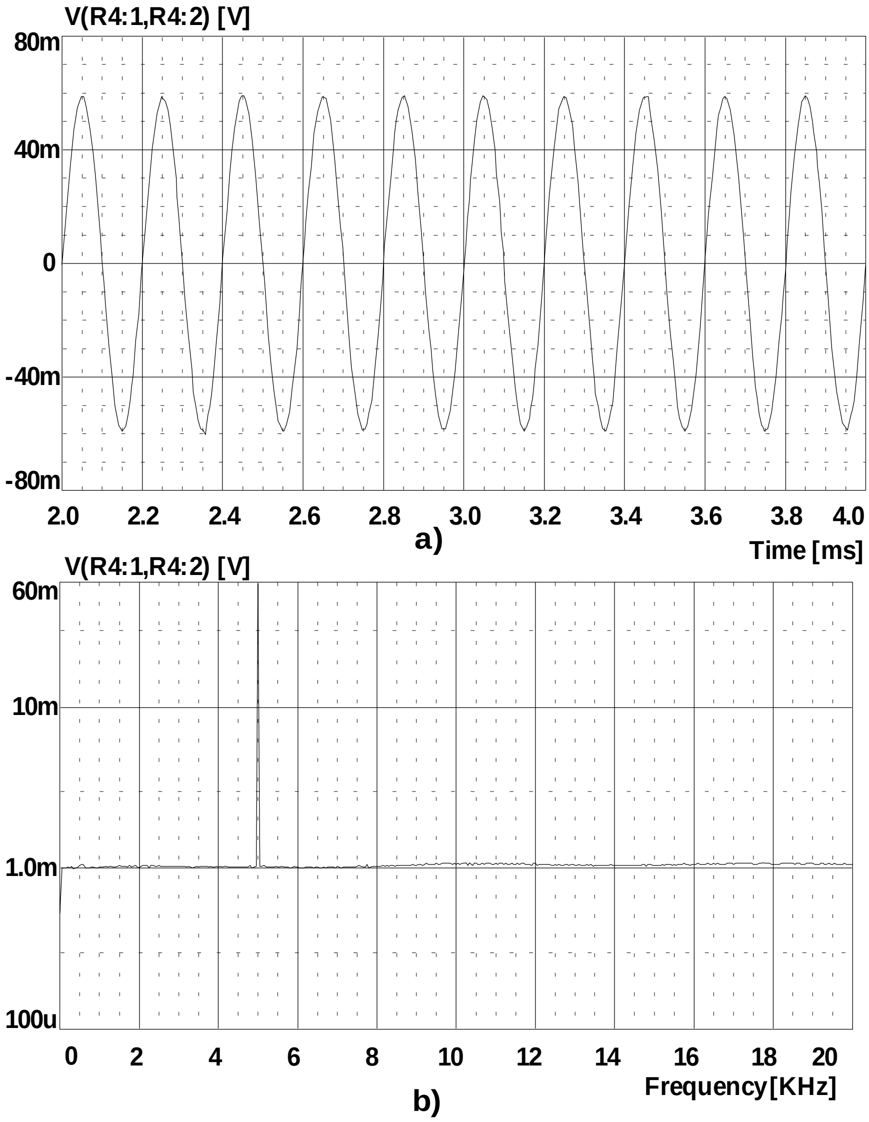

Fig. 6 The recovered signal a) Time waveform b) Spectrum

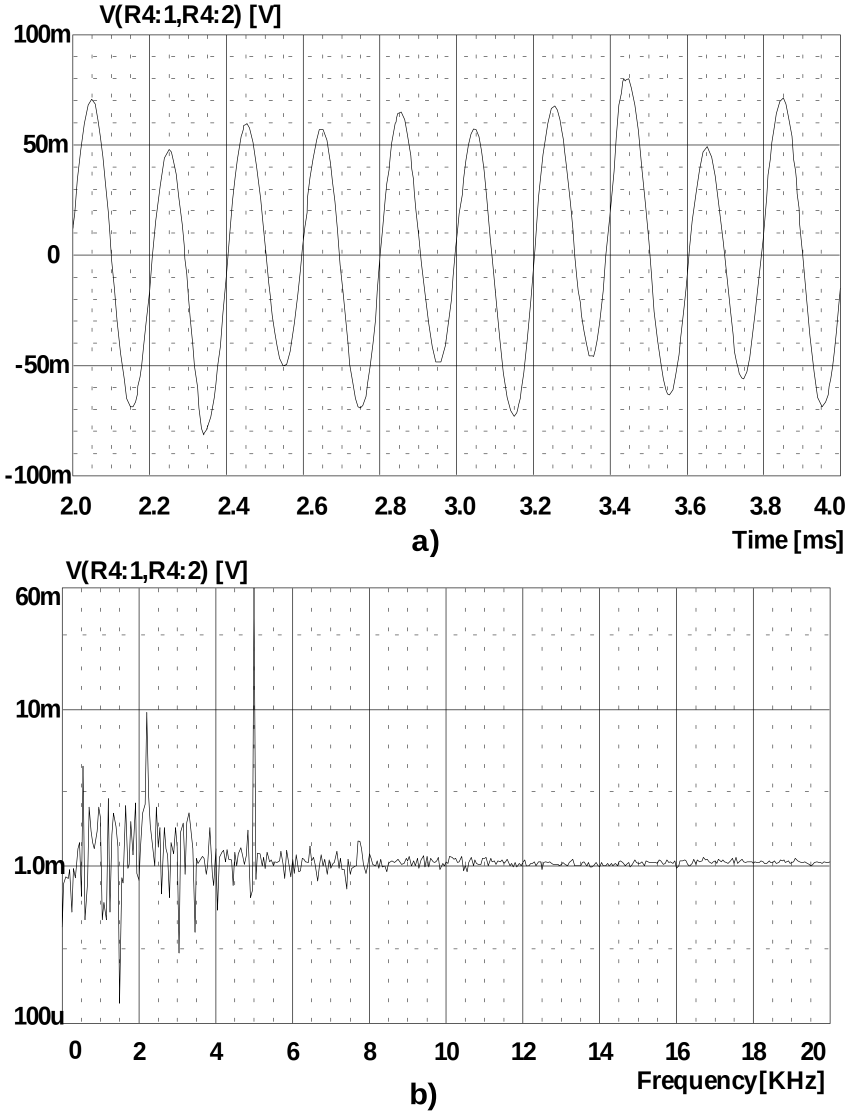

Fig. 7 The recovered signal with 2% capacitor Cc1 (10,5nF) mismatch a) Time waveform b) Spectrum

4. SIMULATION RESULTS

We simulate the communication system via Chua's circuit in Fig. 3 by PSpice software. The system is tested using various kinds of signals, for example audio signal ("gong"), sinusoidal signal, etc.

From these simulation results, we conclude the followings:

- The communication systems are easily built (see Fig.3).
- The waveforms of the transmitted chaotic signal $v_1(t)$ can mask the input signal $v_s(t)$, if its amplitude is small (see Fig. 4).
- The transmitted signals have broad spectra, and can mask the spectra of the input signals (see Fig. 5).
- The informational signals are recovered with sufficient quality from the transmitted signals (see Fig. 6).
- This system has the high sensitivity of the parameter mismatch. To eliminate the masking signal, very accurate knowledge of the parameter of the system is required to synchronize the chaotic signal (see Fig. 7).

5. CONCLUSION

Research into the use of chaos for spread spectrum communication is increasingly common [5] and [13]. For analogue communications, chaos masking and chaos modulation are used to spread the voice signals in order to prevent eavesdropping and otherwise increase security. We have demonstrated the feasibility of using Chua's circuits to implement a secure communication system. This system has the advantages of transmitting a spread-spectrum signal, and having enhanced sensitivity to parameter variations.

