VLSI CHAOTIC PULSE CODED MODULATOR USING NEURAL TYPE CELLS

Louiza Sellami[1,2], *Mona E. Zaghloul*[3], and *Robert W. Newcomb*[2]

1: Electrical Engineering Department, U.S. Naval Academy 105 Maryland Ave, Annapolis, MD 21402, USA
E-mail: sellami@eng.umd.edu, URL: http://web.usna.navy.mil/~sellami
2: Electrical Engineering Department, University of Maryland, College Park, MD 20742, USA
E-mail: newcomb@eng.umd.edu, URL: http://www.ee.umd.edu/newcomb/mslab.html
3: Electrical Engineering and Computer Science Department, George Washington University,
Washington, DC 20052, USA. E-mail: zaghloul@seas.gwu.edu

ABSTRACT

A means of modulating information signals in both additive and multiplicative ways by chaotic signals is considered. The chaotic signals are obtained from neural type cells set to their chaotic oscillation mode. The information containing signals are modulated by these chaotic signals by introducing each as the input to a differential pair.

1. INTRODUCTION

Electronic circuits exhibiting well-understood chaotic behavior have potential applications in emerging classes of complex dynamic electronic networks and systems making use of chaotic signals. In particular, these circuits can be employed as basic components in the VLSI synthesis of neural networks, secure communication, and control systems based on chaos synchronization [1]-[6]. On the one hand the fact that chaos has been identified in the sensory information processing performed by biological neurons motivates looking for artificial neural networks based upon chaotic neurons. On the other hand, the self-synchronization property that can be achieved in some classes of chaotic systems have led to different implementations of communications schemes [1][3]. These focus mainly on chaotic masking schemes where chaotic outputs of nonlinear circuits are used to hide information signals.

The neural type cell (NTC) is one such circuit that is inspired from the biological neuron (soma) and which can produce chaotic-like pulse coded oscillations by encoding input stimuli (voltage) into pulse rates of an output signal [7]. The generation and coding of pulses is regulated by nonlinear hysteresis characteristics. Since its introduction as the basic component in an integrable MOS design of neuristors [7], the NTC has been studied extensively and has been used as the primary subcircuit for the generation of pulses in pulse coded neural networks. In particular, its range of oscillations has been improved by using a nonlinear load resistor and its discrete structure converted to an all MOS integrated one [8][9]. Additionally, it has been shown previously that coupled NTCs are capable of generating chaotic-like signals and self-synchronization, which are key properties, in chaotic communication circuits [10][11]. These two properties give the motivation for investigating signal masking schemes via NTCs.

This paper presents VLSI circuits for additive and multiplicative masking of information signals using chaotic-like signals. The additive and multiplicative masking schemes are achieved by modulating the input and the tail currents of a differential pair, respectively, with a chaotic-like signal generated by two coupled NTCs set up to their oscillation mode. PSpice simulation runs are done on the circuits to indicate their performances.

2. THE NEURAL TYPE CELL

The NTC is an electronic voltage-controlled oscillator which produces a train of analog pulses whose shapes are determined by the input voltage. When the input exceeds a certain DC threshold level, the output signal starts to oscillate with a frequency approximately proportional to the input signal level. As shown in Figure 1, the basic NTC circuit contains a capacitor, C_L, three resistors, R_1, R_3, and R_L, and three MOS transistors, M_{n1}, M_{n2}, and M_{p1}. The input voltage is applied at the gate of M_{n1} and the output voltage is measured at the drain of M_{p1}. Feedback is achieved via the connection between the drain of M_{p1} and the gate of M_{n2}. Its operation is based upon nonlinear hysteresis characteristics given by the source current of M_{p1} versus V_{mem} [12]. The way to obtain oscillations in the NTC is to pass a load line through the vertical sides of the hysteresis curve to give unstable equilibrium points. Then

0-7803-4455-3/98/$10.00 © 1998 IEEE

a capacitor at the node of the junction of the hysteresis and the load line subcircuits gives the dynamical behavior. Because a linear resistive load line produces pulses over only a limited range of the input voltage, the load line subcircuit, R_L, has been previously altered into a suitable nonlinear MOS resistor given by M_{p3}-M_{p5} and M_{n5}-M_{n8} in Figure 2. This allows for a wider oscillation range in the design with the whole structure converted to an all MOS transistor circuit suitable for VLSI fabrication [8]. In the next section we give the all MOS NTC circuit and show how two NTC circuits can be coupled to generate chaotic-like signals.

