VLSI Chaos Generation - Hysteresis and the Neural Type Cell

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Abstract:

A chaotic type of response is shown to exist in two coupled neural type cells.

After a review of the basic neural type cell, improvements in it are given to reflect a more biologically oriented design. The hysteresis developed in the cell is reviewed and used to give an explanation of how chaos might be generated. Finally the two coupled cells are presented along with the chaos-like self oscillations obtained.

I. Introduction

Since its introduction [1] as the basic component in an integrable MOS neuristor, the neural type cell (NTC) has proven of interest as the primary subcircuit for generating pulses in pulse coded neural networks. Consequently, it has undergone a number of studies and improvements [2][3]. In particular its operation is based upon hysteresis, as was originally shown to be needed in neural pulse circuits by Crane [4, p. 42]. The hysteresis present is actually very interesting and has been investigated in [5]; in particular the size and shape of the hysteresis varies with the input to the NTC. The philosophy of obtaining oscillations in the NTC is to pass a load line through the vertical sides of the hysteresis to give unstable equilibrium points. Then a capacitor at the node of the junction of the hysteresis and the load-line subcircuits gives the dynamical behavior which varies with the input to the cell. Because a linear resistive load line gives very limited behavior, the load line portion of the NTC has previously been expanded into a suitable nonlinear resistor which allows for much more flexibility in design [3] with the whole structure translated into CMOS transistor form so that the NTC can be fabricated using VLSI techniques. Here we exploit the added flexibility gained by using the nonlinear load line to make it easier to interpret biological activities of live cells in terms of components in the NTC. And since sinusoidally forced squid axons have been shown to exhibit chaotic behavior [6] we finally show how chaotic responses can be induced in the NTC by obtaining chaotic like behavior out of two coupled NTCs.

We use CMOS transistors which can easily be fabricated by VLSI techniques via the MOSIS facility. Thus, we use transistor data from a MOSIS run N21H of 04/28/93 for which the key Spice parameters are KPn=5.048E-5, KPp=1.908E-5, VTOn=0.858, VTOp=-0.889, LAMBDAn=1.844E-2, LAMBDAp=5.012E-2.

II. The Basic Neural Type Cell

In Fig. 1a) we present the original basic NTC which uses MOS transistors and linear resistors. This basic NTC consists of an NMOS input transistor, Mn1, which serves to drive current through its load resistor R1 once the input voltage, Vin, is above the threshold voltage of Mn1; this gives the threshold of stimulability. The current through R1 in turn serves to turn on the PMOS transistor, Mp1. When Mp1 is turned off, the case when Vin=0, there is no current in RL and no voltage on CL. But as Mp1 turns on CL charges up and drops the drain voltage of Mp1. In the meantime, with Mp1 turned on there is output current in R3 which when it gets large enough turns on Mn2 to draw more current through R1, the regeneration giving a sharp drop in the gate voltage of Mp1 which gives a very rapid rise in the current in R3, that is, in the output voltage which serves to mimic an action potential. When Vin is later dropped the voltage held on CL must be discharged before a further action potential can occur, giving the refractory period. The action of Mp1 is very nonlinear, however, and, thus, the operation is best investigated by looking at the current into the source (upper terminal) of Mp1. This source current has hysteresis the nature of which is dependent upon Vin and equilibrium points are where this hysteresis intersects the (load) line of current coming down through R1. The situation is shown in Fig. 1b) which is obtained by replacing CL in Fig. 1a) by running a transient analysis using a slow triangular function voltage source. Action potential like oscillations occur when the load line intersects both vertical portions of the hysteresis; since the intersections are unstable equilibria, the system flips between the two equilibria at a rate proportional to CL.

III. The Biologically Motivated Modifications

Because the basic NTC pulses over only a very limited range of Vin and uses resistors, modifications have been made to use only MOS transistors and to make RL nonlinear to horizontally intersect the hysteresis [3]. We begin with those modifications to create the NTC used here, and shown in duplicate in Fig. 2, one at the top and one at the bottom (with added indices 1 & 2 on respective components). The NTCs of Fig. 2 are made more in line with biological functions. The first change is very minor, being a shift of the potential reference by tying the lowest potential to -Vss rather than ground; by connecting the capacitor CL to ground its upper node can now be considered to mimic the membrane of a biological cell. The insertion of Mp5 is to make it act as a fixed resistor, the RL of Fig. 1, something like the membrane leakage resistor. The remainder of the transistors to the right of it duplicate the load resistor configuration of [3] with the exception that Mn5 is added to allow control of this resistor so that modulation of the current into the "membrane" node can occur, essentially following the trend of ideas of biological neuron simulations [7]. A modulating voltage on the gate of Mn5 allows the current into the membrane node to be modulated, for example by other neurons, as will be done in the next section. With these changes in mind, it is easy to envisage other biologically motivated improvements, such as putting dynamics into RL by a capacitor to ground from the internal node, int2, or second messenger changes by connecting pool outputs on the gate of Mn5. Different effects are then easily incorporated by choice of W/L ratios of the load transistors.

IV. Coupled NTCs with Chaotic Like Oscillations

Figure 2 shows the connection of the two NTCs (modified as per section III) which give the chaotic responses of Fig. 3. In Fig. 2 the output of each cell is connected to the control node, gate of Mn5, of the load, RL, of the other NTC. The two cells are essentially the same except that CL1=0.5nFd and CL2=0.05nFd and dynamics is added at the output node via Cout. Because we are dealing with pulse repetition, the chaos most strongly shows up in the number of pulses occurring in repetition intervals, rather than in amplitude changes, though some of the latter can be seen. Also the first (top) NTC is set to strongly drive the second (bottom) NTC, so the output pulses of the first NTC are essentially unaffected by those of the second NTC. This indicates that we should be able to get chaotic behavior from just one NTC but in the present circuit the feedback from the second NTC back to the first is actually needed to maintain the chaotic like behavior.

