NEURAL - TYPE MICROSYSTEMS: SOME CIRCUITS AND CONSIDERATIONS

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EXTENDED ABSTRACT Neural - type microsystems are electronic systems which have the pulse handling capabilities of neural biological systems. As such, they offer potentialities for being the next generation of computing and/or signal processing systems. In these systems there are two general classes of subsystems, those handling signal transmission and those combining signals, these being somewhat analogous to the nerve axon and the synaptic junction, respectively. Consequently, it is advantageous to have simple primary cells for each of the two kinds of signal handling capabilities and such that the main considerations of system performance can be determined by the interconnection scheme of the primary cells. Attention is being paid to the generation of circuits which can be readily converted to VLSI realization so that systems of considerable complexity become possible.

Original work in the area centered on modeling of Hodgkin-Huxley types of equations as well as the neuristors of H. Crane around which an extensive bibliography resulted [1]. Following up on these ideas but developing the resulting pulse properties rather than carrying out simulation of equations, led to simple bipolar circuits [2] from which the more recent CMOS results stem [1]. In pursuing these latter, new properties have been observed, such as that of voltage controllable pulse repetition rates [3] or neural type pulse modulation [4].

Figure 1 shows an MOS neural-type circuit which exhibits the desired properties including a voltage controllable pulse repetition rate. The circuit of Fig. 1 has the very valuable property that, on splitting the line resistor R_L between sections, there is no distinction between input and output of a section. Consequently all signal leads would be completely interchangeable in any circuit constructed wholly from such devices. Describing equations for a totally distributed Fig. 1 can be set up [1] as

$$(\partial^2 v/\partial x^2) = r_\ell c_\ell (\partial v/\partial t) + r_\ell f(v, v_c), \qquad (1a)$$

$$(\partial v_c/\partial t) = c_2^{-1} g(v, v_c) \qquad (1b)$$

with $v(x,t)$ having $v(0,t) = v_{in}(t)$ specified [here $r_\ell = R_L/\Delta x$, $c_\ell = C_L/\Delta x$, $c_2 = C_2/\Delta x$; $f(\cdot,\cdot)$ and $g(\cdot,\cdot)$ are nonlinear functions from the MOS transistors]. Equations of this form are known as nonlinear diffusion equations in mathematics. Stimulated by the problems in neural modeling, there has recently been considerable interest in such equations by mathematicians [1] who have treated special cases. But each section in our circuit is lumped and hence a different approach is needed, especially for handling large scale systems comprised of many sections.

Further circuit developments have led to the use of binary hysteresis. For this we introduce the first order nonlinear state-variable equations

$$\dot{x} = -(b+1)x - a - bH(x_t) + bu \qquad (2a)$$

$$y = x \qquad (2b)$$

where a and b > 0 are suitably chosen constants, u is the input, y is the output, and H is the binary hysteresis described by

$$H(x_t) = \begin{cases} H_0 & \text{if } x(t) \geq x_0 \\ -H_0 & \text{if } x(t) \leq -x_0 \\ \begin{cases} H_0 \text{ if } H(x_{t\_}) = H_0 \\ -H_0 \text{ if } H(x_{t\_}) = -H_0 \end{cases} & \text{if } -x_0 < x(t) < x_0 \end{cases} \qquad (3)$$

where H_0 and x_0 are positive constants of the hysteresis (and $t\_$ is t approached from the left [= instant before t]). These equations can be readily realized in op-amp form and give the responses needed for neural-type systems [5]; all MOS circuit realizations are presently under intensive study [6].

Besides the generation and transmission of neural-type pulses it is important to combine them in various ways, say at junctions [7]. There are a number of different classes of junctions with Fig. 2 showing one type of dynamic excitatory junction while through the use of complementary transistors inhibitory behavior can be obtained. The operation of Fig. 2 is briefly described as follows: an above threshold (positive) input pulse v_j draws current in R_j which, with a time constant σ_j, shapes the current i_j; all such currents sum in R_Σ to turn on the output transistor that shapes the pulse with time constant T. Transistor nonlinearities also shape the output into a desired characteristic.

The ultimate use of such circuits is for achieving ease of realization in modular form for complicated systems. Toward this various classes of neural-type modules are under development, including various (to this date, six) cell-type modules [8]. From these, different kinds of systems can be constructed, such as retinal [9] or cerebellum [10] type. This has led to a study of

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classes of interconnections of neural-type modules for which stability properties can be determined [11].