3. NTC CHAOS GENERATOR

Figure 2 shows an all MOS transistorized version of the NTC of Figure 1 where the transistor M_{p6} has been added to allow for an inhibitory mode of operation. Also, the various nodes for connecting with a second NTC are indicated. The generation of chaotic-like signals is achieved by coupling two of these NTCs where the output of each cell is connected to the control node (gate of M_{n6}) of the transistorized effective R_L load of the other NTC. The two NTCs are the same, except for the two values of capacitance C_L which will be set to two different values for use in generating chaotic-like signals for the modulators. The basic idea is the use of bidirectional feedback in the coupled NTCs that is controlled by the output capacitors and the differences in pulse repetition rates of the two NTCs' self-oscillations. Previously obtained results [10] indicate that chaos-like behavior most strongly shows up in the number of pulses occuring in repetitive intervals rather than in amplitude variations. These results also show that although chaos-like response can be obtained with a single NTC, two coupled ones are more easily adjusted to sustain the chaotic-like behavior.

4. CHAOTIC PULSE CODED MODULATOR

Chaotic signal masking has recently emerged as one of the new application of chaos in communications. The basic idea behind the chaotic masking treated here is to modulate the information signal by direct addition or multiplication. At the receiving end the information could be recovered after some signal processing operations.

The Additive Modulator

The main components of the additive modulator circuit of Figure 3 are the two NTC subcircuits (NTC1 and NTC2) coupled together to generate a chaotic-like signal and the differential pair subcircuit shown in Figure 4. The NTC subcircuits are identical except that NTC1 has $C_{L1} = 0.01$ nF and NTC2 has $C_{L2} = 0.03$ nF. These are coupled as explained in section 3 so that the loads jump around on the hysteresis. Also, dynamics are inserted at the output node of each NTC via C_{out} which is set to $C_{out1} = 0.1$ pF for NTC1 and $C_{out2} = 1$ pF for NTC2. The chaotic signal applied to the noninverting input of the differential pair acts as the masking signal to the information signal (sinusoid) applied at the inverting input of the differential pair. The differential pair tail current is set by the adjustable voltage $V_{tail} = -3$ V. The output voltage is a scaled version of the sum of the two differential pair input voltage signals. A test stage, composed of an inverter and a load resistance R_1, is added in Figure 3 at the output for measurement purposes.

The Multiplicative Modulator

The multiplicative modulator, given in Figure 5, is similar to the additive one except that now the information signal is applied at the tail of the differential pair and the inverting input is biased at -2 V. The resulting output signal is the product of the two signals. As in the additive modulator, a test stage is added to measure the output signal.

5. SIMULATION RESULTS

PSpice simulations shown in Figures 6 and 7 were run with the two modulator circuits where the information signal is a sinusoid of -3 V offset voltage, 1 V amplitude and 1 MHz frequency. The masking signal is the chaotic-like pulses generated by the coupled NTCs. The input voltage is set to -2 V for NTC1 and -2.13 V for NTC2. Several tests were run with various values of capacitance C_L, with those shown obtained for $CL1 = 0.5$ nF and $C_{L2} = 0.05$ nF. Also, the frequency of the information signal was varied and the results show that the chaotic masking is more visible at frequencies in the MHz range. Figure 6 shows the output of the additive modulator and Figure 7 shows the output of the multiplicative modulator. Except for the effect, both modulate the top signal of Figure 7.

6. CONCLUSIONS

In this paper two means (additive and multiplicative) of modulating (masking) a signal by a chaotic signal are presented. The chaotic signal is generated by two coupled all MOS NTCs which, except for some large capacitors, are suitable for VLSI implementation. The two types of modulators are developed based on the coupled NTCs and a differential pair connected so as to achieve the desired modulation scheme. PSpice simulations are run on the two circuits which indicate that the performance could be satisfactory by a proper adjustment of the frequency of the information signal.

7. REFERENCES

[1] V. Milanovic and M. E. Zaghloul, " Synchronization of Chaotic Neura Networks and Applications to Communications," *International Journal of Bifurcation and Chaos*, Vol. 6, No. 12B, pp. 2571–2585, 1996.

[2] V. Milanovic, K. M. Syed, and N. E. Zaghloul, "Combating Noise and Other Channel Distortions in Chaotic Communications," *International Journal of Bifurcation and Chaos*, Vol. 7, No. 1, pp. 215–225, 1997.

[3] H. Leung and J. Lam, "Design of Demodulator for the Chaotic Modulation Communication System," *IEEE Transactions on Circuits and Systems I*, Vol. 44, No. 3, pp. 262-267, 1997.