V. Discussion

In the above we have presented modifications of the NTC which allow for coupled NTCs to generate chaotic behavior. The philosophy is straightforward, we wish to modulate the oscillation of one NTC by those of another but in such a way that the coupling is always different, this being controlled by the output capacitors and the differences in pulse repetition rates of the two NTCs' self oscillations. However, it remains to be proven that chaos is actually generated. For that we believe the strongest proof will result by looking at the return map of the signals passing over the hysteresis and showing that this has a period three point. It should be noted that the two coupled NTCs presented here are not externally driven, say by sensor inputs. As such the resulting chaos might possibly represent something like arrythmias in the neural excitation of the heart or epileptic signals. Finally we mention that the circuit is set up for VLSI realization, though size optimizations, etc., remain to be undertaken.

Acknowledgments: We wish to thank Professor M. Zaghloul for inviting us to prepare a paper on chaotic behavior which led us to develop the above circuits.

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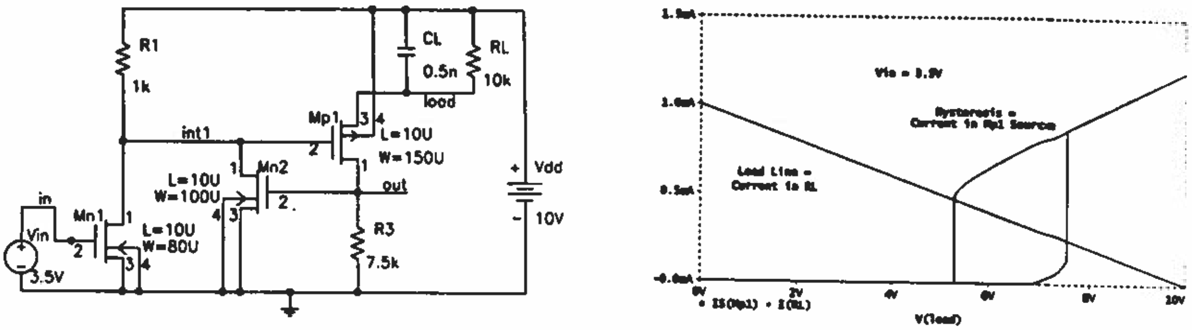

a) b)

Figure 1: a) The Basic Neural Type Cell (NTC) and b) its Hysteresis & Load Line

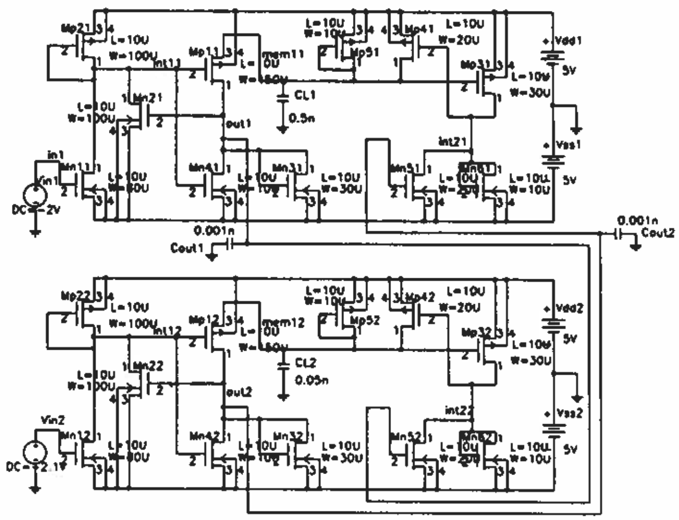

Figure 2: Two Coupled NTCs

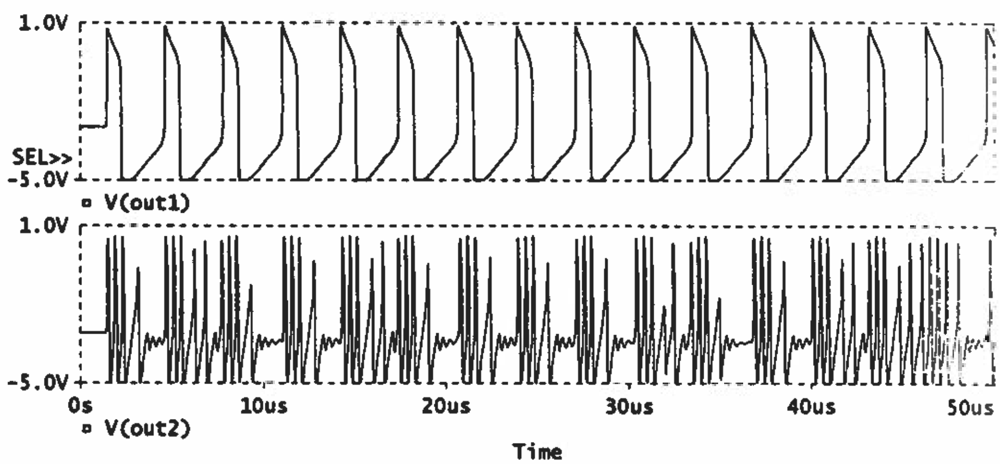

Figure 3: Chaotic Like Response from the NTCs in Fig. 2

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Volume I

Sponsored by the International Neural Network Society