Besides open problems mentioned above, a number of others are of significant interest some of which are cataloged as follows:

Future and Emerging Research Problems:

a. Perfection of previous circuits
   1. Neural type lines
      α. With controllable pulse repetition (use of substrate)
      β. Completely distributed
      γ. Hysteretic type
   2. Neural type junctions
      α. Construction and testing of available circuits
      β. Pulse control and gating circuits
      γ. Synchronization circuits
   3. Mathematical theories needed
      α. Descriptions for non-distributed lines
      β. Theory for binary hysteresis circuits used
      γ. Solutions of nonlinear diffusion equations
      δ. Velocity determination in dynamic steady state
      ε. Functional theory of neural-type junctions
b. New types of circuits
   1. SAW
   2. Optical fiber
   3. CCD and I^2L
   4. Nonlinear capacitor
c. Subsystem realizations (properties, construction, testing)
   1. Retina type
   2. Cerebellum type
   3. Picture processors
   4. Translation of physiological systems data into circuit and mathematical systems concepts
   5. Large scale system mathematics

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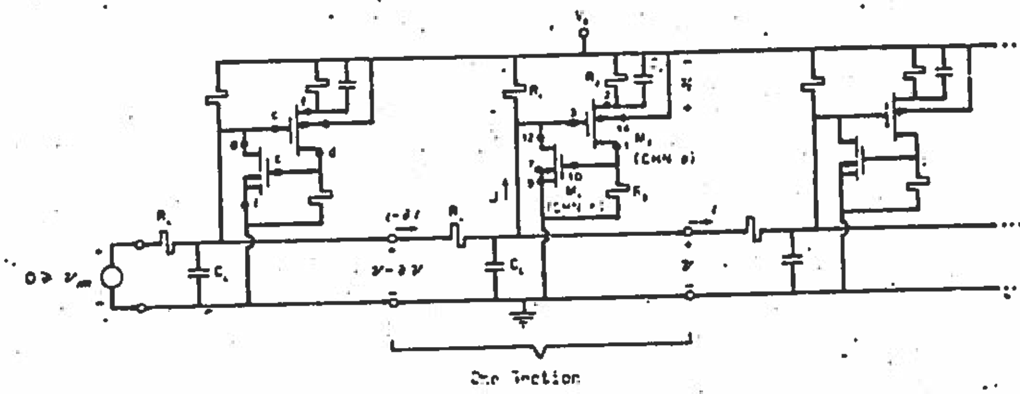

Figure 1

Basic neural-type line circuit for negative pulse transmission

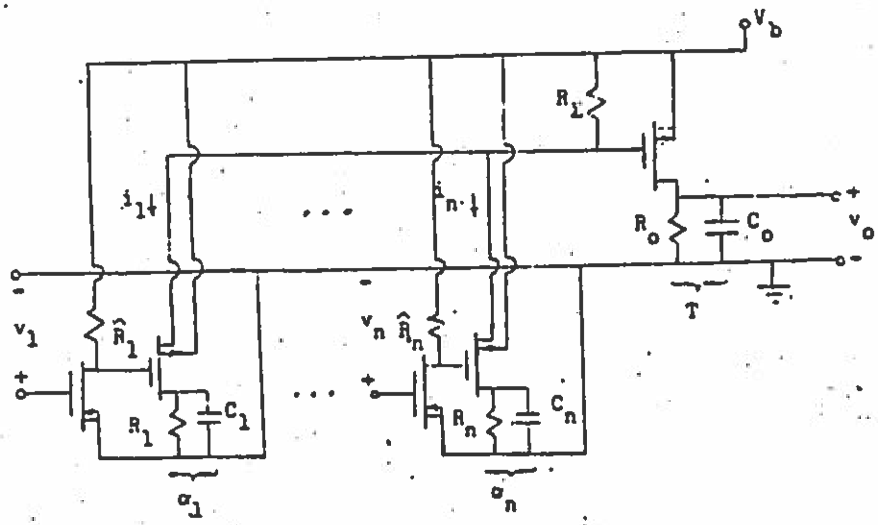

Figure 2

Dynamic Neural - Type Junction, Positive Pulse System

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