[4] C. L. Koh and T. Ushio, "Digital Communication Method Based on M-Synchronized Chaotic Systems," *IEEE Transactions on Circuits and Systems I*, Vol. 44, No. 5, pp. 383-390, 1997.

[5] N. J. Corron and D. W. Hahs, "A New Approach to Communications Using Chaotic Signals," *IEEE Transactions on Circuits and Systems I*, Vol. 44, No. 5, pp. 373–382, 1997.

[6] T L. Vincent, "Control Using Chaos," *IEEE Control Systems*, Vol. 17, No. 6, pp. 65–76, 1997.

[7] R. W. Newcomb, "Neural Type Microsystems: Some Circuits and Considerations," *Proceedings of the IEEE Conference on Circuits and Computers (ICCC'80)*, Portchester, NY, October 1980, pp. 1072–1074.

[8] T. W. Tsay, M de Savigny, N. El-Leithy, and R. W. Newcomb, "An All MOS Neural Type Cell," *Proceedings of the Midwest Symposium on Circuits and Systems*, pp. 776-779, Monterey, CA, May 14-17, 1991.

[9] G. Moon, M. Zaghloul, M. de Savigny, and R. W. Newcomb, "Analysis and Operation of a Neural Type Cell," *Proceedings of the IEEE International Symposium on Circuits and Systems*, Singapore, 1991, pp. 2332-2334.

[10] A. Hodge and R. W. Newcomb, "VLSI Chaos Generation - Hysteresis and the Neural Type Cell," *Proceedings of the 1995 World Congress on Neural Networks*, Washington, D. C., July 17-21, pp. 250-253, 1995.

[11] A. Hodge, M. E. Zaghloul, and R. W. Newcomb, "Synchronization of Neural Type Cells," *Proceedings of the IEEE International Symposium on Circuits and Systems*, pp. 582–585, Atlanta, GA, May 12-15, 1996.

[12] N. El-Leithy and R. W. Newcomb, "Hysteresis in Neural Type Circuits," *Proc. of the Int. Symposium on Circuits and Systems*, Espoo, Finland, June 1988, pp. 993–996.

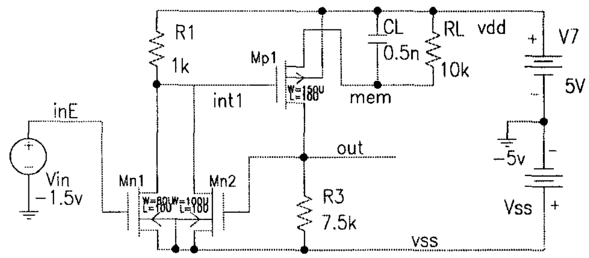

Figure 1: The basic NTC circuit.

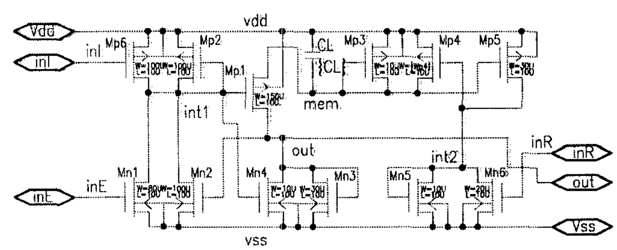

Figure 2: The all MOS NTC circuit.

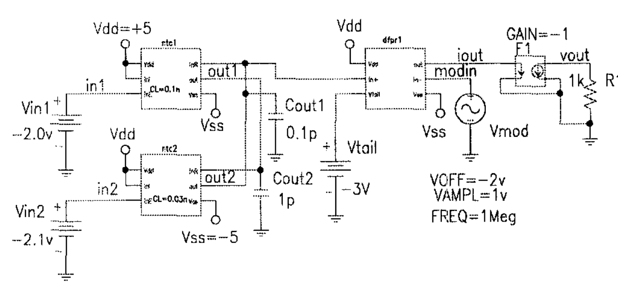

Figure 3: Circuit diagram of the additive modulator.

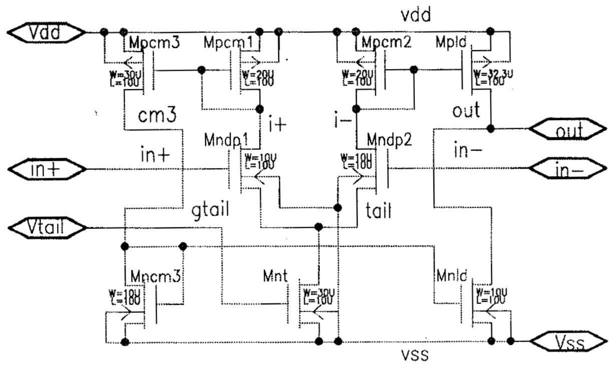

Figure 4: The differential pair.