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BIOGRAPHY

Pavol Galajda was born in 1963 in Košice, Slovak Republic. He received the Ing. (M.Sc.) degree in electrical engineering from the FE TU in Košice and CSc. (Ph.D.) degree in radioelectronics from FEI TU in Košice, in 1986 and 1995, respectively. At present he is an assistant professor at the Department of Electronics and Multimedial Communications, FEI TU in Košice. His research interest is in nonlinear circuits theory, chaos in spread spectrum communication systems and multiple-valued logic.

Dušan Kocur was born in 1961 in Košice, Slovakia. He received the Ing (MSc) and CSc (PhD) degree in radioelectronics from the Faculty of Electrical Engineering, Technical University of Košice, in 1985 and 1990, respectively. He is Associate Professor at the Department of Electronics and Multimedia Communications of his Alma Mater. His research interests are digital signal processing, especially linear and nonlinear time-invariant and adaptive digital filters, higher order spectra, spread spectrum and CDMA transmission systems.

Rudolf Zetík was born on 2.4.1974. He received the Ing. (MSc) degree in radioelectronics from the Technical University of Košice, in 1997. He defended his PhD. in 2001; his thesis title was "Dual L-Wigner Distribution and Application of Time-Frequency Signal Representations in Ultra-Wideband Radar Systems". Since February 2001 he is working as a assistant at the Department of Theoretical Electrotechnics and Electrical Measurement of Technical University in Košice. His research interest includes digital signal processing, especially spectral analyses of signals, time-frequency representations of signals, CDMA systems and radars.