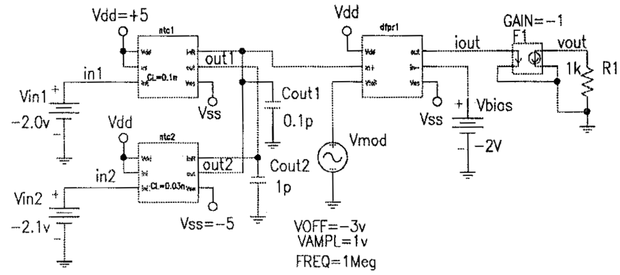

Figure 5: Circuit diagram of the multiplicative modulator.

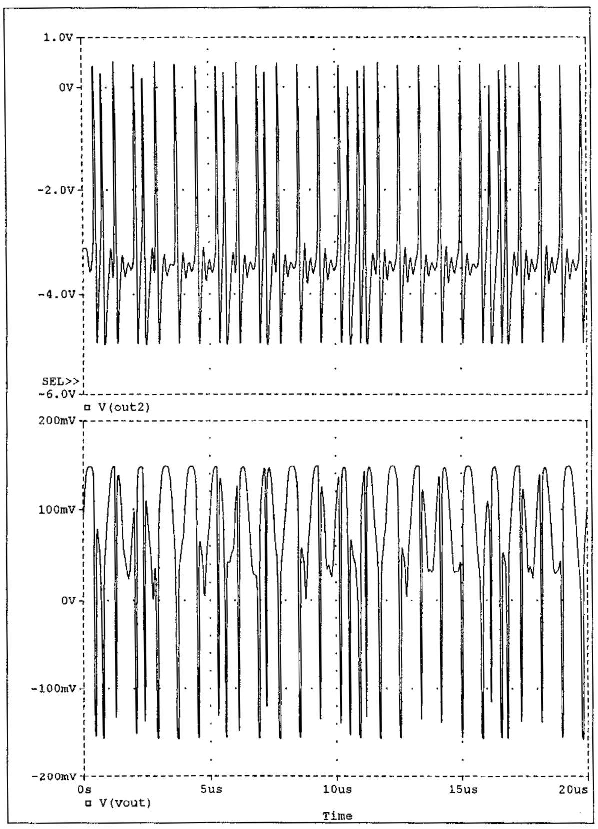

Figure 6: PSpice simulated curves for the additive modulator. The top curve is the chaotic signal, the bottom curve is the masked signal.

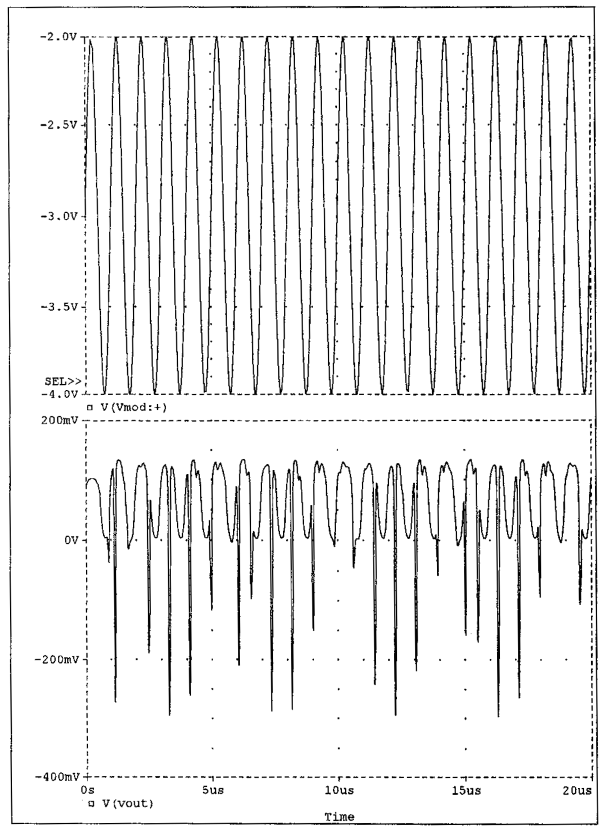

Figure 7: PSpice simulated curves for the multiplicative modulator. The top curve is the information signal, the bottom curve is the masked signal.